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OAK RIDGE NATIONAL LABORATORY
TECHNOLOGY LOGIC DIAGRAM

VOLUME 1

TECHNOLOGY EVALUATION

PART A

Decontamination and Decommissioning

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Prepared for the
Office of Technology Development
U.S. Department of Energy

1993
Edition

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ORNL/M-2751/V1/Pt. A

Oak Ridge National Laboratory Technology Logic Diagram

Volume 1
Technology Evaluation

Part A
Decontamination and Decommissioning

Prepared for the Office of Technology Development
U.S. Department of Energy

September 1993

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CONTENTS

LIST OF TABLES vii
LIST OF FIGURES ix
ACKNOWLEDGMENTS xi
ACRONYMS AND INITIALISMS xv
FOREWORD xvii

1. INTRODUCTION 3
   1.1 OAK RIDGE NATIONAL LABORATORY 3
   1.2 ORNL MISSION 4
   1.3 ORNL DECONTAMINATION AND DECOMMISSIONING PROBLEM DEFINITION 6
      1.3.1 ORNL Facilities Already in D&D Program 6
      1.3.2 Isotope Facilities Scheduled for D&D Program 12
      1.3.3 ORNL Special-Case Facilities 14
      1.3.4 Summary of Contaminants 14
   1.4 ORNL ROADMAP 17
      1.4.1 Introduction 17
      1.4.2 Roadmapping Methodology 17
      1.4.3 Summary of Major Committed Milestones 18
   1.5 REFERENCES 19

2. DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM 23
   2.1 PURPOSE AND SCOPE 23
   2.2 STAFFING FOR THE TLD 24
   2.3 TECHNICAL APPROACH 26
   2.4 TECHNOLOGY RANKINGS 30
      2.4.1 Overall Assessment 30
      2.4.2 Status of Technology 31
      2.4.3 Estimates for Time to Maturity 31
   2.5 REFERENCES 33

3. CHARACTERIZATION 37
   3.1 INTRODUCTION 37
   3.2 TECHNOLOGY OPTIONS 38
      3.2.1 Characterization Technology Options 38
      3.2.2 Crosscutting Technologies 41
   3.3 SCIENCE AND TECHNOLOGY NEEDS 42
   3.4 IMPLEMENTATION NEEDS 43
   3.5 TECHNOLOGY RANKINGS 44
   3.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 53

4. DISMANTLEMENT/DISASSEMBLY 63
   4.1 INTRODUCTION 63
      4.1.1 Problem Area/Constituents for Dismantlement at ORNL 69
   4.2 TECHNOLOGY OPTIONS 71
      4.2.1 Massive Containment, Reactor Pools, Buried Tanks, and Structural Concrete 71

000004

4.2.2 Steel Structures—High-Level and Low-Level Contamination 71
4.2.3 Asbestos Materials 71
4.2.4 Major Equipment Removal 71
4.2.5 Entombment 71
4.2.6 Retrieval 74
4.2.7 Predisposal Staging 74
4.2.8 Needed Enabling Technologies 74
4.3 SCIENCE AND TECHNOLOGY NEEDS 76
4.4 IMPLEMENTATION NEEDS 77
4.5 TECHNOLOGY RANKINGS 78
4.5.1 Introduction 78
4.5.2 Rankings 78
4.5.3 Conclusions and Recommendations 78
4.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 84
4.7 REFERENCES 88

5. DECONTAMINATION 91
5.1 INTRODUCTION 91
5.2 TECHNOLOGY OPTIONS 104
5.2.1 Introduction 104
5.2.2 Bulk Decontamination Methods 104
5.2.3 Chemical Surface Cleaning Methods 106
5.2.4 Metal Refining Methods 107
5.2.5 Mechanical Surface Removal Methods 108
5.2.6 Surface Cleaning Methods 109
5.2.7 Thermal Surface Removal Methods 110
5.3 SCIENCE AND TECHNOLOGY NEEDS 111
5.3.1 Introduction 111
5.3.2 Bulk Decontamination 111
5.3.3 Chemical Surface Cleaning 111
5.3.4 Metal Refining 112
5.3.5 Mechanical Surface Removal 112
5.3.6 Surface Cleaning 112
5.3.7 Thermal Surface Removal 112
5.4 IMPLEMENTATION NEEDS 113
5.4.1 Introduction 113
5.4.2 Summary of Implementation Needs 113
5.5 TECHNOLOGY RANKINGS 116
5.5.1 Ranking Method 116
5.5.2 High-Ranking Existing Technologies 116
5.5.3 High-Ranking Technologies Requiring Development 121
5.5.4 Implementation 121
5.5.5 Remotization 122
5.5.6 Components with Induced Radiation 122
5.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 123
5.7 REFERENCES 125

6. ROBOTICS/AUTOMATION 129
6.1 INTRODUCTION 129

6.2 TECHNOLOGY OPTIONS 130
6.2.1 Stabilized Hot Cells (Bldgs. 3026C, 3028, 3029, 3030, 3031, 3038, 3047, 3517, and 3019A) 130
6.2.2 Abandoned Hot Cells (Bldgs. 3019B, 3033 and 3033-A, 3042, 3505, 3515, 3517, 4507 and 7025) 134
6.2.3 Reactors and Reactor Support Facilities (Bldgs. 3001, 3005, and 3042) 134
6.3 SCIENCE AND TECHNOLOGY NEEDS 136
6.3.1 Control Methods for Operator Assistance During Remote Operations (ROBA-41-OL) 136
6.3.2 Combined Mobility/Manipulation Capabilities (ROBA-34-OL) 136
6.3.3 Wheeled/Tracked Vehicles (ROBA-1-OL) 136
6.3.4 Tool Caddies and Rapid Changeout Mechanisms (ROBA-21- and 24-OL) 136
6.3.5 Single-/Dual-Arm Manipulators with Force-Reflection/Tactile Capabilities (ROBA-16-OL) 137
6.4 IMPLEMENTATION NEEDS 138
6.4.1 Cold Test Facilities for Verifying the Effectiveness of the Robotic Device 138
6.4.2 Operator Training on Advanced Control Systems and/or Human-Machine Interfaces 138
6.5 TECHNOLOGY RANKINGS 139
6.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 142

7. REGULATORY COMPLIANCE 149
7.1 INTRODUCTION 149
7.2 RESOURCE CONSERVATION AND RECOVERY ACT 151
7.2.1 Closure of Tank Systems 151
7.2.2 Land Disposal Restrictions 160
7.2.3 Treatment Units 161
7.2.4 Corrective Action Management Units 162
7.3 CLEAN WATER ACT 164
7.3.1 Direct Discharge to Surface-Water Bodies 164
7.3.2 Storm-Water Discharges 164
7.4 CLEAN AIR ACT 165
7.4.1 Process Emissions 165
7.4.2 Fugitive Dust Emissions 165
7.4.3 Asbestos Emissions 166
7.5 NATIONAL ENVIRONMENTAL POLICY ACT 167
7.5.1 Wetlands and Floodplains 167
7.5.2 Aquatic Resources 167
7.5.3 Rare, Threatened, or Endangered Species 171
7.5.4 Historic Sites and Archaeological Findings 171
7.6 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION 172
7.7 RADIATION PROTECTION STANDARDS 173
7.7.1 DOE Orders 173
7.7.2 Generic BRC Levels for Radioactive Wastes 175
7.8 REFERENCES 177

APPENDIX: PARTIAL 1992 AND 1993 TECHNICAL TASK PLAN SEARCH DATA-BASE LISTING 181

LIST OF TABLES

Table		Page
1.1	Outstanding characteristics of contaminants	15
2.1	Subelement categories in the Technology Logic Diagram	27
2.2	Scale for overall assessment rating	31
2.3	Scale for status of technology	31
2.4	Definitions for progress of development and time periods	32
2.5	Correspondence of terms for state of the technology	32
3.1	Rankings of characterization technologies for D&D	45
3.2	Characterization technologies under development by DOE	54
4.1	Rankings of dismantlement technologies for D&D	79
4.2	Dismantlement technologies under development by DOE	85
5.1	ORNL decontamination problems	92
5.2	Decontamination technologies	105
5.3	Summary of implementation needs	114
5.4	Rankings of decontamination technologies for D&D	117
5.5	Decontamination technologies under development by DOE	124
6.1	Relationship of robotics/automation technologies to D&D	131
6.2	Rankings of robotics/automation technologies for D&D	139
6.3	Robotics/automation technologies under development by DOE	143
7.1	Federal and state regulations applicable to D&D activities at ORNL	152
7.2	Rules of the TDEC Bureau of Environment Division of Air Pollution Control	165
7.3	Location-specific regulations applicable to D&D activities at ORNL	168
7.4	Surface contamination guidelines	174

LIST OF FIGURES

Figure		Page
1.1	Aerial view of the Oak Ridge National Laboratory	5
1.2	Bethel Valley Reactor Area	7
1.3	Fission Product Development Laboratory, Waste Evaporation Facility, and Fission Product Pilot Plant	7
1.4	Homogeneous Reactor Experiment and Molten Salt Reactor Experiment	8
1.5	Molten Salt Reactor Experiment layout	10
1.6	Molten Salt Reactor containment cell (prior to start-up)	11
1.7	The Old Hydrofracture Facility (foreground)	13
1.8	The 3000-gal Storage Tank	13
2.1	The ORNL Technology Logic Diagram Team	25
4.1	Decontamination and Decommissioning sequence chart	64
4.2	Typical operating face of mechanical processing cell	65
4.3	Typical chemical processing hot cell with roof plug removed	65
4.4	Conventional manual dismantlement technique in low-radiation areas	66
4.5	Drain tank cell for Molten Salt Reactor Experiment during construction	67
4.6	Homogeneous Reactor Experiment Facility Schematic	68
4.7	Integrated, heavily shielded facility (dismantlement concept)	72
4.8	Potential dismantlement end effectors	73

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ACRONYMS AND INITIALISMS

ACM	asbestos-containing material
ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
BRC	below regulatory concern
CAA	Clean Air Act
CAMU	Corrective Action Management Unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWA	Clean Water Act
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EM	environmental management
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
ER/WM	environmental restoration/waste management
ES&H	Environmental, Safety, and Health
FFA	Federal Facility Agreement
FWCA	Fish and Wildlife Conservation Act
HSWA	Hazardous and Solid Waste Amendments
LDR	land disposal restriction
LLLW	liquid low-level waste
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
R&D	research and development
RA	remedial action
RACM	regulated asbestos-containing material
RCRA	Resource Conservation and Recovery Act
TCA	Tennessee Code Annotated
TDEC	Tennessee Department of Environment and Conservation
TLD	Technology Logic Diagram
TRU	transuranic
TTP	Technical Task Plan
USC	United States Code
WM	waste management

FOREWORD

The *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) was developed to provide a decision-support tool that relates environmental restoration (ER) and waste management (WM) problems at Oak Ridge National Laboratory (ORNL) to potential technologies that can remediate these problems. The TLD identifies the research, development, demonstration, testing, and evaluation needed to develop these technologies to a state that allows technology transfer and application to decontamination and decommissioning (D&D), remedial action (RA), and WM activities. It is essential that follow-on engineering studies be conducted to build on the output of this project. These studies will begin by selecting the most promising technologies identified in the TLD and finding an optimum mix of technologies that will provide a socially acceptable balance between cost and risk.

The TLD consists of three fundamentally separate volumes: Vol. 1 (*Technology Evaluation*), Vol. 2 (*Technology Logic Diagram*), and Vol. 3 (*Technology Evaluation Data Sheets*). Part A of Vols. 1 and 2 focuses on D&D. Part B of Vols. 1 and 2 focuses on RA of contaminated facilities. Part C of Vols. 1 and 2 focuses on WM. Each part of Vol. 1 contains an overview of the TLD, an explanation of the program-specific responsibilities, a review of identified technologies, and the rankings of remedial technologies. Volume 2 (Pts. A, B, and C) contains the logic linkages among EM goals, environmental problems, and the various technologies that have the potential to solve these problems. Volume 3 (Pts. A, B, and C) contains the TLD data sheets, which are expanded versions of logic paths from Vol. 2.

The focus of Vol. 1, Pt. A, is D&D, and it has been divided into seven chapters. The first chapter is an introduction, which defines problems specific to the D&D Program for ORNL. Chapter 2 provides a general overview of the TLD. Chapters 3 through 6 are the categories which together make up D&D activities: characterization, dismantlement/disassembly, decontamination, and robotics and automation. The final chapter contains regulatory compliance information concerning D&D.

The technology evaluations contained in these volumes are based on the best information available during compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. L. Fellows, Editor, *Oak Ridge National Laboratory Technology Logic Diagram*, Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

1. INTRODUCTION

1.1 OAK RIDGE NATIONAL LABORATORY

The Oak Ridge National Laboratory (ORNL) was built in 1943 as part of the World War II Manhattan Project. Its original mission was to produce and chemically separate the first gram quantities of plutonium as part of the national effort to produce the atomic bomb. The peacetime history of the laboratory first began in the late 1940s. Through 1973, ORNL was concerned with the development of nuclear technology for electrical power generation. From 1973 to 1980, ORNL was largely devoted to finding solutions for the energy crisis. The primary missions since 1980 have been to conduct applied research and engineering development in support of U.S. Department of Energy (DOE) programs in fusion, fission, conservation, fossil, and other energy technologies and to perform basic scientific research in selected areas of the physical and life sciences. The Laboratory also operates "user facilities" for the benefit of university and industry researchers and supplies radioactive isotopes that are not otherwise commercially available.

1.2 ORNL MISSION

The mission statement that follows was reproduced from the *ORNL Institutional Plan FY 1993–FY 1998.*[1] ORNL, which is managed by Martin Marietta Energy Systems, Inc., for DOE, is one of the nation's premier research institutions (see Fig. 1.1 for aerial view of ORNL). The primary mission of the Laboratory is to perform leading-edge research and development (R&D) in support of the nonweapons roles of DOE. Significant elements of ORNL's mission are to perform basic and applied research that is of importance to the nation; to provide the scientific and technical community with unique national user facilities; to improve the nation's competitiveness through technology development and transfer by partnering universities and industry; and to improve science and math education through contributions to the national initiative.

ORNL will accomplish the mission through its core competencies:

- energy production, conservation, and utilization technologies;
- materials sciences and engineering;
- physical, chemical, and engineering sciences;
- biological and life sciences;
- environmental sciences and technologies;
- computational sciences; and
- manufacturing sciences and technologies.

The principal sponsor of ORNL's work is DOE, but, in a larger sense, the Laboratory serves many national—even international—customers. ORNL staff are involved in research on global energy and environmental problems and in the development of technologies that will improve U.S. competitiveness in international markets. The Laboratory's more fundamental scientific research, much of which is done in collaboration with researchers from around the world, contributes to the storehouse of human knowledge; this work, therefore, has a very broad customer base. In the conception, construction, and operation of national research facilities, the Laboratory's customers are drawn from major segments of the scientific and technical community. Much of the applied research and technology development work at ORNL is expected to provide services for other government agencies and private companies.

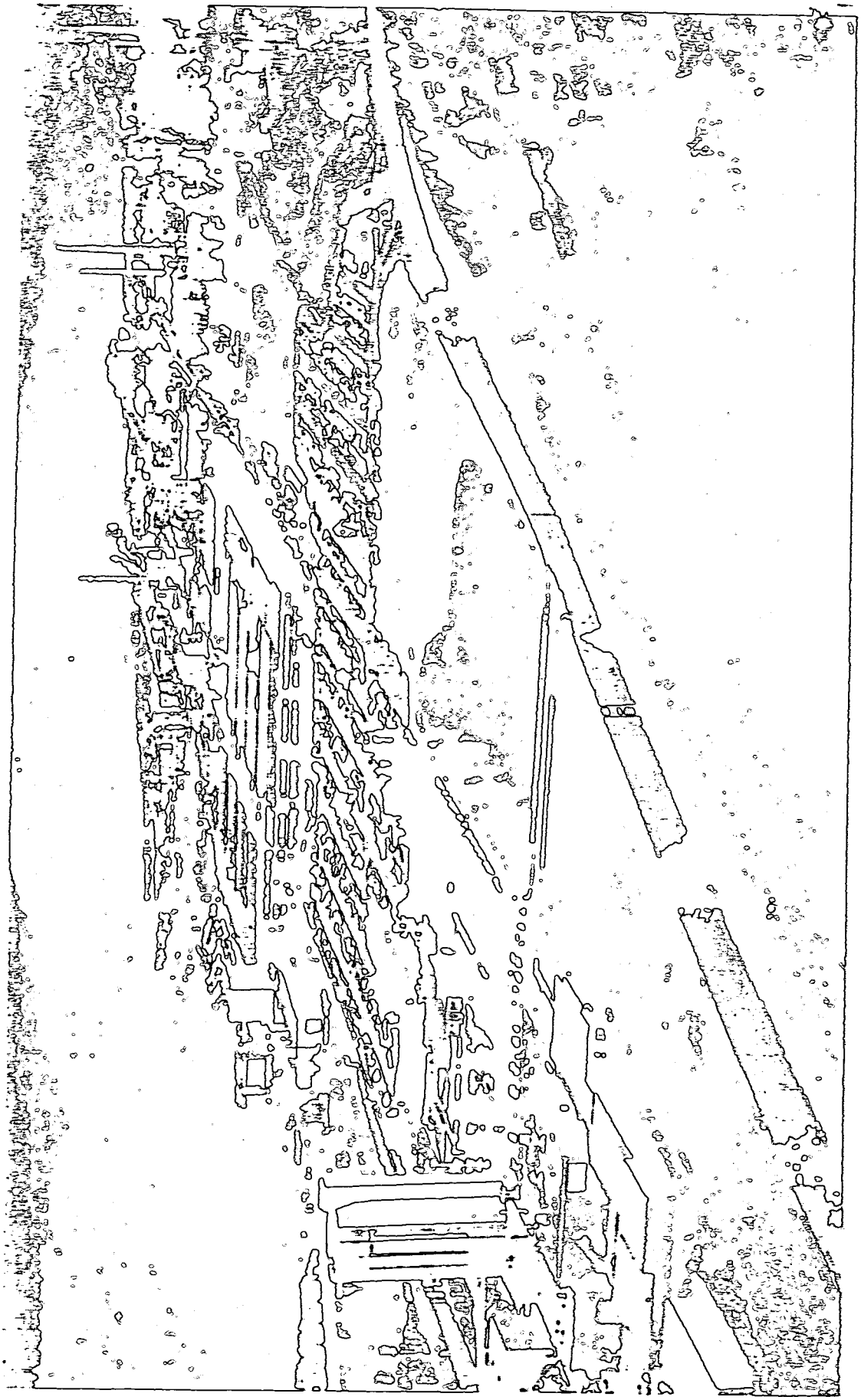

Fig. 1.1. Aerial view of the Oak Ridge National Laboratory.

1.3 ORNL DECONTAMINATION AND DECOMMISSIONING PROBLEM DEFINITION

Past R&D, isotope production, and waste management (WM) programs at ORNL have resulted in a significant surplus of contaminated facilities. These facilities range in size and complexity from shielded shipping casks to large experimental reactors. The programs that formerly used these facilities had both defense and nondefense sponsors.

Currently, there are 39 individual facilities awaiting decommissioning. These facilities are grouped into 17 major decommissioning projects identified in Sect. 1.3.1. In addition, there are 16 isotope facilities described in Sect. 1.3.2 that are undergoing safe shutdown before being accepted by and turned over to the decontamination and decommissioning (D&D) program. Section 1.3.3 describes two additional facilities that will require D&D and are also part of the "official" list of ORNL D&D problems.[2]

1.3.1 ORNL Facilities Already in D&D Program

This section briefly describes the facilities that have already been accepted into the ORNL D&D Program. Figure 1.2 shows the Bethel Valley reactor area with the Metal Recovery Facility, Fission Product Pilot Plant, and Waste Evaporator Facility in the background. The Fission Product Development Laboratory, Waste Evaporator Facility, and Fission Product Pilot Plant are shown in Fig. 1.3. The Homogeneous Reactor Experiment and the Molten Salt Reactor Experiment are seen in Fig. 1.4.

Building 3001 ORNL Graphite Reactor (see Fig. 1.2) was the first reactor constructed at ORNL, being placed in service in 1943 at a 1-MW power level. It was an air-cooled, graphite-moderated and -reflected, heterogeneous, natural-uranium-fueled reactor. The support facilities for Graphite Reactor include the Graphite Reactor Filter House (3002), the Graphite Reactor Fan House (3003), and the Graphite Reactor Exhaust Stack (3018).

Building 3005 Low-Intensity Test Reactor was a water-moderated and -cooled reactor, using enriched uranium as fuel and beryllium as a reflector for the purpose of supplying a variety of irradiation facilities for ORNL and other research groups. The reactor was originally designed for a 500-kW power level but was converted to a 3-MW testing reactor prior to permanent shutdown in 1968. The Low-Intensity Test Reactor is supported by an air cooler (3077).

Building 3042 Oak Ridge Research Reactor (see Fig. 1.2) was a 20-MW materials testing reactor built in 1958. It was used for neutron beam experiments, isotope production, and materials irradiation. It was shut down in 1987, and all fuel was removed. The Oak Ridge Research Reactor is supported by a pool cooling tower and annex (3086), the cooling tower (3103), the heat exchanger pit (3102), the demineralizer (3004), and the pump house (3085).

Building 3087 Oak Ridge Research Reactor Heat Exchanger—This water-to-air heat exchanger was the original heat dissipation system for the Oak Ridge Research Reactor. When the reactor power level was increased from 20 MW to 30 MW in 1960, the radiators were replaced by a water-to-water heat exchanger and cooling tower heat dissipation system.

Building 3505 Metal Recovery Facility was a pilot- and small-scale production nuclear fuel reprocessing plant used for the processing of various waste-solution, scrap, and miscellaneous fuel elements for the recovery of uranium, plutonium, neptunium, and americium.

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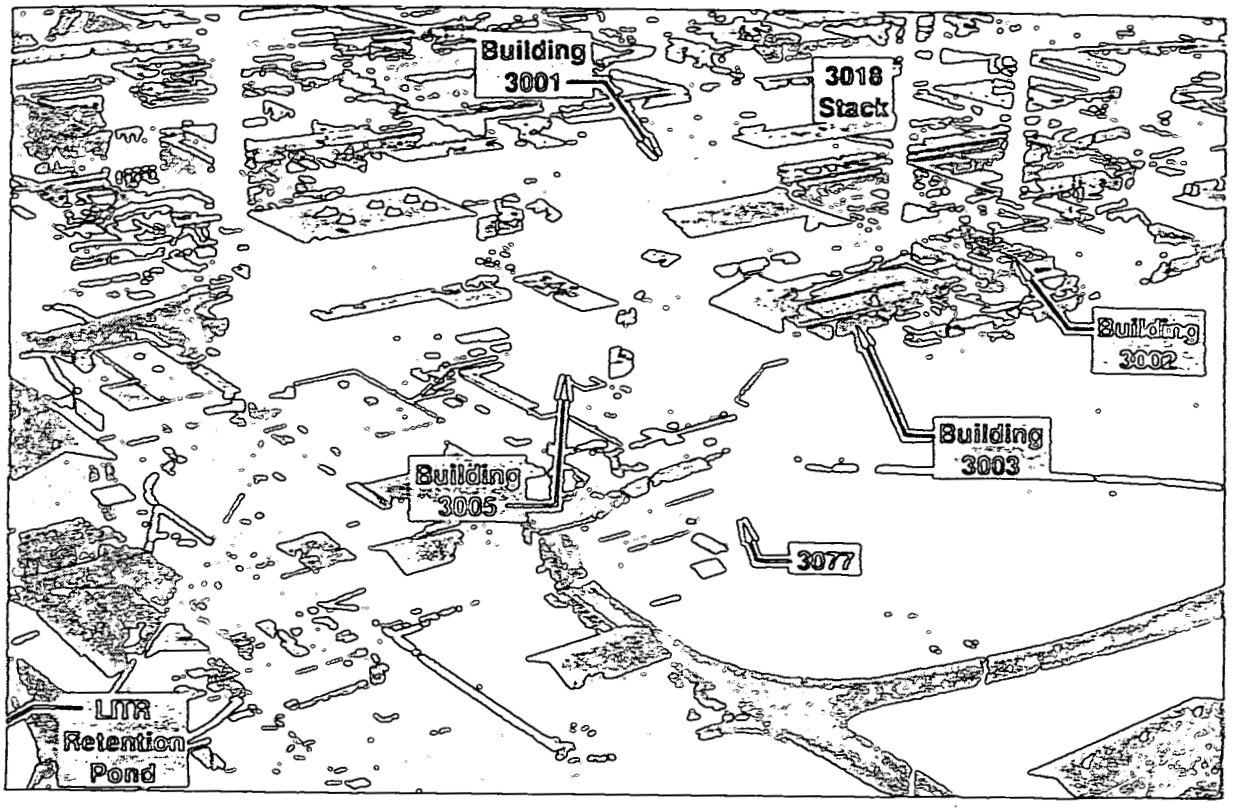

Fig. 1.2. Bethel Valley Reactor Area.

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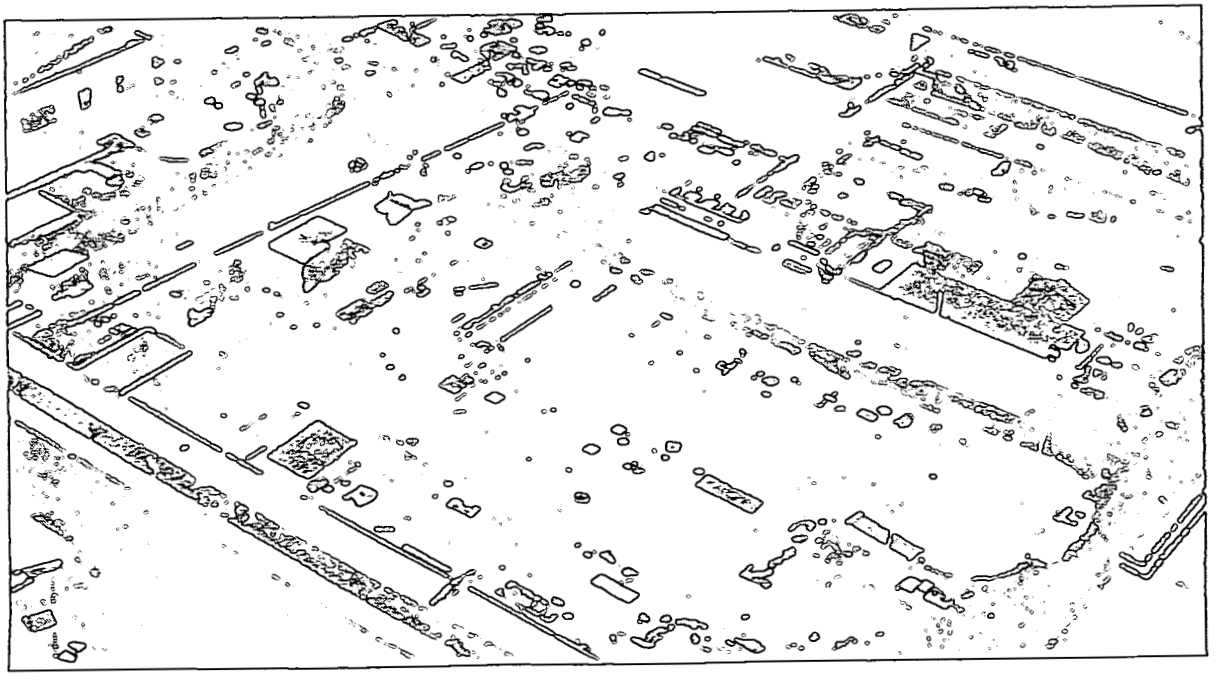

Fig. 1.3. Fission Product Development Laboratory, Waste Evaporation Facility, and Fission Product Pilot Plant.

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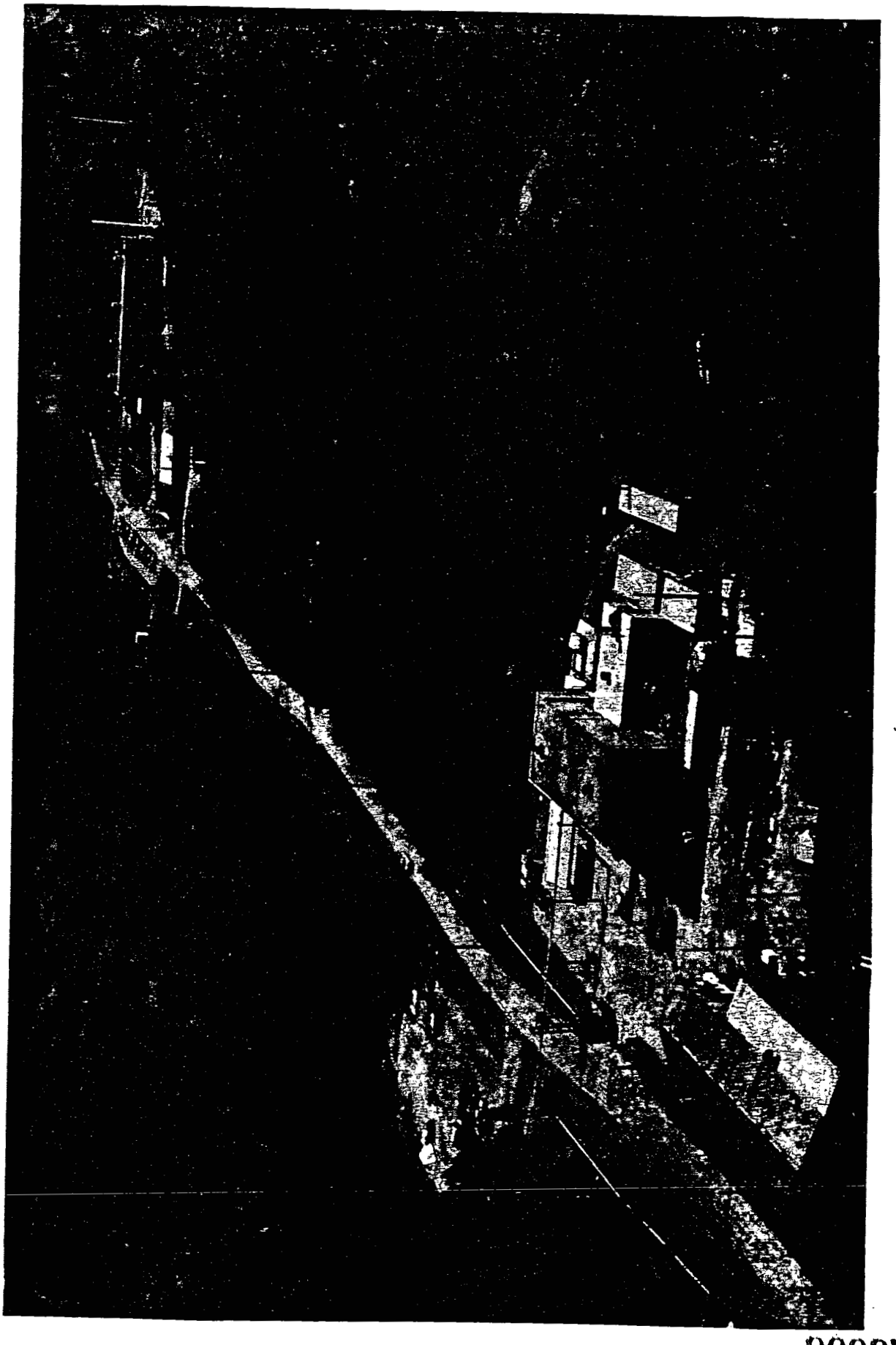

Fig. 1.4. Homogeneous Reactor Experiment and Molten Salt Reactor Experiment.

Building 3506 Waste Evaporator Facility received the liquid low-level waste (LLLW) streams from ORNL laboratories and other processing areas during the 1950s for concentration prior to final disposition by shale fracture techniques.

Building 3515 Fission Product Pilot Plant was used in the fission product recovery development program for the separation of curie quantities of various radionuclides from LLLW streams. It was abandoned in 1958 when it was replaced by the FPDL.

Building 3517 Fission Product Development Laboratory Inactive Cells went on line in 1958 to separate kilocurie quantities of fission products from Redox- and Purex-type waste streams. In 1975, the chemical processing cells were shut down and maintained in protective storage. Some initial decontamination was performed, but subsequent funding restrictions limited the scope of this effort.

Building 4507 High-Level Chemical Development Laboratory was designed and operated as a laboratory and small-scale pilot plant for development studies of reactor-fuel processing, separation and recovery of transuranic (TRU) materials, and separation of fission products from aqueous wastes.

Building 7500 Homogeneous Reactor Experiment housed two experimental aqueous homogeneous reactors that were developed for nuclear power application analyses. The Homogeneous Reactor Experiment is supported by the waste evaporator (7502), the cooling tower (7554), the charcoal absorber pit (7557), the waste evaporator loading pit (7558), the charcoal absorber valve pit (7559), and the decontamination pad (7561).

Building 7503 Molten Salt Reactor Experiment was a single-region, unclad graphite-moderated, homogeneous-fueled reactor built to investigate the practicality of the molten salt reactor concept for central power station applications. The circulating fuel solution was a mixture of lithium-, beryllium-, and zirconium-fluoride salts, containing uranium fluoride as the fuel. The Molten Salt Reactor Experiment is supported by the filter pit (7511), the exhaust stack (7512), the cooling tower (7513), the supply air filter house (7514), and the diesel generator house (7555). Figure 1.5 shows the elevation layout; the reactor cell can be seen in Fig. 1.6.

Building 7852 Old Hydrofracture Facility was an experimental and operational plant for the injection of waste grout into a fractured shale formation. The experimental design was tested in 1964–1965 using dilute and concentrated waste solutions. Beginning in 1966, operational injections of concentrated liquid waste from the ORNL LLLW system were routinely made until facility shutdown in 1980. A pump house and four bulk storage bins comprise the Old Hydrofracture Facility ancillary facilities. Figure 1.7 is a photograph of the facility.

Building 9201-3 Mezzanine Storage Tank (Y-12) is a 3000-gal storage tank that was used from 1958 to 1969. Until recently it was believed that this tank was used as a reservoir for machine shop cutting oil during development of molten salt reactor technology. However, recent information suggests that this tank held cleaning solution for the decontamination facility.[3,4] The tank shown in Fig. 1.8 is contaminated with uranium,[4] thorium, molten salt, and an oil residue.

Building 9201-3 Coolant Salt Technology Facility (Tritium Test Loop) was built in 1958 and was used to support the development of molten salt reactor technology and specifically to study the effects of injecting tritium into a flow of boron trifluoride.

Building 9201-3 Molten Salt Corrosion Loop was built in 1958 for the preparation and handling of fuel for molten salt reactor technology development and the Molten Salt Corrosion Loop.

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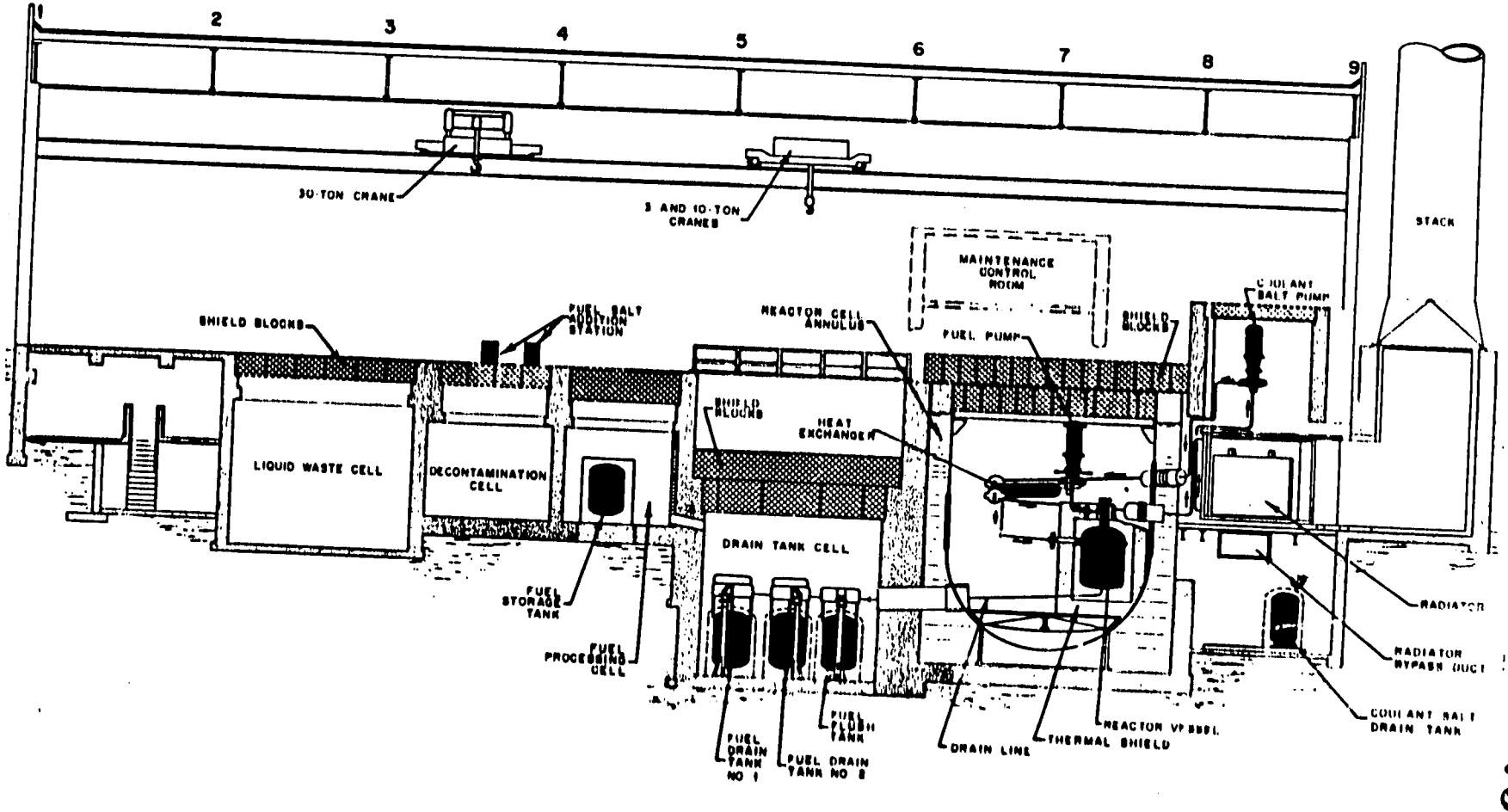

Fig. 1.5. Molten Salt Reactor Experiment layout.

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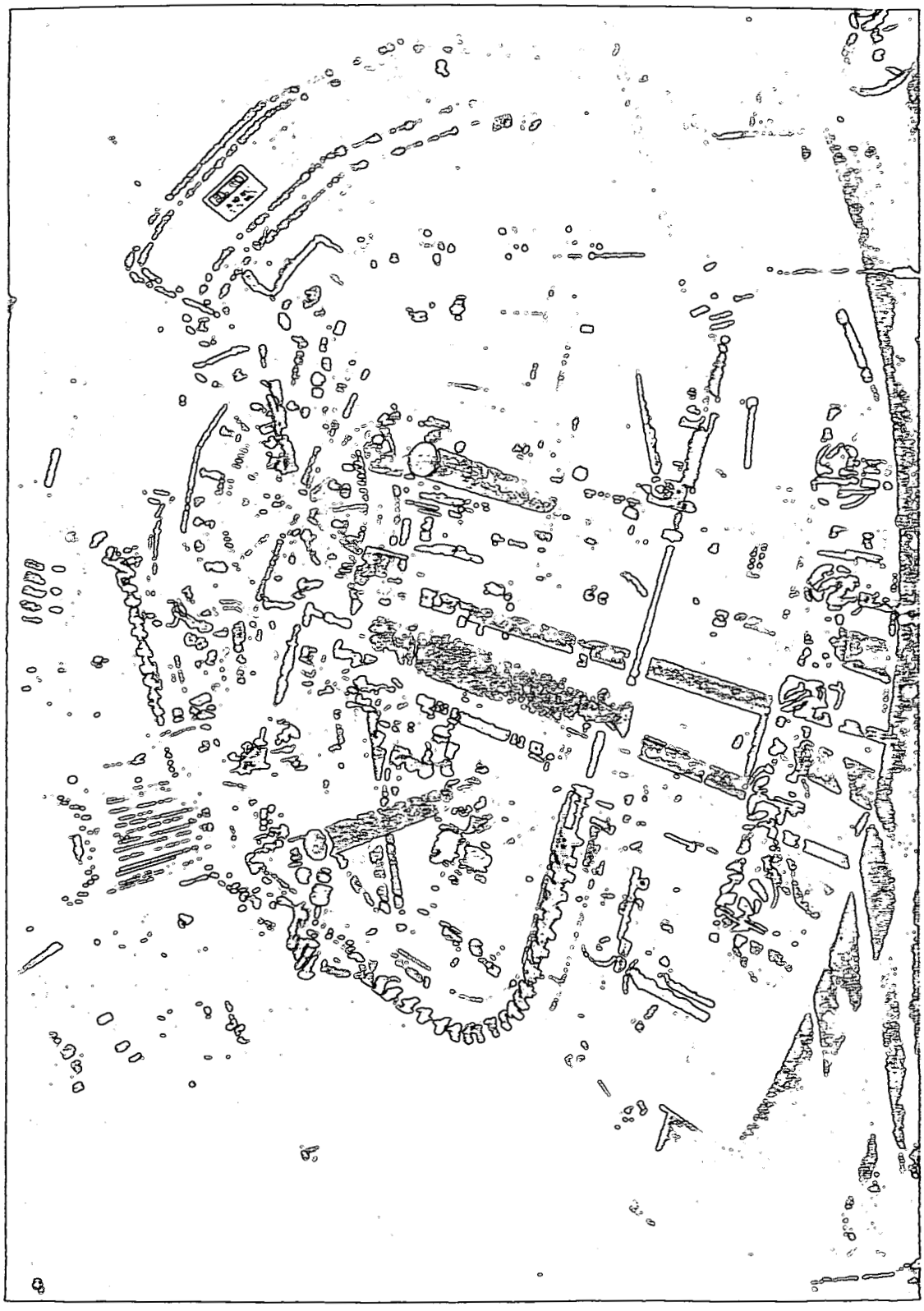

Fig. 1.8. Molten Salt Reactor containment cell (prior to start-up).

Building 9419-1 Decontamination Facility was used to decontaminate equipment and materials associated with the development of molten salt reactor technology from 1958 to 1969.

Shielded Transfer Tanks were used to ship ^{137}Cs-loaded ion exchange resins for processing from Richland, Washington, to ORNL.

1.3.2 Isotope Facilities Scheduled for D&D Program

The following facilities are scheduled for acceptance into the D&D program.

Building 3026-C Krypton-85 Enrichment Facility was constructed in 1943 and was used for about five years to develop methods of isolating fission products. After the war, the effort shifted to processing radioisotopes for research and medical purposes.

Building 3028 Alpha Powder Facility was constructed in 1950 and originally housed the Short-Lived Fission Product Cells and the separation facility, which was a four-story ion-exchange column. The facility was converted to manipulator cells in the early 1960s and expanded to the Short-Lived Fission Product Facility.

Building 3029 Source Development Laboratory was constructed in 1952 and originally contained a system of remotely operated barricades and a small manipulator cell that is now called Cell 4. Cell 1 was used for ^{60}Co-source fabrication, and Cell 3 was built for ^{137}Cs-source fabrication. Cell 2 was built by enclosing the space between Cells 1 and 3 and was used for waste handling and as a pass-through between the cells.

Building 3030 Radioisotope Production Laboratory-C was designed for limited production and development processing of reactor-produced beta-/gamma-emitting radioisotopes for industrial, medical, and research applications.

Building 3031 Radioisotope Production Laboratory-D was designed for limited production and development processing of reactor-produced beta-/gamma-emitting radioisotopes for industrial, medical, and research applications.

Building 3033 Radioactive Gas Processing Facility houses the tritium and krypton production facility. The facility was constructed in the late 1940s and was used to process gaseous isotopes.

Building 3033-A Actinide Fabrication Facility was constructed in about 1960 and was used to house and contain the facilities for the production, loading, welding, and decontamination of neutron dosimeter materials, as well as the weighing and packaging of milligram-to-gram quantities of actinide materials for research applications. The building has been used almost exclusively for the preparation and distribution of highly purified actinide isotopes for the Isotopes Program.

Building 3038 Isotope Research Materials Laboratory was constructed to house all the radioisotope shipping activities for ORNL. The building has been in operation since 1949. Originally, the entire facility was dedicated to radioisotope shipping as follows: the east portion (3038-E) contained the analytical chemistry laboratory, which performed analyses of short-lived radioisotopes prior to shipment; the middle section (3038-M) housed the radioisotope handling and transfer barricade; and the west section housed the packaging, inspection, and shipping activities. In 1968, the west portion of the shipping area was converted into the Alpha Handling Facility area by adding water-shielded hot cells and glove boxes for fabrication of targets.

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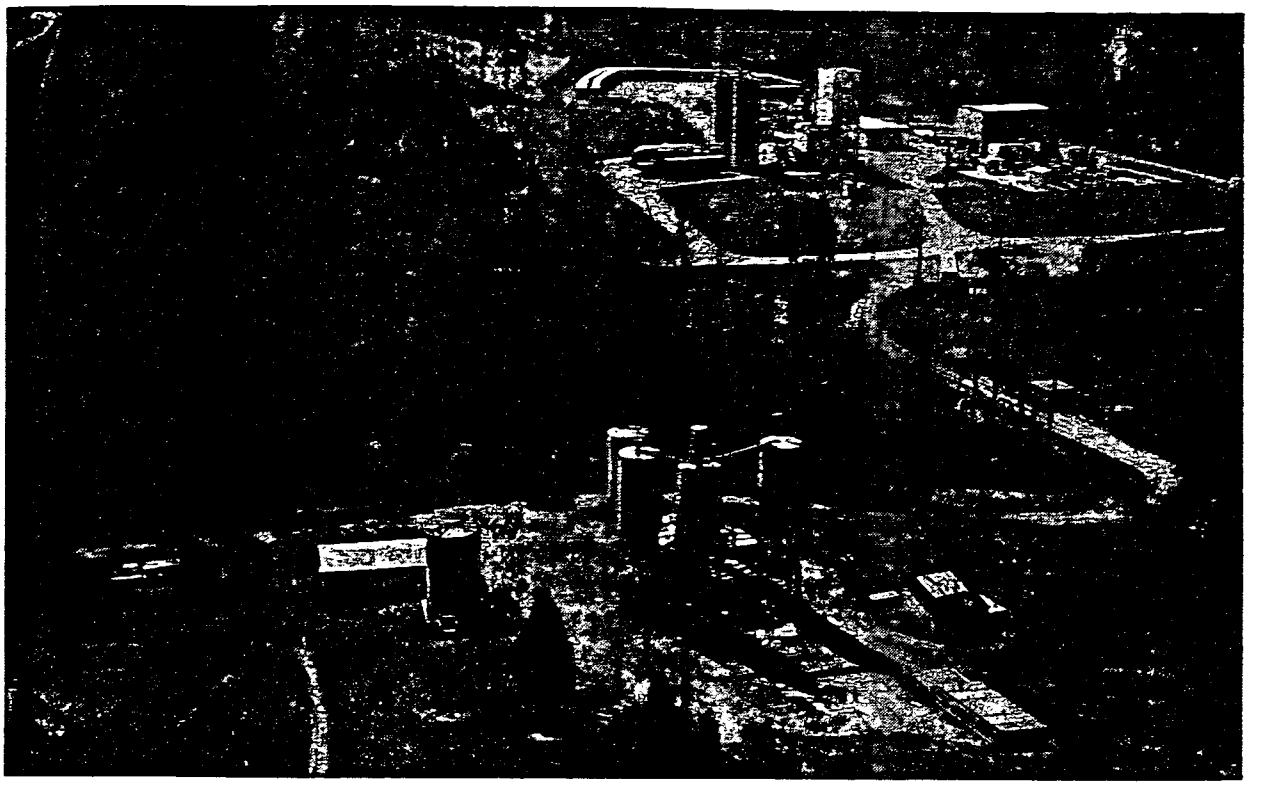

Fig. 1.7. The Old Hydrofracture Facility (foreground).

ORNL-Photo-8136-87

Fig. 1.8. The 3000-gal Storage Tank.

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Building 3047 Radioisotope Development Laboratory was constructed in about 1962 as part of the isotopes program. The facility housed four high-level beta/gamma cells, one alpha hot cell, seven laboratories for handling low-level materials, a decontamination room, offices, and service areas. During operations, isotopes handled within the facility included ^{60}Co, ^{152}Eu, ^{154}Eu, ^{153}Gd, ^{14}C, and other alpha and beta/gamma isotopes specifically identified individually. All process operations in the building have been shut down.

Building 3093 Storage Cubicle for Krypton was constructed in the late 1940s and was used to support the gaseous isotopes processes. The permanent storage cubicle in Building 3093 contains four charcoal-filled storage tanks. It consists of a nonventilated reinforced-concrete enclosure.

Building 3099 Storage Pad is a concrete pad used for temporary storage of prepackaged shipments, casks, and other materials. All radioactive materials located on the pad are stored in accordance with U.S. Department of Transportation (DOT) or equivalent regulations for shipment of radioactive materials contained in a minimum double containment designed to prevent leaks and spills.

Building 3118 Radioisotope Production Laboratory-H is basically a shed covering the rear-entry doors to the hot cells in Bldgs. 3030 and 3031. It may be used for forklift storage and as a waste staging area during shutdown activities.

Building 3517 Fission Products Development Laboratory went on line in 1958 to separate kilocurie quantities of fission products from Redox- and Purex-type waste streams. Following the shutdown of the chemical processing cells in 1975, radioisotope processing continued in the manipulator cells at a reduced level until April 1989, when the building was placed in standby.

Building 7025 Tritium Target Facility was installed in the late 1960s to house a tritium target fabrication system. The facility was used to produce titanium tritide accelerator targets for the Lawrence Livermore National Laboratory. The system has also been used to prepare metallurgical samples for helium embrittlement studies related to fusion energy materials research. In later years, the ThO_2/UO_2 evaporator was moved to Bldg. 7025 and was used to prepare hundreds of oxide-thin films for a variety of customers.

1.3.3 ORNL Special-Case Facilities

The D&D project intends to perform D&D of Bldgs. 3019-A and -B together.

Building 3019-A Radiochemical Development Facility is used for dispensing and storing fissile material and for radiochemical process experimentation and development. This project is currently funded by Defense Programs and will remain funded for several more years.

Building 3019-B High-Level-Radiation Analytical Facility was built in 1955 and was used for separating, processing, and analyzing highly radioactive samples from many ongoing ORNL programs. These samples included fission and activation products, and uranium, plutonium, and other TRU materials. No project claims ownership of this facility.

1.3.4 Summary of Contaminants

Outstanding characteristics of the contaminants in a selection of these facilities are summarized in Table 1.1.

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Table 1.1. Outstanding characteristics of contaminants

Facility	Highest contamination	Location	Contaminants
ORNL Graphite Reactor	2–4 R/h	Surfaces, reactor core, duct work, process piping, and equipment	Fission products and traces of plutonium, ^{14}C, ^{55}Fe, ^{137}Cs, ^{90}Sr, and ^{60}Co
Low-Intensity Test Reactor	200–300 R/h	Interior surfaces of reactor tank and primary water piping	Corrosion products and long-lived fission products
Oak Ridge Research Reactor	>50,000 R/h	Surfaces, reactor core, process piping, and equipment	Primarily ^{60}Co, ^{137}Cs, and ^{90}Sr
Metal Recovery Facility	600 mrad/h 2,500,000 dpm/100 cm^2	Cell walls and floors	Most likely ^{137}Cs and ^{239}Pu
Waste Evaporator Facility	1–10 mrad/h 1,350 dpm/100 cm^2 transferable 11,400 dpm/100 cm^2 transferable	Valve pit, piping, and some surfaces	^{137}Cs and ^{90}Sr
Fission Product Pilot Plant	1–100 R/h (prior to entombment)	Entombed in concrete (surfaces, piping, valving, and controls)	Primarily ^{137}Cs and ^{90}Sr and possibly Ce and Ru
Fission product development laboratory	10–10,000 R/h	Cell surfaces, process equipment, and piping	Primarily ^{137}Cs and ^{90}Sr; also ^{144}Ce and ^{147}Pm
High-Level Chemical Development Laboratory	250,000,000 dpm/100 cm^2	Cell surfaces and equipment	Transuranic materials and fission products
Homogeneous Reactor Experiment	600 R/h 32,000 dpm/100 cm^2 (max)	Cell walls, equipment surfaces, and process piping	Primarily ^{90}Sr, ^{137}Cs, and other fission and corrosion products

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Table 1.1 (continued)

Facility	Highest contamination	Location	Contaminants
Molten Salt Reactor Experiment	2200 R/h	Reactor vessel, fuel storage cells, process piping, and equipment	Primarily ^{60}Co and other fission products
Old Hydrofracture Facility	8 R/h (max)	Surfaces, equipment, and piping	Fission products, ^{137}Cs, ^{90}Sr, and ^{60}Co
Coolant Salt Technology Facility	1,000,000 dpm/100 cm^2 (max) 1,000 dpm/100 cm^2 transferable 3,500 dpm/100 cm^2 transferable	Interior of flow system (pumps, tanks, valves, and piping)	Tritium
Molten Salt Corrosion Loop	50,000 dpm/100 cm^2 (max) 1,200 dpm/100 cm^2 transferable 3,500 dpm/100 cm^2 transferable	Interior of fuel handling cell and support equipment	^{233}U, ^{228}Th, and low levels of transferable Be
Decontamination Facility	Low levels of alpha	Surface	Tritium
Shielded transfer tanks	2-400 mrad/h	Surface	^{137}Cs
3000-gal glass-lined storage tank in 9201-3	4,000 dpm/100 cm^2	Surface	U, Th, Oil

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1.4 ORNL ROADMAP

1.4.1 Introduction

The *Strategic Roadmap for the Oak Ridge Reservation* is a generalized planning document that identifies broad categories of issues that keep ORNL outside full compliance with the law and other legally binding agreements.[5] The *Strategic Roadmap for the Oak Ridge Reservation* identifies possible generic paths to compliance, issues, and the schedule for resolution of the issues. The role of the *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) is then to identify specific site issues (problems), identify specific technologies that can be brought to bear on the issues, and assess the current status and readiness of these remediation technologies within the constraints of the schedule commitment.

Regulatory requirements and commitments contained in the *Strategic Roadmap for the Oak Ridge Reservation* are also included in the TLD as constraints to the application of immature technological solutions. Some otherwise attractive technological solutions may not be employed because they may not be deployable on the schedule enumerated in the regulatory agreements. Conversely, negotiators in the process of defining regulatory agreements may fruitfully take cognizance of the TLD assessments in order to schedule remediation milestones that allow the use of cheaper, faster, better, or safer technologies.

The roadmap for ORNL includes a list of 46 comprehensive logic diagrams for WM of low-level, radioactive-mixed, hazardous, sanitary and industrial, and TRU waste. The roadmapping process gives comparisons of the installation as it exists to the way the installation should exist under full compliance. The identification of the issues is the goal of roadmapping. This allows accurate and timely formulation of activities. The following information is excerpted from the *Strategic Roadmap for the Oak Ridge Reservation*.

1.4.2 Roadmapping Methodology

The roadmapping methodology is divided into nine steps and covers three phases—assessment, analysis, and issue resolution.

The assessment phase identifies the current status and background of the installation. This phase is accomplished in four steps: (1) identifying installation assumptions that provide for the conduct of environmental management (EM) activities; (2) identifying regulations and codes of federal, state, and local levels, DOE Orders, and other agreements that DOE is responsible to comply with; (3) describing those DOE commitments, which include Inter-Agency Agreements and Federal Facility Agreements (FFAs); and (4) preparing a schedule that includes all commitments with all currently budgeted and forecast activities.

The analysis phase identifies key issues and actions needed for resolution. This phase is accomplished in four steps: (1) identification of issues that prevent the installation from accomplishing EM objectives; (2) analysis of issues to determine the root causes; (3) conversion of issues to needs for the resolution of issues and the identification of activities that satisfy those needs; and (4) preparation of the schedule for the desired activities.

The issue-resolution phase merges the issue resolution activities with ongoing and planned activities as the ninth and final step. Specific recommendations for modifications, additions, or deletions to current plans are formulated and captured in Activity Data Sheets or are forwarded to DOE Headquarters for resolution.

1.4.3 Summary of Major Committed Milestones

Although the FFA for the Oak Ridge Reservation (ORR) does not address D&D directly, it does contain major committed milestones for ORNL which may impact the D&D process and technology development indirectly in the form of time, resource and budget constraints and directly in that D&D sites determined to have newly identified releases of hazardous substances to the environment will be incorporated into the FFA Appendix E list of sites requiring remedial action (RA). Likewise, although the ORNL roadmap does not impose any requirement or constraints on the technologies that may be developed for use in D&D of ORNL facilities, several major environmental regulations are addressed which could place constraints of the application of immature technological solutions. Therefore, this document provides a discussion of regulatory drivers for D&D activities and technologies in Chap. 7.

1.5 REFERENCES

1. *Oak Ridge National Laboratory Institutional Plan FY 1993–FY 1998*, ORNL/PPA-92/3, U.S. DOE and Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., November 1992.

2. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge Natl. Lab., October 29, 1992.

3. R. Montgomery, personal communication to R. D. Bundy (Notebook 11888, p. 66), Oak Ridge, Tenn., February 26, 1993.

4. R. Montgomery and S. M. Anderson, personal communication to R. D. Bundy (Notebook 11888, p. 68), Oak Ridge, Tenn., March 2, 1993.

5. *Strategic Roadmap for the Oak Ridge Reservation, March 1992*, U.S. DOE Field Office—Oak Ridge and Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., March 26, 1992.

2. DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM

2.1 PURPOSE AND SCOPE

The purpose of the TLD is to provide a planning document for DOE, DOE operating contractors, and private industry that relates the environmental restoration/waste management (ER/WM) problems at ORNL to the technologies that can be used to remediate these problems. In doing so, the status of each potential remediation technology is evaluated. This is a significant focus of the diagram preparation.

Several important aspects impacting implementation of each technology are folded into the evaluation so that the appropriateness of each technology can be evaluated:

1. Potential efficacy of the technology—how successful will its application be to the site problem?
2. Level of maturity of the technology—when can it be applied to site problems?
3. Level of WM required for the technology—what wastes are generated as a result of the use of the technology?

The TLD addresses the enforceable compliance and cleanup agreements that have designated timetables for ameliorating the specific site problems. For potentially attractive but immature technologies, or those for which improvement paths (which make them faster, better, safer, and cheaper) are visualized, priorities are assigned to technology development activities.

Because of enforceable compliance agreements, DOE is bound by Executive Order 12088, which requires the Secretary of the Department of Energy to submit a plan and request sufficient funding each year to comply with federal pollution control standards. This document will aid in the annual planning and budget submittals.

This document will address all current D&D problems that have been identified at ORNL. The technology listings in the diagrams were judged to be reasonably applicable to D&D at ORNL.

The TLD provides several benefits to the DOE community. The diagram identifies technologies that can be used for EM programs. It serves as a vehicle to identify the deficiencies in technologies that otherwise have potential to (1) foster faster remediation; (2) allow safer project activities; (3) result in better remediation efforts; and (4) allow these projects to be accomplished at a lower cost to DOE and the United States. Improving existing technologies, demonstrating the applicability of promising technologies, developing immature technologies, and supporting fundamental technology investigations are options that DOE can pursue to deploy technologies necessary for successful EM of DOE facilities. The diagram will highlight areas for private industry and university involvement in EM.

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The formulation of the ORNL TLD was led by many of the same professional staff that formulated and published the *Oak Ridge K-25 Site Technology Logic Diagram*, with participation from across ORR. Although a number of ORNL personnel were involved, about half of the team was selected from other Energy Systems organizations in Oak Ridge, such as the K-25 Site, the Y-12 Plant, Central Engineering, and other DOE contractors. The personnel from these organizations represent input to the TLD from programs under the DOE Deputy Assistant Secretaries of Waste Management (EM-30), Environmental Restoration (EM-40), and Technology Development (EM-50), as well as professionals not associated with these programs. Figure 2.1 shows a staffing plan for the ORNL TLD Team.

Specialists worked as members of each team formed for the *subelement* categories shown. Representatives from each team served on a coordinating committee, which functioned as a common communication forum for the TLD. More than 100 specialists were involved in this effort. The teams (1) compiled the site problems in terms that were applicable to each team; (2) identified and evaluated technologies that could be applied to remediate the problems; (3) furnished, through the technology evaluation, information on the opportunities that were evident for development and improvement in each technology; and (4) furnished the requirements for deployment of these developed and improved technologies.

Technology evaluation was a significant component of the TLD effort. Team members identified potential technologies, but it was not necessary for the technology evaluation experts to become familiar with the concepts of the TLD before their evaluations. The data sheets allowed the evaluations to be performed on a systematic basis. The data sheets (Vol. 3, Pts. A, B, and C) provide detailed information and the basis upon which the diagram (Vol. 2, Pts. A, B, and C) was devised.

000035

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Fig. 2.1. The ORNL Technology Logic Diagram Team.

000036

2.3 TECHNICAL APPROACH

This section describes the overall layout and development of the TLD. The logical progression flows from (DOE) EM Goal → EM Problem → ORNL Problem → Problem Area (Target Constituent) → Reference Requirements → Subelement → Alternative (Generic Technology) → Technology → Technology Status → Science/Technology Need → Implementation Need.

Three different levels of information are provided. First, the technologies are evaluated and ranked in Vol. 1, Pts. A, B, and C. Second, more detailed diagrams are provided in Vol. 2, Pts. A, B, and C. Although each large sheet contains the entire logic path, several sheets are necessary to describe each evaluation area. Finally, each single logic path is published as a technology data sheet. These sheets are the most detailed source of information about each technology and are provided in Vol. 3, Pts. A, B, and C.

The information found under each logic element is described below.

EM Goal has three components: cleanup legacy, prevent future insult, and develop environmental stewardship. These problems are shared by all elements of the DOE complex to varying extents.

EM Problem contains problem areas agreed upon by EM/DOE: such as decommissioning of facilities (D&D); cleanup of soils, ground water, and surface water (RA); and WM from inception to final disposition.

ORNL Problem describes the problem areas identified at ORNL. These problem areas have been defined by D&D, environmental restoration (ER), and WM staff. The magnitudes of the site problems will be indicated in terms of floor areas, estimated metal tonnages, etc.

Problem Area/Constituent addresses subelement-specific list (see below) of problems, all of which are traceable directly to the ORNL problems.

Reference Requirements refers the reader to the final chapters of Vol. 1, Pts. A, B, and C. Requirements can only be determined after consideration of detailed site-, waste-, and technology-specific characteristics.

Subelement specifies the different components that must be addressed to solve the problem. All D&D activities have been categorized into the following subelement groups: characterization, decontamination, dismantlement, robotics/automation, materials disposition, and regulatory compliance.[1] The subelements for RA are characterization; treatment and fixation; retrieval; robotics/automation; materials disposition; and regulatory compliance. The subelements for WM are waste retrieval; characterization; processing; stabilization; minimization; packaging, handling, and transportation; disposal; and regulatory compliance. Table 2.1 lists the various subelements for D&D, RA, and WM.

Alternative defines the general technology approaches that may be applied to the problem.

000037

Table 2.1. Subelement categories in the Technology Logic Diagram

Area of environmental management	Subelements (or "Universe" of Activities)					
Decontamination and decommissioning	Characterization	Decontamination	Dismantlement	Robotics/ automation	Materials disposition	Regulatory compliance
Remedial action	Characterization	1. Treatment 2. Fixation	Retrieval	Robotics/ automation	Materials disposition	Regulatory compliance
Waste management	Characterization	1. Processing 2. Stabilization 3. Minimization	1. Transportation 2. Retrieval 3. Disposal	Robotics/ automation	Materials disposition	Regulatory compliance
	Crosscutting			Crosscutting	Crosscutting	Crosscutting

000038

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Technology identifies specific technologies that may be applied to remediate the problem.

Status provides information on the status of the technologies identified in the previous column using the standard categories.

Some accepted technologies are *fully developed* or *commercially available* and if so are noted. These terms are used to denote slightly different meanings. *Fully developed* means that both the basis of the technology and the methods for designing remediation equipment or operations using the method are well known and covered in public literature. *Commercially available* means that the technology is offered by one or more commercial firms, but the data, design methods, or experience needed to assess the technology are not fully available to the public. The only difference in these two categories is that the public's ability to assess the performance and reliability of the technology is restricted for commercial technology. It suggests an unknown degree of risk in the commercially available technologies that cannot be fully evaluated with generally available information (even though the amount of risk may be negligible).

- *In-Use*—technology is presently being used to remediate the identified problem.
- *Accepted*—demonstrated technology exists for use at ORNL and is accepted by site personnel.
- *Demonstration*—technology is available but is not demonstrated and/or accepted for the problem at ORNL.
- *Predemonstration*—technology is under laboratory-, bench-, or pilot-scale testing.
- *Evolving Technology*—technology status is at a conceptual or preconceptual stage.
  - *Conceptual*—a scientific or knowledge basis for the technology exists.
  - *Preconceptual*—only a partial scientific or knowledge basis of the technology exists.

These classifications should provide indirect, relevant information on the present view of the short-term or long-term availability of technologies.

Several different areas are specifically addressed to further clarify the status designations chosen above.

- *Efficacy*—the effectiveness of the technology in remediating the problem. Normally, quantitative measures are given for the technology's performance in standard practice, such as estimating the final dpm/cm^2 of surface contamination for a decontamination technology; the time to cut a 24-in. pipe for a dismantlement technology; the analysis time and lower detection limit for a characterization technology.
- *Waste*—output from the technology. This describes the nature and volume of both the waste and the potentially useful materials.

Science and Technology Needs are perceived needs, where support or development is needed for an "immature" technology. Science needs are related to the fundamental understanding of the scientific phenomena that form the basis for the technology. These needs are typically for laboratory or bench-scale experiments. Technology development needs identify areas where work is necessary to successfully implement scientific principles that will lead to a technology. Technology improvement needs suggest improvements that will make a current technology more economical to apply, safer, and more effective or efficient. The demonstration of a technology on a site-specific problem is classified as a technology improvement need.

If scientific needs are specified, it should be understood that the needs of scientific technology development or improvement are necessary to implement newly developed scientific understanding. Likewise, testing a technology development opportunity implies that technology improvements are also likely to be needed.

DOE funding for a project that addresses the technology deficits is indicated by a Technical Task Plan (TTP) number, Activity Data Sheet number, or other reference number. Other work related to the technology area may also be referenced.

Most new technologies that are not in common use will require a large-scale test or demonstration to show that they are capable of achieving expected results on the site-specific problem. These tests demonstrate that a suitable and workable process or facility can be designed, built, and operated successfully. They show that no unknown condition prevents the process or facility from functioning as it was designed and that the equipment can last an acceptable lifetime. Demonstrations are intended to provide final tests of all aspects of a technology. If, however, particular questions remain about the technology, these are specifically mentioned on the diagram.

Implementation Needs or specialized needs were evaluated for both development of a technology and deployment of a mature technology. These needs were evaluated in the areas of (1) resources such as financial or personnel; (2) hardware such as process equipment, development equipment, and computers; (3) software such as models, procedures, computer programs; (4) facilities such as labs, shops, and buildings; and (5) education such as training classes or degreed personnel. An estimate of the cost of the process and any potential cost payback are also given. Only extraordinary needs are highlighted, (i.e., those needs that would require long lead time or unusual procurements, such as line items for facility construction).

The cost of applying the technology and the payback cost potential has been estimated. There are many reasons for payback, such as reducing the waste volume compared to a reference process, the sale of useable products, and the reduction of labor compared to a reference technology.

When standard laboratory facilities are sufficient, facility needs are not identified. Since the facilities on ORR are relatively extensive—including the K-25 Site, ORNL, and the Y-12 Plant—the diagram does not address needs for standard facilities but focuses on unique facility needs.

However, additional conventional facilities may be needed to meet the technology needs for RA at ORNL because the available facilities may not provide adequate capacity for testing the various technologies. To assess the availability of standard facilities for these programs, it will be necessary to know (1) the rate at which technology development in Oak Ridge will proceed and (2) the extent at which other programs will compete for the facilities.

Throughout the technology evaluation a method of conveying information about the ranking and status of each technology and its application is used to communicate separate information about the following:

- Overall assessment of the applicability of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for usefulness.)
- Significance of site problem to which the technology is applied (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site. This is expressed in number of years and depends on the current state of its development.
- The cost for bringing the technology from its present state to a level acceptable for commercial or large-scale use. The costs are presented as $M or $K, which indicates the number of millions or thousands of dollars without escalation.
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate). This includes annual ranking costs for software.

An example of a ranking follows:

H-5-5 ($3.5M;N)

This means that this technology has a high overall usefulness; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

2.4.1 Overall Assessment

Following are the criteria used to determine the overall assessment of a technology and its application.

- *Waste Generation Reduction*—ability of the technology to minimize additional waste generation (1–no confidence, 5–complete confidence).
- *Compliance with Requirements [Applicable or Relevant and Appropriate Requirements (ARARs)]*—confidence that the technology will comply with applicable, relevant, and appropriate requirements (1–no confidence, 5–complete).
- *Environmental, Safety, and Health (ES&H)*—ability of the technology to meet the requirements of ES&H (1–no confidence, 5–complete).
- *Versatility*—ability of the technology to meet a wide range of requirements and to adapt to changes in requirements (1–no confidence, 5–complete).
- *Complexity*—ability of the technology to be deployed without requirements for extraordinary levels of expertise, training, and oversight (1–very high level of requirements, 5–low level of requirements).
- *Technical Risk*—confidence that the technology will work at the site(s) being evaluated (1– no confidence, 5–complete confidence).
- *Technical Maturity*—readiness of the technology for deployment at large (commercial) scale (1–very immature-idea for research, 5–ready for commercial application).
- *Development Required*—relative amount of time required to bring the technology to commercial application (1–all research, development, and demonstration steps required, 5–now commercial/no tests required).

000041

- *Development Cost*—relative cost of bringing the technology to commercial application (1–highest cost for development of a technology within a technical area, 5–no costs, not even field testing).
- *Process Cost*—relative cost of process in terms of unit production costs in application (1–prohibitively expensive relative to other methods, 5–very inexpensive compared with other methods).

After scoring the criteria, the scores were averaged and the overall assessment rating was determined by the scale in Table 2.2.

Table 2.2. Scale for overall assessment rating

Assessment code	Code meaning	Score	Meaning
E	Essential		No other processes or technology available for essential requirement
H	High	3.67 to 5	High potential for application
M	Medium	2.33 to <3.67	Medium potential for application
L	Low	<2.33	Low potential for application

2.4.2 Status of Technology

The development state for technology was assessed using the scale provided in Table 2.3.

Table 2.3. Scale for status of technology

State of Technology	Score
Accepted	5
Demonstration needed	4
Predemonstration—evolving	3
Conceptual	2
Preconceptual	1

2.4.3 Estimates for Time to Maturity

Definitions for progress of development and time periods, which were used as guidelines for estimating the total period required to bring technology to the state of large scale application (state of acceptance), are provided in Table 2.4.

Table 2.4. Definitions for progress of development and time periods

Step in development	Definition of step	Years
	New technology	
Applied research	Work required to define scientific feasibility	1–3
Development	Bench or engineering scale to define scaling of the technology	2–3
Pilot	Integrated test of process or technology at less than full scale	3–4
Prototype demonstration	Integrated demonstration at full scale	3–5
Commercialization or mature application	Application of the technology at large scale	1–2
	Adaptation of existing technology (existing at mature state)	
Synthesis demonstration	Combining existing technologies to meet requirement—demonstrate at pilot scale	2–3
Field test	Testing on the exact site problems and configuration	1–3

These stages of development correspond to the state of the technology and are shown in Table 2.5.

Table 2.5. Correspondence of terms for state of the technology

Status of technology	Score	Development period expressed by time	Development stages
Accepted	5	Available	Mature
Demonstration	4	Short range	Field test
Predemonstration	3	Medium range	Development, pilot, prototype, or synthesis of technology
Evolving—conceptual	2	Long range	Development
Evolving—preconceptual	1	Unknown	Applied research

000043

2.5 REFERENCES

1. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge National Laboratory, October 29, 1992.

3. Characterization

3. CHARACTERIZATION

3.1 INTRODUCTION

D&D problem areas require characterization to answer the following questions:

1. What contaminants are present?
2. How concentrated are the contaminants?
3. Where are they?
4. How far have they spread?

Identification of the chemical form of the contaminant may also be important, in some cases, for designing treatment schemes. Characterization is needed to locate and quantify contamination and to define contaminant boundaries in or on tanks, pipes, pavement, concrete, plaster, metal structures, insulation, and equipment in buildings. It is required to meet regulatory requirements, to permit risk assessment, and to guide decontamination and dismantling. The technologies involve, for the most part, analyses in the field, although laboratory analyses may also be required. The main contaminant groups of concern are radioactive elements and heavy metals. Organic compounds are of minor importance except for oils, polychlorinated biphenyls (PCBs), and reprocessing chemicals, such as normal hydrocarbons and tributyl phosphate.

This chapter presents the characterization technologies required to support D&D at ORNL; brief overviews of the science/technology needs to bring the technologies to a useable level; implementation needs to deploy these technologies; and rankings of these technologies for D&D.

3.2.1 Characterization Technology Options

Characterization technology options for D&D at ORNL are listed in Table 3.1 of Sect. 3.5, along with their rankings. All technologies are not required for each problem; many of the technologies for a given constituent are optional. Many of these technologies are broadly applicable to a variety of constituents and D&D problem areas, and they are listed in Vol. 2 under a "general" problem category. This reflects the applicability of a technology to more than one group of constituents (e.g., radioactive elements and metals) and to more than one problem area (e.g., pipes and tanks). Under this general heading, the technologies are grouped as the following alternatives: sampling design, sample collection, sample preparation, detection/measurement—field methods, and detection/measurement—laboratory methods. Technologies specific to a group of constituents are then listed in Vol. 2 under a specific alternative: radioactive elements (which includes both specific radionuclides and radioactivity), inorganic constituents (cations, anions, and elemental metals such as mercury), organic constituents, physical characteristics, and pathogens. These constituent-specific technologies are subdivided by their deployment in the field or laboratory. Technologies for in situ and ex situ determinations are included in the field and laboratory classifications. Simple and common characterization technologies such as for pH measurements are omitted for simplicity in this compilation. Following "general" listings are specific ORNL problems for which certain technologies are particularly needed.

3.2.1.1 Sampling Design

The main technologies needed under this alternative are statistical designs or approaches for planning sample collection. Although these technologies are not as critical to D&D as they are in remediation of large areas (e.g., burial grounds), they still may be useful in designing sampling strategies for areas such as concrete or asphalt pads and building walls.

3.2.1.2 Sample Collection

Sample collection methods exist for most of the D&D problems at ORNL, but many are inadequate or expensive, and technology improvements are needed. An example is the sampling of surfaces for contamination. Refinements are needed in laser and flashlamp surface desorption methods for organics and other contaminants. Sample coring methodologies are particularly important to determine contaminant depth penetration (as in concrete pads). Because sample collection may have to be conducted in high-radiation fields, the DOE as low as reasonably achievable (ALARA) principle is important in the adaptation and development of such technologies.

Concerns about sample collection are most relevant to ex situ methods of analysis in which samples are collected for transport to the analytical instrumentation.

3.2.1.3 Sample Preparation

One of the largest technology needs is the adaptation of conventional sample preparation methods to the special requirements of radioactive samples, where

containment in a radiochemical hood (low activities of alpha, beta, or gamma-emitting samples) or glove box (primarily for samples with alpha activities of 10^6 disintegrations per minute and greater) or shielding in a hot cell (generally, samples with beta/gamma radiation fields of 500 mR/h or greater) may be required. This includes upgrading organic and inorganic preparation methods and also regulatory leaching procedures. Current methodologies have not been able to meet regulatory requirements in some applications. High-pressure ashing is an example of a critically needed technology for preparing samples for inorganic and radiochemical analyses.

3.2.1.4 Detection/Measurement—Field Methods

These are very important technologies for D&D. Field measurement technologies are needed to define areas and boundaries of contamination. They can also screen samples in the field such that only those with significant contamination are returned to the laboratory for more extensive and expensive characterization. Field-method technologies are also discussed under specific contaminant group alternatives. In this general alternative, major needs are for field measurement technologies for determining radionuclide and heavy metal contamination and, to a lesser extent, certain organics. Deployment of these measurement technologies with robotics and automation is an important crosscutting area that promises to streamline and reduce costs of such surveys. Please refer to the robotics and automation chapter (Chap. 6) of this volume.

3.2.1.5 Detection/Measurement—Laboratory Methods

Laboratory-based technologies capable of multianalyte (e.g., inorganic and organic components) determinations are listed under the "general" alternative, while constituent group-specific technologies are presented under the specific alternatives. A technology need general to laboratory measurements is contamination control of the analytical equipment. This need goes hand-in-hand with adaptation of the sample preparation technologies for radioactive samples.

3.2.1.6 Data Analysis/Management

A wide range of information management and data analysis technologies will be needed, perhaps in some cases required, to support the level of tracking and accounting necessary to assure compliance with environmental laws and guidelines for conduct of activities. Configuration management support will be needed to meet the demands of working in a highly regulated environment, especially in dealing with hazardous materials. Decision aids, including simulation models, databases, full text information retrieval applications, and expert systems will be needed to assist with planning. Statistical analysis, graphical display, and geographical information system support will be needed to assist with analysis and interpretation of data. Large amounts of information and data will need to be transferred between the various groups of people working on the various aspects of the ER effort. Quick, reliable access to data or information distributed among many different organizations will be needed. All of these areas of support are best taken care of using computer networks. Network communications support then becomes yet another area of technology that must be included. The demands on project management and support made by environmental legislation, requirements for safe handling and processing of very hazardous materials,

and having adequate resources to deal with problems on the large scales that are involved make use of automation and networked computing capabilities essential or highly important.

3.2.1.7 Radioactive Elements—Field Methods

Fieldable technologies are needed to define areas of radiological contamination and to quantify radionuclides or radiation fields. They can reduce the sample load (and thus costs) for laboratory analyses and ensure that only the most important contaminated samples are sent to the laboratory for detailed analysis. Technologies for detecting surface contamination are particularly important to D&D.

3.2.1.8 Radioactive Elements—Laboratory Methods

A general technology need is the upgrading of radiochemical laboratory procedures and equipment to make them more rapid and efficient, and to reduce the generation of secondary laboratory wastes. This is important in view of the greatly increased sample load anticipated from WM and the need to minimize costs and wastes. A particularly important technology need is the development and validation of inductively coupled plasma-mass spectrometry methods for determining long-lived, low-specific activity radionuclides. Traditional chemical separation and counting methods are labor intensive and require long counting periods to meet sensitivity requirements. The inductively coupled plasma-mass spectrometry methods also can determine nonradioactive metals.

3.2.1.9 Inorganics—Field Methods

Technologies for determining inorganic composition, particularly on surfaces, are needed for the same reasons as described above for fieldable methods for radioactive elements. Promising technologies include X-ray fluorescence, which is especially useful for quickly measuring surface contamination by heavy metals.

3.2.1.10 Inorganics—Laboratory Methods

There are many established, accepted laboratory methods for inorganic analyses. Adaptation and upgrading these technologies to meet the special requirements of radioactive samples is required. A particularly useful technology is inductively coupled plasma-mass spectrometry methods.

3.2.1.11 Organics—Field Methods

Fieldable methods for organic compounds will be required for numerous deployments in large numbers. The technologies require development to make them more rugged and reliable in the field, simpler to operate so that the technical expertise required to use them is reduced. Fieldable gas chromatography and immunoassay-based field test kits for selected organic compounds or mixtures such as PCBs are high-priority technologies.

Fieldable methods for determining surface contamination by PCBs, oils, and fuel reprocessing chemicals (mainly tributyl phosphate and hydrocarbon residues) will be especially important to specific applications in D&D.

3.2.1.12 Organics—Laboratory Methods

Technologies that determine regulated and DOE-unique compounds (e.g., chelators or chelated radionuclides) are required. Improvements that will reduce secondary waste generation, and increase analytical speed and efficiency are needed in these technologies. Supercritical fluid extraction as a virtually waste-free preparation method and liquid chromatography-mass spectroscopy for nonvolatile analytes are examples of technologies that would greatly support D&D if developed and deployed.

3.2.1.13 Physical—Field Methods

Remote sensing of physical properties is needed to assist decontamination tasks. Fiber-optic systems for measuring multiple physical variables are important fieldable technologies.

3.2.1.14 Physical—Laboratory Methods

Characterization of contaminated materials and objects testing of structures are important technology needs.

3.2.2 Crosscutting Technologies

An important area of technology crosscutting is robotics and automation. This is particularly relevant in two areas of characterization: sample collection or field surveys in situations too hazardous or remote for direct human participation (as during the decontamination of highly radioactive hot cells or equipment) and preparation of highly radioactive samples for analysis (as for highly radioactive samples of scrabbled concrete). These crosscutting technologies are discussed in Chap. 6 of this volume.

7751

The basic R&D needs for characterization technologies range from none to considerable. Many characterization technologies are already mature and available on site. Examples of such technologies are gas chromatography-mass spectrometry, for identification and quantification of regulated organic compounds, and inductively coupled plasma-emission spectroscopy, for metals. Some development is required for fieldable-chromatographic instrumentation to determine surface contamination by organic compounds.

Other technologies will require basic research or development. The specific needs are explained in the *Technology Evaluation Data Sheets*, which are included in Vol. 3, Pt. A. Important examples are the surface contamination sampling technologies, such as surface heating by laser and direct interfacing to ion trap mass spectrometry. Development of advanced radiation sensors for field surveys of radiation fields and surface radionuclide contamination is another good example.

000051

3.4 IMPLEMENTATION NEEDS

Implementation needs, like science and technology needs, range from none to considerable. Instruments and U.S. Environmental Protection Agency (EPA) protocols already exist for determining many regulated organics and inorganics. These technologies have essentially no implementation needs and are ready as is for samples that contain no significant radioactive components. Other mature technologies are available on site, but some work is needed to deploy them. This work may entail calibration for the specific constituents and/or sample matrices or adaptation for deployment in certain locations, such as fieldable-gas chromatography or radiation sensors. Performance validation for method quality assurance is included in the implementation costs. Other technologies are not available on site, and it will require greater effort to obtain them and implement them at ORNL.

Some facility upgrades at ORNL are also required to handle the anticipated sample load. This is particularly true for radioactive samples that require shielding or containment and for which current facilities are inadequate.

3.5 TECHNOLOGY RANKINGS

The priorities assigned to the characterization technologies for D&D at ORNL are included in the last column of Table 3.1. The ranking system is essentially the same as that explained in Chap. 2, Sect. 2.3, in this volume.

Table 3.1. Rankings of characterization technologies for D&D

Alternative	Data sheet code number	Technology	Ranking[a]
Generally applicable to all D&D problem areas			
Sampling design	CHAR-252-OL	Sequential sampling plans	M-3-.5 ($.1M;$.5Kam[b])
	CHAR-71-OL	Optimization of sampling designs	H-5-.5 ($.1M;N)
	CHAR-228-OL	Sampling program configuration management system	E-5-1 ($.5M;$50Kam)
Sample collection	CHAR-20-OL	Ultrasonic extraction	M-4-1 ($.2M;$400/sample)
	CHAR-62-OL	In situ solvent extraction	M-4-2 ($.4M;N)
	CHAR-81-OL	Sampling and mixing methods	E-5-1 ($.2M;N)
	CHAR-82-OL	Punch cores	H-5-1 ($.3M;N)
	CHAR-67-OL	Metallographic sectioning and sample preparation	H-4-0 ($0M;<$500/sample)
	CHAR-64-OL	Multiangle drilling for depth profiling of containments	H-4-1 ($.2M;N)
	CHAR-271-OL	Sampling interface system for surface contamination by organics	H-4-3 ($.775M;N)
	CHAR-87-OL	Flashlamp heating to release or desorb surface and subsurface contaminants	H-4-2 ($.5M;N)
	CHAR-86-OL	Laser ablation for sample collection	H-4-2 ($.5M;N)
Sample preparation	CHAR-205-OL	Radioactive sample preparation	H-4-1 ($.1M;N)
	CHAR-208-OL	Supercritical fluid extraction of organics	H-4-1 ($.33M;$100/sample)
	CHAR-201-OL	Supercritical fluid extraction of inorganics	M-3-2 ($.2M;N)
	CHAR-209-OL	Adaptation of the EPA[c] toxicity characteristic leaching process for use with radioactive samples	H-5-1 ($.45M;N)
	CHAR-19-OL	Microwave digestion	H-5-1 ($.2M;$100/sample)
	CHAR-203-OL	High-pressure ashing for sample preparation	H-4-1 ($.1M;N)
Detection/ measurement—field methods	CHAR-25-OL	Fiber-optic chemical sensors	H-5-1 ($1M;$10/sample)
	CHAR-264-OL	Ion mobility mass spectrometry	M-5-2 ($1M;$50/sample)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Detection/ measurement—field methods (continued)	CHAR-23-OL	Immunoassay detection	H-5-3 ($1M;$50/sample)
	CHAR-84-OL	Portable Raman spectrometer	M-5-2 ($1M;$10/sample)
	CHAR-27-OL	Optical absorption spectroscopy	H-5-1 ($.6M;$50/sample)
	CHAR-59-OL	Air monitoring	H-5-0 ($.25M;$500/sample)
	CHAR-18-OL	Infrared spectroscopy (wavelength dispersion)	M-5-1 ($.5M;$100/sample)
	CHAR-52-OL	Personnel monitoring	H-5-1 ($.2M;N)
	CHAR-10-OL	Electrochemical methods	M-4-2 ($.5M;$100/sample)
	CHAR-15-OL	Laser photoacoustic spectroscopy	M-5-2 ($.4M;N)
	CHAR-92-OL	Portable luminescence detection	M-5-1 ($.5M;$10/sample)
Detection/ measurement-lab methods	CHAR-204-OL	Contamination control—analytical equipment	H-5-2 ($.5M;N)
	CHAR-8-OL	Fourier transform infrared spectroscopy	M-4-1 ($.2M;$100–500/sample)
	CHAR-48-OL	Isotopic dilution mass spectroscopy	H-4-0 ($0M;$100–1000/sample)
	CHAR-11-OL	Nuclear magnetic resonance	M-4-0 ($0M;$200–500/sample)
	CHAR-3-OL	Secondary ion mass spectrometry	H-4-0 ($0M;$50–400/sample)
	CHAR-9-OL	Ultraviolet/visible spectroscopy	H-5-0 ($.1M;$50–200/sample)
	CHAR-4-OL	Laser ionization mass spectrometry	M-4-0 ($0M;$100/sample)
	CHAR-10-OL	Electrochemical methods	M-4-1 ($.25M;>$100/sample)
Data analysis/ management	CHAR-221-OL also DISM-152-OL	Network architecture with integrated workstations	E-5-1 ($.5M;$50Kam)
	CHAR-233-OL	Hazard analysis expert system	E-5-2 ($.5M;$150Kam)
	CHAR-234-OL	Application of approximate reasoning to data analysis/evaluation	E-5-2 ($.5M;$150Kam)
	CHAR-253-OL	Spatial sample and data analysis plans	H-3-0.5 ($.1M;$.5Kam)

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Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Data analysis/ management (continued)	CHAR-251-OL	Statistical methods for the analysis of large data sets	M-3-3 ($.5M;$.5Kam)
	CHAR-250-OL	Quality control for measurement processes	E-4-.25 ($.05M;$.5Kam)
	CHAR-249-OL	Analysis of censored data	H-4-.25 ($.05M;$.5Kam)
	CHAR-44-OL	Criticality indices	L-2-1 ($.25M;N)
	CHAR-53-OL	Modeling of volatile organic compounds migration in porous materials	M-4-1 ($.2M;N)
	CHAR-241-OL	Task scheduling aids	M-4-1 ($.05M;N)
	CHAR-225-OL	Fractals used to select models for material transport in porous media	M-2-2 ($.5M;$20Kam)
	DISM-151-OL	Project information access services (needed enabling technologies)	E-5-1 ($.5M;$100Kam)
	DISM-153-OL	Client/server access to standards and regulatory guidelines (needed enabling technologies)	E-5-0.5 ($.25M;$25Kam)
	DISM-154-OL	Data access services (needed enabling technologies)	E-5-1 ($.5M;$200Kam)
	DISM-181-OL	Geographic information system for DOE sites (needed enabling technologies)	E-5-1 ($1M;$200Kam)
	DISM-155-OL	Automated scanning and conversion of engineering drawings (needed enabling technologies)	E-5-2 ($2M;$300Kam)
	DISM-171-OL	Simulated walk-through facility for robotics task sequence analysis (needed enabling technologies)	E-5-1 ($.3M;$60Kam)
	DISM-191-OL	Computer-based training systems (needed enabling technologies)	E-5-1 ($.3M;$100Kam)
	DISM-172-OL	Computer-aided task analysis and procedure preparation (needed enabling technologies)	E-5-1 ($.5M;$150Kam)
	DISM-157-OL	Client/server architecture for data-base access (needed enabling technologies)	E-5-1 ($.5M;$200Kam)

000056

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Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Data analysis/ management (continued)	DISM-158-OL	Hypertext information systems (needed enabling technologies)	E-5-1 ($.3M;$150Kam)
	CHAR-240-OL	Fiber-optic detection and monitoring system (intelligent materials)	M-4-3 ($3M;$1K/container)
	DISM-156-OL	3-D CAD data base of buildings and structures (needed enabling technologies)	E-5-2 ($2M;$300Kam)
	DISM-173-OL	Generalized object-oriented simulation software (needed enabling technologies)	E-3-2 ($.5M;$200Kam)
	DISM-174-OL	Automated engineering system life cycle planning (needed enabling technologies)	E-5-1 ($.3M;$60Kam)
	DISM-175-OL	Automated system reliability and safety analysis (needed enabling technologies)	E-5-2 ($.5M;$150Kam)
Radioactive elements—field methods	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 ($.1M;$100/sample)
	CHAR-102-OL	Passive monitors for weak beta radionuclides	M-4-2 ($.6M;$20/sample)
	CHAR-103-OL	Thermoluminescence dosimeter array for spatial characterization of alpha contamination	M-4-3 ($.6M;$20/sample)
	CHAR-65-OL	Long-range alpha detector	M-4-1 ($.4M;$100/sample)
	CHAR-263-OL	Portable gamma-ray scintillometers	H-4-0 ($0M;$100/sample)
	CHAR-269-OL	Advanced radiation monitors	M-4-2 ($.4M;$50/sample)
	CHAR-216-OL	Bubble dosimeters for neutron flux	M-4-1 ($.2M;$15/sample)
	CHAR-105-OL	Tritium/beta/gamma floor scanner	H-4-0 ($0M;N)
	CHAR-95-OL	Electret passive surface alpha monitor	H-4-1 ($.3M;$15/sample)
	CHAR-96-OL	Alpha track etch detectors for surface alpha contamination	H-4-1 ($.4M;$10/sample)
Radioactive elements—laboratory methods	CHAR-107 and 266-OL	Neutron activation	H-4-1 ($.2M;$300/sample)
	CHAR-106-OL	Sodium iodide-germanium gamma spectroscopy	H-4-0 ($0M;N)

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Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Radioactive elements—laboratory methods (continued)	CHAR-202-OL	Radioanalytical procedures	H-4-2 ($1M;N)
	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 ($.1M;$100/sample)
	CHAR-97-OL	Photon electron rejecting alpha liquid scintillation	H-4-0 ($0M;N)
	CHAR-268-OL	Gamma-ray spectrometry	H-5-0 ($.1M;$100/sample)
	CHAR-267-OL	Liquid scintillation counting	H-5-0 ($.1M;$100/sample)
	CHAR-40-OL	Radiographic imaging	M-4-1 (N;N)
Inorganics—field methods	CHAR-76-OL	Atomic emission spectroscopy	M-4-1 ($.2M;N)
	CHAR-6 and CHAR-219-OL	Portable X-ray fluorescence	H-5-1 ($.2M;$25/sample)
	CHAR-111-OL	Laser ablation; inductively coupled plasma; atomic emission spectroscopy	H-5-3 ($1M;N)
Inorganics—laboratory methods	CHAR-78-OL	Inductively coupled plasma—mass spectroscopy	H-4-2 ($1M;$200/sample)
	CHAR-77-OL	Inductively coupled plasma spectroscopy	H-4-0 ($.1M;$200/sample)
	CHAR-76-OL	Atomic emission spectroscopy	H-4-0 ($.1M;$200/sample)
	CHAR-50-OL	Ion chromatography	H-4-0 ($0.1M;$100/sample)
	CHAR-37-OL	Electron diffraction	M-4-0 ($0M;$100/sample)
	CHAR-36-OL	Wavelength dispersive X-ray spectroscopy	M-4-0 ($0M;$100/sample)
	CHAR-35-OL	Energy dispersive X-ray spectroscopy	M-4-0 ($0M;$100/sample)
	CHAR-34-OL	Transmission electron microscopy	M-4-0 ($0M;$100/sample)
	CHAR-33-OL	Scanning electron microscopy	M-4-0 ($0M;$100/sample)
	CHAR-17-OL	Particle-induced X-ray emission	M-4-0 ($0M;$100/sample)
	CHAR-24-OL	Cold-vapor (mercury) analysis	H-4-0 ($0M;$100/sample)
	CHAR-266-OL	Neutron activation analysis	H-4-1 ($.2M;$200/sample)

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Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Inorganics—laboratory methods (continued)	CHAR-31-OL	Powder X-ray diffraction	M-4-0 ($0M;>$100/sample)
	CHAR-1-OL	Electron spectroscopy for chemical analysis	M-4-0 ($0M;$200–$600/sample)
	CHAR-2-OL	Auger electron spectroscopy	M-4-0 ($0M;$300–$800/sample)
	CHAR-56-OL	Glow discharge ionization mass spectroscopy	H-4-1 ($.5M;N)
Organics—field methods	CHAR-100-OL	Portable gas chromatograph/electron capture detection for analyzing PCBs[d]	H-4-0 ($.25M;$50/sample)
	CHAR-5-OL	Portable volatile organic compound detectors	H-5-0 ($.25M;$10/sample)
	CHAR-110-OL	Fluorescence diagnosis of contaminated surfaces	M-3-2 ($1M;$10/sample)
	CHAR-85-OL	Infrared absorption (laser-based source)	M-4-2 ($.5M;N)
	CHAR-262-OL	Gas chromatography in the field	H-5-0 ($.25M;$50/sample)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-4-1 ($.2M;<$50/sample)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-5-2 ($.2M;$50/sample)
Organics—laboratory methods	CHAR-206-OL	Analytical methods for chelators and decontamination agents	M-3-1 ($.25M;$500–$1000/sample)
	CHAR-207-OL	Capillary zone electrophoresis	M-3-1 ($.25M;$300/sample)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-5-1 ($.25M;$300/sample)
	CHAR-66-OL	Gas chromatography—fourier transform infrared spectroscopy	M-4-2 ($.5M;$400/sample)
	CHAR-89-OL	Liquid chromatography—mass spectrometry	M-4-1 ($.3M;$500/sample)
	CHAR-88-OL	Gas chromatography—mass spectrometry	E-5-0 ($0M;$200–$800/sample)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	H-5-1 ($.2M;$10/sample)

000059

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Organics—laboratory methods (continued)	CHAR-94-OL	Gas chromatography	H-5-0 ($0M;$300/sample)
	CHAR-93-OL	Laser ablation organic mass spectrometry	H-5-1 ($.3M;<$500/sample)
	CHAR-265-OL	Surface-enhanced Raman scattering	H-4-1 ($.15M;N)
Physical—field methods	CHAR-246-OL	Instrument response models for remote sensing	E-5-2 ($0.6M;$200Kam)
	CHAR-248-OL	Fiber-optic systems for measuring multiple physical variables	E-5-3 ($1M;$.25/sample event)
Physical—laboratory methods	CHAR-26-OL	Particle size analysis	M-4-0 ($0M;$1000/sample)
	CHAR-32-OL	Optical microscopy	M-4-0 ($0M;$100–$800/sample)
	CHAR-58-OL	Magnetic resonance imaging	M-4-0 ($.2M;N)
	CHAR-46-OL	Holographic imaging	M-4-0 (N;N)
	CHAR-39-OL	Inorganic cemetitious matrix composites model	M-4-0 (N;N)
	CHAR-38-OL	Nondestructive testing for concrete	M-4-0 (N;N)
	CHAR-61-OL	Modeling of heterogeneous materials sampling	H-4-0 ($.3M;N)
	CHAR-42-OL	Radiation-induced segregation model	H-4-2 ($.5M;N)
Building 9203-1, 3517, and 3019 fuel reprocessing or oil D&D problem areas			
Field methods	CHAR-85-OL	Infrared absorption (laser-based source)	M-3-2 ($.5M;N)
	CHAR-05-OL	Portable volatile organic compound detectors	H-3-0 ($.25M;$10/sample)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-3-2 ($1M;$50/sample)
	CHAR-15-OL	Laser photoacoustic spectroscopy	H-3-3 ($.775M;N)
	CHAR-262-OL	Gas chromatography in the field	H-3-0 ($.25M;$50/sample)
	CHAR-18-OL	Infrared spectroscopy (wavelength dispersion)	M-3-1 ($.5M;$100/sample)
	CHAR-25-OL	Fiber-optic chemical sensors	H-3-1 ($1M;$10/sample)

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Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Laboratory methods	CHAR-88-OL	Gas chromatography—mass spectrometry	E-3-0 ($0M;$200–$800/sample)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-3-1 ($.25M;$300/sample)
	CHAR-93-OL	Laser ablation organic mass spectrometry	H-3-1 ($.3M;<$500/sample)
	CHAR-206-OL	Analytical methods for chelators and decontamination agents	H-3-1 ($.25M;$500–$1000/sample)
	CHAR-89-OL	Liquid chromatography—mass spectrometry	M-4-1 ($.3M;$500/sample)
Building 9201-3 asbestos piping insulation PCB D&D problem area			
Field methods	CHAR-100-OL	Portable gas chromatograph/electron capture detection for analyzing PCBs	H-3-0 ($.25M;$50/sample)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-3-2 ($.2M;$50/sample)
	CHAR-15-OL	Laser photoacoustic spectroscopy	H-3-3 ($.775M;N)
Laboratory methods	CHAR-94-OL	Gas chromatography	H-3-0 ($0M;$300/sample)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-3-1 ($.25M;$300/sample)

[a] The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b] Kam = Thousands of dollars annual maintenance.
[c] EPA = Environmental Protection Agency
[d] PCBs = polychlorinated biphenyls

3.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the characterization technologies listed in Table 3.1. Table 3.2 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with the complete set of characterization technologies listed in the TLD, Vol. 1, Pts. A, B, and C. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding characterization technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Characterization technologies for which no matches were found are omitted from the table. When many matches were found, specific TTPs may or may not be cited, but it is noted that many exist. The relevance column indicates the degree of overlap between the technologies listed in Vol. 1, Pts. A, B, and C, and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 3.2. Characterization technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Auger electron spectroscopy (AES)	CHAR-2-OL	OR121115	M	Uses EDX[c] for U analysis
Laser ionization mass spectroscopy	CHAR-4-OL	CH101101		Laser-ablated inductively coupled plasma (ICP)
Portable volatile organic compound detectors	CHAR-5-OL	CH101104	H	Portable volatile organic compound (VOC) analyzer
Portable X-ray fluorescence	CHAR-6-OL	RL321114	H	Field-portable XRF
		RL321113	H	Develop field-portable XRF
Fourier transform infrared spectroscopy	CHAR-8-OL	AL221108	M	Uses Fourier transform infrared (FTIR) for chromium
		AL239002	L	Uses in-package tests
		CH111203	M	Integration demo: sensors, monitoring
		CH131001	H	FTIR analysis of waste
Ultraviolet/visible spectroscopy	CHAR-9-OL	OR121101	H	In situ fiber-optic probe development
		OR101101	H	In situ fiber-optic derivative ultraviolet (UV) spectroscopy
		CH101101	H	Mobile ICP atomic emission spectroscopy
		AL213204	M	Robotics to include AES
		AL221108	M	Uses AES for chromium
		CH114101	M	CATD[d] and TTP[e]: sensors, monitors
Electrochemical methods	CHAR-10-OL	RL321112	H	Stripping voltametry
Nuclear magnetic resonance	CHAR-11-OL	RL132002	M	Using technique on polymers
Laser photoacoustic spectroscopy	CHAR-15-OL	AL113101	M	Technology studies
		AL121122	M	Use on Fernald soil samples
		CH101104	M	Portable VOC analyzer
		CH131001	M	Photoacoustic spectroscopy
Infrared spectroscopy (wavelength dispersion)	CHAR-18-OL	CH101104	L	FTIR (but not atmospheric)
Microwave digestion	CHAR-19-OL	AL132006	H	Microwave detoxification of mixed waste
		OR123101	H	Lead lab for EPA SW-846 mixed waste adaptation
		AL123101	H	EPA SW-846 for mixed waste
Ultrasonic extraction	CHAR-20-OL	RF121204	L	Ultrasonic cleaning at RFP[f]

Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Fiber-optic chemical sensors	CHAR-25-OL	OR101101	H	Fiber-optic derivative UV spectrometry
		ID111701	M	Innovative technology development
		SF211203	H	Fiber-optic Raman system development
		SR132003	H	Infrared fiber-optic spectrophotometer
		Many more		Widely pursued technology
Optical absorption spectroscopy	CHAR-27-OL	OR101101	M	Fiber-optic version
		SF211203	H	Fiber-optic differential absorption spectrometer
Scanning electron microscopy	CHAR-33-OL	OR121115	M	One example of widely used technology
		Many More		
Transmission electron microscopy	CHAR-34-OL	OR121115	M	Example. Mature technology; needs careful sample preparation
Energy dispersive X-ray spectroscopy	CHAR-35-OL	AL221108	M	Using on Cr mobility study
Electron diffraction	CHAR-37-OL	AL121120	H	Site geochemistry characterization use
		AL121122	H	Site geochemistry characterization use
		AL221108	H	Cr mobility studies
		OR121115	H	U solubility in soil study
Inorganic cementitious matrix composites model	CHAR-39-OL	CH331001	L	Cement matrix grout development and application
Computer tomography	CHAR-41-OL	AL221123	M	Electromagnetic tomography (especially water) of underground sites
		SF223203	H	Developing CT for waste drum inspection
Subsurface complexation model	CHAR-45-OL	AL931102	L	Geochemistry: Monticello, Utah
		ID111701	L	Chelation: lanthanides, actinides
		RL331002	L	Chemical barriers in-ground
Ion chromatography	CHAR-50-OL	Many		Accepted and widely used
Modeling of volatile organic compounds migration in porous materials	CHAR-53-OL	None except soil		Much work directed at soil
Membranes for sample collection and concentration	CHAR-55-OL	OR111204	M	HEPA[g] filter
		AL131007	M	VOC in air sampling
		AL221107	L	Borehole membrane liner
		SR121106	L	Membrane use
Glow discharge ionization mass spectroscopy	CHAR-56-OL	AL131007	M	Membrane sampling ion trap mass spectrometry

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Magnetic resonance imaging	CHAR-58-OL	RL132002	M	Using technique on polymers
Air monitoring	CHAR-59-OL	Many		Widely used. Tailor to application need
Tomographic seismic monitoring	CHAR-60-OL	AL201101	H	Seismic tomography development, use SRID[h]
		AL221123	M	Underground imaging (resistance)
		CH221101	M	Seismic wave measurement of clay at Savannah River
		SF121101	H	High-resolution seismic imaging
		SF121102	M	Underground imaging (resistance)
		AL021102	M	Seismic survey and analysis
Modeling of heterogeneous materials sampling	CHAR-61-OL	SR132003	L	Chemometric models tank waste spectrophotometry
In situ solvent extraction	CHAR-62-OL	SR121107	L	Vacuum extraction of VOC from soil at SRID
		Many more	L	
Long-range alpha detector	CHAR-65-OL	AL131002	H	LRAD developed, used at Fernald
Atomic emission spectroscopy	CHAR-76-OL	Many		Widely used technique
Inductively coupled plasma spectroscopy	CHAR-77-OL	CH101101	H	Mobile ICP-AES development
		Many		Widely used technology
Inductively coupled plasma—mass spectroscopy	CHAR-78-OL	OR111105	M	Direct sampling ion-trap mass spectrometer (ITMS)
		AL113101	M	Covered in field screening project
Sampling and mixing methods	CHAR-81-OL	AL131003	H	Use on Fernald soil
		NV031001	H	Use on Nevada Test Site soil
Portable Raman spectrometer	CHAR-84-OL	OR121101	H	Fiber-optic raman sensor development
		OR101101	H	Employ sensor on aromatic hydrocarbons (HCs)
		RL401206	M	Use raman sensing in hot cell
		SF211203	H	Development raman sensor for RL401206
Infrared absorption (laser-based source)	CHAR-85-OL	RL401206	M	Near IR absorption
		SF211203	H	Near IR raman with diode laser
Laser ablation for sample collection	CHAR-86-OL	CH101101	H	Laser ablation ICP development
Gas chromatography—mass spectrometry	CHAR-88-OL	Many		Widely used

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Liquid chromatography—mass spectrometry	CHAR-89-OL	AL113101	M	Considered in field screening
		ID101301	H	Used on hydrophobic organic compounds (HOCs)
		SR132002	H	Used on cesium extraction project
Direct sampling ion-trap mass spectrometer	CHAR-90-OL	OR101102	H	Development
		OR101103	H	Development and application
		OR101105	H	Use with army toxic materials
		OR121103	H	Use at SRIDP[1]
		Others		
Portable luminescence detection	CHAR-92-OL	OR121201	H	Luminescence spot test for PCBs
Laser ablation organic mass spectrometry	CHAR-93-OL	CH101101	H	Laser ablation ICP
Gas chromatography	CHAR-94-OL	Many		Widely used
Photon electron rejecting alpha liquid scintillation	CHAR-97-OL	ORNL-DOSAR Facility	H	Evaluate uranium resuspension at Weldon Springs cleanup
Portable gas chromatograph/electron capture detection for analyzing PCBs	CHAR-100-OL	RL321101	M	HOC monitoring off-gas treatment project VOC-nonarid
Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	CHAR-101-OL	OR121101	H	In situ fiber-optic probe development
Sodium iodide-germanium gamma spectroscopy	CHAR-106-OL	AL131004	M	Gamma detector used in project
		AL931001	M	Gamma detector used in project
Neutron activation	CHAR-107-OL	AL911201	M	Neutron activated fission for detection of uranium
		AL921101	M	Prompt fission neutron logging
		AL931001	M	Neutron activated fission
Fluorescence diagnosis of contaminated surfaces	CHAR-110-OL	OR121101	M	In situ fiber-optic probe development
Laser ablation; inductively coupled plasma; atomic emission spectroscopy	CHAR-111-OL	CH101101	H	Laser ablation ICP
		CH501301	H	Field test, Fernald
On-line supercritical fluid extraction—multidetector gas chromatography	CHAR-115-OL	AL123101	M	Use for SW-846 methods
		ID4231010	M	Use for SW-846 methods
Ground-penetrating radar	CHAR-124-OL	AL921102	H	Used on mixed waste landfill
		NV001102	M	Airborne tests
		RL313203	H	Tested on landfill

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Electrical and electromagnetic detection of ground and geologic features	CHAR-125-OL	SF121102	H	Underground imaging (resistance)
Seismic methods (refraction, profiling, reflection)	CHAR-126-OL	AL201101	H	Seismic tomography development, use SRID
		CH221101	M	Seismic wave measurement of clay at Savannah River
		SF121101	H	High-resolution seismic imaging
		AL921102	M	Seismic survey and analysis
Magnetics	CHAR-128-OL	AL911201	H	Tensor magnetic gradiometer
		AL921102	M	Landfill characterization
		ID132003	H	Use for site characterization
Supercritical fluid extraction of inorganics	CHAR-201-OL	ID111701	H	Lanthanides and actinides with lariat crown ethers
Radioanalytical procedures	CHAR-202-OL	CH013102	L	EM[j] analytical laboratories performance evaluation
Contamination control—analytical equipment	CHAR-204-OL	AL213203	L	Characterization automation
Radioactive sample preparation	CHAR-205-OL	OR123101	M	Adapted SW-486 methods for radioactive mixed waste analysis
Analytical methods for chelators and decontamination agents	CHAR-206-OL	AL132002	M	Polymers for Pu and Am concentration for wastewater
Capillary zone electrophoresis	CHAR-207-OL	SF213203	M	Robotic cross cutting advanced technology
Supercritical fluid extraction of organics	CHAR-208-OL	ID111701	L	Lanthanides and actinides with lariate crown ethers
Adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples	CHAR-209-OL	RF101205	L	Incineration alternatives
Fissile material locator/profiler	CHAR-212-OL	NV021701	H	Associated particle imaging
		AL931001	L	Multispectral neutron logging
X-ray fluorescence for in situ monitoring of toxic heavy metals	CHAR-219-OL	RL321114	H	Field-portable XRF
		RL321113	H	Field-portable XRF development
Sampling program configuration management system	CHAR-228-OL	Many	H	Used at many other sites
Configuration management system	CHAR-229-OL	Many	H	Used at many other sites

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Fiber-optic systems for measuring multiple physical variables	CHAR-248-OL	SF213203	H	Microsensor systems development
Quality control for measurement processes	CHAR-250-OL	CH013101	H	Analytical management—quality assessment program (EML[R])
Sequential sampling plans	CHAR-252-OL	Many	H	Accepted and widely used
Spatial sample and data analysis plans	CHAR-253-OL	Many	H	Accepted and widely used
Solid sorbent sampling for airborne organics	CHAR-254-OL	AL113101	M	Field screening study
Soil/sediment sampling for volatile organics analysis	CHAR-256-OL	Many	H	Widely found
In situ ground-water flow meter	CHAR-258-OL	OR121104	H	Colloidal borescope
Ground-water discharge location	CHAR-259-OL	Many	H	Accepted and widely used
Waste drum gamma activity monitor	CHAR-261-OL	SF223203	H	Waste facilities operation & sorting technology
		SR113201	H	Savannah River robotics, waste facilities operations
Gas chromatography in the field	CHAR-262-OL	ALTTPMSA	M	Mobile sample analysis laboratory
Portable gamma-ray scintillometers	CHAR-263-OL	AL112101	L	Field screening studies
		SF223203	M	Used in waste facilities operations
Surface-enhanced Raman scattering	CHAR-265-OL	OR121101	H	Spectroelectrochemical sensors
		SF211203	M	Advanced fiber-optic spectroscopy for inorganic contaminants
Neutron activation analysis	CHAR-266-OL	AL131004	M	Multispectral neutron logging
		AL031001	H	Multispectral neutron logging
Liquid scintillation counting	CHAR-267-OL	AL931102	L	Chemical barriers demonstration
		ORNL-DOSAR Facility	H	U resuspension evaluation
Gamma-ray spectrometry	CHAR-268-OL	RL132002	M	Polymer concentration of U and Pu (gamma technique)
Advanced radiation monitors	CHAR-269-OL	AL121218	M	Real time emission monitor
		ID111701	M	Fiber-optic thermoluminescence dosimeter monitor development
		ID121210	M	BWID contamination control

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Sampling of heterogeneous wastes	CHAR-270-OL	AL123101	M	Adapted SW-846 methods for mixed waste analysis
Sampling interface system for surface contamination by organics	CHAR-271-OL	CH101101	H	Laser ablated ICP mass spectrometer
SEAMIST inverted membrane	CHAR-273-OL	AL221107	H	Landfill characterization system
Hydrofracture ground-water monitoring	CHAR-274-OL	Many	H	Accepted and widely used
Sediment sampling	CHAR-276-OL	OR113203	H	Robotics advanced technologies

[a] TTP = Technical Task Plan identifier.
[b] The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagram* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

[c] EDX = energy-dispersive X-ray analysis
[d] CATD = Center for Advanced Technology Development
[e] TIP = Technology Information Program
[f] RFP = Rocky Flats Plant
[g] HEPA = high-efficiency particulate air
[h] SRID = Savannah River Integrated demonstration
[i] SRIDP = Savannah River Integrated Demonstration Project
[j] EM = environmental management
[k] EML = Environmental Measurements Laboratory

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4. DISMANTLEMENT/DISASSEMBLY

4.1 INTRODUCTION

The dismantlement section of the TLD addresses site-specific problems and needed technologies that appear to offer the most promise for remediation. Figure 4.1, the D&D Sequence Chart, was prepared as a potential process for identifying steps by the dismantlement team. Please note that all steps in the sequence highlighted by the bold, outlined boxes are considered dismantlement tasks.

Figures 4.2–4.6 show typical facilities at ORNL that are included in the D&D Program. Of specific interest is Fig. 4.5. The Molten Salt Reactor Experiment facility still contains the highly radioactive fuel shown in the tanks in Fig. 4.5. The Molten Salt Reactor Experiment was a single-region, unclad-graphite-moderated, homogeneous-fueled reactor built for investigation of the practicality of the molten salt reactor concept for power station applications. The circulating molten fuel was a mixture of lithium, beryllium, and zirconium-fluoride salts, containing uranium fluoride as a fuel (^{233}U). Figure 4.6 is a layout of the Homogeneous Reactor Experiment. The Homogeneous Reactor Experiment facility housed two experimental reactors that were developed for nuclear power applications analysis. The fuel in these reactors was an aqueous liquid and has been removed from the facilities.

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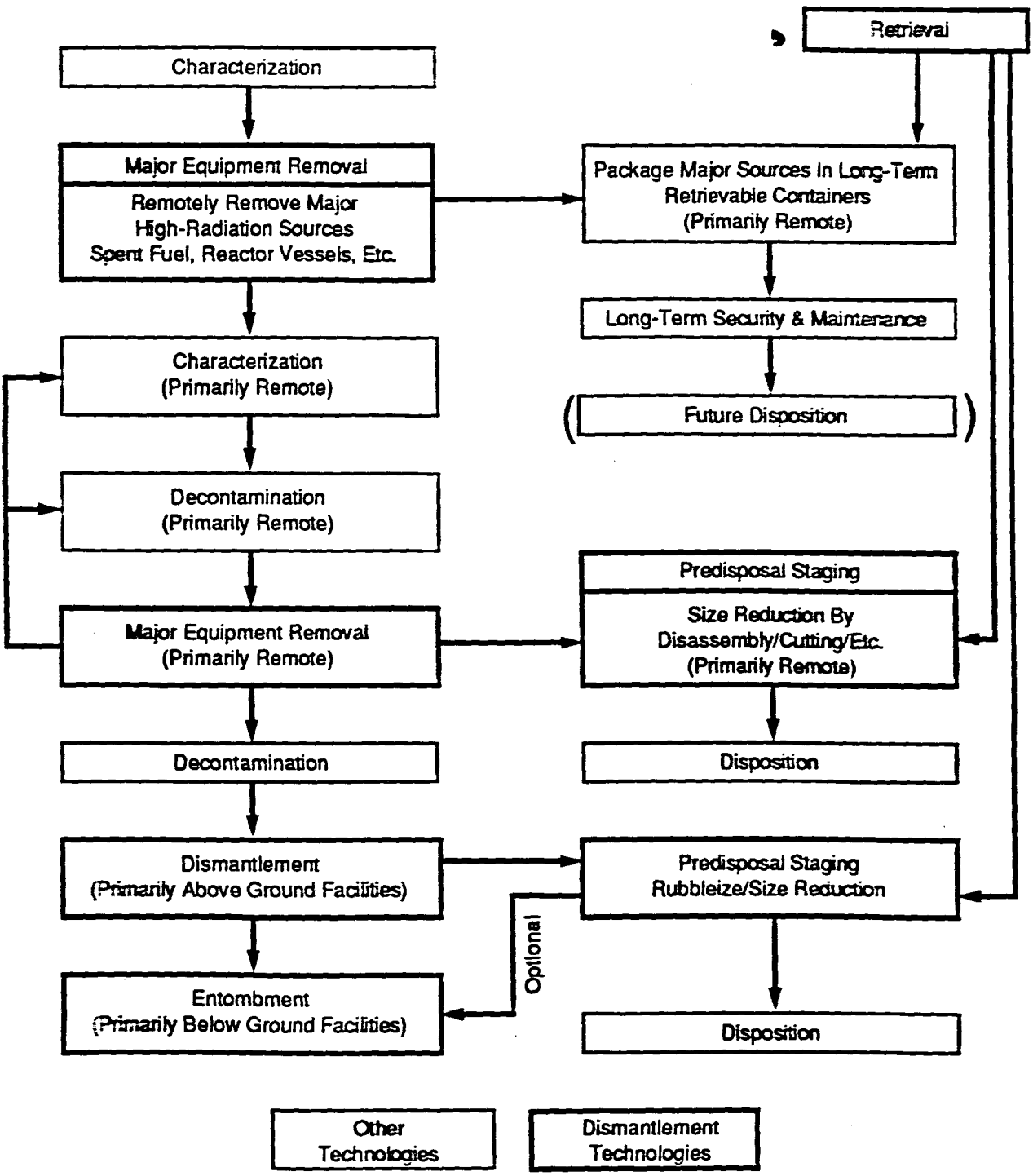

Fig. 4.1. Decontamination and Decommissioning sequence chart.

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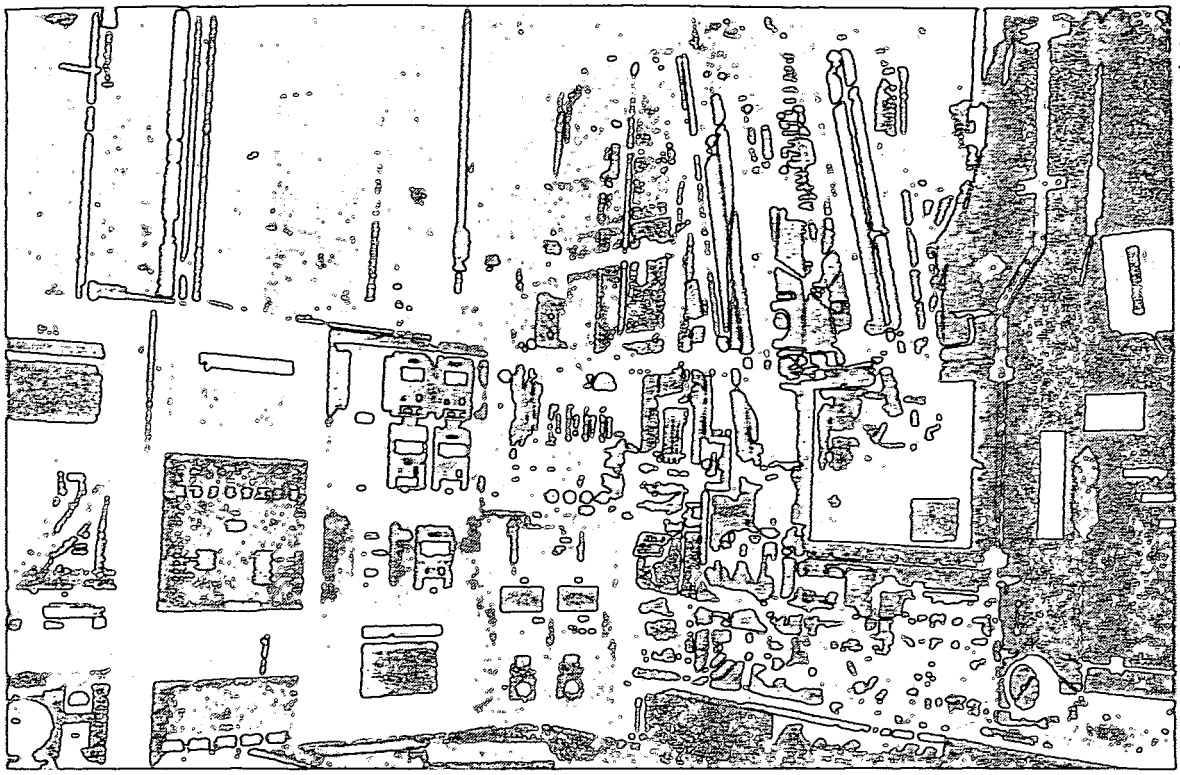

Fig. 4.2. Typical operating face of mechanical processing cell.

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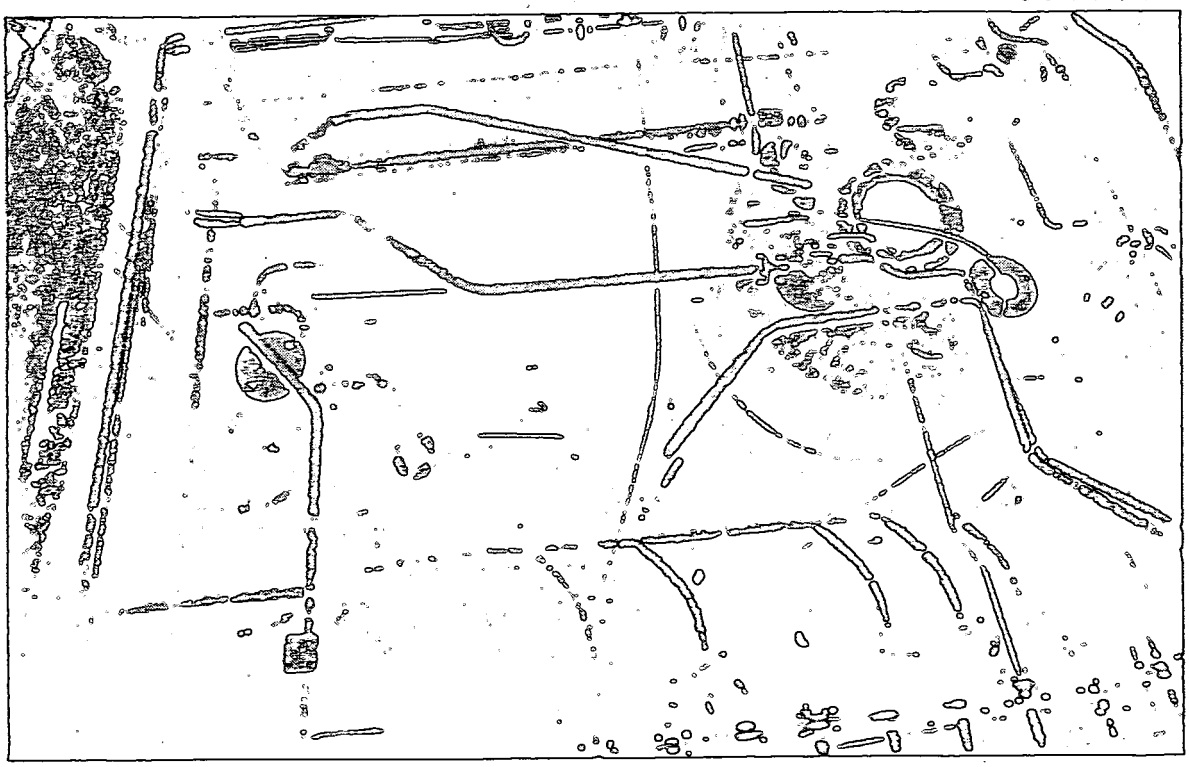

Fig. 4.3. Typical chemical processing hot cell with roof plug removed.

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Fig. 4.4. Conventional manual dismantlement technique in low-radiation areas.

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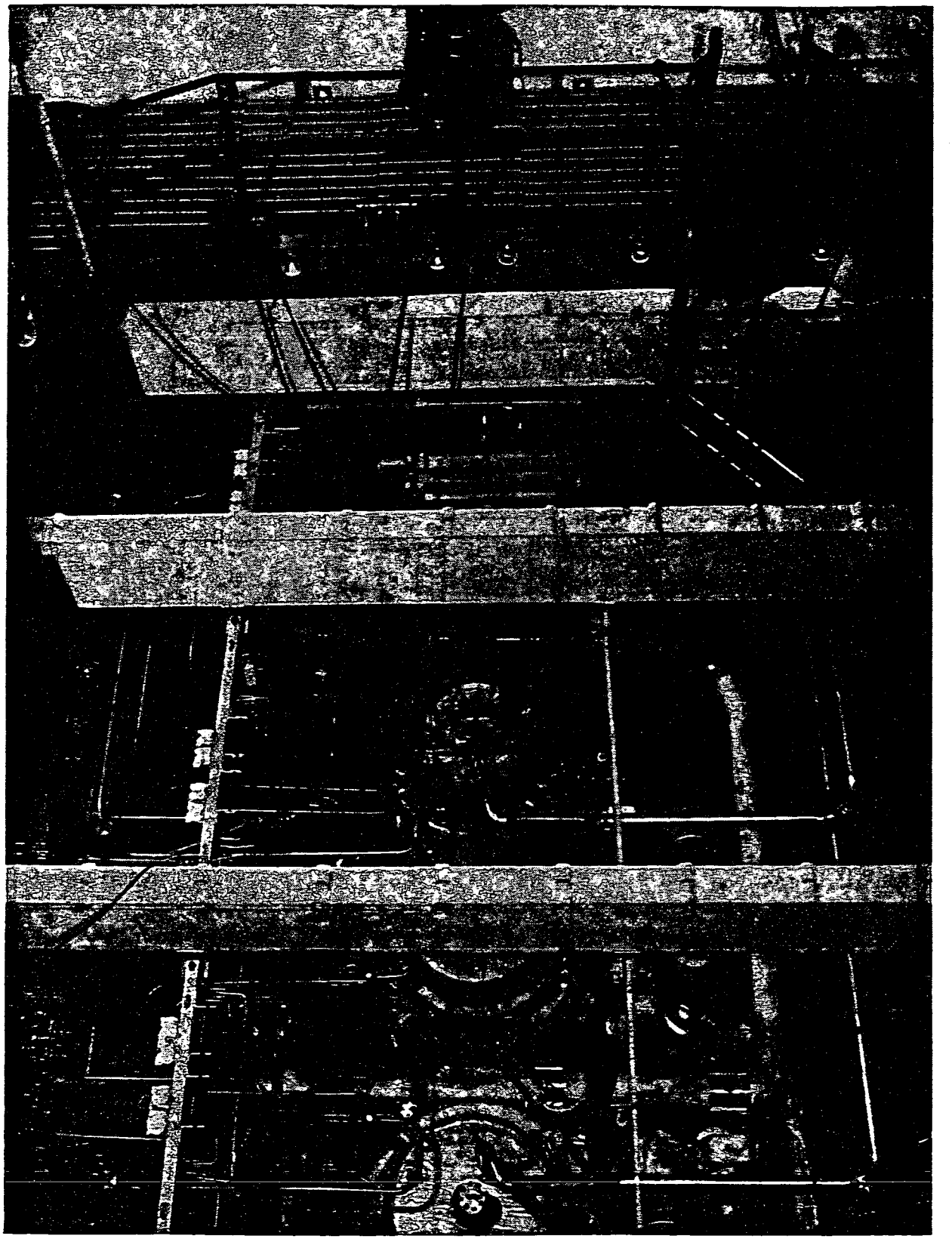

Fig. 4.5. Drain tank cell for Molten Salt Reactor Experiment during construction.

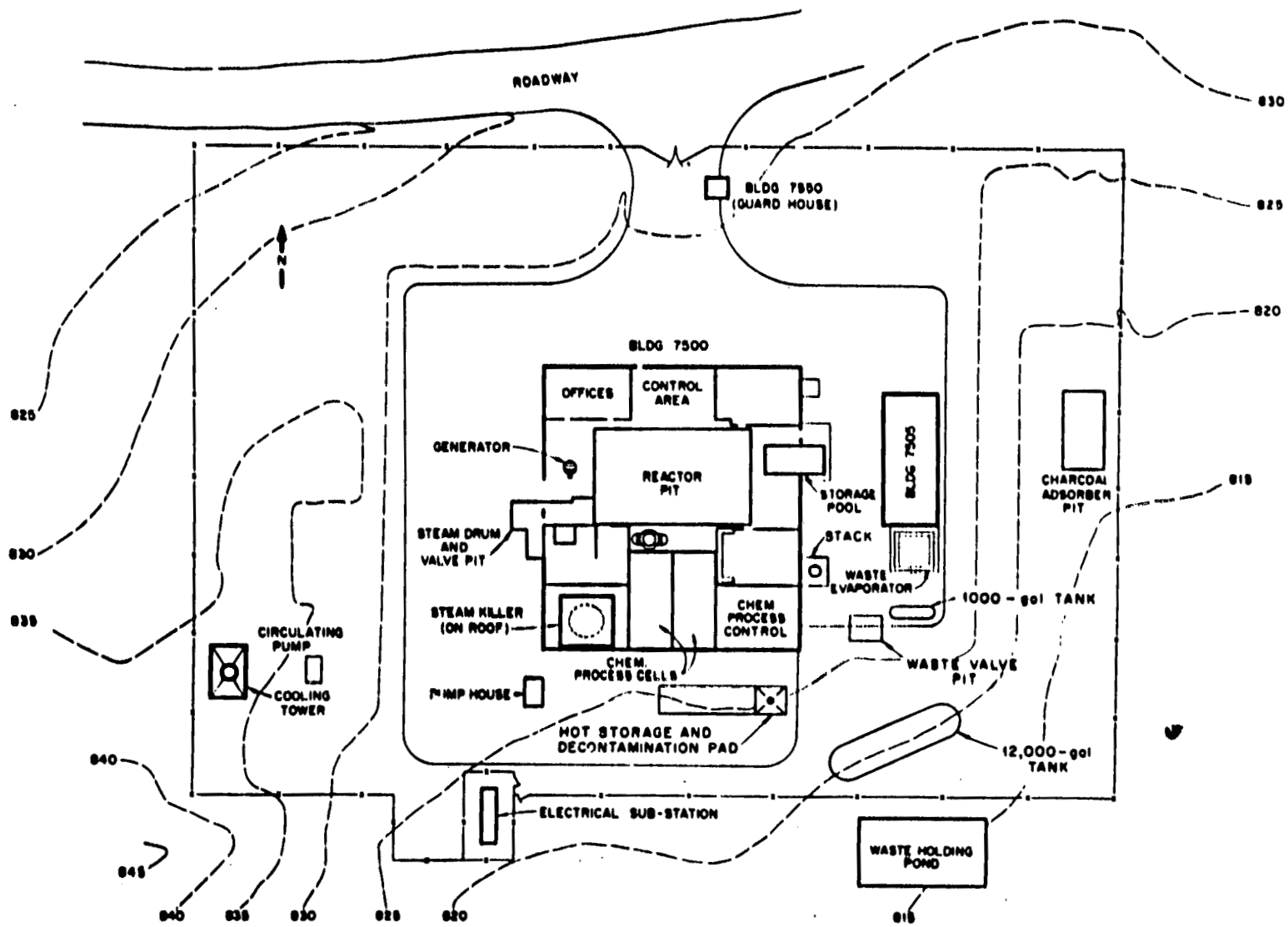

Fig. 4.6. Homogeneous Reactor Experiment Facility Schematic.

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4.1.1 Problem Area/Constituents for Dismantlement at ORNL

4.1.1.1 Massive Containment

These technologies will address problems associated with the removal of mechanical and chemical hot-cell structures, which is primarily heavily reinforced concrete contaminated with ^{60}Co, ^{137}Cs, ^{90}Sr, and other fission products. Radiation fields may exceed 2,500 R/h. An example of this is the fuel storage cell in the Molten Salt Reactor Facility.

4.1.1.2 Reactor Pools

These technologies will address problems associated with the removal of pool-type structures such as the Oak Ridge Research Reactor. These structures may be contaminated with ^{60}Co, ^{90}Sr, ^{137}Cs, ^{14}C, ^{55}Fe, and other fission products. Technologies here are similar to those listed under Massive Containment except emphasis is placed on under water applications. Radiation fields on surfaces may exceed 50,000 R/h. An example of this problem is the Oak Ridge Research Reactor Pool.

4.1.1.3 Buried Tanks

These technologies are selected for their applicability to buried tanks such as the Gunite Tanks. Also in this category would be buried vaults housing tanks or housing underground process equipment. These structures are typically contaminated with all possible contaminants listed in Sect. 4.1.1.1.

4.1.1.4 Structural-Only Concrete

This problem category addresses technologies typical for nonnuclear deconstruction.

4.1.1.5 Steel Structures—High-Level Contamination

These technologies are directed toward removal of steel structural materials that are possibly heavily contaminated with ^{137}Cs, ^{90}Sr, Ce, and Ru. Radiation levels may be 10–100 R/h. An example of this is secondary containment structure of the Homogeneous Reactor Experiment.

4.1.1.6 Steel Structures—Low-Level Contamination

These technologies are directed toward removal of steel structural materials that are contaminated with trace quantities of fission products, plutonium, ^{14}C, ^{55}Fe, ^{137}Cs, ^{90}Sr, and ^{60}Co. An example of this problem is the roof structure of the Oak Ridge Graphite Reactor.

4.1.1.7 Asbestos Removal

These technologies address the removal of asbestos materials contaminated with trace amounts of fission products, ^{137}Cs, ^{239}Pu, ^{233}U, and ^{228}Th. An example of this problem is the Molten Salt Corrosion Loop. Maximum radiation levels are 3500 dpm/100 cm^2, transferable.

4.1.1.8 Major Equipment Removal

These technologies are applicable to equipment removal, size reduction, and packaging of items contaminated with minor to very significant amounts of radioactive isotopes, including fission products, ^{60}Co, ^{137}Cs, ^{90}Sr, and TRU materials. Examples of this problem are the fuel storage tanks and piping in the fuel storage cells in the Molten Salt Reactor Facility and the process piping and equipment in the experimental cells of the Oak Ridge Research Reactor.

4.1.1.9 Entombment

These technologies are the last step of dismantlement, used after other D&D steps have been completed. They are applicable to either temporary or permanent isolation of the remaining facilities. An example of this would be filling the basement structures with an impermeable material (concrete) to affix the remaining contamination.

4.1.1.10 Retrieval

These technologies are applicable to the exhumation of equipment previously buried or stored in ways currently deemed unacceptable. An example of this would be the removal of highly contaminated pieces of equipment buried in a solid waste burial ground that are contributing significantly to underground waste plumes or other RA problems.

4.1.1.11 Equipment Predisposal Staging

This function will address the predisposition of dismantled equipment. Examples of these would be shredding of equipment for size reduction and/or packaging of such items. All technologies in the dismantlement tasks are applicable here if properly integrated.

4.1.1.12 Enabling Technologies

Dismantlement activities will almost always be conducted in a highly regulated environment covering conduct of operations, handling of hazardous materials, transportation of materials and equipment, equipment calibration and maintenance, and disposal of many kinds of wastes. Large amounts of different kinds of information and data must be accessible for planning, training workers, and assuring high quality of operations. The most cost-effective and reliable way to meet such requirements is to make extensive use of computing technology. Data bases are needed to store maps, locations of engineered structures, waste storage areas, locations of contamination, drawings of as-built structures, properties of hazardous materials, and much more. In some cases additional mapping of structures will be required, especially for problem areas in which remote manipulation or robotic systems must be used. Convenient and reliable access to information must be provided through the use of networks and graphical displays. Automated planning tools will be essential to keeping up with constantly evolving regulatory requirements. Robust and reliable tagging systems will be needed for tracking materials. The wide range of computing technologies identified for this area will have to be integrated according to an overall system plan or architecture that constitutes a Network Information System so that these technologies can work together effectively.

4.2 TECHNOLOGY OPTIONS

4.2.1 Massive Containment, Reactor Pools, Buried Tanks, and Structural Concrete

Seven technologies were identified for these problem constituents. See Table 4.1 in Sect. 4.5.2 for the most favored technologies. Successful application of these technologies to concrete in D&D of ORNL will depend on how well they can be integrated with robotics and/or automatic systems. All the technologies have been used at nuclear facilities with varying success. Also, more efficient application will depend on improved protective systems for operators and maintenance personnel.

4.2.2 Steel Structures—High-Level and Low-Level Contamination

Removal of steel structures, as seen in Fig. 4.1, will be a process varying from remote removal to conventional removal, depending upon the contamination level. Twelve technologies were identified that are potentially useful in dismantlement of structural steel. See Table 4.1 for the most favored technologies. For highly contaminated structures, successful application will depend on the technology's effective integration with remote delivery systems. Also, success will depend on limiting the spread of contamination during D&D operations.

4.2.3 Asbestos Materials

Six technologies were identified for the removal of asbestos materials. The generic categories are either to cut the asbestos loose or strip it away. Both scenarios will require packaging of loose asbestos materials and reduction and/or collection of airborne asbestos. The focus these activities is to keep the asbestos from becoming more contaminated so that the resulting materials can be disposed of at minimum cost. Also, containment of any contaminated asbestos or matrix-materials dust must be achieved during removal.

4.2.4 Major Equipment Removal

Sixteen technologies were identified for removing equipment from ORNL facilities. Twelve technologies involve some form of cutting. All of the technologies are commercially available. The major task in applying these systems will be to cut and remove the contaminated equipment while containing the contamination. It is important to provide safety for workers by maintaining the proper engineering of the containment systems. A combination of dismantlement and robotics will remove the worker from the actual cutting site and automation of the repetitive tasks will provide maximum benefits.

Figures 4.7 and 4.8 depict concepts that were considered during the technology identification stage. The concepts shown are for remote removal of equipment from a typical reactor process cell.

4.2.5 Entombment

Entombment was identified as a problem area/constituent after discussions with knowledgeable personnel at other DOE sites, as well as ORNL D&D personnel planning future activities. Most facilities at ORNL will require some form of entombment activity

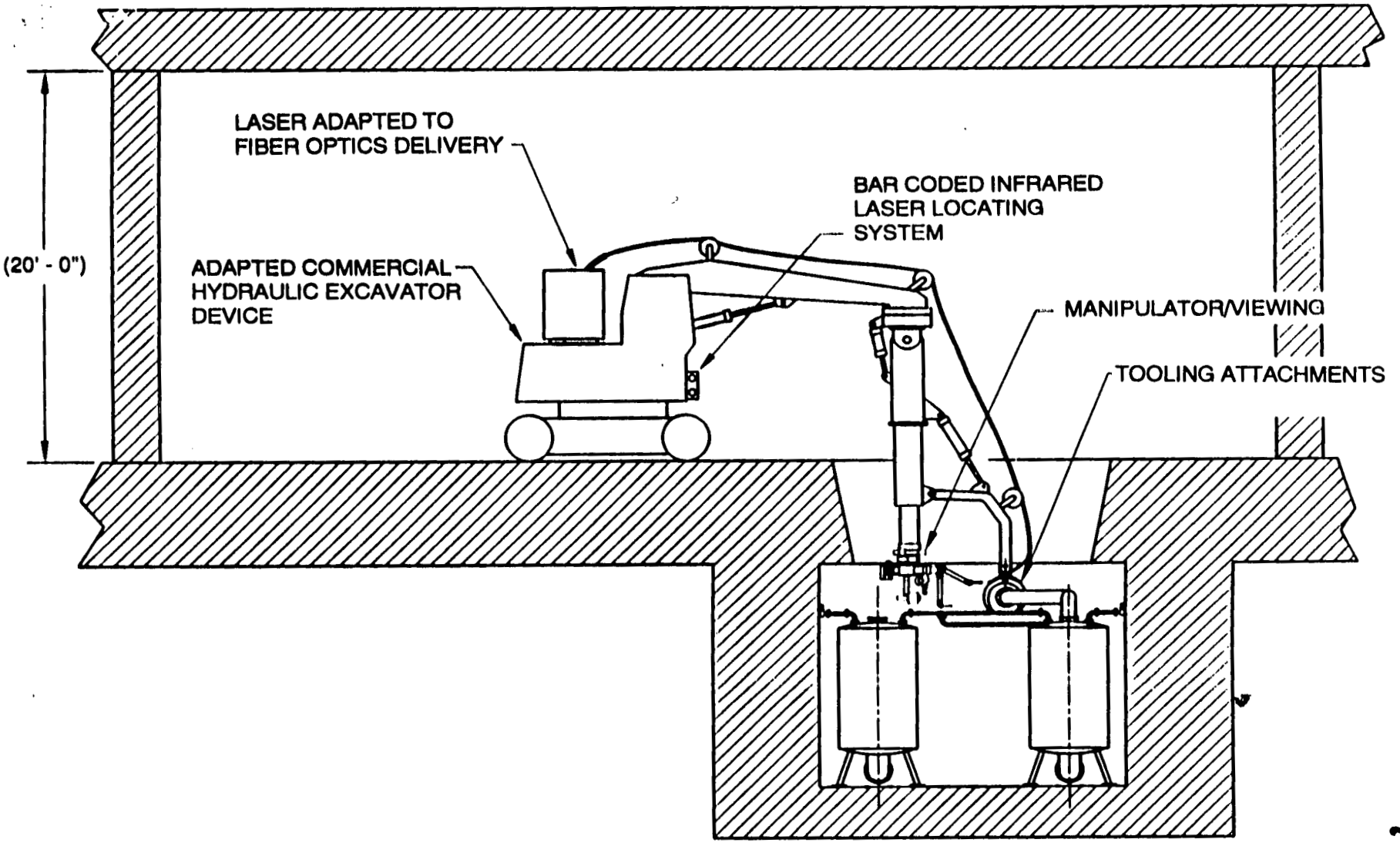

Fig. 4.7. Integrated, heavily shielded facility (dismantlement concept).

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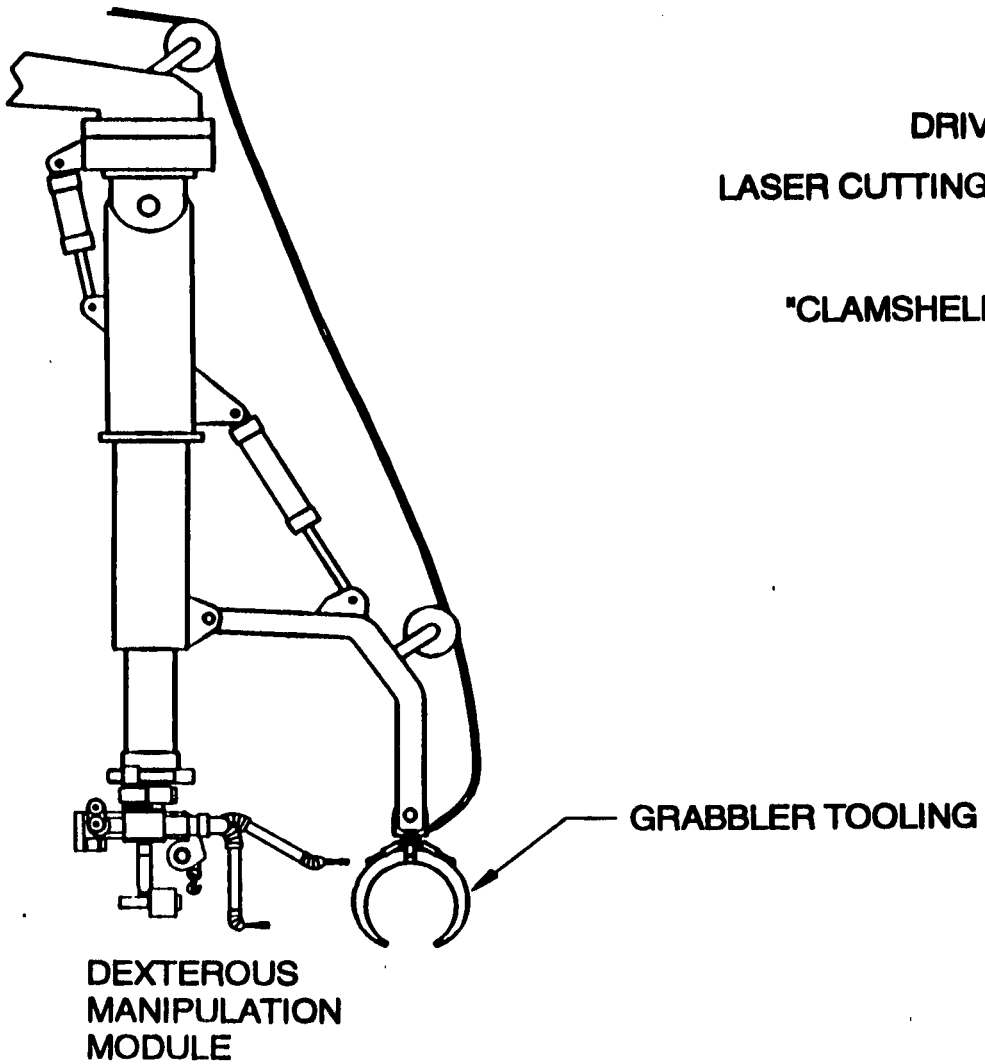

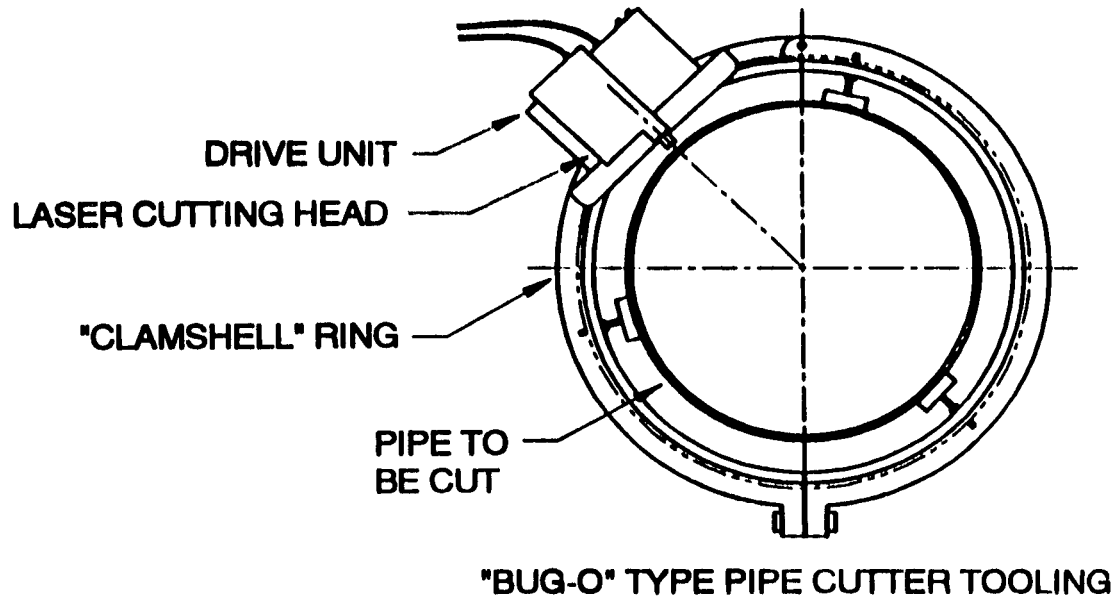

Fig. 4.8. Potential dismantlement end effectors. Many others are possible for characterization, decontamination, and dismantlement.

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before completing D&D processing and reaching the end state. Entombment includes all technologies that result in isolation of contaminated materials from the biosphere for a long period of time. Technologies included under "dismantlement" address those entombment activities that will isolate large pieces of equipment either removed from facilities, retrieved from past burial operations, or left in a facility and isolated in place. Eleven technologies were identified as applicable to entombment.

4.2.6 Retrieval

Dismantlement includes some tasks that are included as retrieval tasks under RA. Mechanical exhumation of equipment items and packaged items that, if removed today, should have been handled as dismantlement tasks. These items will be retrieved from burial grounds and handled in the "dismantlement flow" shown in Fig. 4.1.

Six technologies were identified and are included in the RA volumes. The data sheets are in Vol. 3, Pt. B. The Logic Flow Diagram in Vol. 2, Pt. B, includes these technologies relative to the specific site problems, and Vol. 1, Pt. B includes a description of their ranking for the RA-site problems.

4.2.7 Predisposal Staging

After equipment is removed for dismantlement, a decision is required as to the ultimate disposal options. Technologies will be required to inspect, reduce size, package, and temporarily hold items prior to transfer to the selected disposition activity areas. At ORNL this will most likely mean establishing a staging facility with capacity to remotely process equipment items. The Oak Ridge Research Reactor with its currently functional pool, may serve as a possible handling facility for such tasks. Two specific technologies were identified, but virtually all dismantlement technologies would be useful in this conceptual facility.

4.2.8 Needed Enabling Technologies

Twenty-four technologies were identified in this area. These technologies will, if properly engineered into the overall D&D ORNL facilities, provide benefits to dismantlement as well as other tasks. Current as-built information does not provide detailed descriptions of what is in the contaminated facilities. Process equipment has been removed, modifications have been made, and items have been stored in the facilities without accurately updating the engineering information.

Examples of benefits from enabling technologies include:

- updated engineering drawings for the facilities to be dismantled,
- accurate 3-dimensional inventories of materials,
- reasonably accurate location of equipment to permit positioning of automatic dismantlement tooling,
- dismantlement tooling utilization planning to aid the scheduling of equipment and manpower,
- real-time status feedback to deconstruction schedules and progress reports,
- continual waste and recycle materials inventories and tracking,
- query capability for investigation of alternative approaches and processes,

- accessible data for establishing a common mission and goal, plan, and
- conceptual 3-dimensional modeling capability for studying other technologies without actual procurement of equipment.

All of the technologies identified under "Enabling Technologies" are intended to enhance or improve the available engineering data bases. Computer-based data bases that would provide accurate 3-dimensional models can be generated. This data could be used to record characterization information, decontamination data, equipment locations, and related technologies by specific location in the facilities. Then this data could be used to guide automated tooling and/or robotics during the dismantlement process, while providing a real-time, automatic, updated data base.

Any demonstration of state-of-the-art technologies would provide guidance in the future on these D&D efforts. In fact, the ORNL facilities could be viewed as potential candidates for Integrated Demonstrations and/or test beds to serve as surrogates for facilities at other sites where remote equipment and tooling are needed. Therefore, the study group recommends including these technologies into any future D&D development effort or demonstration.

Two enabling technologies were identified under the alternative of Dismantlement Support. These are an automation technique for directing cutting called "point and direct" and "updated designs for protective clothing."

The studies to the time of this document have put emphasis on the use of currently demonstrated technologies. Among the high-cost items included in this analysis is their dependency on labor intensive techniques and the necessary protective clothing. Experience indicates that 30–50% of the cost can be attributed to reduced crew efficiency due to protective clothing and equipment required. This cost can be offset by automated dismantlement tooling and sophisticated delivery systems, thereby reducing manual labor and improving protection to D&D workers.

Some manner of manual work will always be required regardless of the degree of automation used in the dismantlement tasks. To this degree the development of improved (cheaper, recyclable, lighter, more convenient, etc.) protective equipment is certainly justified.

New, more efficient, versions of clothing and protective equipment have the potential of saving vast sums of money and labor. Respirators, face masks, air packs, cloth suits, air-tight suits, gloves, shoe covers, laboratory coats, air-conditioned and filtered-equipment cabs, etc., need improved designs to reduce cost in a massive dismantlement project such as a diffusion plant and its support facilities.

4.3 SCIENCE AND TECHNOLOGY NEEDS

An extensive search has been made of potential dismantlement technologies that are applicable to ORNL facilities scheduled for D&D. Of the 100 technologies identified, all are existing in the commercial sector or have been used at other sites for D&D tasks. The primary science needs are in the areas of reduction of secondary contamination and adaptation of robotics delivery systems. The rankings given in Table 4.1 depend, to significant degree, on reduction of secondary-waste volume and spread to secondary volumes.

The other significant science and technology needs are the development of information systems. Dismantlement activities will almost always be conducted in a highly regulated environment covering conduct of operations, handling of hazardous materials, transportation of materials and equipment, equipment calibration and maintenance, and disposal of many kinds of wastes. Large amounts of different kinds of information and data must be accessible for planning, training workers, and assuring high quality of operations. The most cost effective and reliable way to meet such requirements is to make extensive use of computing technology. Data bases are needed to store maps, locations of engineered structures, waste storage areas, location of contamination, drawings of as-built structures, properties of hazardous materials, and much more. In some cases, additional mapping of structures will be required, especially for problem areas in which remote manipulation or robotic systems must be used. Convenient and reliable access to information must be provided through the use of networks and graphical displays. Automated planning tools will be essential to keeping up with constantly evolving regulatory requirements. Robust and reliable tagging systems will be needed for tracking materials. The wide range of computing technologies identified for this area will have to be integrated according to an overall system plan or architecture that constitutes a Network Information System so that these technologies can work together effectively.

4.4 IMPLEMENTATION NEEDS

All of the dismantlement technologies identified require some demonstration to become accepted at the ORNL Site. Implementing even basic technologies, such as torch cutting, will require robotic delivery systems. Implementation of a technology at ORNL centers around timely, adequate demonstration in an integrated system.

An integrated demonstration of dismantlement technologies is needed and recommended so that proper conceptual engineering information can be generated and evaluated. From this information, well-conceived specifications could be prepared for the eventual large-scale dismantlement equipment. This would avoid the need for conservative selection of currently proven processes.

In this dismantlement study, technologies have been investigated individually. Integration of multiple new technologies would magnify the potential benefits. Significant cost and safety benefits would likely result from the cascading effect in an integrated demonstration. The integrated demonstration needed would require selection of areas within ORNL to be dismantled under very controlled conditions. In these areas of the buildings, each of 20–30 technologies would be applied under controlled conditions and evaluated for efficiency of operation. The technologies could then be integrated either through computer modeling techniques or actual demonstrations.

4.5 TECHNOLOGY RANKINGS

4.5.1 Introduction

Selection of technologies for development and use in the D&D facilities at ORNL is a very difficult task. Multidimensional trade-offs are required relative to the availability, complexity, and cost of technologies that appear applicable but have not been demonstrated and/or accepted at ORNL. Also, the variety of facilities makes selection of generic technologies difficult. For example, technologies applicable to hot cells may have limited usefulness for reactor pools. This section reports the evaluation of technologies in a systematic way and recommends those showing the most potential for future use and development.

This development should occur through inclusion in future demonstrations or in on-going development activities at appropriate installations. The data show that directed R&D of the recommended candidate technologies will significantly reduce the cost of D&D at ORNL facilities. Also, benefits can be further magnified if candidate systems spin off benefits to other DOE sites through the sharing of engineering documentation or actual hardware transfer. Table 4.1 shows rankings of the most favored technologies.

All technologies were ranked against the criteria as described in detail in Sect. 2.1. In some cases the criteria may have been interpreted differently by teams, depending upon the problem being addressed. For example, "versatility" for dismantlement is almost exclusively interpreted as "applicability to robotic tooling," but other teams may take "versatility" as "application to a variety of problems."

The general ranking scheme is described in detail in Sect. 2.1.

4.5.2 Rankings

After ranking the technologies, the more promising technologies are apparent. Throughout the TLD exercise, it can be shown that the most advantageous application of any dismantlement technology requires its incorporation into a dismantlement system. When designed, these systems would include not only dismantlement technologies but possibly all of the teams' needs merged into one or more systems for example, decontamination and characterization technologies may use the same delivery system. If inclusive systems are designed, they will magnify the potential benefits.

All of the technologies in Table 4.1 will require a timely and adequate demonstration in an integrated demonstration, and proper specifications must be prepared by Engineering based on data from integrated demonstrations.

Dismantlement technologies are grouped by the ORNL Problem for dismantlement. The rankings of the technologies are based on perceived benefits, assuming that they are adequately addressed in an integrated demonstration and proper specifications are prepared by Engineering based upon development and engineering data available.

4.5.3 Conclusions and Recommendations

All of the technologies addressed are applicable to the dismantlement of typical ORNL facilities. Each technology has an area that it would benefit if applied. An integrated demonstration of dismantlement technologies is needed and recommended (see Sect. 4.4).

A carefully integrated systems approach to the dismantlement of ORNL facilities will show the need for much off-site support. Some problems at ORNL, such as the

Table 4.1. Rankings of dismantlement technologies for D&D

Data sheet code numbers	Technology	Ranking[a]
	Massive containment	
DISM-11-OL	High-pressure abrasive water jet	H-5-5 ($5.5M;$10/ft^2)
DISM-12-OL	Diamond wire cutting	M-5-5 ($3.5M;$100/ft^2)
DISM-16-OL	Deep microwave demolition	M-5-9 ($5M;$6/ft^2)
	Reactor pools	
DISM-21-OL	High-pressure abrasive water jet	M-4-7 ($5.5M;$15/ft^2)
DISM-25-OL	Demolition compounds	M-4-6 ($4M;$90/ft^3)
DISM-28-OL	Microwave demolition	M-4-10 ($7M;$60/ft^2)
	Buried tanks	
DISM-31-OL	High-pressure abrasive water jet	H-4-7 ($5.5M;$80/ft^3)
DISM-33-OL	Explosive cutting	M-4-7 ($2.5M;$60/ft^3)
DISM-35-OL	Demolition compounds	M-4-8 ($4M;$90/ft^3)
	Structural-only concrete	
DISM-48-OL	Grappler	H-2-1 ($1M;$8/ft^3)
DISM-42-OL	Diamond wire cutting	H-2-0.5 ($1.5M;$10/ft^3)
DISM-44-OL	Conventional—jack hammer, headache ball, etc.	H-2-0 ($0M;$20/ft^3)
DISM-41-OL	High-pressure abrasive water jet	M-2-1 ($2M;$10/ft^3)
DISM-46-OL	Demolition compounds	M-2-2 ($1.5M;$25/ft^3)
	Steel structures—high-level contamination	
DISM-51-OL	Laser cutting	H-4-6 ($2.5M;$1000/cut)
DISM-53-OL	Abrasive water jet	H-4-3 ($750K;$100/h)
DISM-62-OL	Explosive cutting	H-4-3 ($1.3M;$12000/cut)
DISM-56-OL	Plasma arc cutting	M-4-4 ($1M;$1300/cut)
DISM-57-OL	Oxygen cutting	E-4-2 ($200K;$100/cut)
DISM-61-OL	Grapple and massive mobile shearing	E-4-1.5 ($250K;$250/cut)
DISM-60-OL	Conventional disassembly	E-4-2 ($800K;$75/bolt & $600/cut)

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Table 4.1 (continued)

Data sheet code numbers	Technology	Ranking[a]
Steel structures—low-level contamination		
DISM-72-OL	Abrasive water jet	H-2-2 ($250K;$100/h)
DISM-71-OL	Laser cutting	H-2-4 ($2.5M;$900/cut)
DISM-74-OL	Plasma arc cutting	M-2-4 ($250K;$600/cut)
DISM-76-OL	Conventional Disassembly	E-2-1 ($200K;$10/bolt & $300/cut)
DISM-77-OL	Grapple and massive mobile shearing	E-2-1 ($N/A;$150/cut)
DISM-75-OL	Oxygen cutting	E-2-N/A ($N/A;$150/cut)
Asbestos removal		
DISM-82-OL	Conventional/automated with vacuum system	H-3-6 ($200K;$30/ft^3)
DISM-84-OL	Laser cutting	H-3-3 ($3.5M;$50/ft^3)
DISM-83-OL	CO_2 blasting	M-3-7 ($3.5M;$60/ft^3)
DISM-85-OL	High-pressure abrasive water jet	M-3-6 ($3.5M;$50/ft^3)
Major equipment removal		
DISM-92-OL	Plasma arc cutting	H-5-4 ($2–3.5M;$50/ft^3)
DISM-100-OL	Advanced automatic fixtures, bug-o, etc.	H-5-3 ($1.5–2.5M;$30/ft^3)
DISM-95-OL	Advanced laser cutting	H-5-5 ($2.5–4M;$50/ft^3)
DISM-93-OL	High-pressure water jet	H-5-4 ($2–4M;$40/ft^3)
DISM-90-OL	Mechanical saws	M-5-1 ($250K;$40/ft^3)
Entombment		
DISM-113-OL	Encasement—subsurface waste storage with void reduction	H-4-3 ($0.5M;$10/ft^3)
DISM-115-OL	Engineered storage—for very "hot" items, future disposal	H-4-8 ($7M;$400/ft^3)
DISM-118-OL	Sensors for monitoring entombment integrity	H-4-3 ($0.8M;$1K/sensor)
DISM-114-OL	Permanent entombment	H-4-3 ($1M;$15/ft^3)
DISM-112-OL	Capping—aboveground environmental barrier	H-4-3 ($0.5M;$3/ft^3)

Table 4.1 (continued)

Data sheet code numbers	Technology	Ranking[a]
Needed enabling technologies		
DISM-191-OL	Computer-based training systems	H-4-1 ($.2M;$100K/yr)
DISM-159-OL	Electronic catalog descriptions and source locations of site historical data	H-4-2 ($2M;150K/yr)
DISM-156-OL	3-D CAD data base of buildings and structures	H-4-2 ($2M;300K/yr)
DISM-155-OL	Automated scanning and conversion of engineering drawings	H-4-2 ($2M;300K/yr)
DISM-151-OL	Project information access services	H-4-1 ($0.5M;100K/yr)
DISM-153-OL	Client/server access to standards and regulatory guidelines	H-4-0.5 ($.25M;$25K/yr)
DISM-172-OL	Computer-aided task analysis and procedure preparation	H-4-1 ($0.5M;150K/yr)
DISM-143-OL	Computer-based D&D information retrieval system	H-4-2 ($0.5M;300K/yr)
DISM-171-OL	Simulated walk-through facility for robotics task sequence analysis	H-4-1 ($.3M;60K/yr)

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

disposition of the Molten Salt Reactor Experiment's fuel storage tanks, are beyond the capabilities of even the most advanced, conceived technologies. Therefore, engineered-storage facilities are a key element of any major D&D of ORNL facilities. By carrying the integration of D&D technologies one step further, an interesting scenario develops within the Oak Ridge area.

Facilities exist in Oak Ridge, such as the expansive diffusion facilities at the K-25 Site, that may make ideal storage facilities for cask and safe containers containing items not considered for ultimate disposal. Therefore, integration of D&D efforts at ORNL and the K-25 Site should be considered.

Several advantages would be realized from an integration of D&D at the K-25 Site and ORNL:

1. Empty diffusion buildings, especially K-33 and K-31, are in excellent structural condition with heavy-duty concrete floors, large cranes, and handling capability already in place. If a use can be made of these structures, then disposal of a large amount of transite and low-level contaminated structural material can be avoided.
2. Removal, safe packaging, and storage at the K-25 Site of the high-level items will not increase the contamination level of the diffusion buildings.
3. Well-engineered, safe packaging of the high-level items will not increase the contamination level of the diffusion buildings.
4. Shipment of properly packaged high-level items from the K-25 Site to the ultimate disposal facilities—such as Yucca Mountain or a salt repository—will be simple, relative to the handling and transport required if special individual casks were constructed now.

A typical reactor-type facility should be selected at ORNL as the target facility that will demonstrate the selected technologies from this study. A systems approach must be taken to integrate the selected technologies, not only for dismantlement but for all teams, so that the problems at the target facility are addressed. In addition to this system, a much larger "Mega System" should be considered to integrate the K-25 Site D&D efforts with ORNL's. Such action will take advantage of all resources in the D&D arena—such as the massive buildings at the K-25 Site—and will reduce or eliminate all problems at both sites.

It is further recommended that this effort commence as soon as possible in order to take advantage of the vast technical experience still existing in Oak Ridge. Many technical personnel are still available, either still employed or retired, who worked hands-on with the facilities scheduled for D&D at both sites. The value of this resource cannot be overstated. The following are factors currently available at ORNL:

- partial, but well-cataloged, on-site engineering data bases for as-built condition;
- existing designs for dismantlement tooling (for past maintenance and process);
- on-site engineering personnel and other technical personnel, as part of a skilled three-plant organization, that will have extensive experience in many areas, including
  - hot-cell operations,
  - technology development,
  - remote handling and maintenance,
  - glove box design and operation,
  - special tooling design,
  - weapons dismantlement,
  - nuclear materials production and packaging,
  - RA, and
  - WM; and
- project management expertise in all of the above.

Also available and specific to ORNL are the following:

- radiation hazard–experienced personnel;
- development facilities for laboratory testing;
- integrated staff of health physics, maintenance, and other support groups;
- immediate access to Y-12 and K-25 personnel with readily available, related skills;
- minimum hazards to the public because of the isolated location of the facilities; and
- experience in dealing with all nuclear isotopes.

4.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the dismantlement technologies listed in Table 4.1. Table 4.2 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with this list of dismantlement technologies. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding dismantlement technology code by TTP number. When no FY 1993 matches were found and the searchers (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Dismantlement technologies for which no matches were found are omitted from the table. When many matches were found, only one or two were cited. The relevance column indicates the degree of overlap between the listed dismantlement technologies and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 4.2. Dismantlement technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
High-pressure abrasive water jet (massive containment)	DISM-11-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (massive containment)	DISM-16-OL	OR101204	H	Microwave concrete decontamination development
High-pressure abrasive water jet (reactor pools)	DISM-21-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (reactor pools)	DISM-28-OL	OR101204	H	Microwave concrete decontamination development
High-pressure abrasive water jet (buried tanks)	DISM-31-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (buried tanks)	DISM-38-OL	OR101204	H	Microwave concrete decontamination development
High-pressure abrasive water jet (structural-only concrete)	DISM-41-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (structural-only concrete)	DISM-47-OL	OR101204	H	Microwave concrete decontamination development
Grappler (structural-only concrete)	DISM-48-OL	AL221205	L	Small-scale shear
Abrasive water jet (steel structures, highly contaminated)	DISM-53-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Plasma arc cutting (steel structures, highly contaminated)	DISM-56-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development
Plasma arc saw (steel structures, highly contaminated)	DISM-58-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development
Thermal arc water jet (steel structures, highly contaminated)	DISM-59-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development

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Table 4.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Grapple and massive mobile shearing (steel structures, highly contaminated)	DISM-61-OL	AL221205	L	Small-scale shear
Abrasive water jet (structural steel, mild contaminants)	DISM-72-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Plasma arc cutting (structural steel, mild contaminants)	DISM-74-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development
Grapple and massive mobile shearing (structural steel, mild contaminants)	DISM-77-OL	AL221205	L	Small-scale shear
High-pressure abrasive water jet (asbestos)	DISM-85-OL	AL221205	L	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Plasma arc cutting (major equipment removal)	DISM-92-OL	ID413200	H	Plasma arc cutting
		SR113201	H	Plasma arc cutting
High-pressure water jet (major equipment removal)	DISM-93-OL	RL332003	M	Water jet
High-pressure abrasive water jet (major equipment removal)	DISM-97-OL	AL221205	H	Robot-mounted abrasive water jet
		AL221302	M	
		RL332003	L	
Plasma arc saw cutting (major equipment removal)	DISM-98-OL	ID413200	H	Plasma arc cutting
		SR113201	H	Plasma arc cutting
Thermal arc water jet cutting (major equipment removal)	DISM-99-OL	ID413200	M	Plasma arc cutting
		SR113201	M	Plasma arc cutting
Advanced automatic fixtures, bug-o, etc. (major equipment removal)	DISM-100-OL	AL221205	L	Robot-mounted shear and abrasive water jet
Grappler/gross shearing and lifting (major equipment removal)	DISM-103-OL	AL221205	L	Small-scale shear
Thermoset polymer/thermal plastic stabilization (entombment)	DISM-109-OL	CH321201	H	Polymer solidification of sludge
		RF111203	H	Polymer encapsulation
Ground-water diversion (entombment)	DISM-110-OL	CH331001	L	Study of waste migration control
Temporary entombment/clay fill (entombment)	DISM-111-OL	CH331001	L	Study of waste migration control
		CH321101	M	In situ containment

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Table 4.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Capping—aboveground environmental barrier (entombment)	DISM-112-OL	CH321101	H	In situ containment
		AL221111	H	Capping and stabilization
Encasement—subsurface waste storage with void reduction (entombment)	DISM-113-OL	CH321101	H	In situ containment
		AL221111	M	Capping and stabilization
Permanent entombment (entombment)	DISM-114-OL	CH321101	M	Grout solidification
		CH321201	L	Polymer solidification of sludge
		RF111203	L	Polymer encapsulation
Engineered storage—for very "hot" items, future disposal (entombment)	DISM-115-OL	RL438005	M	Spent fuel casks use for liquids
Hydraulic isolation (entombment)	DISM-116-OL	AL221111	M	Landfill-site capping
		AL931102	L	Ground-water treatment
Sensors for monitoring entombment integrity (entombment)	DISM-118-OL	RL421103	M	Horizontal drilling development
		SF221102	M	Electrical resistance tomography
		SR121101	L	Directional drilling use
Modular entombment—with provisions for future removal (entombment)	DISM-119-OL	ID132006	M	Burial Waste Integrated Demonstration waste form integration and limits
Shredding, sorting, compaction (equipment predisposal staging)	DISM-131-OL	SF223203	L	Waste facility operation
Generalized object-oriented simulation software (needed enabling technologies)	DISM-173-OL	RL321104	L	Engineering simulator software
Geographic information systems for DOE sites (needed enabling technologies)	DISM-181-OL	SR121102	L	Info system at Savannah River Site Idaho

[a] TTP = Technical Task Plan identifier.

[b] The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

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4.7 REFERENCES

1. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge National Laboratory, October 29, 1992.

5. Decontamination

5. DECONTAMINATION

5.1 INTRODUCTION

In general, decontamination is accomplished either by removing the contaminants from surfaces with little damage or by intentionally removing a layer of the contaminated surface along with the embedded contaminant. The energy needed to remove the surface layer may be either mechanical, chemical, or thermal. Bulk decontamination requires entirely different techniques, such as incineration, smelting, or leaching. Removal of contaminants from surfaces is based upon cleaning techniques that have been used for decades. Many procedures and reagents used in decontaminating equipment and facilities in the nuclear industry were first developed and used for cleaning conventional nonnuclear plants.[1] Decontamination procedures were developed to provide high-decontamination efficiencies and moderate-corrosion attack on the surface. Additional criteria to be met were prompt availability of equipment, simple operation and control, acceptable time requirements, satisfactory safety aspects, acceptable costs of application, planned future use of facility, and minimal amounts of wastes. The choice of a decontamination procedure for a particular application will depend upon the importance and priorities assigned to the various criteria, the characteristics of the system to be decontaminated, and the specific capabilities at the facility. The requirements for moderate-corrosion attack and for prompt availability of equipment have little weight for D&D compared to that for decontamination for maintenance and reuse of existing equipment in operating plants.

To develop the decontamination section of the TLD, the first step was to list the decontamination technologies that are in use, under development, or being proposed. For the Problem Area/Constituent logic element of the diagram, a list of problems specific to decontamination and traceable directly to ORNL problems was developed. This list consisted of the various contaminated substrates (e.g., concrete, equipment, structural steel, etc.) and the particular hazardous contaminants that can be found residing on or throughout each substrate (i.e., surface or bulk contamination). For each problem, technologies were identified that could potentially be used for decontamination.

The development of the list of problems for ORNL involved (1) interviews with personnel familiar with the history of the facility or facilities of interest, (2) review of documents describing the contamination problems at the various facilities, and (3) tours of the facilities by the decontamination team members. Based on the results of these activities, a detailed list of ORNL decontamination problems was generated and is presented in Table 5.1. Table 5.1 specifies the types of substrates that are contaminated, the types of contaminants present on each substrate, the radiation levels existing as a result of the contamination, and examples of the particular situations (i.e., the facility and the equipment or surfaces that are contaminated) that exhibit the listed combinations of substrate, contaminants, and radiation levels. While Table 5.1 is as complete as possible, the particular situations that are listed should be regarded as examples of the contaminated equipment and surfaces, not as an exhaustive list.

Table 5.1. ORNL decontamination problems

Substrate	Contaminant	Radiation level[a]	Example
Stainless steel pipe interior	Uranyl sulfate, fission products (F.P.), corrosion products (C.P.)	H	Homogeneous Reactor Test (HRT) process piping
	F.P., C.P.	M	Molten Salt Reactor Experiment (MSRE) off-gas system
	F.P., C.P.	M	Oak Ridge Research Reactor (ORR) demineralizer piping (outside pool)
	Cs-137, Sr-90	M	Building 3517 process piping and tankage
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	L	Graphite Reactor process piping
Stainless steel pipe exterior	Uranyl sulfate, F.P., C.P.	H	HRT process piping
	F.P., C.P.	M	MSRE off-gas system
	F.P., C.P.	M	ORR demineralizer piping (outside pool)
	Cs-137, Sr-90	H	Building 3517 process piping and tankage
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor process piping
Steel pipe interior	F.P., C.P.	M	MSRE off-gas system
	U, Th, molten salt (M.S.)	VL	Drain lines from molten salt cells, Bldg. 9201-3
	U, Th, coolant salt (C.S.)	VL	Drain lines from coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	VL	Drain lines from Bldg. 9419-1
Copper tubing interior	U, Th, H-3, M.S.	L	Instrument and air lines in coolant cell, Bldg. 9201-3
Copper tubing exterior	U, Th, H-3, M.S.	VL	Instrument and air lines in coolant cell, Bldg. 9201-3
Steel pipe exterior	F.P., C.P.	M	MSRE off-gas system
Steel pipe, painted, exterior	U, Th, M.S.	L	Handrail, Bldg. 9201-3
INOR-8 piping exterior	U-Be-Li-F, TiF^3, F.P.	H	MSRE reactor piping
INOR-8 piping interior	U-Be-Li-F, TiF^3, F.P.	H	MSRE reactor piping
INOR-8	U-Be-Li-F, TiF^3, F.P., activation products (A.P.)	H	MSRE reactor
	U-Be-Li-F, TiF^3, F.P.	H	MSRE fuel processing system
	Trace U-Be-Li-F, F.P.	H	MSRE storage tank
Aluminum piping exterior	F.P., C.P	H, M, L	ORR primary coolant piping
	F.P., C.P., A.P.	VL	Low-Intensity Test Reactor (LITR) water piping exterior

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Aluminum piping interior	F.P., C.P.	H, M, L	ORR primary coolant piping
	F.P., C.P., A.P.		LITR water piping exterior
Stainless steel	F.P., C.P.	H	Piping southeast of 7500
347 stainless steel	F.P., C.P.	H	Tank SE of 7500
Stainless steel	F.P., C.P.	M	ORR hot cell liners
	F.P., Cm-147, Pm-241, Am	M	Building 3028 hot cell liners
	Cs-137, Sr-90, Co-60, Ir-192	H	Building 3029 hot cell liners
	43 Beta, gamma emitters	M	Building 3030 hot cell liners
	Gd-153, Am-241	L	Building 3031 hot cell liners
	P-32, Am-241	L	Building 3032 hot cell liners
	Cs-137, Sr-90, Co-60	M	Building 3517 hot cell liners
	transuranic (TRU), F.P.	L	Building 3505 hot cell liners
	Cs, Sr, Co, Cm, Eu, Am, Pu	M	Building 3047 hot cell liners
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	M	Building 7852 hot cell liners
	U-233, Pu-239, F.P.	H, M	Building 3019 hot cell liners
	H-3, Kr-85	VL	Building 3033 process piping
	Pu-238, Am-241, Cm-244	VL	Glove boxes in Bldg. 3038
	Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I	L	Glove boxes and cell interiors in Bldg. 3038
	Cs-137, Sr-90	L	Stainless steel tank (SST) cask wall
	H-3	VL	Building 7025 process piping
	H-3, Actinides	VL	Building 7025 hoods, glove box
Zircalloy 2	Uranyl Sulfate, F.P., C.P., A.P.	H	HRT reactor
Stainless clad steel	Uranyl sulfate, F.P., C.P.	H	HRT pressure vessel
High-density concrete	F.P., C.P., A.P.	H	HRT structure
Carbon steel plate	F.P., C.P.	H	Membrane between HRT concrete
	Cs-137, Sr-90, Co-60, Ir-192	M	Building 3029, Cell 2 wall
Asphalt pavement	F.P., C.P.	VL	Pavement over 55-gal drum 7500 Cells
	Heavy water, F.P.	M	Pulsefeeder pumps

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Concrete	Uranyl sulfate, F.P.	M	Floor under and shield around evaporator in 7500
	F.P., C.P.	H, M, L	ORR biological shield
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90,	M	Graphite Reactor biological shields
	Co-60, A.P.	M	Graphite Reactor canal
		L	Graphite Reactor duct work
		L	Graphite Reactor stack
	F.P., C.P., A.P.	L	Slab supporting LITR components
	F.P., Cm-244, Pm-147, Am-241	M	Building 3028 hot cell interiors
	Cs-137, Sr-90, Co-60, Ir-192	M	Building 3029 hot cell interiors
	43 Beta, gamma emitters	M	Building 3030 hot cell interiors
	Gd-153, Am-241	L	Building 3031 hot cell interiors
	P-32, Am-241	L	Building 3032 hot cell interiors
	Cs-137, Sr-90	VL	Building 3036 floor
	Cs-137, Sr-90, Co-60	M	Building 3517 hot cell interiors
	U, Th, M.S.	L	Roofs of molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Floor of Bldg. 9419-1
	U, Th, M.S.	L	First floor of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	M	Cell interiors in Bldg. 3038
	TRU, F.P.	L	Building 3505 hot cell interiors
	F.P.	VL	Building 3506 hot cell interiors
	F.P.	M	Building 3515 hot cell interiors
	Cs, Sr, Co, Cm, Eu, Am, Pu	M	Building 3047 hot cell interiors
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	M	Building 7852 pump house pads
	U-233, Pu-239, F.P.	H, M	Building 3019 hot cell interiors
Brick/tile	U, Th, M.S.	L	One wall of molten salt cell, Bldg. 9201-3
Brick	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 exterior walls

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Painted concrete	F.P., TRU	L, VL	ORR hot cell interiors, floors, cell faces
	F.P., Cm-147, Pm-241, Am	L,VL	Building 3028 hot cell interiors, floors, cell faces
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 cell faces
	43 Beta, gamma emitters	VL	Building 3030 floors, cell faces
	Gd-153, Am-241	VL	Building 3031 floors, cell faces
	P-32, Am-241	L, VL	Building 3032 floors, cell faces
	H-3, Kr-85	VL	Building 3033 cell faces
	Cs-137, Sr-90	VL	Building 3036 floors
	Cs-137, Sr-90, Co-60	VL	Building 3517 high bay floors, cell faces
	U, Th, C.S.	L	Floor of coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Floor of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	M, L, VL	Cell floors, surfaces in Bldg. 3038
	TRU, F.P.	VL	Building 3505 floors, cell faces
	F.P.	VL	Building 3506 hot cell interiors
	F.P.	VL	Building 3515 floors, cell faces
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 floors, cell faces
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 floors, cell faces
	U-233, Pu-239, F.P.	H, M	Building 3019 hot cell interiors, floors, cell faces
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, A.P.	VL	Graphite Reactor biological shield exterior

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Sheet steel	Cs, Sr, TRU, Co-60	VL	7500 high bay area
	Cs, Sr, TRU, Co-60	VL	MSRE exterior siding
	F.P.	VL	ORR building siding
	F.P., TRU	VL	Building 3028E charging area
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 exterior walls
	43 beta, gamma emitters	VL	Building 3030 siding/interior walls
	Gd-153, Am-241	VL	Building 3031 siding/interior walls
	P-32, Am-241	VL	Building 3032 siding/interior walls
	H-3, Kr-85	VL	Building 3033 siding/interior walls
	Cs-137, Sr-90	VL	Building 3036 siding/interior walls
	Cs-137, Sr-90, Co-60	VL	Building 3517 interior/exterior walls
	U, Th, M.S.	L	Three walls of molten salt cells, Bldg. 9201-3
	U, Th, C.S.	L	Walls of coolant salt cells, Bldg. 9201-3
	U, Th, C.S.	L	Roof of coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Upper floors of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 interior walls
	TRU, F.P.	VL	Building 3505 siding
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu		Building 7852 building interior walls
	U-233, Pu-239, F.P.	VL	Building 3019 siding
	H-3, Actinides	VL	Building 7025 siding
	F.P., Pu, C-14, Fe-55, C-137, Sr-90, Co-60	VL	Graphite Reactor building siding
Corrugated steel sheet	U, Th, M.S.	L	Floor of molten salt cells, Bldg. 9201-3
Sheet metal (painted)	U, Th, C.S., H-3, Oil	L	Floor of coolant salt cell, Bldg. 9201-3
Aluminum	F.P., C.P, A.P.	H, M, L	ORR reactor vessel, pool liner
Metal	U, Th, M.S.	L	Scales, hoist, size metal parts in Bldg. 9419-1

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Structural steel	Cs, Sr, TRU, Co-60	VL	7500 high bay area
	Cs, Sr, TRU, Co-60	VL	MSRE building structure
	F.P.	VL	ORR steel building structure
	F.P., TRU	VL	Building 3028E steel structure
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 structure
	43 Beta, gamma emitters	VL	Building 3030 steel building structure
	Gd-153, Am-241	VL	Building 3031 structure
	P-32, Am-241	VL	Building 3032 structure
	H-3, Kr-85	VL	Building 3033 structure
	Cs-137, Sr-90	VL	Building 3036 structure
	Cs-137, Sr-90, Co-60	VL	Building 3517 structure
	U, Th, M.S.	VL	Frame of Bldg. 9419-1
	U, Th, H-3, M.S.	L	Frame of coolant cell
	U, Th, M.S.	L	Frame of molten salt cells and equip., Bldg. 9201-3
	U, Th, M.S.	L	Frame & stairs of Bldg. 9419-1
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 structure
	TRU, F.P.	VL	Building 3505 structure
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 structure
	Cs-137, Sr-90	VL	SST steel structure
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 structure
	U-233, Pu-239, F.P.	VL	Building 3019 structure
	H-3, Actinides	VL	Building 7025 structure
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor building structure
Steel grating	U, Th, M.S.	L	Upper floors of molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Stairs in Bldg. 9419-1

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Concrete block	Cs, Sr, TRU, Co-60	VL	Building 7500 interior/exterior walls
	F.P., C.P.	VL	MSRE Building interior/exterior walls
	F.P.	VL	ORR Building interior/exterior walls
	F.P., TRU	VL	Building 3028 interior/exterior walls
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 interior/exterior walls
	Gd-153, Am-241	VL	Building 3031 stacked shielding
	P-32, Am-241	VL	Building 3032 interior/exterior walls
	Cs-137, Sr-90	VL	Building 3036 interior walls
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 interior walls
	Cs-137, Sr-90, Co-60	VL	Building 3517 interior/exterior walls
	TRU, F.P.	L	Building 3505 hot cell interiors
	TRU, F.P.	VL	Building 3505 interior/exterior walls
	F.P.	VL	Building 3505 exterior walls
	F.P.	VL	Building 3515 interior/exterior walls
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 interior/exterior walls
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 interior/exterior walls
	U-233, Pu-239, F.P.	VL	Building 3019 interior/exterior walls
Plaster/concrete block	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 interior walls

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Tiled concrete	Cs, Sr, TRU, Co-60	VL	Building 7500 floors
	F.P., C.P.	VL	MSRE building floors
	F.P.	VL	ORR building floors
	F.P., TRU	VL	Building 3028 floors
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 floors
	43 Beta, gamma emitters	VL	Building 3030 floors
	Gd-153, Am-241	VL	Building 3031 floors
	P-32, Am-241	VL	Building 3032 floors
	H-3, Kr-85	VL	Building 3033 floors
	Cs-137, Sr-90	VL	Building 3036 floors
	Cs-137, Sr-90, Co-60	VL	Building 3517 floors
	U, Th, C.S.	L	Floor of coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Floor of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 floors
	TRU, F.P.	VL	Building 3505 floors
	F.P., alpha	VL	Building 3505 floors
	F.P.	VL	Building 3515 floors
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 floors
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 floors
	U-233, Pu-239, F.P.	VL	Building 3019 floors
	H-3, Actinides	VL	Building 7025 floors
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor building floors

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Wood/sheet rock	Cs, Sr, TRU, Co-60	VL	Building 7500 interior walls
	F.P., C.P.	VL	MSRE building interior walls
	F.P.	VL	ORR building interior walls
	F.P., TRU	VL	Building 3028 interior walls
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 interior walls
	43 Beta, gamma emitters	VL	Building 3030 interior walls
	Gd-153, Am-241	VL	Building 3031 interior walls
	P-32, Am-241	VL	Building 3032 interior walls
	Cs-137, Sr-90	VL	Building 3036 interior walls
	Cs-137, Sr-90, Co-60	VL	Building 3517 Bldg. 3517 interior walls
	TRU, F.P.	VL	Building 3505 interior walls
	F.P.	VL	Building 3505 interior walls
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 interior walls
	U-233, Pu-239, F.P.	VL	Building 3019 interior/exterior walls
	U, Th, M.S.	VL	Rafters of Bldg. 9204-1
	U, Th, M.S.	L	Pallets in Bldg. 9419-1
	Be	VL	Frame of Be Bldg. in Bldg. 9201-3
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor building internal walls
Wood/asphalt	F.P.	VL	Building 3505 roof
Tar and felt roofing	Cs, Sr, TRU, Co-60	VL	Building 7500 roof
	F.P., C.P.	VL	MSRE building roof
	F.P.	VL	ORR building roof
	F.P., alpha	VL	Building 3028 roof
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 roof
	Cs-137, Sr-90	VL	Building 3036 roof
	43 Beta, gamma emitters	VL	Building 3030 roof
	Gd-153, Am-241	VL	Building 3031 roof
	P-32, Am-241	VL	Building 3032 roof
	H-3, Kr-85	VL	Building 3033 roof
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 roof
	Cs-137, Sr-90, Co-60	VL	Building 3517 roof
	F.P., alpha	VL	Building 3505 roof
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 roof
	U-233, Pu-239, F.P.	VL	Building 3019 roof

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Graphite	C-14, A.P.	H	MSRE moderator
	Alpha (U, Pu)	L	Piece in molten salt cells, Bldg. 9201-3
	C-14, Fe-55, Cs-137, Sr-90, Co-60, F.P., Pu, A.P.	M	Graphite Reactor Moderator
Charcoal	F.P., C.P.	M	MSRE off-gas system
Stainless Steel	F.P., C.P.	M	MSRE liquid waste system
Fiberglass insulation, Al foil, and wire	F.P., C.P.	H	MSRE coolant piping
	Cs-137, Sr-90, Co-60	VL	Insulation in Bldg. 3517
	TRU, F.P.	VL	Building 3505 insulation
	U-233, Pu-239, F.P.	VL	Building 3019 insulation
Asbestos insulation	U, Th	VL	Pipe insulation in Bldg. 9419-1
	U, Th, H-3, M.S.	L	Piping insulation in coolant salt cell, Bldg. 9201-3
	U, Th, M.S., PCB	L	Piping insulation in molten salt cells, Bldg. 9201-3
Transite	U, Th, M.S.	L	Walls of molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Bldg. 9419-1 Walls
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 waste pit roof
Glass-lined stainless steel	U, Th, M.S., Oil	VL	3000-gal tank in Bldg. 9201-3
Metal process piping and equip. (interior)	U, Th, M.S.	VL	Molten salt cells in Bldg. 9201-3
	U, Th, C.S., H-3	VL	Coolant salt cells in Bldg. 9201-3
Metal process piping and equip. (exterior)	U, Th, M.S.	L	Molten salt cells in Bldg. 9201-3
	U, Th, C.S., H-3	L	Coolant salt cells in Bldg. 9201-3
Metal piping and tank	U, Th, M.S.	L	Near 3000-gal tank in Bldg. 9201-3

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Table 5.1 (continued)

Substrate	Contaminant	Radiation level[a]	Example
Metal equipment	U, Th, M.S.	VL	Building 9419-1
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor equipment
Instruments	U, Th, C.S.	L	Coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Molten salt cells, Bldg. 9201-3
Electrical boxes	U, Th, C.S.	L	Coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Molten salt cells, Bldg. 9201-3
Electrical conduit	U, Th, C.S.	L	Coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Building 9419-1
Electrical heating elements	U, Th, M.S.	L	On five molten salt vats, Bldg. 9201-3
Light fixtures	U, Th, M.S.	L	Building 9419-1
Electrical cables and thermocouple wire	U, Th, M.S.	L	Molten salt cell, Bldg. 9201-3
Notebooks and paper	U, Th, H-3, M.S.	L	Items in coolant salt cell, Bldg. 9201-3
Rubber hose and plastic tubing	U, Th, M.S.	L	Molten salt cell, Bldg. 9201-3
Rubber hose	U, Th, M.S.	L	Items in Bldg. 9419-1
Ladder, scales, vacuum cleaner	U, Th, M.S.	L	Molten salt cell, Bldg. 9201-3
Steel	Cs, Sr, Co, Cm, Eu, Am, Pu	M	Building 3047 in-cell crane
	C.P., F.P., A.P.	H	LITR tank internal surfaces
Steel	Cs-137, Sr-90	VL	SST cask wall
Ion exchange resin	Cs-137, Sr-90	M	SST cask resin

[a] H = >100 R/h; M = 1-100 R/h; L = 0.01-1 R/h; VL = background to 0.01 R/h. (Most values are estimates.)

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Because of the large number of problems listed, some simplification was necessary to limit the size of the decontamination logic diagram. This was done by dividing the problems into different groups. The criterion for assigning a problem to a particular group was that all problems in that group could, in general, be treated by the same decontamination technologies. Finally, having identified the technologies applicable to each group of problems and with the detailed information for each technology as provided in the *Technology Evaluation Data Sheets*, the decontamination section of the TLD was developed.

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5.2.1 Introduction

The scope of this activity is to decontaminate DOE surplus facilities (systems or components), particularly at ORNL. Reasons or requirements for decontamination include the following:

- to permit unrestricted reuse/recycle,
- to permit reuse of the item in the DOE complex,
- to reduce worker-radiation exposure,
- to avoid potential criticality accidents,
- to permit or enhance disposal, and
- to separate the hazardous from the radioactive constituents during decontamination.[2]

This section summarizes the decontamination technologies that have been demonstrated or that have the potential to fulfill these requirements.

Decontamination technologies have been grouped into six generic technologies as follows:

- bulk decontamination methods,
- chemical surface cleaning methods,
- metal refining methods,
- mechanical surface removal methods,
- surface cleaning methods, and
- thermal surface removal methods.

As suggested by the name, surface removal methods take off the surface layer of the substrate (e.g., metal, concrete, etc.) itself and, at the same time, any fixed or loose (i.e., transferable) contamination that is present on the surface. The surface cleaning methods remove the fixed or loose contamination without disturbing the surface of the substrate. The metal refining and the bulk decontamination methods remove contamination that is distributed throughout the substrate.

The decontamination technologies that have been identified are grouped according to generic technology in Table 5.2. The technologies listed are at various levels of development, including (1) in an available stage that is accepted by industry, (2) in the demonstration phase, (3) under study at the laboratory scale, and (4) at the conceptual stage. A brief description of the technologies is provided in the following sections.

5.2.2 Bulk Decontamination Methods

Solvent extraction removes organics from bulk materials simply by dissolution. The technology could be applied as a "factory style" process in either a batch or continuous fashion. For waste-volume reduction, separation of the contaminants from the solvent and recycling of the solvent would be needed. Also, the solvent would have to be removed from the decontaminated material by a method such as heating or vacuum. The chemical leaching technology would be applied in a manner similar to that of solvent extraction. The chemical leaching and biological technologies are essentially the same as described under chemical surface cleaning. Solvent extraction and chemical leaching are well-established technologies in current use.

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Table 5.2. Decontamination technologies

Bulk decontamination methods

1. Solvent extraction
2. Incineration
3. Dry heat
4. Chemical leaching
5. Catalytic extraction process
6. Vacuum (low pressure)
7. Transmutation

Chemical surface cleaning methods

1. Chemical foams
2. Chemical gels
3. Organic acid treatment
4. Fluoboric acid treatment
5. Inorganic acid treatment
6. Detergent treatment
7. REDOX treatment
8. Chelation treatment
9. Electropolishing
10. Gas phase
11. UV/ozone (UV light activation)
12. Electromigration

Metal refining methods

1. Smelt purification
2. Electrorefining
3. Leach/electrowinning

Mechanical surface removal methods

1. Ultrahigh-pressure water
2. Shot blasting
3. Scabblers/scarifiers
4. Grit blasting
5. Centrifugal cryogenic CO_2 blasting
6. Ice blasting
7. Supercritical CO_2 blasting
8. Plastic pellet blasting
9. Hand grinding, honing, scraping
10. Automated grinding
11. Metal milling
12. Concrete milling
13. Explosive

Surface cleaning methods

1. Compressed air cryogenic CO_2 blasting
2. High-pressure water
3. Superheated water
4. Water flushing
5. Steam cleaning
6. Hand brushing
7. Automated brushing
8. Sponge blasting
9. Hot air
10. Dry heat (roasting)
11. Solvent washing to remove radiological contamination
12. Solvent washing to remove organics
13. Strippable coatings
14. Vacuum cleaning
15. Ultrasonic cleaning

Thermal surface removal methods

1. Microwave scabbling
2. Plasma torch
3. Laser heating
4. Laser etching and ablating
5. Plasma surface cleaning
6. Plasma etching/fluorination
7. Flashlamp cleaning

Incineration of various materials is accepted by the EPA. The incineration of contaminated combustible building materials is common in the nuclear industry. The waste generated will depend upon the design of the incinerator and the ash content of the material being burned. The fly ash and smoke particles have to be contained with particular care.[3]

The technology of dry heat (e.g., calcination) would be used to remove volatiles such as oils and PCBs. Treatment of off-gases to remove the volatilized contaminants would be necessary.

The catalytic extraction process is similar to smelt purification in that a furnace is used to form a molten metal bath. In the catalytic extraction process, the bath is used not only to purify metal but also, at the high-operating temperatures, to effectively destroy hazardous-organic materials such as aromatic hydrocarbons and PCBs. Also, mixing is better in the catalytic extraction process because material is introduced from the bottom of the process; control of the oxidation potential is better with the catalytic extraction process because oxygen, rather than air, is injected into the furnace. The process has not been used commercially to treat scrap contaminated with radionuclides. Waste generated could include radioactive slag and wet scrubber solutions.

Very limited use of vacuum (i.e., low pressure to remove volatile compounds) has been made for bulk decontamination. Some information has been obtained on a proprietary vacuum-based process for removing water soluble Cr^{+6} from transite sheeting surfaces. Vacuum can also be used to remove contamination from porous materials by boiling solvents out of the material if the solvent foams out and the solvent is collected.[3] Because of their low-vapor pressures, the technique would probably be rather ineffective for most oils and PCBs.

Transmutation appears to be the only technology capable of eliminating induced radiation, which results from exposure of material to high-neutron fluxes. The neutron fluxes, such as those near the core of a fission reactor, often result in the change of some of the atoms in the exposed material to radioactive species that are chemically identical isotopes of the other unchanged atoms in the material. Thus, the radioactive isotope cannot be removed from the base material by chemical means. (If the induced radiation comes from different elements from the bulk of the material, chemical methods such as metal refining techniques could be used to decontaminate the material.) Transmutation might be used to convert radioactive isotopes into nonradioactive ones by bombarding the radioactive species with neutrons or alpha particles. This technique could only be used if particles could be found that have energies such that the cross-sections of the radioactive isotopes were much larger than those of the nonradioactive isotopes. Otherwise this technique might generate as much, or more, radioactivity than it eliminated. Even then, the practicality of this technology is doubtful.

5.2.3 Chemical Surface Cleaning Methods

Technologies comprising chemical foams, chemical gels, acid treatments, caustic treatments, and redox treatments involve reaction with the contaminant to form a species that is dissolved in the cleaning solution and thereby removed from the substrate. Depending upon the strength of the chemical solution, physical degradation of the surface can also occur. Foams and gels are used to enhance the performance of the chemicals and to reduce subsequent waste volumes by holding the decontamination chemical in better contact with the contaminated surface. These methods of application can be used for in situ decontamination of exterior surfaces. The other solutions may be applied in dipping baths, in loop systems, or through spraying. Recovery would be a

problem in the use of the spraying technique for decontamination of exterior surfaces unless decontamination is done in a spray booth with suitable critically safe drains. Spray booths similar to car washes are used at gaseous diffusion plants to decontaminate the interior and exterior of disassembled equipment. For waste volume reduction, regeneration and recycling of the chemical is necessary. Depending upon the strength or reactivity of the chemical, decontamination factors range from as low as five to ten up to several hundred. British Nuclear Fuels, Ltd., uses several different chemical technologies to decontaminate equipment from the Capenhurst Diffusion Plant to below regulatory concern (BRC) of British limits.

Electropolishing selectively removes contaminant metal ions from a metal surface. This method, using an electrolyte and electricity, has usually been applied on small areas. For waste-volume reduction, separation of the contaminant from the electrolyte and recycling of the electrolyte would be needed.

Gas-phase decontamination uses a strong fluorinating gas to convert uranium fluoride and oxyfluoride deposits inside gas-tight equipment to uranium hexafluoride gas, which could then be recovered with chemical or cold traps. Lab studies have shown that over 99.9% uranium removal can be obtained by reaction at room temperature.[4] However, thorium and protactinium fluorides and most of the fluorides of elements formed in the decay chains of ^{235}U and ^{238}U are not volatile. Treatment of the off-gases will generate wastes from liquid scrubbers and dry-chemical traps when using current technology.

Plasma etching and fluorination technologies may be used to enhance performance of gas-phase decontamination. The plasmas of fluorinating gas can be created to promote room-temperature chemical reactions, converting uranium fluoride and oxyfluoride deposits into uranium hexafluoride gas. A research project would be needed to perform a feasibility test in the gas-phase facility.

The UV/ozone and electromigration technologies are in the evolving technology stage. In the use of UV/ozone to remove oils, greases, and solvents, UV light produces ozone from oxygen and also excites and/or dissociates contaminant molecules. These reactive species then produce CO_2 and water vapor (and HCl in the case of chlorinated solvents). Electromigration uses an electric potential to cause migration of metal ions from a surface into an electrolyte. The technology may be applied in a localized area or as a "factory style" process in batch fashion to contaminated areas. For waste-volume reduction, separation of the contaminant from the electrolyte and recycle of the electrolyte would be needed.

5.2.4 Metal Refining Methods

Smelt purification involves adding oxidizing fluxes to scrap metal that will react with impurities when the metal is heated. The contaminants are removed in the slag that forms and floats to the top of the molten metal. Lab-scale and large-scale studies of smelt purification of radioactive metals have been made. Good results were obtained with the easily oxidized elements like uranium, but reportedly the more noble technetium is not removed by this technology. Estimates of capital and operating costs for smelting 90,000 tons of DOE scrap metal have been developed.

Electrorefining is a well-established, commercial technology but is much less established for decontaminating radioactive metal. Electrorefining uses an electrolysis cell that contains an anode made from contaminated metal and deposits a cathode of pure metal. A voltage applied between the cathode and anode causes metal to ionize from the anode and to plate out on the cathode. Lab-scale tests that electrorefined contaminated nickel resulted in plate out of technetium with the nickel on the cathode. The electrolytic

waste solutions from this process will be characterized as mixed wastes. Decontamination and recycle of the electrolytic solutions will be needed. Studies to determine the electropotentials, current densities, and concentrations to use might make this method successful. At the thermodynamic limit, this process can separate all elements adequately.[3]

In the leach/electrowinning process, impure metal is dissolved, the solution is passed through a purification step, and purified metal is then plated out on a cathode in an electrolytic cell. This process is a well-established, commercial method for producing nickel from ore but is not used commercially to refine contaminated nickel metal. As in the case of electrorefining, decontamination and recycle of the electrolytic solutions will be needed. Technetium can be removed by ion exchange with the impure metal solution.

5.2.5 Mechanical Surface Removal Methods

Most of the technologies in this generic group involve impacting or blasting a surface with a high-velocity stream of fluid or solid particles. These technologies include ultrahigh-pressure water, shot blasting, grit blasting, centrifugal cryogenic CO_2 blasting, ice blasting, supercritical CO_2 blasting, and plastic pellet blasting. The supercritical CO_2 blasting is under development by industry.[5] The centrifugal CO_2 blasting technology is being developed using the DOE Fusion Energy Program's centrifuge pellet acceleration method. The others are accepted and used by industry for decontamination work. The grit and shot blasting technologies will remove the surface layer of most substrates. The other blasting methods will remove concrete surface layers. For purposes of cost reduction and waste minimization, separation of the removed contamination and recycle of the working fluid or solid particles would be desired. For technologies using CO_2, separation is facilitated as the solid or supercritical CO_2 converts to the gaseous phase during impact with the surface being decontaminated. But containment and collection of the contaminated dust could be a problem depending upon the configuration of the surface being blasted.

Mechanical scarifiers and scabblers are available for removing a surface layer of contaminated concrete. Scarifier heads usually have several carbide tips; multiple-head machines are used for large-surface floor or wall applications. Scabblers use moving chains, saws, and steel bars or rollers. The method is effective but is slow and can generate airborne contaminants.

Manual methods such as scraping tend to be labor intensive and slow and might result in excessive worker exposure to radiation or contamination. Grinding, honing, and milling machines are commercially available for decontaminating surfaces. These machines would be more suitable for regular surfaces. The explosive technique involves the selective detonation of small explosive charges in the surface of concrete to shatter the surface layer.

Since the technologies in this generic group remove the surface layer of the substrate, 100% decontamination should result if the depth of penetration of the contamination is less than the depth of surface removal and if back-contamination can be prevented. For blasting technologies, the waste generated will consist of the particular blasting medium and the contaminated layer of substrate that is removed. If the blasting medium can be separated, the waste generated by the technologies in this generic group will consist primarily of the detached substrate layer. These techniques will also produce a small volume of contaminated filters. Recycle systems for ultrahigh-pressure water will probably produce small volumes of contaminated ion exchange media and other components such as filter cakes or sludges.

5.2.6 Surface Cleaning Methods

Surface cleaning methods remove the fixed and/or loose contamination without disturbing the surface of the substrate. They should be particularly effective for loose contamination. Several technologies that are described in the mechanical surface removal methods group may also be listed in this group in their less-aggressive modes. These include scraping, ultrahigh-pressure water, shot blasting, grit blasting, centrifugal cryogenic CO_2 blasting, ice blasting, supercritical CO_2 blasting, and plastic pellet blasting. Depending upon the operating conditions or the particular substrate being treated, these technologies can achieve decontamination without affecting the substrate surface. Other blasting technologies in this generic group are compressed air cryogenic CO_2 blasting, sponge blasting, high-pressure water, superheated water, hot water, and steam.

In this CO_2 blasting method, the cryogenic pellets are accelerated by compressed air rather than by centrifugal force. The sponge blasting technology decontaminates by blasting surfaces with various grades of patented, water-based urethane foam particles using 110 psig air as the propellant. The foam is absorptive and can be used either dry or wet to treat a variety of surface contaminants such as oils, greases, lead compounds, chemicals, and radionuclides. A nonaggressive grade of foam is used for surface cleaning on sensitive or otherwise critical surfaces. Aggressive grades, which are impregnated with abrasives, are capable of removing tightly adherent materials such as paints, protective coatings, and rust and can roughen concrete and metallic surfaces if desired. High-pressure (500–1000 psi) water sprays are used extensively in the nuclear industry for smearable contamination. Decontamination factors of 1.5–10 are typically obtained, depending upon the amount of fixed contamination. Superheated-water (300–400°F and several hundred psi) machines are commercially available. Their use is usually limited to floors. Commercial equipment using steam and hot-water jets for decontamination is also available.

Manual decontamination methods of brushing and scrubbing will remove loose contamination but are ineffective for fixed contamination. Also, they have the same undesirable features of the manual methods in the mechanical surface removal group.

Solvent washing is typically used for organic contamination such as oils and PCBs. Loose or smearable contamination may also be removed by this method. To minimize waste, solvent recovery is needed. All low-boiling organic solvents are Resource Conservation and Recovery Act (RCRA) hazardous by the rules and increase the cost of operation.

The strippable coating technology involves "painting" a surface with, for example, a water-based organic polymer. When dry, the coating can be removed, along with the contaminants captured by the coating, mechanically, chemically, or, in the case of "auto-release" coatings, by vacuuming. Decontamination factors are reported to range from as low as three to five up to several hundred, depending upon how tightly the contaminants are bound to the surface.

The technology of dry heat (e.g., roasting) would be used to remove volatiles such as mercury, tritium oils, and PCBs.

The use of vacuum cleaners and their filters is accepted and widely used for removing and collecting loose contamination at gaseous diffusion plants. This method is often used to clean up during and after grinding, honing, scraping, and other surface removal methods. Vacuuming might be effective for removing loose contamination that has settled on girders, other nonvertical surfaces, cracks, etc.

Ultrasonic cleaning has been used for many years to remove surface-contamination from relatively small metal parts. Use of this technology on a large scale would likely require separation of the contaminants from the cleaning fluid so that the fluid could be recycled.

5.2.7 Thermal Surface Removal Methods

For surface removal of concrete, the microwave scabbling and plasma torch methods flash the hydration water in the concrete to steam. The resulting volume expansion fractures the concrete surface. Removal of the debris captures most of the contamination.

The plasma torch, flashlamp, and laser heating methods remove the surface layer of other substrates by supplying enough heat to the surface to cause vaporization. The laser ablation method removes surface layers by photochemical and photothermal processes. The vaporized materials and contaminants may then be captured by vacuum removal with a cover-gas stream, thus effecting decontamination. The plasma torch method will produce a significantly higher gas-flow rate than the laser method. Because of the unidirectional nature of these technologies, application to complex geometries might be a problem. Burn-through could also occur when treating walls.

In plasma cleaning, glow discharges might be used either to clean the inside surfaces of vessels or, in reactive plasma cleaning, to produce chemically reactive species that clean contaminated surfaces by the processes of chemisorption, reaction, and desorption or gasification. For example, with an oxygen plasma, oxygen atoms, ozone, and UV photons convert hydrocarbons to CO_2 and water vapor, and a fluorine plasma may provide for separation and recovery of valuable uranium by converting it to UF_6. For the latter, the low volatility of UF_6 would need to be taken into account in the system design. Because of the relatively low-melting point of metal fluorides, burn-through with aggressive fluorine plasmas would have to be prevented. This could be done by monitoring the production of UF_6 and other off-gases and by controlling the plasma discharge parameters. The UF_6 gas can be recovered and the excess fluorine reused. Plasma cleaning is routinely used to clean the inside of fusion devices before the main plasma is lighted. A pollution control methodology for the effluent gas from the plasma treatment step would be needed.

For the technologies in this generic group that remove the surface layer of the substrate, 100% decontamination should result if a sufficient depth of surface is removed. Thus, control of the depth of surface removal is a critical factor. The waste generated will consist primarily of the detached substrate layer.

The thermal surface removal technologies produce smokes that have smaller particle sizes than the dusts resulting from mechanical surface removal. The smokes from thermal surface removal will be harder to remove by filtration than the dusts from mechanical surface removal.[3]

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5.3.1 Introduction

This section summarizes the science and technology needs of the decontamination technologies that were described in Sect. 5.2.2, irrespective of how high they were ranked by the ranking process. The science (i.e., basic research) needs usually apply to technologies that are in the evolving or predemonstration phase. Technology development needs are related to those technologies in the predemonstration or demonstration phase; whereas, technology improvement needs pertain to technologies that have been demonstrated or accepted. The science and technology needs have also been grouped into the six generic technologies.

5.3.2 Bulk Decontamination

The effectiveness of the catalytic extraction process should be demonstrated for the materials and contaminants of interest at ORNL.

Literature searches of existing cross-section data are needed to determine whether transmutation is a feasible technology for decontaminating items like reactor cores that have induced radiation from exposure to high-neutron fluxes. Such a search would determine whether combinations of particles and energies exist such that the cross-section for radioactive isotopes are sufficiently larger than those for nonradioactive isotopes that the radioactive species could be "burned out" of the matrix of nonradioactive atoms. Additional cross-section determinations may also be needed.

5.3.3 Chemical Surface Cleaning

The fluoboric acid technology generates a metal waste as a result of surface removal. The optimum material for solidification of this waste needs to be determined.

To advance the gas-phase technology, laboratory studies should be continued to determine the feasibility of the process and, if results are favorable, a demonstration of a mobile system for in situ decontamination should be conducted.[6] If recovery of an unreacted fluorinating agent is to be a part of the process, research to determine the best method will be needed. This method will then need to be demonstrated. Separation of reaction by-products could be a problem.

Research projects would be needed to investigate the feasibility of using the UV/ozone technologies for surface decontamination. A pilot-scale UV/ozone decontamination system, which is available from a private company, could be used for such a study.

Several aspects of electromigration require fundamental evaluation. Selection of the best characteristics for an electrolyte to cause migration of all contaminants to the surface is needed. Concrete imbibing studies are needed to evaluate the flow or migration mechanism. Parametric studies are needed to optimize operating conditions. Electrolyte gels must be developed for nonhorizontal surfaces. Systems that will recycle electrolytes must be designed and demonstrated.

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5.3.4 Metal Refining

For the electrorefining technology, a recycle system for the electrolyte solution needs to be developed.

5.3.5 Mechanical Surface Removal

For waste minimization, a water treatment and recycle system needs to be developed for the ultrahigh-pressure water and ice blasting technologies. Also, improved vacuum systems are needed to recover the water to prevent the spread of contamination when cleaning equipment and structures with complex geometries. For the abrasive blasting technologies—shot, grit, and plastic pellet—more durable materials that resist deformation and abrasion and can be recycled through the process more times are needed for waste minimization. Higher-velocity and harder-cryogenic CO_2 pellets are needed to increase the aggressiveness of this technology and extend its usefulness to more difficult decontamination applications. Again, better containment methods are needed to avoid the spread of contamination.

The supercritical CO_2 technology, which appears promising because of its similarity to ultrahigh-pressure water, requires development work to establish it as an accepted technology. Better containment methods for the dust that is generated are also needed for the grinding and milling technologies.

Capabilities for remote operation of the mechanical surface removal technologies for use in areas of high levels of radiation or contamination need to be developed.

5.3.6 Surface Cleaning

The surface cleaning technologies that use either liquid water or steam have the same needs for development of water recycle systems and improved vacuum systems as listed for ultrahigh-pressure water and ice blasting under the mechanical surface removal technologies.

The solvent washing technology needs to identify and demonstrate solvents that are more environmentally acceptable. Water is the standard for these techniques.

5.3.7 Thermal Surface Removal

For microwave scabbling, development and testing of a mobile concrete-removal prototype should be completed. Mathematical modeling is recommended for optimization of concrete-removal rates and efficiencies. Remote operation requires the development of remote-controlled robotic arms for the microwave applicator and the vacuum collection system. Development of real-time monitoring sensors to monitor the progress of decontamination would help to minimize wastes.

Commercially available laser heating, laser ablation, and flashlamp systems should be evaluated on a bench scale for possible use on decontamination problems at ORNL. If these tests are successful, larger-scale demonstrations should be initiated.

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5.4.1 Introduction

This section summarizes the implementation needs of the decontamination technologies that were described in Sect. 5.2.2. Implementation needs include (1) technology development/improvement and (2) prerequisites to successful technology deployment after demonstration or acceptance.

5.4.2 Summary of Implementation Needs

The specific implementation needs of each technology are detailed in the data sheets. In this section, only those needs that are considered significant, primarily in terms of resources, are cited. Table 5.3 shows three such implementation needs and the specific technologies that have these needs. In Table 5.3, the relation of a need to a particular technology is indicated either by an "X" or, whenever available, by the estimated cost of providing that need.

The three implementation needs listed in Table 5.3 are R&D/DEMO, WASTE, and ROBOTICS. The first need pertains to those technologies that have not advanced to the accepted status level and need R&D and/or demonstration programs to bring the basic decontamination technology to that level. The second need is usually associated with accepted technologies for which the development of systems for waste collection, waste treatment, waste minimization, or material recycle is recommended. The last need is related to those technologies that are adaptable to remote-controlled operation. Reasons for implementing remote-controlled operation include (1) necessity (e.g., due to high-radiation levels), (2) improvement of the operability of the equipment, and (3) increase of the decontamination efficiency.

One implementation need worthy of note is for the incineration technology. Installation of a new incinerator similar to the K-1435 incinerator might require as much as 8–10 years for writing an environmental impact statement, holding public hearings, and obtaining the necessary permits—TSCA, RCRA, National Emission Standards for Hazardous Air Pollutants (NESHAP), and Clean Air Act (CAA).[7] Streamlining of this process would be needed if implementation of this technology is required within a shorter time period and for less money.

000120

Table 5.3 Summary of implementation needs

Technology	Implementation need[a]		
	R&D/Demo[b]	Waste[c]	Robotics[d]
Bulk decontamination			
Solvent extraction	<2	X	
Incineration		X	
Dry heat		X	
Chemical leaching	<1	X	
Catalytic extraction process	3–5	X	
Vacuum (low pressure)	1–3	X	
Transmutation	0.1–10	X	X
Chemical surface cleaning			
Chemical foams	1–4	X	
Chemical gels	1–4	X	
Organic acid treatment	0.4–1	X	
Fluoboric acid treatment		X	
Inorganic acid treatment		X	
Detergent treatment		X	
REDOX treatment	–1	X	
Chelation treatment		X	
Electropolishing	0.4–1	X	
Gas phase	5	X	
Biological	0.3–0.6	X	
UV/ozone (UV light activation)	<1		
Electromigration	1.0	X	
Metal refining			
Smelt purification	3–5	X	
Electrorefining	3	X	
Leach/electrowinning	<1	X	
Mechanical surface removal			
Ultrahigh-pressure water	1.3	X	X
Shot blasting		X	X
Scabblers/scarifiers		X	X
Grit blasting		X	X
Centrifugal cryogenic CO_2 blasting	<1	X	X
Ice blasting	0.25	X	X
Supercritical CO_2 blasting	0.25–1	X	X

000121

Table 5.3 (continued)

Technology	Implementation need[a]		
	R&D/Demo[b]	Waste[c]	Robotics[d]
Plastic pellet blasting		X	X
Hand grinding, honing, scraping		X	
Automated grinding	<1	X	X
Milling—metal			
Milling—concrete		X	X
Explosive	1–4	X	
Surface cleaning			
Compressed air cryogenic CO_2 blasting	~0.5	X	
High-pressure water	~1.2	X	X
Superheated water	~1.2	X	X
Water flushing	~1.2	X	X
Steam cleaning	~1.2	X	X
Hand brushing			
Automated brushing	<1	X	X
Sponge blasting	~1.2	X	
Hot air	1–5	X	
Dry heat (roasting)	0.2–1	X	
Solvent washing (radioactive contamination)	<1	X	
Solvent washing (organic contamination)		X	
Strippable coatings		X	
Vacuum cleaning			
Ultrasonic cleaning		X	
Thermal surface removal			
Microwave scabbling	2.5	X	X
Plasma torch	<0.5	X	X
Laser heating	2+	X	X
Laser etching and ablating	2–3	X	
Plasma surface cleaning	4	X	
Plasma etching/fluorination	2+	X	
Flashlamp cleaning	2.5	X	

[a]Numbers in table are costs in millions of dollars. An "X" indicates the relation of a need to a particular technology.
[b]R&D/Demo = research and development and/or demonstration
[c]Waste = waste collection systems
[d]Robotics = technologies that are adaptable to remote-controlled operations

000122

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5.5.1 Ranking Method

Decontamination technologies applicable to ORNL D&D problems were ranked using the method described in Sect. 2.4. The rankings for the decontamination technologies are given in Table 5.4. Individuals that were assigned specific technologies first ranked the technologies. Because of the experience of these persons, their estimates of the time required to bring the technologies to maturity was believed to be more accurate than the guidelines given in Table 2.4. The rankings originally assigned to the various technologies were reviewed by other team members. If the team members disagreed with the original ranking, the ranking was discussed among the team, and the team arrived at a consensus ranking that was then used.

Because of the large number of variables that could affect the projected unit processing cost at ORNL, the Decontamination Team had great difficulty estimating reasonable values for this parameter. To achieve greater specificity for estimating the unit-processing cost, operating costs were based on decontamination of relatively large areas of concrete floor for all technologies applicable to this problem. For technologies that were only applicable to the decontamination of metals, the operating cost was based on decontamination of large sections of sheet metal. For technologies that were not applicable to either concrete or metals, unit processing costs were estimated for the applications that would give the lowest cost. Even so, the costs given in Table 5.4 should be regarded as approximate at best, treated only as relative values, and not used for estimating job costs.

5.5.2 High-Ranking Existing Technologies

Many existing technologies were ranked high. These technologies and the improvements recommended in them are briefly discussed in this section. No development or technology improvements are recommended for many of the high-ranking existing technologies.

5.5.2.1 Mechanical Surface Removal Methods

Mechanical surface removal methods are good for decontaminating concrete and exterior metal items. Mechanical scabblers are available and have been used extensively for decontaminating concrete surfaces. No secondary waste streams other than the removed concrete surface layer are produced. Mechanical scabblers have problems with uniform application on irregular and nonhorizontal surfaces. However, this problem is typical of other technologies for concrete decontamination and is one of the areas for development.

Shot blasters and grit blasters are also available and have been used extensively for decontaminating concrete and metal surfaces. The volume of waste shot created is a reasonably small fraction of the waste created from removing a concrete surface layer. The relative proportion of waste grit is larger. Grit blasting is more effective than shot blasting for decontaminating metal surfaces. The proportion of waste shot or grit created is greater for metal surfaces than for concrete surfaces. More durable blasting materials that resist abrasion and can be recycled through the process more times for waste minimization would improve the utility of these technologies. Shot and grit blasting are not recommended inside hot cells.

000123

Table 5.4. Rankings of decontamination technologies for D&D

Data sheet code number	Technology	Ranking[a]
	Bulk decontamination methods	
DCON-1-OL	Solvent extraction	M-2-1 (<$2M;N)
DCON-2-OL	Incineration	M-2-12 ($30M;$10/lb)
DCON-4-OL	Dry heat (bulk roasting)	L-1-1 ($2M;N)
DCON-5-OL	Chemical leaching	M-3-2 ($1M;<$1/ft^2)
DCON-6-OL	Catalytic extraction process	H-5-4 ($20M;$1/lb)
DCON-7-OL	Vacuum (low pressure)	L-1-2 ($2M;N)
DCON-78-OL	Transmutation	L-1-10 ($500M;N)
	Chemical surface cleaning methods	
DCON-8-OL	Chemical foams	M-4-1 ($3M;$0.50–$2/ft^2)
DCON-9-OL	Chemical gels	M-4-2 ($3M;N)
DCON-10-OL	Organic acid treatments	H-4-2 ($2M;N)
DCON-11-OL	Fluoboric acid treatments	H-4-2 ($2M;N)
DCON-12-OL	Inorganic acid treatments	M-3-0 ($4M;N)
DCON-13-OL	Detergent treatments	M-4-0 ($0M;>$1/ft^2)
DCON-14-OL	REDOX treatments	M-4-1 ($3M;<$1/ft^2)
DCON-15-OL	Electropolishing	M-4-2 ($3M;>$1/ft^2)
DCON-16-OL	Gas phase decontamination	M-4-4 ($5M;<$0.50/lb)
DCON-17-OL	Biological surface cleaning	L-2-3 ($1M;–$1/ft^2)
DCON-19-OL	Ultraviolet light/ozone	M-4-2 ($1M;–$1/ft^2)
DCON-20-OL	Electromigration	M-3-3.5 ($1.2M;N/ft^2)
DCON-21-OL	Chelation treatment	M-4-2 ($1.5M;<$1/ft^2)
	Metal refining methods	
DCON-31-OL	Smelt purification	H-3-3 ($100M;–$1/lb)
DCON-32-OL	Electrorefining	M-2-5 ($200M;$6/lb)
DCON-34-OL	Leach/electrowinning	M-2-5 ($200M;$3.80/lb)
	Mechanical surface removal methods	
DCON-35-OL	Ultrahigh-pressure water	H-5-1 ($1.7M;$1/ft^2)
DCON-36-OL	Shot blasting	H-3-0 ($<0.1M;–$1/ft^2)
DCON-37-OL	Scabblers/scarifiers	H-4-2 ($0.5M;$5/ft^2)

000124

Table 5.4 (continued)

Data sheet code number	Technology	Ranking[a]
DCON-38-OL	Grit blasting	H-4-0 (\$<0.1m;~\$5/ft^2)
DCON-39-OL	Centrifugal cryogenic CO_2 blasting	H-5-2 (\$1.0M;<\$1/ft^2)
DCON-40-OL	Ice blasting	H-5-1 (\$<1.0M;\$1/ft^2)
DCON-41-OL	Supercritical CO_2 blasting	H-5-1 (\$0.75+M;>\$1/ft^2)
DCON-42-OL	Plastic pellet blasting	M-4-0 (\$<0.1M;~\$1/ft^2)
DCON-43-OL	Hand grinding, honing, scraping	H-2-0 (\$<0.1M;~\$1/ft^2)
DCON-44-OL	Automated grinding	H-2-1 (~\$1M;\$1;N)
DCON-45-OL	Metal milling	M-2-1 (\$0.15M;\$17.50/ft^2)
DCON-47-OL	Concrete milling	M-1-2 (\$<1M;\$0.75/ft^2)
DCON-48-OL	Explosive	L-2-5 (\$4M;\$50/ft^2)
	Surface cleaning methods	
DCON-51-OL	Compressed-air cryogenic CO_2 blasting	H-4-1 (\$0.7M;>\$1/ft^2)
DCON-52-OL	High-pressure water	M-3-1 (\$1.3M;<\$1/ft^2)
DCON-53-OL	Superheated water	M-4-1 (\$1.4M;~\$1/ft^2)
DCON-54-OL	Water flushing	M-4-1 (\$1.3M;<\$1/ft^2)
DCON-55-OL	Steam cleaning	M-4-1 (\$1.3M;~\$1/ft^2)
DCON-56-OL	Hand brushing used to remove surface contamination	H-2-0 (\$0M;\$1/ft^2)
DCON-57-OL	Automated brushing	M-3-2 (\$1M;\$300/ft)
DCON-58-OL	Sponge blasting	M-3-1 (\$1.3M;\$2/ft^2)
DCON-59-OL	Hot air stripping	L-1-1 (\$2M;N)
DCON-60-OL	Dry heat roasting	L-2-3 (\$5M;N)
DCON-61-OL	Solvent washing to remove radiological contamination	M-3-2 (\$1M;N)
DCON-62-OL	Solvent washing to remove organics	H-2-2 (\$0.4M;N)
DCON-63-OL	Strippable coatings	M-3-0 (\$<0.1M;>\$1/ft^2)
DCON-64-OL	Vacuum cleaning	M-4-0 (\$<0.1M;\$1/ft^2)
DCON-65-OL	Ultrasonic cleaning	M-2-1 (\$0.1M;>\$2/ft^2)

Table 5.4 (continued)

Data sheet code number	Technology	Ranking[a]
	Thermal surface removal methods	
DCON-71-OL	Microwave scabbling	H-3-2 ($2.5+M;>$1/ft^2)
DCON-72-OL	Plasma torch	H-4-1 ($0.5M;~$1/ft^2)
DCON-73-OL	Laser heating	M-4-4 ($3M;$1/ft^2)
DCON-74-OL	Laser etching and ablation	M-4-4 ($3.5M;>$1/ft^2)
DCON-75-OL	Plasma surface cleaning	H-4-2 ($1.0M;>$1/ft^2)
DCON-76-OL	Plasma etching/fluorination	M-3-3 ($5M;>$2/ft^2)
DCON-77-OL	Flashlamp cleaning	H-3-3 ($2.5M;~$1/ft^2)

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

Ultrahigh-pressure water blasting is also available and accepted for concrete and metal decontamination. The depth of the concrete surface that is removed can be controlled by varying the water pressure and unit speed. A water recycle system may be available for some environments but generally will have to be developed and demonstrated for each specific application.

Supercritical CO_2 blasting, which is under development commercially, should act very much like ultrahigh-pressure water except that no water will remain that must be treated. Development of this technology should be completed. Commercial cryogenic CO_2 pellet blasting has been used to decontaminate tools at nuclear power plants. More abrasive high-speed pellets from a centrifugal cryogenic CO_2 pellet blasting system under development may be needed to remove many contaminants at ORNL. This technology should be effective in decontaminating metal and concrete surfaces.

Ice blasting offers the advantage that the pellet melts to form water rather than becoming a waste. The contaminated wastewater formed by the melting ice particles must then be treated for discharge in commercially available evaporators. Remote-controlled operation of the cleaning head is desirable for some applications and will be required for others (e.g., decontamination of hot cells). Consequently, the adaptation of the equipment to a robotics control system would be necessary.

5.5.2.2 Advanced Catalytic Extraction Process

The advanced catalytic extraction process is widely applicable to contaminated metals and nonmetals. The catalytic extraction process is similar to smelt purification when applied to contaminated metal refining but reportedly mixes better and maintains better control of the oxidation potential. For contaminated nonmetals, the catalytic extraction process acts similar to an incinerator but reaches higher temperatures and generally has longer processing times with more intimate contact of the contaminant with the molten metal bath. Impurities are removed by the off-gas treatment system as well as slags. This technology should be demonstrated on materials and contaminants of interest at ORNL.

5.5.2.3 Fluoboric Acid

Fluoboric acid effectively decontaminates concrete and metals by removing up to a few millimeters of the surface. Fluosilicic acid can also decontaminate concrete, brick, and similar masonry surfaces. The acid can be electrolytically regenerated and recycled. One treatment option is neutralization and precipitation with solidification in cement. Another treatment is ion exchange with solidification of the ion exchange resin or mineral in cement. The optimum materials for solidification of these wastes needs to be determined. Treatment systems that permit recycle of decontamination agents are needed for fluoboric acid and all liquid-based systems.

5.5.2.4 Organic Acids

Organic acids were used by British Nuclear Fuels, Ltd., as part of the treatment to decontaminate the Capenhurst Gaseous Diffusion Plant. Tests should be conducted to further verify that this process will remove the contaminants of interest at ORNL from the substrate metals on which they are found. Implementable waste treatment technologies in the United States are different than in Great Britain, but in most ways their controls are equally demanding.

5.5.2.5 Smelting

Smelting would be an attractive secondary decontamination method if a *de minimus* limit were in place for bulk-contaminated materials. The additional purification that would be obtained by using smelting as a secondary decontamination step would permit the use of primary decontamination technology that is only partially effective while still providing thorough overall decontamination. Primary decontamination technologies that leave some contamination behind (e.g., in cracks and crevices) could be used. Previously bulk contaminated metals cannot be recycled to the commercial sector for reuse no matter how well they have been decontaminated because the U.S. does not have a *de minimus* limit. Metals could be recycled within the DOE system to make shield blocks, waste containers, and other items without a *de minimus* limit. However, use of these items would still have to be accepted by the user or acceptance would have to be mandated by DOE headquarters. Techniques for improving the purification of aluminum and for removing technetium should be developed if possible.

5.5.2.6 Grinding, Brushing, and Vacuuming

Hand grinding, brushing, and vacuuming will continue to find applications in areas of negligible radiation because of their very low capital cost. These technologies are very effective for some applications. Remotized versions of these technologies are needed in higher-radiation or -contamination areas.

5.5.2.7 Solvent Washing

Solvent washing is an effective way to remove organic contamination. However, environmentally acceptable solvents must be used. Solvents that are less damaging to the environment need to be identified and demonstrated.

5.5.3 High-Ranking Technologies Requiring Development

Microwave scabbling is a potentially attractive decontamination method for concrete. Development of this technology should be continued. The secondary waste is the removed concrete surface layer. Microwave scabbling may result in the removal of a deeper concrete layer than is desired, with attendant generation of more secondary waste than is necessary. Because there is no reaction force, this technology appears particularly suitable for use on walls and ceilings and for remote use in hot cells and other high-radiation areas.

Use of a plasma torching is a potentially attractive decontamination method for concrete and metal that should be investigated. This technology could be effective, generate little secondary waste, and have low-capital and operating costs. Development and demonstration should not take long or be very expensive.

Plasma surface cleaning and flashlamp cleaning are potentially attractive decontamination methods for metals that should also be investigated. They could be effective and generate little secondary waste. Capital costs could be higher, especially for plasma surface cleaning. Flashlamp cleaning would be ideal for decontamination of hot cells, other higher-radiation areas, and difficult-to-reach areas since it acts remotely.

All of these technologies should be developed to the point that capital and operating costs can be estimated.

5.5.4 Implementation

Technologies that generate mists, dusts, and smokes will require effective vacuum and filtration systems. Smokes generated by most thermal surface removal methods have smaller particle diameters than dusts generated by mechanical surface removal methods or mists generated from liquid decontamination techniques and will require particularly effective filtration systems. Many will require glove boxes or special decontamination rooms.

Operating costs that are achievable in clean environments are less important than donning and doffing, setup and breakdown, and waste disposal costs. Because these costs appear to run just under $\$1/ft^2$ under the most favorable conditions, estimated costs for the fastest and least labor intensive decontamination methods tended to be estimated at about $\$1/ft^2$.

5.5.5 Remotization

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Remotization is needed for decontamination in areas having moderate- or high-radiation fields. Mechanical control of decontamination operations will also be helpful during the decontamination of walls, ceilings, and similar surfaces. Since decontamination operations at ORNL—unlike those at the K-25 Site—will be characterized by few replications of a given task, automation will not be needed. Remotization should be accomplished by teleoperation with an operator in the loop rather than by use of an independent robot.

5.5.6 Components with Induced Radiation

Decontamination of metal components with induced radiation, such as reactor cores, is generally not feasible. Metal refining technologies will be ineffective in most cases because the induced radiation comes from atoms that are isotopes of and chemically identical to the bulk of the metal atoms. In principal, transmutation could be used but only if the radioactive isotope had a larger cross section than the base metals. In any event, this would be a prohibitively expensive operation. In general, these components will have to be removed and disposed of in their radioactive state. Concrete with induced radiation can be removed, leaving clean concrete (or concrete that can be decontaminated as indicated in the logic diagram). Similarly, equipment that is partially contaminated with induced radiation is decontaminated by cutting out only the parts with induced radiation.

000129

5.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the decontamination technologies listed in Table 5.2. Table 5.5 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with this list of decontamination technologies. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding decontamination technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Decontamination technologies for which no matches were found are omitted from the table. When many matches were found, only one or two were cited. The relevance column indicates the degree of overlap between the listed decontamination technologies and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 5.5. Decontamination technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Solvent extraction	DCON-1-OL	OR-373-AH	H	Organic extraction from sludge Mature technology
Catalytic extraction process	DCON-6-OL	ID421201	H	Molten metal/salt extraction
Chemical gels	DCON-9-OL	RL332003	M	Hanford Tank example. Widely used
Detergent treatments	DCON-13-OL	RL132002	L	Supporting technology
Biological surface cleaning	DCON-17-OL	AL121121	L	Biological cleaning of soil
Electromigration	DCON-20-OL	AL231009	L	Electrokinetic removal of Cr from soil
Chelation treatments	DCON-21-OL	ID111701 AL1320028	M H	Chelation and extraction of lanthanides and actinides Removal of metal ions from wastewater
Smelt purification	DCON-31-OL	ID132011 ID421201	L M	Arc melter vitrification Actinide concentration
Leach/electrowinning	DCON-34-OL	ID421201	L	Mentions LMFBR[c] fuel reprocessing— Accepted Ni Ore refining
Ultrahigh-pressure water	DCON-35-OL	SF221205	M	Use on WHC[d] UST[e] cleaning
Scabblers/scarifiers	DCON-37-OL	RL332003	M	Accepted
Hot air stripping	DCON-59-OL	RF121204	M	Rocky Flats Integrated Demo
Solvent washing to remove radiological contamination	DCON-61-OL	OR132012 RL321204	M L	Sludge washing at ORNL MVST[f] Innovative chemical separations
Solvent washing to remove organics	DCON-62-OL	RL321204	M	Innovative chemical separation
Microwave scabbling	DCON-71-OL	OR101204	H	Demonstrated small scale
Plasma torch	DCON-72-OL	OR113206 AL223201 SR113201	M H H	Combined with Robotics Used at SRTC Used at SRTC WFO[g]
Transmutation	DCON-78-OL	AL121207 (FY 92)	M	Accelerator based

[a] TTP = Technical Task Plan identifier.
[b] The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

[c] LMFBR = Liquid Metal Fast Breeder Reactor
[d] WHC = Westinghouse Hanford Company
[e] UST = underground storage tanks
[f] MVST = Melton Valley storage tanks
[g] WFO = work for others

000131
275 1

5.7 REFERENCES

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6. E. B. Munday, *Advanced Gas-Phase Decontamination Technology*, TTP OR-1-4-20-08, Office of Technology Development, Oak Ridge National Laboratory, February 13, 1993.

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6. Robotics/Automation

6. ROBOTICS/AUTOMATION

7751

6.1 INTRODUCTION

Robotic devices and automation will be required for the decommissioning of facilities at ORNL to displace humans from what are, in some cases, very hazardous environments. Specific applications of robotics/automation for the various types of facilities are described in detail in Sect. 6.2.

It should be noted that robotics/automation supports the characterization, dismantlement, and decontamination activities that are required for D&D primarily through the deployment of sensors and tools required for these activities.

000134

The robotics/automation technologies required for D&D of various facilities at ORNL are listed in Table 6.1. As shown in the table, the technologies are grouped into nine functional areas, each representing a different element of a robotic or automation system.

For convenience, the different types of facilities requiring D&D have been grouped into the following categories. These categories and the problems likely to be encountered at each type of facility (particularly for the application of robotics/automation technologies) are described in the remainder of Sect. 6.2.

6.2.1 Stabilized Hot Cells (Bldgs. 3026C, 3028, 3029, 3030, 3031, 3038, 3047, 3517, and 3019A)

In assessing the applicability of various robotic/automation technologies for the decommissioning of stabilized hot cells, it is assumed that standard shutdown procedures will have been completed prior to bringing the facility into the D&D program. These assumptions include (1) all loose, unanchored equipment will have been dismantled and removed from the cell, (2) all in-process, radioactive materials will have been taken out of the cells, (3) limited decontamination will have been performed to remove known gross contamination, (4) general cell characterization will have been performed, (5) LLLW system within the cell will be permanently plugged and will not be available for D&D activities, and (6) the cells will still be connected to the central off-gas system.

Tasks that must, in general, be performed robotically for these stabilized hot cells include the following:

- *Characterization*—Although a general characterization may have been performed at the time of shutdown, a more rigorous characterization will probably be required, particularly for the service penetrations, off-gas ducts, and transfer ports.
- *Decontamination*—To effectively decontaminate the cells, access must be created to all surfaces. This will require that decontamination and dismantlement proceed as integrated activities rather than sequentially. Robotics will have to be used for both types of activities. Further, since the LLLW system may no longer be functional, decontamination wastes will have to be removed from the cell by other means and probably handled remotely by robotic devices.
- *Dismantlement*—Depending on the ultimate disposition for the hot cell, dismantlement activities may include the cutting-up or dismantling of remaining process equipment (generally that equipment permanently installed in the cells), pipe removal, manipulator removal, hoist removal, dismantlement of transfer systems, cell windows, and filter houses. These activities will have to be performed remotely and probably with some form of secondary containment.
- *Terminal Activities*—These tasks (which may be part of the RA program and depend on the final disposition planned for the facility) could include activities such as filling/plugging/removing penetrations, backfilling of the hot cell with grout or clay caps, entombing of the cell, or total removal of the structure. Although many of these tasks may not have to be performed robotically, some, like disconnecting the facility from the cell ventilation system, may require remote operations.

000135

Table 6.1. Relationship of robotics/automation technologies to D&D

Robotics/ automation technology	Facility categories					
	Hot cells		Reactors, fuel		Reactor support buildings	Storage buildings
	Stable	Abandon	Solid	Liquid		
Mechanical—mobility						
ROBA-1-OL			X[a]	X	X	X
ROBA-5-OL			X	X	X	
ROBA-6-OL	X	X	X	X	X	
ROBA-7-OL	X	X		X		
ROBA-8-OL			X	X	X	
ROBA-9-OL			X	X		
ROBA-10-OL	X	X	X	X	X	X
ROBA-11-OL	X	X	X	X		
ROBA-12-OL	X	X	X	X	X	
ROBA-13-OL	X	X	X	X	X	X
Mechanical—manipulation						
ROBA-14-OL	X	X				
ROBA-15-OL	X	X				
ROBA-16-OL		X	X	X	X	
ROBA-19-OL			X	X		
Mechanical—mechanisms						
ROBA-20-OL (for characterization)						
ROBA-21-OL	X	X	X	X	X	
ROBA-22-OL			X	X	X	

000136

Table 6.1 (continued)

Robotics/ automation technology	Facility categories					
	Hot cells		Reactors, fuel		Reactor support buildings	Storage buildings
	Stable	Abandon	Solid	Liquid		
Mechanical—end-of-arm tooling						
ROBA-23-OL		X	X	X		
ROBA-24-OL	X	X	X	X	X	X
ROBA-25-OL	X	X	X	X	X	X
ROBA-26-OL			X	X		
Controls—algorithms						
ROBA-27-OL	X	X	X	X	X	X
ROBA-28-OL			X	X	X	X
ROBA-29-OL			X	X	X	
ROBA-30-OL	X	X	X	X	X	X
ROBA-31-OL	X	X	X	X	X	X
ROBA-32-OL		X	X	X		
ROBA-33-OL		X	X	X		
ROBA-34-OL			X	X	X	X
ROBA-35-OL			X	X		
ROBA-36-OL			X	X		
ROBA-37-OL	X	X	X	X	X	X
Controls—human/machine interface						
ROBA-38-OL	X	X	X	X	X	X
ROBA-39-OL			X	X		
ROBA-40-OL		X	X	X	X	
ROBA-41-OL		X	X	X	X	
ROBA-42-OL		X	X	X	X	

000137

Table 6.1 (continued)

Robotics/ automation technology	Facility categories					
	Hot cells		Reactors, fuel		Reactor support, buildings	Storage buildings
	Stable	Abandon	Solid	Liquid		
Sensors—perception						
ROBA-43-OL	X	X	X	X	X	X
ROBA-44-OL			X	X		
ROBA-45-OL			X	X		
ROBA-46-OL			X	X	X	
Sensors—control						
ROBA-48-OL	X	X	X	X	X	
ROBA-50-OL	X	X	X	X	X	
ROBA-51-OL		X	X	X		
ROBA-52-OL		X	X	X	X	
Other technologies						
ROBA-53-OL	X	X	X	X	X	X
ROBA-54-OL		X	X	X		
ROBA-55-OL (for characterization)						
ROBA-56-OL (for characterization)						
ROBA-57-OL	X	X	X	X	X	X
ROBA-58-OL (for characterization)						
ROBA-59-OL (for characterization)						

[a]An X signifies that a technology is applicable to a facility category.

000138

Challenges that will be encountered in the D&D of stabilized hot-cell are listed below.

- *Very limited access into/within the cells*—In some cases, the only access is through the horizontal transfer ports. Further, many of the cells are rather small and odd shaped with limited maneuvering room in the cell.
- *Limited access to some buildings*—Accessibility to the cells in some buildings is somewhat limited and may require some amount of decontamination and dismantlement of the facility before the cells, themselves, can be accessed.
- *Lack of hot drains*—This may add to the difficulty of the robotic tasks since the waste disposal streams will probably require remote handling.

6.2.2 Abandoned Hot Cells (Bldgs. 3019B, 3033 and 3033-A, 3042, 3505, 3515, 3517, 4507 and 7025)

There are a number of hot-cell facilities at ORNL that were basically abandoned at the time of termination of programs' funding operations of the cells. These facilities currently receive minimum monitoring and only the most essential surveillance and maintenance. The hot cells are in various stages of disrepair. In some cases, manipulators do not function and viewing windows have deteriorated to the point of being useless. Large volumes of loose equipment and general waste are believed to exist in these hot cells. Decommissioning of these cells will require the same types of tasks as in the case of stabilized hot cells as described above. However, because of the condition of the cells, manipulators and windows will not be available to assist in the operations. In these cases, the use of robotics will be more extensive than the case of the stabilized hot cells. Robotics will be needed to make initial entry into the cells to characterize the condition of the cell and to perform the initial removal of any inventory and loose equipment. The characterization and decontamination tasks in these cells will be much more difficult than with the stabilized facilities. However, once these tasks are completed, the dismantlement and terminal activities will be very similar to those required at the stabilized facilities.

6.2.3 Reactors and Reactor Support Facilities (Bldgs. 3001, 3005, and 3042)

Various types of reactors are included in the D&D program. These include both liquid-fueled reactors (Molten Salt Reactor Experiment and Homogenous Reactor Experiment) and solid-fueled reactors (both water and air cooled).

The broad variety in types of reactors, as well as reactor support facilities, will present significant robotics/automation challenges, particularly since the facilities are in varying stages of stabilization. It is assumed, with the possible exception of the Molten Salt Reactor Experiment, that before D&D efforts are initiated, all reactors and facilities will be stabilized to a point that will permit reasonable robotic access. Specific facilities to be decommissioned include the following:

- *ORNL Graphite Reactor, Filter House, Fan House, and Exhaust Stack*—This was an air-cooled reactor and the only unusual problems are fuel capsules that ruptured during operation, causing the graphite pile to be very radioactively hot. Also the east face of the reactor must be maintained as a national historic monument. The system is reasonably well contained and accessible and is a good candidate for robotic

applications, particularly for the crushing and packaging of the graphite core—which, because of the high radiation levels, must be performed remotely.

- *Low-Intensity Test Reactor and Cooling Tower*—The contamination levels associated with this reactor are low compared to other facilities. The facility is reasonably accessible and is also a good candidate for the robotic deployment of characterization, dismantlement, and decontamination tools and sensors. The only unusual problem is the need to access multiple levels (a problem common to most reactor facilities), implying either a robotic platform capable of negotiating stairs or, if radiation levels are not too high, hands-on deployment by humans. The cooling tower associated with this reactor is also internally contaminated. However, the dismantlement of this tower should be relatively straightforward and, indeed, may be possible by using suited workers rather than robotic devices.
- *Oak Ridge Research Reactor, Pool Cooling Tower, Reactor Cooling Tower, Heat Exchanger Pit, Demineralizer, and Pump House*—This reactor and its associated facilities will require extensive use of robotics/automation for decommissioning. Almost every aspect of this decommissioning task presents unique problems, not only because many of the components are very hot, but also because of the existence of other chemically hazardous materials (e.g. asbestos, oils, chromates, lead, etc.). It should be noted that the original water-to-air radiator heat exchanger was replaced by a cooling tower system in 1960. The need for decommissioning of the cooling tower is not known at this time.
- *Molten Salt Reactor, Filter Pit, Exhaust Stack, Cooling Tower, Supply Air Filter House, and Diesel Generator House*—Many components of this system are very hot and will require robotic deployment of sensors and tooling. Accessibility is considered to be a major problem. Radiation hardening of some robotic components, including sensors, may be required. The need for a tool caddie is also an important consideration to minimize the number of trips into the highly contaminated areas. This facility, compared to other facilities, is not well defined and numerous unanticipated problems can be expected in the decommissioning effort.
- *Homogenous Reactor Experiment, Waste Evaporator, Charcoal Absorber Pit, Waste Evaporator Loading Pit, Charcoal Absorber Valve Pit, and Decontamination Pad*—Although some components in these facilities are relatively hot, the present plan for limited decontamination and dismantlement limits the application of robotics/automation. To the extent that robotics are used, accessibility, including maneuvering room for the robotic device, are considered to be the major problem.
- *Storage pads*—It is not anticipated that these facilities will present any unique problems for robotics/automation.

Each of the categories of facilities identified above require a somewhat different mix of robotics/automation technologies. Table 6.1 shows which technologies are applicable to each kind of facility.

Specific needs, with a short explanation of the reason why additional R&D is required, are given below for robotics/automation. These needs are also related to the specific types of facilities requiring D&D.

6.3.1 Control Methods for Operator Assistance During Remote Operations (ROBA-41-OL)

In the past, remote operations have been typically inefficient. Research leading to the development of operator assists would improve the efficiency of these operations. There are a number of possible avenues that could be pursued, but the most productive are considered to be Dynamic Allocation of Function Research and Machine Learning Research. These increased capabilities would be particularly useful in highly constrained environments such as those likely to be encountered in abandoned hot cells and reactor facilities.

6.3.2 Combined Mobility/Manipulation Capabilities (ROBA-34-OL)

R&D is required to permit mobility and manipulation to occur as parallel rather than sequential activities with the objective being to increase the efficiency of remote operations. Control algorithms must be developed and tested to permit this type of operation. This capability would be beneficial in almost all application of robotics to D&D activities. For example, in conducting radiation surveys of contaminated areas, it would be considerably more efficient to move the deployment vehicle as the manipulator arm carrying the detectors is sweeping the area rather than first moving the vehicle and then moving the arm in a sequential manner.

6.3.3 Wheeled/Tracked Vehicles (ROBA-1-OL)

Although a multitude of robotic vehicles are commercially available, none appear to meet all the needs of D&D activities. The ability of this technology is to (1) efficiently work and navigate in constrained areas (for example, in abandoned hot cells or in the coolant piping of reactor systems), (2) be easily decontaminated or transported, and (3) manage cabling systems required for power or data transmission. These features are not totally available in any commercial system.

6.3.4 Tool Caddies and Rapid Changeout Mechanisms (ROBA-21- and 24-OL)

In the D&D of many of the ORNL facilities, entry into the contaminated area for a robotic device is difficult and time consuming. It is essential that the robotic device carry all the required tools anticipated for the D&D activity and that the system be designed to easily access and perform tool changeout. Although this R&D need may appear to be trivial, it is an area that has not been adequately addressed in previous programs, and there is probably no other feature that would increase the efficiency of remote operations as much as this capability.

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6.3.5 Single-/Dual-Arm Manipulators with Force-Reflection/Tactile Capabilities (ROBA-16-OL)

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Many D&D tasks can only be performed by single-arm manipulators because of access constraints. Other tasks require dual-arm capabilities. Similarly, some tasks require full-force reflection capabilities, while other tasks need no-force reflection. No commercial systems can function in either the single- or dual-arm mode, particularly when force-reflection capabilities are also required. R&D leading to the development of this type of system would reduce costs (multiple units would not have to be procured) and increase operational efficiency.

000142

6.4 IMPLEMENTATION NEEDS

For D&D activities, high-priority implementation needs are explained below with a summary explanation of why the need is important.

6.4.1 Cold Test Facilities for Verifying the Effectiveness of the Robotic Device

A lesson too frequently learned in remote operations is that cold test facilities are essential for verifying the ability of the robotic device to perform the required tasks. These test facilities can usually be relatively simple and inexpensive partial mockups of the anticipated work area, but they are absolutely needed, particularly for complex operations in constrained areas.

6.4.2 Operator Training on Advanced Control Systems and/or Human-Machine Interfaces

Present operators of robotic devices are trained as teleoperators (i.e., they control all motions and make all decisions on how to proceed with the completion of the task). Enhanced control systems, equipped with operator assistance capabilities, are a new concept for the operators, and they must be adequately trained on these systems to realize the systems' full potentials. Arms with greater than 6 degrees of freedom, which may be required for some D&D tasks, also present a unique problem for the operators (i.e., they may be operating slave arms with more degree of freedom than their own arms, and it is easy to become disoriented). Adequate training is an implementation need that must be provided. Note that the cold test facilities identified above as an implementation need can also serve as training facilities for the operators.

6.5 TECHNOLOGY RANKINGS

The rankings of the robotics/automation technologies required for D&D activities is given in Table 6.2. It should be noted that the criteria used for rankings are biased toward those technologies that are mature and commercially available. Hence, a one-for-one comparison between the rankings and the science and technology needs identified in Sect. 6.3 is not possible because commercially available devices generally require little additional R&D. It should also be noted that several of the criteria suggested for rankings were not considered applicable to robotics/automation. These include (1) compliance with requirements or regulations, (2) ES&H requirements, and (3) unit-processing costs. Others of the criteria have limited applicability to robotics/ automation.

A number of the technologies were considered essential. However, many of these technologies also had a high ranking, which meant they were commercially available. The essential technologies were usually associated with highly ranked site problems also.

The development costs identified in Table 6.2 should be considered rough order-of-magnitude estimates. They have more validity in the comparison of relative costs between various robotics/automation technologies (i.e. they are internally consistent) than they do in their absolute magnitude.

Table 6.2. Rankings of robotics/automation technologies for D&D

Data sheet code number	Technology	Ranking[a]
	Mechanical—mobility	
ROBA-1-OL	Wheeled/tracked vehicles	E-5-2 ($3M;N)
ROBA-5-OL	Pipe/duct crawlers (internal)	M-3-2 ($1M;N)
ROBA-6-OL	Pipe/duct crawlers (external)	M-3-4 ($5M;N)
ROBA-7-OL	Specialized robotic deployment platforms	M-4-3 ($5M;N)
ROBA-8-OL	Mounted robotic platforms	M-2-1 ($5M;N)
ROBA-9-OL	Long-arm deployed robotic platforms	M-4-3 ($5M;N)
ROBA-10-OL	Power sources for mobile platforms	E-5-1 ($0.5M;N)
ROBA-11-OL	Failure recovery systems for mobile platforms	E-5-1 ($0.5M;N)
ROBA-12-OL	Transportation systems for mobile platforms	M-3-1 ($0.5M;N)
ROBA-13-OL	Data/signal transmission	E-5-1 ($1M;N)
	Mechanical—manipulation	
ROBA-14-OL	Long-reach manipulator (light duty)	H-4-2 ($2M;N)
ROBA-15-OL	Long-reach manipulator (heavy duty)	M-4-3 ($5M;N)
ROBA-16-OL	Dexterous manipulator	E-5-1 ($1M;N)
ROBA-19-OL	Compact, high-capacity manipulators	H-5-1 ($1M;N)

Table 6.2 (continued)

Data sheet code number	Technology	Ranking[a]
Mechanical—mechanisms		
ROBA-20-OL	Precise programmable motions	H-5-1 ($0.5M;N)
ROBA-21-OL	Tool caddies	H-4-1 ($0.5M;N)
ROBA-22-OL	Stabilization/support mechanisms or booms	M-3-1 ($0.5M;N)
Mechanical—end-of-arm tooling		
ROBA-23-OL	End effectors/alternatives	E-5-2 ($1M;N)
ROBA-24-OL	End-effector changeout mechanisms	M-3-1 ($0.5M;N)
ROBA-25-OL	General gripper/tool interface	H-4-1 ($0.5M;N)
ROBA-26-OL	Force limiting/compliant mechanisms	M-3-1 ($0.5M;N)
Controls—algorithms		
ROBA-27-OL	Control modes	E-5-N ($N;N)
ROBA-28-OL	Vehicle/mobility driving	E-5-1 ($0.5M;N)
ROBA-29-OL	Vehicle/mobility navigation	M-4-1 ($0.5M;N)
ROBA-30-OL	Manipulation (joint control)	H-4-1 ($0.5M;N)
ROBA-31-OL	Manipulation (cartesian control)	H-4-1 ($1M;N)
ROBA-32-OL	Manipulation (special purpose control)	H-4-2 ($1.5M;N)
ROBA-33-OL	Manipulation (redundancy control)	M-3-2 ($2M;N)
ROBA-34-OL	Combined mobility/manipulation	M-2-2 ($1M;N)
ROBA-35-OL	Safety (collision avoidance)	H-4-1 ($1M;N)
ROBA-36-OL	Safety (load/rate limiting)	H-3-1 ($0.5M;N)
ROBA-37-OL	Emergency shutdown	E-4-1 ($0.5M;N)
Controls—human/machine interface		
ROBA-38-OL	Console (fixed/mobile/suitcase)	E-5-1 ($0.5M;N)
ROBA-39-OL	Console (data handling methods)	M-3-1 ($1M;N)
ROBA-40-OL	Operator interface (command-input)	H-3-1 ($0.5M;N)
ROBA-41-OL	Operator interface (operator assistance)	H-3-2 ($1.5M;N)
ROBA-42-OL	Operator interface (status/alert system)	E-5-1 ($0.5M;N)
Sensors—perception		
ROBA-43-OL	Visual/aural systems	E-5-1 ($1M;N)
ROBA-44-OL	Range finders	M-3-2 ($1.5M;N)

Table 6.2 (continued)

Data sheet code number	Technology	Ranking[a]
Sensors—perception (continued)		
ROBA-45-OL	Proximity probes	M-2-2 ($1M;N)
ROBA-46-OL	Force/torque sensors	M-2-1 ($0.5M;N)
Sensors—control		
ROBA-48-OL	Position/velocity sensors	E-5-1 ($0.5M;N)
ROBA-50-OL	Force/torque	H-3-1 ($0.5M;N)
ROBA-51-OL	Proximity probes as control sensors	H-3-1 ($1M;N)
ROBA-52-OL	Tooling sensors	H-3-1 ($0.5M;N)
Other technologies		
ROBA-53-OL	Field hardening	M-3-1 ($0.5M;N)
ROBA-54-OL	Radiation hardening	E-5-2 ($2M;N)
ROBA-55-OL	Integrated automated analytical laboratory	E-5-2 ($3M;N)
ROBA-56-OL	Information management for sample handling	E-5-1 ($1M;N)
ROBA-57-OL	Sample collection	E-5-1 ($1.5M;N)
ROBA-58-OL	Characterization sensor integration	M-3-2 ($1M;N)
ROBA-59-OL	Sample preparation	E-5-1 ($1M;N)

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

6.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the robotics/automation technologies listed in Table 6.2. Table 6.3 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with the complete set of robotics/automation technologies listed in the *Oak Ridge National Laboratory Technology Logic Diagram*, Volume 1, Parts A, B, and C. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding robotics/automation technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Robotics/automation technologies for which no match was found are omitted from the table. When many matches were found, only one or two were cited. The relevance column indicates the degree of overlap between the technologies listed in Volume 1, Parts A, B, and C and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 6.3. Robotics/automation technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Wheeled/tracked vehicles	ROBA-1-OL	OR113202	M	Robotics for buried waste
		OR113203	H	Crosscutting and advanced technology
		OR113206	H	Demonstration of telerobotic dismantlement
		SR123201	H	Robotics for decontamination and decommissioning (D&D)
Pipe/duct crawler (internal)	ROBA-5-OL	AL213204	L	Miniature robotics
		SF213203	L	Remote microsensor technology
Pipe/duct crawler (external)	ROBA-6-OL	AL223201	H	Robotic external pipe decontamination
		OR113206	H	Robotic asbestos removal
		SR123201	H	Robotic asbestos bagging
Specialized robotic deployment platforms	ROBA-7-OL	AL213204	H	Crosscutting and advanced technology
		SF213203	H	Crosscutting and advanced technology
		SF223203	H	Robotics technology development
		OR113203	H	Crosscutting and advanced technology
Transportation methods for mobile platforms	ROBA-12-OL	AL213205	M	Remote drum handling equipment
Data/signal transmission	ROBA-13-OL	AL213204	H	High-bandwidth long cable, harsh env.
		AL322002	H	Data acquisition modules
		SF213205	H	Data & video telemetry
Long-reach manipulator (light duty)	ROBA-14-OL	RL313202	H	Long-arm, light-duty manipulator for underground tanks
Long-reach manipulator (heavy duty)	ROBA-15-OL	OR113206	H	Demonstration arm collision avoidance
		AL213204	H	Development high-payload long arm
Dexterous manipulators	ROBA-16-OL	OR113202	H	Robotics for buried waste
		AL213201	H	Robotics for buried waste
		AL213202	H	Robotics for buried waste
Precise programmable motions	ROBA-20-OL	AL213204	M	Programmed robotic motion
		SR113201	M	Programmed teleoperated control
		RL332004	M	Short-reach dexterous manipulator
End effectors/alternatives	ROBA-23-OL	AL213201	H	End-effector development
		AL213207	H	End-effector development
		RL332004	H	End-effector development
End-effector changeout mechanisms	ROBA-24-OL	SR123201	M	Robotics for D&D

000148

Table 6.3 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Vehicle/mobility navigation	ROBA-20-OL	OR113203	L	Crosscutting and advanced technology
		OR113205	L	Crosscutting and advanced technology
		RL313203	L	Robotics for buried waste
Manipulation (joint control)	ROBA-30-OL	AL213201	M	Joint failure reconfiguration
Manipulation (special purpose control)	ROBA-32-OL	AL221205	L	In-tank hardware removal
Manipulation (redundancy control)	ROBA-33-OL	AL213104	M	Kinematic redundancy of controls in crosscutting
Safety (collision avoidance)	ROBA-35-OL	AL213201 (Many)	M	Robotics for storage tanks (no new methods developed)
Console (data handling methods)	ROBA-39-OL	AL232002	L	Computer interface/end effector
Operator interface (command input)	ROBA-40-OL	RL313203	L	Robotics for buried waste
		OR113202	L	Robotics for buried waste
Operator interface (operator assistance)	ROBA-41-OL	OR113203	L	Crosscutting and advanced technology
		AL213204	L	Crosscutting and advanced technology
Operator interface (status/alert system)	ROBA-42-OL	OR113203	L	Crosscutting and advanced technology
		AL213204	L	Crosscutting and advanced technology
Range finders	ROBA-44-OL	OR113201 (Many)	L	Robotics storage tanks
Proximity probes	ROBA-45-OL	OR113203	L	Crosscutting and advanced technology
		AL213204	L	Crosscutting and advanced technology
Force/torque sensors	ROBA-46-OL	OR113203	H	Crosscutting and advanced technology
		RL313205	H	Crosscutting and advanced technology
Force/torque	ROBA-50-OL	OR113203	H	Crosscutting and advanced technology
		AL213204	H	Crosscutting and advanced technology
Tooling sensors	ROBA-52-OL	SR123201	M	Robotics for D&D
Field hardening	ROBA-53-OL	AL213204 (Many)	L	Crosscutting and advanced technology
Radiation hardening	ROBA-54-OL	AL213204 (Many)	M	Crosscutting and advanced technology

000149
2251

Table 6.3 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Integrated automated analytical laboratory	ROBA-55-OL	AL213203	H	Robotic contaminant analysis automation
Information management for sample handling	ROBA-56-OL	AL213203	H	Robotic contaminant analysis automation
Sample collection	ROBA-57-OL	AL213203	H	Robotic contaminant analysis automation
Characterization sensor integration	ROBA-58-OL	AL213204	H	Crosscutting and advanced technology
Sample preparation	ROBA-59-OL	AL213203	H	Robotic contaminant analysis automation

[a]TTP = Technical Task Plan identifier.

[b]The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

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2251

7. Regulatory Compliance

7. REGULATORY COMPLIANCE

7.1 INTRODUCTION

Many government-owned facilities that supported the early nuclear energy research and defense programs have no current use and have been retired. Some of these DOE facilities have residual radioactive or chemical contamination levels that require cleanup. The D&D Program is responsible for managing these surplus facilities to protect the public health and environment from radioactive contamination or hazardous materials that may be present. D&D is concerned with the safe caretaking of surplus nuclear facilities until their decontamination, entombment, dismantling and removal, or conversion to another nonnuclear reuse.

Presently there is no law or regulation mandating decommissioning at DOE facilities or setting *de minimis* or BRC radioactivity levels to guide decommissioning activities at DOE facilities. DOE Order 5820.2A, Chap. V (*Decommissioning of Radioactively Contaminated Facilities*), outlines D&D project activities that include: (1) surveillance and maintenance, (2) assessment and characterization, (3) environmental review, (4) engineering design, (5) D&D operations, (6) waste disposal, and (7) closeout. The D&D Program cost-effectively maintains surplus facilities awaiting decommissioning in a safe and secure state and ultimately completes decommissioning activities of the facilities. DOE Order 5820.2A requires that each field organization prepare and maintain a complete list of contaminated facilities, both operational and excess, under its jurisdiction; these facilities may be assigned to other jurisdictional program responsibilities.

The U.S. DOE ORR was placed by the EPA on the National Priorities List under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) on Nov. 21, 1989, effective Dec. 21, 1989 (54 *FR* 48184). As a result of this listing, DOE, EPA, and the Tennessee Department of Environment and Conservation (TDEC) have signed an FFA for ER of the ORR (effective Jan. 1, 1992). An effort is under way to incorporate into the FFA all inactive facilities at the ORR that are known or suspected to contain significant quantities of residual hazardous materials. It is proposed that inactive facilities that contain or could possibly contain hazardous substances that need to undergo a detailed CERCLA assessment will be added to project lists under the FFA. Management of wastes, soil, or debris generated during D&D activities that are within the jurisdictional boundary of a CERCLA operable unit would proceed under the ER umbrella in an attempt to reduce duplication of responses and costs. To meet the needs of the ER schedule for a particular operable unit, the schedule for D&D activities may need to be modified.

As D&D commences or continues, the decommissioning and dismantling activities associated with it and the wastes produced will become subject to a number of federal and state environmental laws as well as DOE Orders. Additional regulatory drivers for these activities may be established through negotiated agreements, with associated compliance requirements and milestones defined therein. DOE Order 5820.2A requires that the regulatory status of each project be identified and that technical engineering planning must assure D&D compliance with all environmental regulations during cleanup activities. To assist in the performance of this requirement, this chapter will define regulatory drivers for those D&D activities that only involve decontamination and dismantling of buildings or structural components. The D&D of a facility generally

includes analysis and/or excavation of the soils 5 ft on each side of the building and 5 ft below the bottom of the building. RA activities performed under CERCLA generally address contaminated soil, ground water, burial grounds and other point and line sources of contamination, as well as pond-waste sludges (see Vol. 1, Pt. B). Volume 1, Pt. B, Chap. 6, will address regulations and negotiated agreements for RA activities proceeding under CERCLA (i.e. FFA ER sites).

In addition to regulatory issues pertaining to D&D and RA, wastes generated under any regulatory umbrella must be managed according to prescribed WM procedures. Volume 1, Pt. C, Chap. 6, will address federal, state, and local codes, DOE Orders, Interagency Agreements and Federal Facility Compliance Agreements as they apply to WM practices at ORNL.

Requirements promulgated under the RCRA, the Clean Water Act (CWA), the CAA, and the Occupational Safety and Health Administration (OSHA) may direct D&D activities at ORNL. Additionally, compliance with a variety of regulations may be required under the National Environmental Policy Act (NEPA). The regulatory summary presented in this chapter has been modified from the ER report *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws.*[1] This summary is meant to represent an overview of potential regulatory compliance issues related to D&D activities and only presents excerpts in the text and tables from the complete set of regulatory requirements. In addition, compliance with other federal, state, and local regulations not addressed here may be required.

000153

7.2 RESOURCE CONSERVATION AND RECOVERY ACT

The purpose of RCRA is to ensure the safe and environmentally acceptable management of hazardous and nonhazardous solid wastes. This law outlines the framework for national programs to achieve environmentally sound management of both hazardous and nonhazardous wastes from "cradle to grave." The Hazardous and Solid Waste Amendments (HSWA) of 1984 both expanded the scope of RCRA and increased the level of detail in many of its provisions.

Minimum national standards for acceptable management of hazardous waste appear in RCRA, although Tennessee has been authorized by EPA to administer and enforce its own standards in lieu of the federal RCRA regulations. Federally authorized state RCRA programs relate only to RCRA standards in place before enactment of HSWA. New regulations imposed in 1984 by HSWA are enforceable under federal law in all states until each authorized state promulgates its own HSWA-related standards. Tennessee received authorization for its base RCRA program effective February 5, 1985 and has received authorization for subsequent revisions to its program. Table 7.1 lists RCRA requirements discussed below, and the corresponding sections of the RCRA-authorized TDEC hazardous-waste management regulations found in TDEC Rules, Chap. 1200-1-11 *et seq.*

RCRA has nine distinct sections (subtitles) that regulate various aspects of hazardous waste. RCRA Subtitle C "Hazardous-Waste Management," regulates the generation, transportation, treatment, storage, and disposal of hazardous waste. Standards for the management of hazardous waste at RCRA-permitted treatment, storage, and disposal facilities were promulgated July 26, 1982, and appear in 40 Code of Federal Regulations (CFR) 264. Standards for interim status treatment, storage, and disposal facilities are found in 40 CFR 265. This text will generally address the Part 264 rather than the Part 265 standards that are virtually identical although at times less stringent.

In general, given that D&D activities only involve buildings, structural components, and possibly abandoned tanks or containers, many of the subparts of Subtitle C will not apply to D&D. The general closure and postclosure standards of Subpart G and specific closure standards for tanks and containers (Subparts J and I, respectively), as well as the standards for treatment of contaminated debris in "containment buildings" (Subpart DD) or miscellaneous treatment units (Subpart X) may apply to D&D activities. These are listed on Table 7.1 and summarized below. In addition, the new final rule implementing Subpart S ("Corrective Action for Solid Waste Management Units"), which may facilitate the integration of D&D and WM activities, is discussed below. In any situation where D&D activities generate waste, compliance with federal and state regulations becomes the responsibility of WM (see Vol. 1, Pt. C, Chap. 6 for a discussion of regulatory drivers for WM).

7.2.1 Closure of Tank Systems

The general requirements for closure are set forth in 40 CFR 264.111 and require that closure minimizes the need for further maintenance, and prevents postclosure escape of hazardous constituents to ground water, surface water, or the atmosphere.

During partial or final closure, all contaminated equipment and structures must be properly disposed of or decontaminated (see Sect. 7.2.2). This process may result in the generation of hazardous waste, and such waste must be handled in accordance with WM requirements (40 CFR 264.114).

000154

Table 7.1. Federal and state regulations applicable to D&D activities at ORNL

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Closure	General performance standard requires elimination of need for further maintenance and control; elimination of postclosure escape of hazardous waste, hazardous constituents, leachate, contaminated runoff, or hazardous waste decomposition products to ground water, surface water, or the atmosphere.	40 CFR[b] 264.110-120 40 CFR 264.111	1200-1-11-.06-7
	All contaminated equipment and structures must be properly disposed of or decontaminated; any waste generated by this process must be handled in accordance with 40 CFR 262.	40 CFR 264.114	1200-1-11-.06-7
Closure, containers	At closure, remove all hazardous waste and residues from the containment system, and decontaminate or remove all containers, liners, bases, or soils.	40 CFR 264.178	1200-1-11-.06(9)(i)
Closure, tanks	At closure, remove all hazardous waste and hazardous waste residues from tanks, discharge control equipment, and discharge confinement structures.	40 CFR 264.197	1200-1-11-.06(10)(h)
Demolition of asbestos-containing structures	Remove all regulated asbestos-containing material (RACM) from a facility being demolished before any activity begins that would break up, dislodge, or disturb the material and preclude access to the material for subsequent removal; certain Category I and II materials are exempt from this requirement.	40 CFR 61.145(c)	

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Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Demolition of asbestos-containing structures *(continued)*	When a facility component is coated or covered with RACM and being removed from the facility as a unit or in pieces, · adequately wet all RACM exposed during cutting or disjoining operations; and · carefully lower each unit to the floor being careful not to dislodge RACM.	40 CFR 61.145(c)(2)	
	If a facility component is stripped of RACM in place, wet the RACM during the stripping operation.	40 CFR 61.145(c)(3)	
	After a facility component has been removed as a unit or in sections, adequately wet the RACM during stripping or use a local exhaust ventilation and collection system designed and operated to collect particulate asbestos emission produced by stripping.	40 CFR 61.145(c)(4) 40 CFR 61.145(c)(4)	
	No visible emissions to the outside air from the ventilation and collection system are permissible. System must be designed and operated in accordance with 40 CFR 61.152.		
	Large facility components may not need to be stripped of RACM if certain requirements are met.	40 CFR 61.145(c)(5)	

000156

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Direct discharge of treatment system effluent	*National Pollutant Discharge Elimination System (NPDES) Permitting Program*	40 CFR 122	1200-4-5
	Use of best available technology economically achievable is required to control toxic and nonconventional pollutants. Use of best conventional pollutant control technology is required to control conventional pollutants. Technology-based limitations may be determined on a case-by-case basis.	40 CFR 122.44(a)	
	The discharge must comply with applicable federal water quality requirements and more stringent state requirements under the Clean Water Act (CWA).	40 CFR 122.44(d) and state regulations approved under 40 CFR 131	1200-4-3-.03
	The discharge must be consistent with the requirements of a Water Quality Management plan approved by EPA under CWA §208(b).	40 CFR 122.44(d)	
	Discharge limitations must be established for all toxic pollutants that are or may be discharged at levels greater than that which can be achieved by technology-based standards.	40 CFR 122.44(e)	
	Develop and implement a best management practice (BMP) program and incorporate in the NPDES permit to prevent the release of toxic constituents to surface waters.	40 CFR 125.100	

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Direct discharge of treatment system effluent *(continued)*	*Criteria and standards for NPDES*	40 CFR 125	1200-4-5
	The BMP program must · establish specific objectives and BMP for the control of toxic and hazardous pollutants; · include a prediction of direction, rate of flow, and total quantity of toxic pollutants, where experience indicates a reasonable potential for equipment failure; and · ensure proper management of solid and hazardous waste in accordance with regulations promulgated under RCRA.[c]	40 CFR 125.104	
	To ensure compliance, discharge must be monitored for · the mass of each pollutant; · the volume of effluent; and · frequency of discharge and other measurements as appropriate.	40 CFR 122.44(i)	
	Approved test methods must be followed for monitored waste constituents. Detailed requirements for analytical procedures and quality control are provided.	40 CFR 136.1-136.3(e)	
	Comply with additional permit conditions, such as · duty to mitigate any adverse effects of any discharge; and · proper operation and maintenance of treatment systems.	40 CFR 122.41(d,e)	

000158

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Fugitive dust emissions	Take reasonable precautions to prevent particulate matter from becoming airborne; no visible emissions are permitted beyond property boundary lines for more than 5 min/h or 20 min/day.		1200-3-8-.010
Land disposal restrictions (LDR)	Treatment and disposal of contaminated soil—Soils containing RCRA hazardous waste are subject to the LDR if moved to another unit.	40 CFR 268 (Subpart C)	
	Treatment and disposal of contaminated debris—Effective November 16, 1992, disposal of contaminated debris resulting from CERCLA response actions is subject to the LDR and/or treatment standards.	40 CFR 268.45	
Operation and maintenance	General postclosure standards require 30-year postclosure care to ensure a closed RCRA unit is maintained and monitored.	40 CFR 264.117	1200-1-11-.06(7)(h)
Sampling/analysis	Must follow designated test methods and detailed sampling and analysis protocols as specified in RCRA; see appropriate subparts for specifications.	40 CFR 124 40 CFR 148 40 CFR 260-262	
Surface-water control	NPDES permit required for storm-water discharges associated with construction activities that result in a disturbance of greater than 5 acres of total land area.	40 CFR 122	1200-4-10-.05
	Sediment and erosion controls and BMPs must be utilized to control runoff from construction activities.	40 CFR 122	1200-4-10-.05
	NPDES permit required for storm-water discharges at industrial sites. Monitoring required to ensure compliance with state water-quality standards.	40 CFR 122	1200-4-10-.04

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Treatment in a miscellaneous unit	Design and operating standards for units in which hazardous waste is treated must ensure protection of human health and the environment.	40 CFR 264.601	1200-1-11-.06(19)(b)
	Prevention of any releases that may have adverse effects on human health or the environment due to migration of waste constituents.		
	Specific considerations must be made to prevent adverse effects in:		1200-1-11-.06(19)(b)
	· ground water or subsurface environment;	40 CFR 264.601(a)	
	· surface water, wetlands, or soil surface; and	40 CFR 264.601(b)	
	· air.	40 CFR 264.601(c)	
Treatment (chemical, physical, or biological)	Hazardous wastes or treatment reagents must not be placed in the treatment process or equipment if they could cause the treatment process or equipment to rupture, leak, corrode, or otherwise fail before the end of its intended life.	40 CFR 265.401	1200-1-11-.05(17)
	Where hazardous waste is continuously fed into a treatment process or equipment, the process or equipment must be equipped with a means to stop the inflow.	40 CFR 265.401	1200-1-11-.05(17)
	General requirements for ignitable, reactive, or incompatible wastes.	40 CFR 265.17	1200-1-11-.05(2)

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2251

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Treatment in a containment building	Owners or operators of containment buildings designed and operated under the requirements of §268.1101 are not subject to the definition of land disposal in RCRA 3004(k) given certain provisions outlined in §268.1100.	40 CFR 264.1100	
	Design and operating standards are intended to assure containment of managed wastes and to prevent exposure to the elements via precipitation, wind, run-on, etc.	40 CFR 264.1101(a)	
	Maintain primary barrier to be free of significant cracks, gaps, corrosion, or other deterioration that could cause release of hazardous substances;	40 CFR 264.1101(c)(1)	
	Take measures to prevent the tracking of hazardous waste outside of the unit by personnel or equipment; and		
	Take measures to control fugitive dust emissions.		
	Obtain certification by a qualified, registered professional engineer that the building design meets the requirements of §268.1101.	40 CFR 264.1101(c)(2)	
	Any condition that could lead to the release of a hazardous substance must be repaired promptly in accordance with prescribed procedures.	40 CFR 264.1101(c)(3)	
	Inspect at least weekly, and keep a log book of the facility's operating record.	40 CFR 264.1101(c)(4)	

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Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC[a] Rules, Chapter
Treatment in a containment building *(continued)*	Secondary containment requirements are listed for management of hazardous wastes containing free liquids or treated with free liquids.	40 CFR 264.1101(b); 40 CFR 264.1101(d)	
	At closure, remove or decontaminate all waste residues, contaminated containment system components, contaminated subsoils, and structures or equipment contaminated with waste and leachate, and manage them as hazardous waste. The closure plan, etc., must meet all the requirements of 40 CFR 264 Subparts G and H.	40 CFR 264.1102(a)	
	If not all contaminated subsoils can be removed from the structure, it must be closed in accordance with the landfill closure and post-closure requirements of 40 CFR 264.310.	40 CFR 264.1102(b)	

[a] TDEC = Tennessee Department of Environment and Conservation
[b] CFR = Code of Federal Regulations
[c] RCRA = Resource Conservation and Recovery Act

Source: E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

000162

275

In addition to the general closure standards, closure standards for tanks and containers may apply if either are present at D&D sites. The specific closure requirements for tank systems are codified at 40 CFR 264.197. For clean closure, these standards require that the operator decontaminate the tank system and secondary containment, remove contaminated soils, and render the tank unfit for further use if it remains on site. If all contaminated soils or wastes cannot be removed from the tank system, the tank system is considered a landfill, and must be closed in accordance with the landfill requirements of 40 CFR 264.310 [40 CFR 264.197(b)].

Similarly, during container closure, all hazardous wastes and residues must be removed from containment systems at closure, and managed as hazardous waste. Remaining containers, liners, bases, and soil containing hazardous waste must be decontaminated or removed (40 CFR 264.178).

7.2.2 Land Disposal Restrictions

EPA determined that the RCRA treatment standards for land disposal of hazardous wastes are generally inappropriate or infeasible when applied to contaminated soil or debris (55 *FR* 8760). Therefore, EPA proposed separate rulemakings to establish treatment standards for disposal of such contaminated soil and debris. The Notice of Proposed Rulemaking for debris appeared January 9, 1992 (57 *FR* 958); final rule, August 18, 1992 (57 *FR* 37194). Debris is defined as "solid material exceeding a 60 mm particle size that is intended for disposal, and is a manufactured object; plant or animal matter; or natural geologic material" (40 CFR 268.2).

This rule promulgates treatment standards for hazardous debris prohibited from land disposal; hazardous debris must be treated by specified technologies based on the type of debris and type of contaminants, or, as an alternative, must meet the land disposal restrictions for the specified prohibited listed or characteristic waste with which it is contaminated. Such treated debris will no longer be subject to the land disposal restriction (LDR) standards or other Subtitle C regulation, and could be reused, returned to the natural environment, or disposed of at a Subtitle D facility. Treatment residuals from the treatment of contaminated debris are subject to the waste-specific treatment standards for the waste contaminating the debris. However, debris removed by spalling techniques will be large pieces of debris, which are not considered by EPA to be classified as a treatment residual; therefore, such treatment debris is still subject to the debris treatment standards.

The rule requires that contaminated debris be treated prior to land disposal using physical or chemical extraction, destruction, or immobilization technologies (40 CFR 268.45). However, since immobilization does not remove contaminants, immobilized debris must still be land disposed as hazardous waste (i.e., at a Subtitle C facility). EPA identifies six categories of debris as well as other miscellaneous types of debris contaminated with PCBs, asbestos, or radionuclides. Hazardous debris that is also contaminated with waste PCBs must comply with both the applicable PCB requirements, and the contaminated debris requirements. Disposal of debris and materials resulting from the cleanup of PCB spills must also comply with the PCB spill cleanup policy of 40 CFR 761.125.

The rule includes treatment standards for debris that contains asbestos, which is also regulated under OSHA and the CAA (see other sections in this report). These debris standards for asbestos are a subset of those required for other types of contaminated debris and include water washing and spraying, vapor-phase solvent extraction,

biodegradation, chemical oxidation or reduction, and macroencapsulation (see preamble to the rule, 57 *FR* 37238).

As with other mixed wastes (see Vol. 1, Pt. B, Sect. 6.4, for a discussion of mixed waste issues at ORNL), debris contaminated with both hazardous and radioactive waste must comply with the RCRA treatability standards for contaminated debris as well as those under the Atomic Energy Act. However, the rule specifically excludes the radioactive mixed wastes, including the D008 radioactive lead solids that have established treatment standards in 40 CFR 268.42 and which may be generated in particle sizes greater than 60 mm (40 CFR 268.2).

The advanced notice of proposed rulemaking for soil appeared October 24, 1991 (56 *FR* 55160); the notice of proposed rulemaking is expected August 1993, final rule August, 1994.[2] Under 40 CFR 268.5, EPA has granted an interim case-by-case extension of the LDR effective date, to May 8, 1993, applicable to all persons disposing of soils contaminated with radioactive mixed waste or RCRA hazardous soils whose best demonstrated available technology is incineration, retorting, or vitrification (57 *FR* 47772, October 10, 1992). In the interim, EPA has developed guidance for obtaining and complying with a treatability variance for soil and debris that are contaminated with RCRA hazardous wastes for which treatment standards have already been set (Office of Solid Waste and Emergency Response Directive 9347.3-06FS, July 1989). Alternate treatment levels are presented for structural functional groups of organics and for ten inorganics based on actual treatment of soil and best management practices for debris. These will be considered as TBC guidance when remedial alternatives are selected and more information becomes available on waste types.

7.2.3 Treatment Units

Treatment of contaminated structural components may be required before D&D is complete. This may occur while the building is in place, or the components may be disassembled and treated in an adjacent area. The new final rule for contaminated debris (Subpart DD) addresses this process.

7.2.3.1 Contaminated Debris

In the debris rule, EPA established a new treatment unit for treating contaminated debris; "containment building" has been added to the definitions of 40 CFR 260.10 to provide for storage and treatment of contaminated debris that does not contain free liquids and is not amenable to treatment in tanks or containers (57 *FR* 979, January 9, 1992). Performance standards for the design and operation of such containment buildings are promulgated in a new Subpart DD (40 CFR 264.1100 and 265.1100 for permitted facilities and interim status facilities, respectively). All containment buildings, permitted or unpermitted, must comply with the same level of performance. These standards would apply to any D&D activities involving dismantlement of structures and subsequent decontamination in an adjacent building. Closure and postclosure care standards appear in 40 CFR 264.1102 (see Table 7.1).

If decontamination of a structure occurs in place (i.e., before dismantlement), physical extraction technologies (such as abrasive blasting or spalling used to treat debris in place that is intended for discard) are subject to the permit standards of 40 CFR 264, Subpart X for miscellaneous units or the interim status standards for chemical, physical, or biological treatment in 40 CFR 265, Subpart Q (preamble to the final rule, 57 *FR* 37241). Requirements for these units are discussed below.

7.2.3.2 Miscellaneous Treatment Units

Treatment in a unit may involve biological, chemical, thermal, or physical processes (see Table 7.1); however, the 40 CFR 264 regulations do not differentiate between these processes, considering them all to be via "miscellaneous treatment units." Standards for the operation and maintenance of miscellaneous units are codified in 40 CFR 264.601 (see "Treatment in a miscellaneous unit," Table 7.1). These standards require location, design, operation, and closure of the unit in a manner that is protective of human health and the environment. Unlike other RCRA units, where the general performance objectives are achieved by specified design standards, only generalized environmental performance standards are applied to miscellaneous units. The general environmental performance standards require that the owner demonstrate prevention of releases to ground water or subsurface media [40 CFR 601(a)], surface waters or wetlands [40 CFR 601(b)], or air [40 CFR 601(c)] that could have adverse effects on human health and the environment. In demonstrating compliance with these standards, the operator must consider both waste and media characteristics.

7.2.3.3 Chemical, Physical, Biological, or Thermal Treatment

The interim status standards of 40 CFR 265 contain specific operating requirements for chemical, physical, or biological treatment (40 CFR 265.401). These standards are applicable to treatment in units other than tanks, surface impoundments, or land treatment facilities. Table 7.1 lists the standards for operation of these units. Per Subpart DD, these standards are legally applicable to operators of facilities whom have complied with the interim status requirements of RCRA 3005(e) until a permit is issued and whom are treating structural components in place. At closure, all hazardous waste and hazardous waste residues must be removed from the treatment unit.

7.2.4 Corrective Action Management Units

A portion of the proposed RCRA Subpart S ("Corrective Action for Solid Waste Management Units") was promulgated as a final rule for corrective action at Corrective Action Management Units (CAMUs) and temporary units (58 *FR* 8658, February 16, 1993). This Rule establishes two new sections in Subpart S: 40 CFR 264.552 (CAMUs) and 40 CFR 264.553 (temporary units). Both of these units function solely to manage wastes that are generated at a RCRA facility for the purpose of implementing RAs (i.e., remediation wastes). As a result of this rule, regulatory requirements for remediation wastes will differ from those for "as-generated" wastes regulated under Subtitle C, particularly LDRs and minimum technology requirements. The CAMU or temporary units designations must be made by the EPA Regional Administrator or a HSWA-authorized state, and such designations would be subject to the public review and comment process as part of a remedy selection. These designations would be incorporated to permit modifications for a facility and would include specifications of applicable design, operating, and closure requirements that may be less stringent than the appropriate 40 CFR 264 standards. As yet, TDEC has not adopted the provisions of this rule.

Under the CAMU provisions, movement and consolidation of remediation wastes within a designated CAMU will not be subject to LDRs or other hazardous-waste land disposal requirements. Also, CAMUs would not be subject to the minimum technology requirements, since they are not classified as landfills, surface impoundments, or waste piles. Placement of remediation wastes into a CAMU from an area at a facility but outside the CAMU or from one CAMU into another CAMU will not trigger land disposal

restrictions or minimum technology requirements, nor will excavation, treatment outside the CAMU, and replacement back in the CAMU. However, movement of wastes from a CAMU to another area in a facility not designated a CAMU would trigger the appropriate land disposal restrictions or minimum technology requirements.

The Regional Administrator may designate tanks and container storage units used for treatment or storage of remediation wastes at a facility as temporary units (40 CFR 264.553). Permit specifications for temporary units must include design, operating, and closure requirements; these may be less stringent than the 40 CFR 264 container and tank system requirements of Subpart I and J, respectively, so long as they are protective of human health and the environment and comply with statutory requirements. There is a one-year time limit for operation of temporary units, subject to a one-year extension by the Regional Administrator.

If D&D activities at a site involve discharges to surface water, compliance with the National Pollutant Discharge Elimination System (NPDES) permitting process may be necessary.

7.3.1 Direct Discharge to Surface-Water Bodies

The regulatory aspects of the CWA include site-specific pollutant limitations and performance standards designed to restore and maintain the chemical, physical, and biological integrity of the nation's surface waters. The NPDES permit program includes applicable effluent standards, monitoring requirements, and conditions for discharge. Tennessee has an EPA-authorized state program that is equivalent to the federal program. NPDES permit TN0002941 regulates discharges from ORNL to the Clinch River and its tributaries. The effluent limitations and monitoring requirements found in the NPDES permit should be analyzed on a site-specific basis for any cleanup at D&D sites that would include discharge of pollutants to surface waters. The current permit has expired (March 31, 1991); however, a submittal for permit renewal was made to TDEC, and ORNL is currently operating under the expired permit. Table 7.1 lists federal requirements for compliance with the NPDES permitting program.

DOE Order 5400.5 contains concentration limits for release of radionuclides in effluents discharged to surface water. These derived concentration guides are based on an annual exposure of 100 mrem/year (see Sect. 7.7.1 for a further discussion).

7.3.2 Storm-Water Discharges

Storm-water discharges from activities at industrial sites involving construction operations that result in the disturbance of five acres total land or more have been included in the final rule for NPDES permits for storm-water discharges. Construction activities include clearing, grading, and excavation (40 CFR 122). For D&D activities involving construction as defined, coverage under a construction activity general permit may be requested by submitting a Notice of Intent 15 days before construction will begin. The general permit requires that a construction site-erosion control plan be submitted before activity begins. Implementation of good site planning and best management practices to control storm-water discharges is required (Rules of the TDEC, Chap. 1200-4-10-.05). A construction activity storm water permitting checklist and a pamphlet describing erosion and sediment control practices are available from the TDEC Office of Water.

TDEC also has an NPDES permit process for regulating storm-water discharges during industrial activity (Rules of the TDEC, Chap. 1200-4-10-.04). Certain storm drains have been included in the existing NPDES permit, and it is possible that the revised permit will include the 40 CFR 122 requirements for storm-water runoff. The monitoring parameters and reporting levels are listed in Chap. 1200-4-10-.04(e) for biological oxygen demand, chemical oxygen demand, total suspended solids, ammonia as nitrogen, oil and grease, pH, floating material, color, sheen, and priority pollutants.

000167

Treatment technologies or demolition techniques utilized at D&D sites might result in the release of air emissions that are regulated under federal and state law. Demolition and renovation of facilities that contain asbestos are also regulated by the CAA.

7.4.1 Process Emissions

Chapter 25, "Air Pollution Control," of the Tennessee Code Annotated (TCA) provides for the purity of the air resources of the state "consistent with the protection of normal health, general welfare and physical property of the people, maximum employment, and the full industrial development of the state." Implementing these objectives are the Tennessee ambient air quality standards established by the TDEC Division of Air Pollution Control, which appear in Chap. 1200-3-3 of the Rules of the TDEC. The ambient standards of Chap. 1200-3-3 are translated into source-specific emission limitations (Rules of the TDEC, Chaps. 1200-3-4 to 1200-3-21) that must be considered if they apply to any of the D&D sites or technologies. Table 7.2 lists sections of the Tennessee air emission standards that should be analyzed on a site-specific basis for each D&D activity or each technology.

Table 7.2. Rules of the TDEC[a] Bureau of Environment Division of Air Pollution Control

Chapter	Subject
1200-3-1	General provisions
1200-3-2	Definitions
1200-3-4	Open burning
1200-3-5	Visible emissions
1200-3-6	Nonprocess emission standards
1200-3-7	Process emission standards
1200-3-8	Fugitive dust
1200-3-11	Hazardous-air contaminants
1200-3-14	Control of sulfur dioxide emissions
1200-3-16	New source performance standards
1200-3-18	Volatile organic compounds
1200-3-21	General alternate emission standards
1200-3-22	Lead emission standards
1200-3-23	Visibility protection
1200-3-24	Stack height regulations

[a]TDEC = Tennessee Department of Environment and Conservation.

Source: E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation. A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

7.4.2 Fugitive Dust Emissions

Elevation of particulate concentrations may result from earth-moving, site-grading, or demolition activities occurring during D&D. The TDEC, Division of Air Pollution Control has promulgated regulations governing fugitive dust emissions (Rules of the TDEC, Chap.

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1200-3-8-.010). An operator must take reasonable precautions to prevent particulate matter from becoming airborne. In addition, fugitive dust may not be emitted as visible emissions beyond property boundary lines for more than 5 min/hr or 20 min/day.

Design standards for containment buildings used to treat contaminated debris include controls sufficient to ensure that there are no visible fugitive dust emissions from any openings (doors, windows, vents, cracks). Additionally, all associated particulate collection devices must be operated and maintained with sound air pollution control devices per 40 CFR 60, Subpart 292 [40 CFR 264.1101(c)(1)(iv)].

7.4.3 Asbestos Emissions

National Emission Standards for Hazardous Air Pollutants are promulgated for particular air emissions from specific sources. Subpart M of 40 CFR 61 establishes standards for inactive waste disposal sites, for asbestos mills and manufacturing operations, for active waste disposal sites, and for disposal of asbestos from demolition or renovation activities. In addition, the NESHAPs for asbestos include standards for demolition and renovation of buildings that contain regulated asbestos-containing material (RACM) in several forms; these standards may be applicable for D&D activities that involve asbestos materials. However, these standards do not stipulate a safe threshold level for airborne asbestos fibers.

Asbestos is defined as "the asbestiform varieties of serpentinite (chrysotile), riebeckite (crocodilite), cummingtonite-grunerite, anthopyllite, and actinolite-tremolite." RACM includes: friable asbestos material (any material containing more than 1% asbestos that, when dry, can be crumbled, pulverized, or reduced to powder by hand pressure); Category I nonfriable asbestos-containing material (ACM) that has become friable; Category I nonfriable ACM that will be subject to sanding, grinding, cutting, or abrading; or Category II nonfriable ACM that has a high probability of becoming, or has become crumbled, pulverized, or reduced to powder by the forces expected to act on the material in the course of demolition or renovation. Category I ACM is defined as asbestos-containing packings, gaskets, resilient floor covering, and certain asphalt roofing products. Category II ACM means any material, excluding Category I products, that contain more than 1% asbestos that, when dry, cannot be crumbled, pulverized, or reduced to powder by hand pressure (40 CFR 61.141).

The notification requirements and procedures for asbestos emission control of 40 CFR 61.145(b) and (c) apply to a facility being demolished if the combined amount of RACM is at least 80 linear meters on pipes or at least 15 square meters on other facility components, or at least 1 cubic meter off facility components where the length and area could not be measured previously. Notification to the Regional Administrator is required for any demolition or renovation activities. The specific requirements are listed in 40 CFR 61.145(b) and include an estimate of the total amount of RACM to be removed and a description of work practices and engineering controls, as well as waste-handling emission controls.

Procedures for asbestos emission controls are listed for both demolition and renovation activities [40 CFR 61.145(c)]. Only those for demolition are summarized in Table 7.1. A person trained in the provisions of the NESHAPs rule must be on-site during any stripping, removing, or other handling of RACM materials [40 CFR 61.145(c)(8)].

Standards for waste disposal for demolition activities are described in 40 CFR 61.150. In general, the standards include wetting of all asbestos-containing waste materials, sealing in leak-tight containers, and controlling all visible emissions during all stages of handling, packaging, and loading for transport to a disposal facility. These requirements fall under the jurisdiction of WM and are not discussed further here.

7.5 NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act of 1969 [42 United States Code (USC) 4321 *et seq.*] establishes policies and goals for the protection of the environment; the Council on Environmental Quality is charged with promulgating regulations to implement the requirements of NEPA. It is understood that DOE will comply with the requirements of NEPA as specified in DOE Order 5440.1D (*National Environmental Policy Act Compliance Program*). This issue has been reaffirmed in the FFA §I(A)(3) and §III(A)(2) and Secretary of Energy Notice of February 5, 1990 (SEN-15-90), which was issued to ensure that DOE's NEPA activities are carried out in a centralized and uniform manner.

DOE has established procedures at 10 CFR 1021 for complying with NEPA as well as the Council on Environmental Quality requirements found at 40 CFR 1500-1508 (57 *FR* 15122, April 24, 1992). NEPA requires documentation in the form of Environmental Impact Statements or Environmental Assessments for any action that may significantly affect the quality of the environment. However, DOE has determined that certain classes of activities under DOE jurisdiction do not individually or cumulatively have a significant effect on the human environment, and therefore, may be eligible for a categorical exclusion for which neither an Environmental Impact Statement nor an Environmental Assessment is required (57 *FR* 15122). Various environmental regulations address specific environmental concerns, and those addressing wetlands, floodplains, other aquatic resources, archaeological and historical resources, and threatened and endangered species are summarized below. A synopsis of the provisions of these laws is given in Table 7.3.

7.5.1 Wetlands and Floodplains

ORNL is located within the Clinch River drainage basin and portions are located within 100- and 500-year floodplains. There are a number of wetlands located at ORNL. Therefore, before any D&D action is taken, pursuant to NEPA, a survey should be conducted of the particular site to determine whether there are wetlands present that could be impacted by D&D activities.

If any D&D activities are selected that would impact floodplains, compliance with the requirements found in Executive Order 11988, 40 CFR 264.18(b), 40 CFR 6.302(b), 40 CFR 6 (Appendix A), and 10 CFR 1022 may be necessary. If wetlands are affected, consideration should be given to Executive Order 11990, 40 CFR 6.302(a), 40 CFR 6 (Appendix A), 10 CFR 1022, CWA §404, and 40 CFR 230 for applicable requirements.

7.5.2 Aquatic Resources

If any D&D actions result in the control or structural modification of a natural stream or water body, the provisions found in the Fish and Wildlife Conservation Act (FWCA) [16 USC 661 *et seq.*] and 40 CFR 6.302(g) may be applicable. The Clinch River, with its various tributaries, and White Oak Creek have all been classified by TDEC for a variety of uses, including protection of fish and aquatic life and wildlife. Therefore, it is possible that compliance with the provisions of the Tennessee Water Quality Control Act (TCA 69-3-101 *et seq.*) would be required if any D&D actions at ORNL would cause, or be likely to cause, harm to wildlife or aquatic life in these waters.

In the event that streambed modifications occur during D&D activities, the requirements of the TDEC Aquatic Resources Alteration Permitting process (Rules of the

Table 7.3. Location-specific regulations applicable to D&D activities at ORNL

Location characteristic(s)	Requirement(s)	Citation(s)
	Wetlands	
Presence of wetlands as defined in Executive Order (EO) 11990 §7(c) and 40 CFR[a] 6, Appendix A §4(j)	Whenever possible, actions must avoid or minimize adverse impacts on wetlands and act to preserve and enhance their natural and beneficial values. Wetlands protection considerations shall be incorporated into planning, regulating, and decision-making processes.	EO 11990 40 CFR 6.302(a) 40 CFR 6, Appendix A 10 CFR 1022
Presence of wetlands as defined in 40 CFR 230.3(t) and 33 CFR 328.3(b)	Action to avoid degradation or destruction of wetlands must be taken to the extent possible. Discharges for which there is a practicable alternative with less adverse impacts or those that would cause or contribute to significant degradation are prohibited. If adverse impacts are unavoidable, action must be taken to enhance, restore, or create alternative wetlands.	Clean Water Act §404 40 CFR 230 33 CFR 320-330
	Floodplains	
Within "lowland and relatively flat areas adjoining inland and coastal waters and other floodprone areas such as offshore islands, including at a minimum, that area subject to a one percent or greater chance of flooding in any given year." [EO 11988 §6(c) and 40 CFR 6, Appendix A §4(d)]	Action shall be taken to reduce the risk of flood loss, minimize the impact of floods on human safety, health and welfare, and restore and preserve the natural and beneficial values of floodplains. The potential effects of actions in floodplains shall be evaluated and consideration of flood hazards and floodplain management ensured. If action is taken in floodplains, alternatives that avoid adverse effects and incompatible development and minimize potential harms shall be considered.	EO 11988 40 CFR 6.302(b) 40 CFR 6, Appendix A 10 CFR 1022

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Table 7.3 (continued)

Location characteristic(s)	Requirement(s)	Citation(s)
Wilderness areas, Wildlife resources, Wildlife refuges, Scenic rivers		
Within area encompassing or affecting waters of the state of Tennessee as defined in TCA[b] 69-3-103(32) and the presence of wildlife or aquatic life	Discharge of "substances" that "will result or will likely result in harm, potential harm or detriment to the health of animals, birds, fish, or aquatic life" is prohibited.	Tennessee Water Quality Control Act of 1977 (TCA 69-3-101 *et seq.*) Stream Use Classifications (TDEC[c] Rule Chap. 1200-4-4)
Within area affecting stream or river and presence of fish or wildlife resources	Action must be taken to prevent, mitigate, or compensate for project-related damages or losses to fish and wildlife resources. Actions that alter a resource require consultation with the FWS[d] and/or appropriate state agency.	Fish and Wildlife Coordination Act (16 USC 661 *et seq.*) 40 CFR 6.302(g)
Location encompassing aquatic ecosystem with dependent fish, wildlife, other aquatic life, or habitat	Degradation or destruction of aquatic ecosystems must be avoided to the extent possible. Discharges that cause or contribute to significant degradation of the water of such ecosystem are prohibited.	Clean Water Act §404 40 CFR 230 33 CFR 320-330
Endangered, Threatened, or Rare Species		
Presence of endangered or threatened species or critical habitat of such species as designated in 50 CFR 17, 50 CFR 226, or 50 CFR 227	Actions that jeopardize species/habitat must be avoided or appropriate mitigation measures taken. Actions that affect species/habitat require consultation with DOI,[e] FWS, and/or state agencies, as appropriate, to ensure that proposed actions do not jeopardize the continued existence of the species or adversely modify or destroy critical habitat.	Endangered Species Act of 1973 (16 USC 1531 *et seq.*) 50 CFR 402 40 CFR 6.302(h) Fish and Wildlife Coordination Act (16 USC 661 *et seq.*)

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Table 7.3 (continued)

Location characteristic(s)	Requirement(s)	Citation(s)
Archaeologic and Historic Resources		
Presence of archaeological resources on public land	Steps must be taken to protect archaeological resources and sites.	Archaeological Resources Recovery Act of 1979 (16 USC 470aa-ll) 43 CFR 7
Presence of archaeologic or historic resources	The Secretary of Interior must be advised of the presence of the data. A survey of affected areas for resources and data must be conducted and steps taken to recover, protect, and preserve data therefrom or request that DOI do so.	Archaeological and Historic Preservation Act (16 USC 469a-c) 40 CFR 6.301
Presence of federally owned, administered, or controlled prehistoric or historic resources; the likelihood of undiscovered resources	Cultural resources included on or eligible for inclusion on the National Register of Historic Places (36 CFR 60) or National Historic Landmark Program (36 CFR 65) must be identified. Action(s) that will affect such resources must be identified and alternatives to the action(s) examined and considered. When alteration or destruction of the resource is unavoidable, steps must be taken to minimize or mitigate the impacts and to preserve records and data of the resource. When all or part of a remedial action is off site, the consultation requirements of 16 USC 470f must be completed.	National Historic Preservation Act (16 USC 470a-w) EO 11593 40 CFR 6.301 36 CFR 800

[a]CFR = Code of Federal Regulations.
[b]TCA = Tennessee Code Annotated.
[c]TDEC = Tennessee Department of Environment and Conservation.
[d]FWS = Fish and Wildlife Service.
[e]DOI = Department of Interior.
Source: E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

TDEC, Chap. 1200-4-7 *et seq.*) may be applicable. General permits are available for such activities as alteration of wet weather conveyances, bank stabilization activities, sand and gravel dredging, and debris removal, with corresponding requirements for protection of aquatic resources. Individual permits may be required by the TDEC Division of Water Pollution Control for certain activities.

7.5.3 Rare, Threatened, or Endangered Species

In addition to several Tennessee state-listed endangered or threatened plants found at ORNL, there are a number of federal- and state-listed endangered or threatened or "in need of management" animal and avian species known to occur in east Tennessee. An in-depth discussion of these species appears in Vol. 24 of *The Resource Management Plan of the Oak Ridge Reservation*.[3] The list of rare and endangered species for the ORR, provided by the state of Tennessee, also includes two state-listed and federally listed endangered clams.[4]

Should any D&D actions at ORNL impact any federally listed endangered or threatened species, the provisions found in the Endangered Species Act of 1973 (16 USC 1531 *et seq.*), 50 CFR 492, 40 CFR 6.302(h), and the FWCA (16 USC 661 *et seq.*) may be legally applicable. If any proposed actions impact state-listed endangered or threatened animal species, the Tennessee Non-Game and Endangered or Threatened Wildlife Species Conservation Act of 1974 (TCA 70-8-101 *et seq.*) may be applicable.

7.5.4 Historic Sites and Archaeological Findings

The ORR, as well as the surrounding region, is rich in both archaeological and historic resources.[5] Although there have not been complete and exhaustive archaeological or historical surveys of the reservation, there have been a number of studies over the years, all indicating the presence of abundant resources on and around the reservation. These surveys are summarized in Vol. 3 of the *Resource Management Plan for the U. S. Department of Energy Oak Ridge Reservation*,[5] which also includes a list and descriptions of most of the documented sites. However, none of the surveys are recent, nor have they covered all of the specific sites where D&D actions may be planned or contemplated. Several laws require that such information be obtained and documented if there is ample reason to suspect the presence of these resources [Archaeological and Historic Preservation Act (16 USC 469a-c); Archaeological Resources Recovery Act of 1979 (16 USC 470aa-ll)].

The National Register of Historic Places lists the Graphite Reactor located at ORNL as an historic site, and the National Historic Preservation Act (16 USC 470a-w) mandates identification of cultural resources eligible for the National Register of Historic Places (36 CFR 60) or the National Historic Landmark Program (36 CFR 65).

If any D&D activity is undertaken that would cause irreparable harm, loss, or destruction to any historic or archaeological site, the provisions of the Archaeological Resources Recovery Act (16 USC 470aa-ll), 43 CFR 7, the Archaeological and Historic Preservation Act (16 USC 469a-c), and 40 CFR 6.301 may be legally applicable. The provisions of this latter statute would also apply to the Graphite Reactor along with Executive Order 11593, 40 CFR 6.301, and 36 CFR 800 *et seq.*

Title I, §126(b) of CERCLA mandated that OSHA promulgate standards for regulation of employee health and safety during hazardous-waste operations at RCRA or CERCLA sites and during emergency response to hazardous substance releases. The final regulations for *Hazardous Waste Operations and Emergency Response* (29 CFR 1910) have appeared in 54 *FR* 9294 (Final Rule, March 6, 1989). These regulations are designed to protect workers involved in cleanup operations at uncontrolled hazardous-waste sites and to provide for worker protection during initial site characterization and analysis, monitoring activities, materials handling activities, training, and emergency response. These regulations do not apply to those workers who would not be exposed.

Federal construction activities involving no potential for hazardous substance exposure are covered by the OSHA standards in 29 CFR 1926 (*Federal Service Contracts*) and 29 CFR 1910 (*General Industry*). Air contaminant permissible exposure limits for general industry for 212 substances were revised and updated on Jan. 19, 1989 (54 *FR* 2332), and are listed in Tables Z-1, Z-2, and Z-3 of the final rule. On July 7, 1992, a U.S. Circuit Court of Appeals vacated and remanded this final rule. The Clinton administration has decided not to appeal this ruling; this means the standards revert back to those in effect before 1989.

Standards for the protection of workers involved in construction, demolition, removal, alteration, or repair activities involving ACMs are listed in 29 CFR 1926.58 and would be applicable to D&D activities. These standards address asbestos as well as tremolite, anthophyllite, and actinolite (refers to the non-asbestos forms of these minerals, and any of these minerals that have been chemically treated or altered). The regulations include requirements for exposure monitoring, engineering controls and work practices, respiratory protection, and hazard communication. A permissible exposure limit is established which requires that no employee be exposed to an airborne concentration of asbestos, tremolite, anthophyllite, or actinolite, or a combination of these, in excess of 0.2 fibers per cubic centimeter of air as an eight-hour time-weighted average [29 CFR 1926.58(c)]. Fibers are additionally described as a particulate form of the above materials, 5 µm or longer, with a length-to-diameter ratio of at least 3 to 1 [29 CFR 1926.58(b)].

DOE also addresses occupational safety in DOE Orders 5480.11 (*Radiation Protection for Occupational Workers*), 5480.4 (*Environmental Protection, Safety, and Health Protection Standards*), 5483.1A (*Occupational Safety and Health Program for Contractors at GOCO Facilities*), and 5480.9 (*Construction Safety and Health Program*), and compliance is required during D&D activities.

7.7 RADIATION PROTECTION STANDARDS

Very few standards are available that are applicable to the cleanup of radioactively contaminated D&D sites at DOE facilities. The Atomic Energy Act and its amendments delegated authority for control of nuclear energy to the Nuclear Regulatory Commission (NRC), EPA, and DOE. The NRC has the authority to issue licenses and promulgate rules regulating NRC-licensed nuclear facilities and their decommissioning; however, DOE is authorized to control all types of nuclear materials at sites under its jurisdiction and is exempt, under the Atomic Energy Act, from the NRC's authority and is not subject to their decommissioning regulations. Although EPA intends to develop public health and environmental radiation protection criteria for cleanup of residual radioactive materials at decommissioned DOE, DOE, and NRC-licensed sites, as well as others (40 CFR 194) EPA has failed to date to promulgate *de minimis* or BRC radioactivity levels that would guide decontamination of the radioactive components at D&D sites. The absence of a regulatory driver for radioactive decontamination is viewed as a deterrent to the orderly planning and implementation of D&D activities.

DOE regulations for handling and cleaning up of radioactive materials and decommissioning activities are outlined in a series of internal DOE Orders, and include policies and guidelines for the management and D&D of radioactively contaminated facilities under DOE ownership or control. These are discussed in Sect. 7.7.1. In the absence of specific decontamination guidelines from EPA or DOE, the efforts of the NRC to establish such criteria are summarized in Sect. 7.7.2.

7.7.1 DOE Orders

DOE Order 5400.5 (*Radiation Protection of the Public and the Environment*, February 8, 1990) establishes standards and requirements for DOE operations "with respect to protection of members of the public and the environment against undue risk from radiation." The basic dose limit defined in DOE Order 5400.5 for routine DOE activities—including monitoring, cleaning up, and controlling of residual radioactive material—is 100 mrem/year. In all instances, the overriding principle of the DOE Order is that all releases of radioactive material shall be ALARA.

DOE Order 5400.5 lists derived concentration guides for radionuclide isotopes that are based on a committed effective dose equivalent of 100 mrem/year for ingestion of air or water. For liquid wastes containing radionuclides that are discharged to surface waters, the best available technology must be used if the receiving water, at the point of discharge, would receive radioactive material at a concentration greater than the derived concentration guides. Guidelines for selecting the best available technology are given. Implementation of the best available technology process is not required if annual releases to surface water are below the derived concentration guide. In the case of releases of multiple radionuclides, the sum of the fractional derived concentration guides must not exceed unity. In addition, effluent releases to surface water must not result in exposures to aquatic organisms that exceed an absorbed dose of 1 rad/d.

Chapter IV of the Order lists guidelines for cleanup of radioactive real and personal property, management of the resulting wastes and residues, and release of property. The guidelines are given for levels of residual surface contamination that will not be exceeded if decontamination is to be considered completed and property released to the public without restrictions on use [5400.5(II.5a)]. These levels are listed for specific isotopes and beta-gamma emitters in general (see Table 7.4). Information on application of the

Table 7.4. Surface contamination guidelines (dpm/100cm^2)[a]

Nuclides[b]	Averages[c,d]	Maximum[d,e]	Removable[d,f]
U-nat., ^{235}U, ^{238}U, and associated decay products	5000	15,000	1000
Transuranics, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, ^{231}PA, ^{227}Ac, ^{125}I, ^{129}I	reserved	reserved	reserved
Th-nat., ^{232}Th, ^{90}Sr, ^{223}Ra, ^{224}Ra, ^{232}U, ^{126}I, ^{131}I, ^{133}I	1000	3000	200
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr and others noted above[g]	5000	15,000	1000

[a]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute measured by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[b]Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[c]Measurements of average contamination should not be averaged over more than 1 m^2. For objects of smaller surface area, the average should be derived for each such object.

[d]The average and maximum dose rates associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively.

[e]The maximum contamination level applies to an area of not more than 100 cm^2.

[f]The amount of removable material per 100 cm^2 of surface area should be determined by wiping an area of that size with dry filter or soft absorbent paper, applying moderate pressure, and measuring the amount of radioactive material on the wiping with an appropriate instrument of known efficiency. When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area should be based on the actual area and the entire surface should be wiped. It is not necessary to use wiping techniques to measure removable contamination levels if direct scan surveys indicate that the total residual surface contamination levels are within the limits for removable contamination.

[g]This category of radionuclides includes mixed fission products, including the ^{90}Sr which is present in them. It does not apply to ^{90}Sr which has been separated from the other fission products or mixtures where the ^{90}Sr has been enriched.

Source: DOE Order 5400.5.

guidelines and requirements presented in the order, including procedures for deriving specific property guidelines for allowable levels of residual radioactive material from basic dose limits, is contained in DOE/CH-8901, "A Manual for Implementing Residual Radioactive Material Guidelines, A Supplement to the U.S. Department of Energy Guidelines for Residual Radioactive Material at FUSRAP and SFMP Sites," June 1989 [5400.5(IV.2)]. DOE proposed for codification as 10 CFR 834 the contents of DOE Order 5400.5 as radiation protection requirements for the public and the environment for DOE and DOE Contractor operations (58 CFR 16268, March 25, 1993).

DOE Order 5820.2A (*Radioactive Waste Management*, Sept. 9, 1988), states that the management of low-level radioactive waste must assure that external exposure to the waste and concentrations of radioactive material that may be released into surface water and soil do not exceed 25 mrem/year to any member of the public. Releases to the atmosphere shall not exceed 10 mrem/year. Reasonable effort should be made to maintain releases to the environment to ALARA levels.

Chapter V of this Order ("Decommissioning of Radioactively Contaminated Facilities") establishes policies and guidelines for the D&D of DOE-owned or controlled radioactively contaminated facilities. In summary, program offices are responsible for placing facilities

in a safe storage condition, providing surveillance and maintenance, and decommissioning excess facilities. The potential for reuse and recovery of materials and equipment must be addressed. Decommissioning project activities are outlined in the Order, and include: (1) surveillance and maintenance, (2) assessment and characterization, (3) environmental review, (4) engineering design, (5) D&D operations, (6) waste disposal, and (7) closeout. The environmental review and engineering design processes must assure that alternative actions and associated environmental issues are identified and assessed and that all regulatory requirements identified during the environmental review process are met.

The order requires that a Decommissioning Project Plan be prepared for approval by the appropriate program office in compliance with DOE Order 4700.1. The Plan must include: characterization data, an evaluation of decommissioning alternatives, plans for meeting the requirements identified in the environmental review process, and detailed administrative, cost, schedule, and management information. Radiological criteria to be used must be approved by the Headquarters program organization and EH-1. In addition, projections must be made of occupational exposures and estimations made of radioactive waste quantities to be generated.

DOE plans to revise DOE Order 5820.2A in order to consolidate all WM requirements for the Office of Environmental Restoration and Waste Management. Revisions are expected to be complete by 1994, and will cover all categories of wastes, including radioactive, hazardous, and sanitary waste.[6]

DOE Order 5480.11 (*Radiation Protection for Occupational Workers*) contains guidelines for worker protection: 5 rem/year and 50 rem/year annual effective dose equivalent for stochastic (cancer) and nonstochastic (systemic) effects, respectively, from both internal and external sources for continuous exposures. Also included in the order are standards for the general public when entering a controlled area. Exposures to the public are limited to an effective dose equivalent of 100 mrem/year. As with the other DOE orders, the ALARA principle prevails. Remediation of radionuclide-contaminated soils must ensure that exposures to on-site workers or public intruders will not exceed these standards. DOE has proposed for codification in 10 CFR 835 the primary standards for radiation protection of occupational workers from normal operation of DOE facilities (56 *FR* 64334, Dec. 9, 1991). A final rule is expected in July 1993. When promulgated, these standards will be legally applicable for cleanup activities at D&D sites.

7.7.2 Generic BRC Levels for Radioactive Wastes

The NRC has developed the concept of a risk threshold to distinguish those radioactive materials that do not warrant regulation to the same degree as other radioactive materials to ensure adequate protection of the public and the environment. The low levels of risk posed by these radioactive materials have been termed BRC. The NRC published a policy statement (55 *FR* 27522, July 3, 1990) to guide its decisions on exemptions of BRC materials from the full scope of the NRC's regulatory program.

The BRC policy was established, in part, to ensure adequate and consistent decisions on acceptable risks posed by decontaminated and decommissioned nuclear facilities. However, the adoption of the BRC policy generated widespread public concern over its implications and a general dissatisfaction with the process the NRC used to develop the BRC policy. Because of these concerns, the NRC declared a moratorium on implementation of the BRC policy and initiated a consensus process to provide advice to the NRC on the full range of issues related to the BRC policy (56 *FR* 36068, July 30, 1991).

The NRC policy stated that the average dose to individuals in a critical group should be less than 10 mrem/year (a hypothetical incremental annual risk of 5×10^{-6}) for each exempted practice. In addition, for such practices that result in widespread distribution of radioactive materials (e.g., consumer products or recycled materials), the NRC recommended an interim dose criterion for individuals in the critical group of 1 mrem/year (a risk of 5×10^{-7}). These individual annual doses translate to a lifetime risk from continuing annual exposures in the order of 10^{-4} and 10^{-5}, respectively.

EPA uses a similar policy in setting *de minimis* risk-based levels for exemption of hazardous chemicals from RCRA Subtitle C regulation (57 *FR* 21450, May 20, 1992). Health-based exemption levels are proposed for systemic toxicants and carcinogens based on reference doses and risk-specific doses, respectively. EPA has proposed a risk level of 10^{-6} to establish exemption criteria for Groups A, B, and C carcinogens (see 51 *FR* 33992, September 24, 1986, for a discussion of EPA's carcinogen classification scheme).

The NRC has made available a "Rulemaking Issues Paper" to enhance the assistance of interested parties in establishing radiological criteria for the decommissioning of NRC-licensed facilities and subsequent release of land and structures for unrestricted use (58 *FR* 4363, January 14, 1993). To assist in the participatory process, the NRC is conducting a series of workshops to address the issues outlined in the paper. NRC staff have identified four possible alternatives to developing radiological criteria. These include risk limits, risk goals, best effort, and return to preexisting background. In addition, the NRC has announced the availability of a report *Residual Radioactive Contamination from Decommissioning: Volume 1, Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent* (NUREG/CR-5512) (57 *FR* 49727, November 3, 1992).

7.8 REFERENCES

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5. M. Sanders, *Resource Management Plan for the U. S. Department of Energy Oak Ridge Reservation, Volume 3, Appendix B: Archeological Considerations*, ORNL-6026/V4, Oak Ridge National Laboratory, July 1984.

6. Report on Defense Plan Wastes 1992, *DOE Issues Radioactive Waste Management Revisions*, pp. 205, December 18, 1992.

APPENDIX

PARTIAL 1992 AND 1993 TECHNICAL TASK PLAN SEARCH DATA-BASE LISTING

Partial 1992 and 1993 Technical Task Plan search data-base listing

AL004201	AL213206	AL231009	CH026001	ID101101	ID425001
AL014204	AL213207	AL232001	CH028001	ID101301	ID431001
AL014209	AL213401	AL232002	CH036001	ID104201	
AL014212	AL214103	AL232004	CH038601	ID105001	NEWDALEY
AL024204	AL221103	AL232005	CH039001	ID111701	NEWPENCE
AL024207	AL221104	AL232006	CH039002	ID114103	NV001102
AL027001	AL221106	AL2332P1	CH101101	ID121102	NV004201
AL034201	AL221107	AL234103	CH101103	ID121103	NV011101
AL101202	AL221108	AL234104	CH101104	ID121110	NV021701
AL113101	AL221110	AL234301	CH111203	ID121114	NV025001
AL121101	AL221111	AL238023	CH114101	ID121203	NV026011
AL121120	AL221112	AL238024	CH123401	ID121204	NV031001
AL121121	AL221114	AL239001	CH124201	ID121208	
AL121122	AL221116	AL239002	CH125001	ID121210	OR013101
AL121125	AL221120	AL239003	CH131001	ID121217	OR014103
AL121202	AL221121	AL239004	CH213101	ID121301	OR014104
AL121215	AL221123	AL239005	CH221101	ID121701	OR021201
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OAK RIDGE NATIONAL LABORATORY
TECHNOLOGY LOGIC DIAGRAM

VOLUME 1

TECHNOLOGY EVALUATION

PART B
Remedial Action

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Prepared for the
Office of Technology Development
U.S. Department of Energy

1993
Edition

ORNL/M-2751/V1/Pt B 7751

Oak Ridge National Laboratory Technology Logic Diagram

Volume 1
Technology Evaluation

Part B
Remedial Action

Prepared for the Office of Technology Development
U.S. Department of Energy

September 1993

Prepared by
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CONTENTS

LIST OF TABLES vii
LIST OF FIGURES ix
ACKNOWLEDGMENTS xi
ACRONYMS AND INITIALISMS xv
FOREWORD xvii

1. INTRODUCTION 3
   1.1 OAK RIDGE NATIONAL LABORATORY 3
   1.2 ORNL MISSION 4
      1.2.1 Environmental Restoration Program 4
   1.3 ORNL LEGACY OF CONTAMINATION 7
      1.3.1 Introduction 7
      1.3.2 Waste Area Groupings 7
   1.4 ORNL PROBLEM DEFINITION 13
      1.4.1 Buried Waste 14
      1.4.2 Pits and Trenches 15
      1.4.3 Tanks 16
      1.4.4 Impoundments 16
      1.4.5 Pipelines 17
      1.4.6 Hydrofracture 17
      1.4.7 Soils and Sediment at ORNL 18
      1.4.8 Ground Water/Surface Water 23
      1.4.9 Priorities 24
   1.5 ORNL ROADMAP 25
      1.5.1 Introduction 25
      1.5.2 Roadmapping Methodology 25
   1.6 ORNL RA STRATEGY 26
      1.6.1 Status of RA Activities at ORNL 28
      1.6.2 Summary of Major Committed Milestones 30
   1.7 REFERENCES 32

2. DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM 37
   2.1 PURPOSE AND SCOPE 37
   2.2 STAFFING FOR THE TLD 38
   2.3 TECHNICAL APPROACH 40
   2.4 TECHNOLOGY RANKINGS 44
      2.4.1 Overall Assessment 44
      2.4.2 Status of Technology 45
      2.4.3 Estimates for Time to Maturity 46
   2.5 REFERENCES 47

3. CHARACTERIZATION 51
   3.1 INTRODUCTION 51
   3.2 TECHNOLOGY OPTIONS 52
      3.2.1 Characterization Technology Options 52
      3.2.2 Crosscutting Technologies 55
   3.3 SCIENCE AND TECHNOLOGY NEEDS 56

3.4 IMPLEMENTATION NEEDS 57
3.5 TECHNOLOGY RANKINGS 58
3.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 66

4. REMEDIAL ACTION 77
4.1 INTRODUCTION 77
4.2 DESCRIPTION OF TECHNOLOGIES CONSIDERED 78
4.2.1 Introduction 78
4.2.2 Buried Wastes 78
4.2.3 Low-Level Waste Tanks 80
4.2.4 Pits and Trenches 80
4.2.5 Soils and Sediments 81
4.2.6 Buried Pipelines 83
4.2.7 Impoundments 83
4.2.8 Hydrofracture 84
4.2.9 Ground Water and Surface Water 84
4.3 SCIENCE AND TECHNOLOGY NEEDS 86
4.3.1 Introduction 86
4.3.2 Buried Wastes 86
4.3.3 Low-Level Waste Tanks 86
4.3.4 Pits and Trenches 87
4.3.5 Soils and Sediments 87
4.3.6 Buried Pipelines 88
4.3.7 Impoundments 88
4.3.8 Hydrofracture 89
4.3.9 Ground Water and Surface Water 89
4.4 IMPLEMENTATION NEEDS 90
4.4.1 Introduction 90
4.4.2 Buried Wastes 90
4.4.3 Low-Level Waste Tanks 90
4.4.4 Pits and Trenches 92
4.4.5 Soils and Sediments 92
4.4.6 Buried Pipelines 92
4.4.7 Impoundments 93
4.4.8 Hydrofracture 93
4.4.9 Ground Water and Surface Water 93
4.5 TECHNOLOGY RANKINGS 94
4.5.1 Introduction 94
4.5.2 Buried Wastes 94
4.5.3 Low-Level Waste Tanks 102
4.5.4 Pits and Trenches 102
4.5.5 Soils and Sediments 103
4.5.6 Buried Pipelines 103
4.5.7 Impoundments 103
4.5.8 Hydrofracture 103
4.5.9 Ground Water and Surface Water 104
4.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 105

5. ROBOTICS AND AUTOMATION 113
5.1 INTRODUCTION 113

5.2 TECHNOLOGY OPTIONS 114
5.3 SCIENCE AND TECHNOLOGY NEEDS 117
5.3.1 Buried Wastes and Buried Pipes 117
5.3.2 Low-Level Waste Storage Tanks 118
5.3.3 Soils 118
5.3.4 Impoundment 119
5.4 IMPLEMENTATION NEEDS 120
5.5 TECHNOLOGY RANKINGS 121
5.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 124

6. REGULATORY COMPLIANCE 131
6.1 INTRODUCTION 131
6.2 OVERVIEW OF ENVIRONMENTAL LAWS AFFECTING RA ACTIVITIES . . . 133
6.3 CHEMICAL-SPECIFIC REGULATIONS 137
6.3.1 Ground Water and Surface Water 137
6.3.2 Air Standards 146
6.3.3 Soil Regulations 154
6.3.4 Nonregulatory Guidance 155
6.4 RADIATION PROTECTION STANDARDS 156
6.4.1 Generic Below Regulatory Concern Levels for Radioactive Wastes 156
6.4.2 Federal Agreements and Legislation 157
6.4.3 EPA Regulations 158
6.4.4 Department of Transportation Regulations 161
6.4.5 DOE Orders 162
6.5 ACTION-SPECIFIC REGULATIONS 169
6.5.1 Comprehensive Environmental Response, Compensation, and Liability Act 169
6.5.2 Resource Conservation and Recovery Act 169
6.5.3 Clean Air Act 174
6.5.4 Clean Water Act 175
6.5.5 Safe Drinking Water Act 205
6.5.6 Toxic Substances Control Act 205
6.5.7 Federal Insecticide, Fungicide, and Rodenticide Act 205
6.5.8 Occupational Safety and Health Administration 206
6.5.9 Federal and State Regulations 206
6.6 LOCATION-SPECIFIC REGULATIONS 207
6.6.1 Caves, Salt-Dome Formations, Salt-Bed Formations, and Underground Mines 207
6.6.2 Faults 207
6.6.3 Wetlands and Floodplains 207
6.6.4 Wilderness Areas, Wildlife Refuges, Wildlife Resources, and Scenic Rivers 215
6.6.5 Rare, Threatened, or Endangered Species 215
6.6.6 Historic Sites and Archaeological Findings 216
6.6 REFERENCES 217

APPENDIX: PARTIAL 1992 AND 1993 TECHNICAL TASK PLAN SEARCH DATA-BASE LISTING 221

000188

LIST OF TABLES

Table		Page
1.1	Contaminants known or suspected to have been released from each ORNL WAG	13
1.2	Problem areas and their related waste area groupings	14
1.3	Summary of SWSAs at ORNL	14
1.4	Summary of hydrofracture grout injections	19
1.5	Remedial action site problem priorities	25
1.6	Fiscal year milestones negotiated with TDEC and EPA through FFA	31
2.1	Subelement categories in the Technology Logic Diagram	41
2.2	Scale for overall assessment rating	45
2.3	Scale for status of technology	45
2.4	Definitions for progress of development and time periods	46
2.5	Correspondence of terms for state of the technology	46
3.1	Rankings of characterization technologies for remedial action	59
3.2	Characterization technologies under development by DOE	67
4.1	Rankings of remedial action technologies	95
4.2	Remedial action technologies under development by DOE	106
5.1	Relationship of robotics/automation technologies to remedial action problems	115
5.2	Rankings of robotics/automation technologies for remedial action	122
5.3	Robotics/automation technologies under development by DOE	125
6.1	Chemical-specific federal regulations for protection of human health	138
6.2	Federal and Tennessee secondary drinking water regulations	145
6.3	Federal ambient water quality criteria for the protection of human health	147
6.4	Tennessee water quality criteria for designated water uses	150
6.5	Federal ambient water quality criteria for the protection of freshwater organisms	153
6.6	Radionuclide-specific standards under the SDWA for ground water and surface water contamination at the Oak Ridge Reservation	159
6.7	Radiation protection standards that may be applicable to Oak Ridge Reservation D&D activities	160
6.8	DOE Order 5400.5, "Radiation Protection of the Public and the Environment"	163
6.9	DOE Order 5820.2A, "Radioactive Waste Management"	168
6.10	RCRA Subtitle C—standards for the treatment, storage, and disposal of hazardous waste	171
6.11	Federal RCRA land disposal regulations	171
6.12	Rules of the TDEC Bureau of Environment Division of Air Pollution Control	175
6.13	Action-specific regulations applicable to decontamination and decommissioning activities at the Oak Ridge Reservation	176
6.14	Location-specific regulations applicable to decontamination and decommissioning activities at the Oak Ridge Reservation	208

LIST OF FIGURES

Figure		Page
1.1	Aerial view of the Oak Ridge National Laboratory	5
1.2	ORNL waste area groupings	8
2.1	The ORNL Technology Logic Diagram Team	39
4.1	Potential buried waste remediation systems	79

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ACRONYMS AND INITIALISMS

AEA	Atomic Energy Act
AES	auger electron spectroscopy
ALARA	as low as reasonably achievable
ANPRM	advance notice of proposed rule making
ARAR	applicable or relevant and appropriate requirement
BDAT	best demonstrated available technology
BMP	best management practice
BRC	below regulatory concern
CAA	Clean Air Act
CAMU	Corrective Action Management Unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSF	carcinogen slope factor
CT	computer tomography
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EM	environmental management
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ES&H	Environmental, Safety, and Health
FFA	Federal Facilities Agreement
FFCA	Federal Facility Compliance Act
FR	Federal Register
FTIR	Fourier transform infrared
HDPE	high-density polyethylene
HMTA	Hazardous Materials Transportation Act
HSWA	Hazardous and Solid Waste Amendments
ICP	inductively coupled plasma
ICP-MS	inductively coupled plasma—mass spectrometry
IR	infrared
ISV	in situ vitrification
LDR	land disposal restriction
LDR-FFCA/ORR	Compliance Agreement Between the U.S. DOE - Oak Ridge Reservation and the EPA, Region IV
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MTR	minimum technology requirement
NARM	naturally occurring and accelerator-produced radioactive material
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NPRM	notice of proposed rule making
NRC	Nuclear Regulatory Commission
NRDA	natural resource damage assessment
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Act

000195

OSHA	Occupational Safety and Health Administration
OU	Operable unit
PCB	polychlorinated biphenyl
R&D	research and development
RA	Remedial Action
RCRA	Resource Conservation and Recovery Act
RF	radio frequency
RfCs	reference concentrations
RfDs	reference doses
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SMCL	secondary maximum contaminant level
SWDA	Solid Waste Disposal Act
SWSA	solid waste storage area
TCA	Tennessee Code Annotated
TDEC	Tennessee Department of Environment and Conservation
TLD	Technology Logic Diagram
TOA	Tennessee/DOE Monitoring and Oversight Agreement
TRU	transuranic
TSCA	Toxic Substances Control Act
TTP	Technical Task Plan
TU	Temporary Unit
UV	ultraviolet
VOC	volatile organic compound
WAG	waste area grouping
WQC	water quality criteria
XRF	X-ray fluorescence

FOREWORD

The *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) was developed to provide a decision-support tool that relates environmental restoration (ER) and waste management (WM) problems at Oak Ridge National Laboratory (ORNL) to potential technologies that can remediate these problems. The TLD uses information from the *Strategic Roadmap for the Oak Ridge Reservation*, *Oak Ridge K-25 Site Technology Logic Diagram* and a previous Hanford TLD.

The TLD identifies the research, development, demonstration, testing, and evaluation needed to develop these technologies to a state that allows technology transfer and application to decontamination and decommissioning (D&D), remedial action (RA), and WM activities. It is essential that follow-on engineering studies be conducted to build on the output of this project. These studies will begin by selecting the most promising technologies identified in the TLD and finding an optimum mix of technologies that will provide a socially acceptable balance between cost and risk.

The TLD consists of three fundamentally separate volumes: Vol. 1 (*Technology Evaluation*), Vol. 2 (*Technology Logic Diagram*), and Vol. 3 (*Technology Evaluation Data Sheets*). Part A of Vols. 1 and 2 focuses on D&D. Part B of Vols. 1 and 2 focuses on RA of contaminated facilities. Part C of Vols. 1 and 2 focuses on WM. Each part of Vol. 1 contains an overview of the TLD, an explanation of the program-specific responsibilities, a review of identified technologies, and the rankings of remedial technologies. Volume 2 (Pts. A, B, and C) contains the logic linkages among EM goals, environmental problems, and the various technologies that have the potential to solve these problems. Volume 3 (Pts. A, B, and C) contains the TLD data sheets.

The focus of Vol. 1, Pt. B, is RA, and it has been divided into six chapters. The first chapter is an introduction, which defines problems specific to the ER Program for ORNL. Chapter 2 provides a general overview of the TLD. Chapters 3 through 5 are organized into necessary subelement categories: RA, characterization, and robotics and automation. The final chapter contains regulatory compliance information concerning RA.

The technology evaluations contained in these volumes are based on the best information available during compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. L. Fellows, Editor, *Oak Ridge National Laboratory Technology Logic Diagram*, Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

1. Introduction

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1. INTRODUCTION

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1.1 OAK RIDGE NATIONAL LABORATORY

The Oak Ridge National Laboratory (ORNL) was built in 1943 as part of the World War II Manhattan Project. Its original mission was to produce and chemically separate the first gram quantities of plutonium as part of the national effort to produce the atomic bomb. The peacetime history of the laboratory first began in the late 1940s. Through 1973, ORNL was concerned with the development of nuclear technology for electrical power generation. From 1973 to 1980, ORNL was largely devoted to finding solutions for the energy crisis. The primary missions since 1980 have been to conduct applied research and engineering development in support of U.S. Department of Energy (DOE) programs in fusion, fission, conservation, fossil, and other energy technologies and to perform basic scientific research in selected areas of the physical and life sciences. The laboratory also operates "user facilities" for the benefit of university and industry researchers and supplies radioactive isotopes that are not commercially available.

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1.2 ORNL MISSION

The mission statement that follows was reproduced from the *ORNL Institutional Plan FY 1993–FY 1998.*[1] ORNL, which is managed by Martin Marietta Energy Systems, Inc., for DOE, is one of the nation's premier research institutions (see Fig. 1.1 for aerial view of ORNL). The primary mission of the laboratory is to perform leading-edge research and development (R&D) in support of the nonweapons roles of DOE. Significant elements of ORNL's mission are to perform basic and applied research that is of importance to the nation; to provide the scientific and technical community with unique national user facilities; to improve the nation's competitiveness through technology development and transfer by partnering universities and industry; and to improve science and math education through contributions to the national initiative.

ORNL will accomplish the mission through its core competencies:

- energy production, conservation, and utilization technologies;
- materials sciences and engineering;
- physical, chemical, and engineering sciences;
- biological and life sciences;
- environmental sciences and technologies;
- computational sciences; and
- manufacturing sciences and technologies.

The principal sponsor of ORNL's work is DOE, but, in a larger sense, the laboratory serves many national—even international—customers. ORNL staff are involved in research on global energy and environmental problems and in the development of technologies that will improve U.S. competitiveness in international markets. The laboratory's more fundamental scientific research, much of which is done in collaboration with researchers from around the world, contributes to the storehouse of human knowledge; this work, therefore, has a very broad customer base. In the conception, construction, and operation of national research facilities, the laboratory's customers are drawn from major segments of the scientific and technical community. Much of the applied research and technology development work at ORNL is expected to provide services for other government agencies and private companies.

Several factors combine to distinguish ORNL from other R&D institutions. The laboratory melds a unique blend of excellent researchers with a large array of world-class facilities to conduct broad interdisciplinary research in areas of national importance. The laboratory's ability to integrate basic research, applied research, technology development, information dissemination, and technology transfer is unsurpassed among research institutions. The style of teaming with industry and academia to bring a multidisciplinary approach to problem solving provides exceptional value to ORNL's customers. Finally, the laboratory's ability to conceive, construct, and manage large, complex projects provides DOE and the nation with a rare resource.

1.2.1 Environmental Restoration Program

The purpose and scope of DOE's national Environmental Restoration (ER) program is contained in the "Environmental Restoration and Waste Management Five-Year Plan"[2] (updated annually). Goals and objectives for the Oak Ridge Reservation (ORR), including ORNL, are identified in the "Environmental Restoration and Waste Management Site-Specific Plan for the Oak Ridge Reservation."[3]

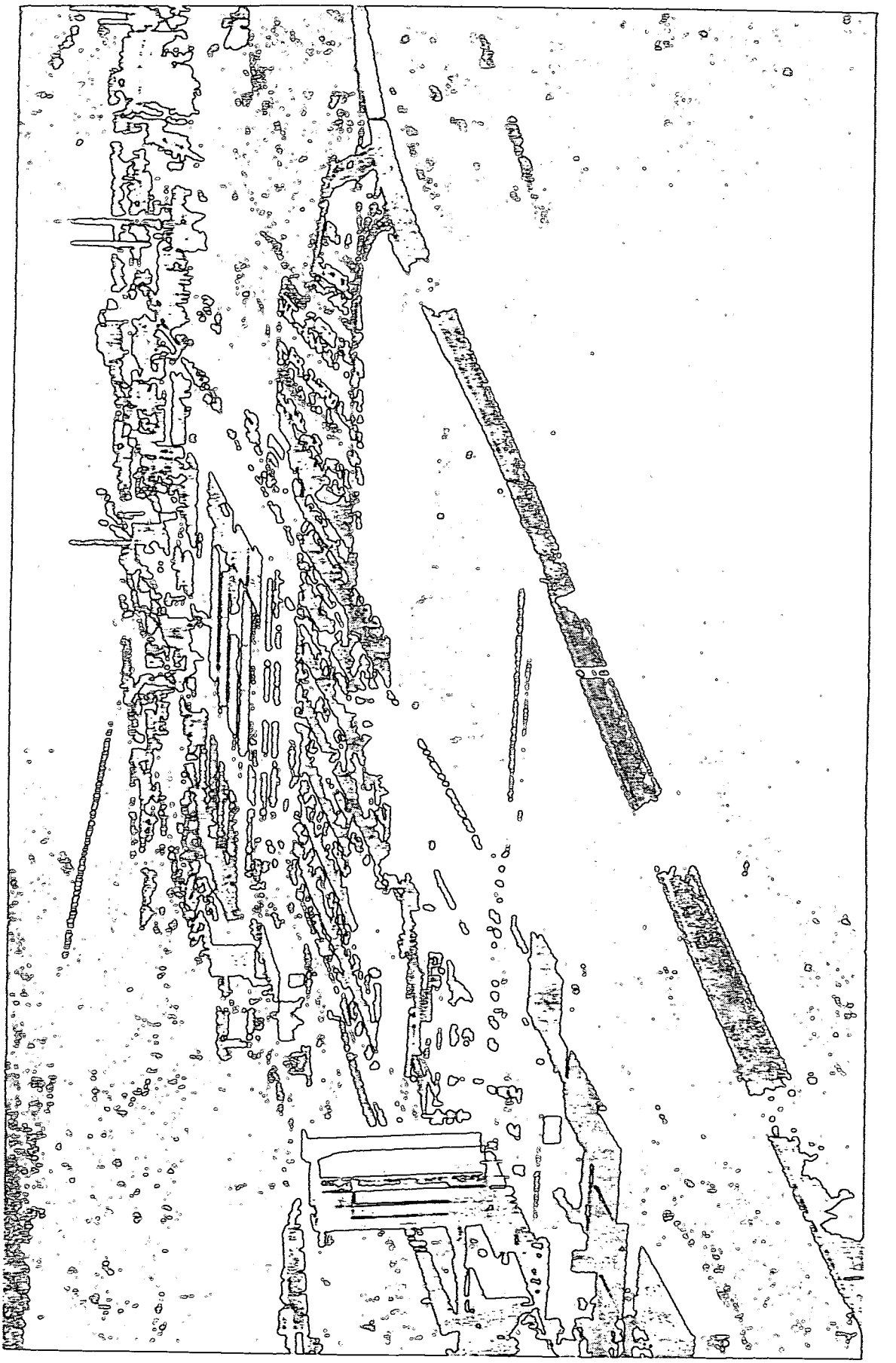

Fig. 1.1. Aerial view of the Oak Ridge National Laboratory.

ER projects assess and clean up DOE sites and facilities that are no longer active. Waste of various types has accumulated at ORR sites from defense and research operations spanning nearly five decades. ER activities are divided into four areas.

1. Assessment of nature and extent of environmental contamination;
2. Remedial action (RA) to clean up inactive waste sites that have the potential for releasing contaminants;
3. Decontamination and decommissioning (D&D) to clean up surplus facilities (see Vol. 1, Pt. A); and
4. Research, development, and demonstration to apply to new technologies to enhance restoration activities.

It is ORR policy to comply with both the letter and spirit of all applicable federal, state, and local regulations and with DOE policies governing environmental protection. Historical practices at many DOE sites, although consistent with the standards of their time, did not fully recognize the potential hazards of certain materials. Many of these past practices are considered inadequate by modern standards. ER activities are conducted to ensure that all inactive ORR facilities meet current requirements for environmental cleanup and waste management (WM).

The fundamental goal of ER is to ensure that contaminants at inactive or surplus facilities and sites are either eliminated or reduced to prescribed, safe levels. Risks from these restored sites should be low and not endanger human health and safety or the environment. This goal is achieved by meeting separate strategic objectives established for RA and D&D (see Vol. 1, Pt. A). The six objectives identified for RA follow:

1. Identify inactive, contaminated facilities and sites at ORR installations;
2. Assess these facilities and sites to determine the nature and extent of contamination;
3. Confine and contain existing contamination to the extent necessary to minimize further spread;
4. Coordinate with regulatory authorities for negotiated agreements that specify the requirements and schedule for cleaning up the identified facilities and sites;
5. Ensure that cleanup strictly complies with these agreements; and
6. Provide long-term monitoring to ensure continuing compliance.

DOE has established four priority levels for ER, reflecting discrete goals:

1. To limit immediate or short-term health risk and contamination;
2. To comply with in-place or pending agreements;
3. To reduce out-year risk, promote out-year compliance, address public concern, and protect DOE missions; and
4. To accelerate overall compliance.

1.3 ORNL LEGACY OF CONTAMINATION

1.3.1 Introduction

The 50 years of operations have produced a diverse legacy of contaminated inactive facilities, research areas, and waste disposal areas that are potential candidates for RA. Remedial activities for the contaminated inactive sites at ORNL were initiated in 1985 under the auspices of the Remedial Action Program.[4] One hundred sixty-four potential RA sites were identified and grouped into 13 categories that included diverse activities such as solid waste storage areas (SWSAs), pipeline leak sites, seepage pits and trenches, hydrofracture injection sites, and the White Oak Creek watershed.

The RA Program has been superseded by the ER Program, which currently includes over 275 sites. ER activities are carried out under the auspices of a Federal Facilities Agreement (FFA) between DOE, U.S. Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC). This document formalized a procedural framework for developing, implementing, and monitoring appropriate response actions in accordance with Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the National Contingency Plan, the Resource Conservation and Recovery Act (RCRA), the National Environmental Policy Act (NEPA), Tennessee State law, and appropriate guidance and policy.[5]

Because of the large number of contaminated sites and the hydrologic complexity at ORNL, the strategy developed in response to regulatory requirements has been oriented toward waste area groupings (WAGs) rather than individual sites. The WAGs are generally defined by watersheds that contain contiguous and similar RA sites. In some cases there has been hydrologic interaction among the sites within a WAG, making individual sites hydrologically inseparable. The use of groupings provides perimeter monitoring around a WAG of both ground water and surface water and the development of a remedial response that is protective of human health and environment. Twenty WAGs were initially identified at ORNL, of which 13 are definite candidates for further RA.

1.3.2 Waste Area Groupings

The concept of WAGs was developed initially to facilitate the investigation of potential sources of releases to the environment. Each WAG represents distinct, small, natural drainage areas that may encompass multiple sources of contaminants. The locations of the 13 individual WAGs are shown in Fig. 1.2. The WAG descriptions that follow are summarized from the WAG 2 Remedial Investigation Plan and the remedial investigation plans for the specific 6 WAGs.

WAG 1. This includes all the operating R&D facilities located within the main security fence at ORNL. Historically, ORNL has been involved in the development, testing, and operation of various reactor concepts; the development and operation of fuel reprocessing technologies; the large-scale production of radioactive and stable isotopes; and the management of wastes from these activities. These activities have been primarily focused in WAG 1, although several other WAGs have also been involved. Over 100 sites in WAG 1 are currently considered candidates for remediation, including radioactive waste collection pipelines and tanks, SWSAs, waste treatment facilities and impoundments, leak and spill sites, and miscellaneous waste handling and storage units. WAG 1 drains directly into White Oak Creek through storm drains and two small tributaries—First Creek and Fifth Creek. Conceptual modeling studies have demonstrated the potential for

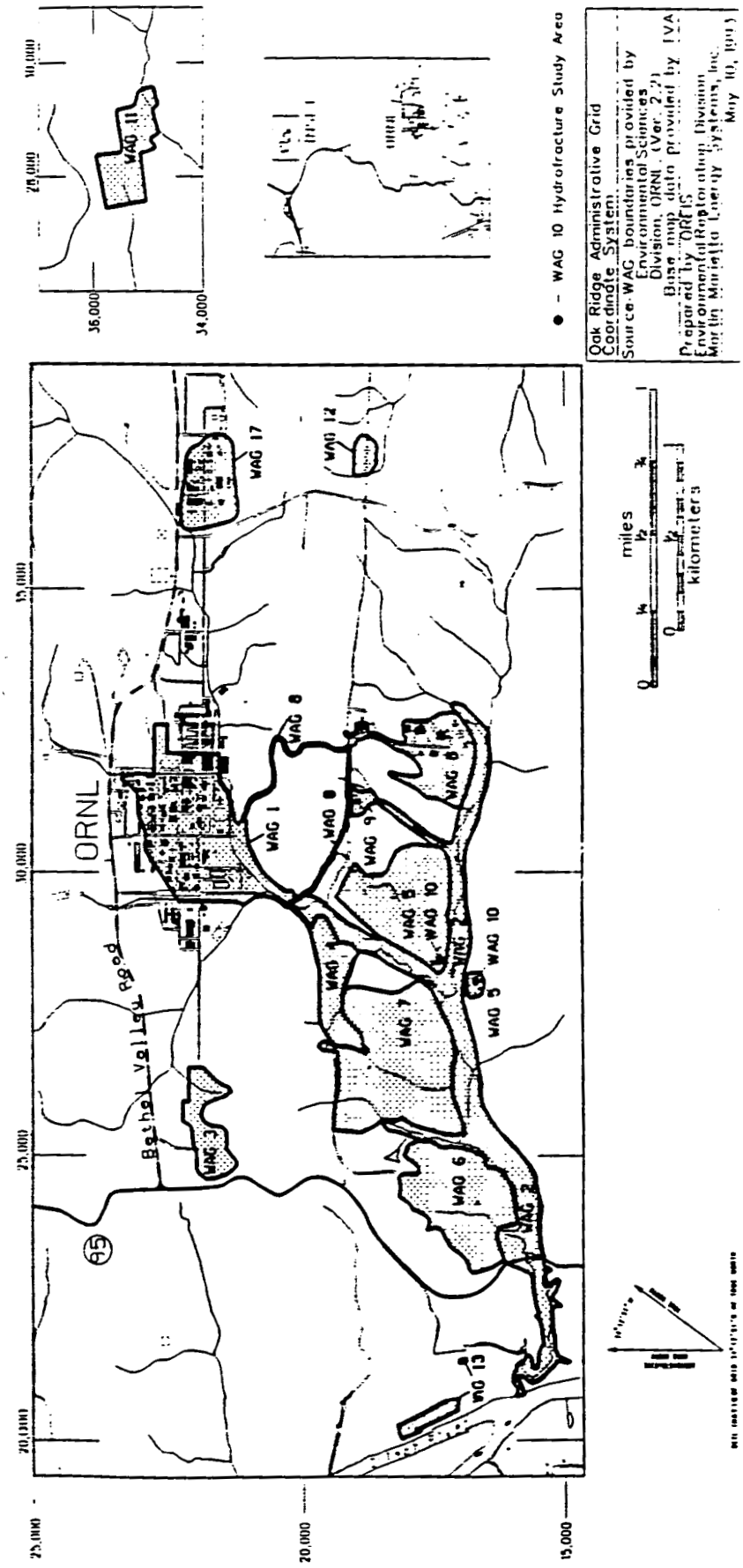

Fig. 1.2. ORNL waste area groupings.

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rapid transport of contaminants along the massive array of subsurface pipeline trenches directly to White Oak Creek and its WAG 1 tributaries.

Virtually every radionuclide, element, and organic compound ever used at ORNL has been used at one time in WAG 1. Historical release data suggest that WAG 1 was a major source for radionuclide and heavy-metal contamination to White Oak Creek.

WAG 2. This grouping includes the major drainage system for ORNL of White Oak Creek and its tributaries and associated floodplain areas. WAG 2 consists of two sites: the area encompassed by the stream channels of White Oak Creek and Melton Branch and White Oak Lake, White Oak Dam, and the embayment leading into the Clinch River and Watts Bar Lake.

In addition to natural drainage, White Oak Creek has received treated and untreated effluents and reactor-cooling water from ORNL activities since 1943. Controlled releases include those from the Nonradioactive Waste Treatment Facility, the Sewage Treatment Plant, and a variety of process-waste holdup ponds throughout the ORNL main plant area (WAG 1). It also receives ground water discharge and surface drainage from WAGs 3, 4, 5, 6, 7, 8, 9, and 17.

Main contaminants in White Oak Creek are ^{90}Sr, ^{60}Co, ^{137}Cs, ^{3}H, and metals (mercury, zinc, and chromium). Hazardous chemicals, including polychlorinated biphenyls (PCBs), may also be present in the stream sediments.

White Oak Lake is a surface impoundment for radioactive and other hazardous wastes that drain from ORNL via the White Oak Creek watershed. It serves as a final settling basin for waste released from ORNL operations and waste storage areas. Contaminants of concern identified to date are ^{90}Sr, ^{137}Cs, thorium, uranium, transuranics (TRUs), and metals (mercury, zinc, and chromium). Hazardous chemicals, including PCBs, may also be present in the stream sediments.

WAG 3. This area includes SWSA 3, the closed scrap-metal area, and the current operating contractors' landfill and is located in Bethel Valley about 1 km (0.6 mi.) west of the west entrance to the main plant area. SWSA 3 and the closed scrap-metal area are inactive landfills known to contain radioactive solid wastes and surplus materials generated at ORNL from 1946 to 1979. The Contractors' Landfill was opened in 1975 and is used to dispose of various uncontaminated construction materials and fly ash from the ORNL steam plant. WAG 3 is drained by Northwest Tributary of White Oak Creek.

Contaminants of concern identified to date in SWSA 3 include small amounts of TRU, ^{90}Sr, and ^{3}H. Most of the metal in the scrap metal area has now been buried in other SWSAs; however, some contaminated tanks and equipment are still stored aboveground. The primary contaminant of concern identified to date is ^{137}Cs. No contaminants of concern are believed to be present at the Contractor's Landfill, but there is no confirming documentation.

WAG 4. Located southwest of the main plant area, WAG 4 consists of three sites: the low-level waste line north of Lagoon Road, pilot pits 1 and 2, and SWSA 4. From 1954 to 1975, liquid-radioactive wastes were transferred to the waste pits and trenches (WAG 7) through the low-level waste line north of Lagoon Road. Two known leak sites were covered with bentonite and asphalt caps in 1983. The pilot pit area (Bldg. 7811) was constructed in late 1955 for use in pilot-scale radioactive waste disposal studies. Currently, three large concrete cylinders embedded in the ground, a control building that is now used to store field and laboratory equipment, and four large concrete cylinders that were used in a municipal waste leaching experiment are all that remain at the site. SWSA 4, covering 9.3 ha (23 acres), was opened for routine solid waste burials from 1951

through 1959 but remained open as a disposal area for uncontaminated fill until 1973. For a period of time, SWSA 4 was designated as the Southern Regional Burial Ground by the Atomic Energy Commission and received wastes from nuclear installations in the eastern United States. Waste from sources outside ORNL accounts for about half of the waste buried in SWSA 4.

Contaminants of concern identified to date include ^{3}H, ^{90}Sr, ^{60}Co, ^{125}Sb, and ^{137}Cs. Radionuclides are the only contaminants stored at the two pilot sites, and no releases have been reported.

WAG 5. Located about 2 km (1.2 mi) south of the main plant area in Melton Valley, this WAG consists of SWSA 5 and SWSA 5 North, two line-leak sites, an old landfill, the process-waste sludge basin, and the surface facilities constructed in support of both Old and New Hydrofracture Facilities (including several low-level waste storage tanks and two impoundments). Melton Branch separates the New Hydrofracture Facility from the remainder of WAG 5. SWSA 5, covering 32.3 ha (80 acres), received radioactive wastes from 1959 through 1973. The area known as SWSA 5 North covers 4 ha (10 acres) and has been used for retrievable storage of TRU wastes since 1970. WAG 5 drains directly into White Oak Creek, Melton Branch, and two unnamed tributaries of White Oak Creek.

About 200,000 Ci of low-level waste and TRU wastes are buried at SWSA 5. In addition, more than 62,000 Ci of TRU waste is in retrievable storage in SWSA 5 North, much of it buried in concrete casks. Eight 190,00-L stainless-steel tanks at the New Hydrofracture Facility Site hold concentrate from the low-level waste evaporator. The Old Hydrofracture Facility pond contains contaminated water and sediments with almost 500 Ci of activity. The predominant isotopes in all the low-level waste facilities are ^{60}Co, ^{90}Sr, and ^{137}Cs. TRU wastes are primarily ^{244}Cm, with lesser amounts of several other isotopes. Some lead and mercury were also buried with the TRU wastes. Ground water in wells and seeps have shown elevated levels of ^{3}H, ^{90}Sr, and ^{137}Cs.

WAG 6. This area consists of three sites: SWSA 6, the emergency waste basin, and the explosives detonation trench. All three facilities are located in Melton Valley, 2 km (1.2 mi) southwest of the main plant area along Lagoon Road. SWSA 6, covering 28 ha (68 acres), is currently the only operating low-level waste disposal site at ORNL. Portions of this site have been closed under RCRA regulations applicable to the disposal of RCRA-regulated waste after 1980. The emergency waste basin was constructed in 1962 as a holding basin if water could not be released from ORNL to White Oak Creek. To date, the basin has not been used. The explosives detonation trench was used for destruction of explosive and shock-sensitive chemicals. WAG 6 drains to White Oak Lake through four unnamed small streams.

Through the end of 1984, more than 250,000 Ci of low-level waste had been disposed of at SWSA 6. RCRA-regulated wastes (e.g., scintillation fluids, oils, cleaning solutions, alcohols, paint thinners, kerosene, jet fuel, acids, and sodium) were disposed of in several trenches and auger holes. These disposal areas have subsequently been covered by high-density polyethylene (HDPE) caps. As the only operating low-level waste disposal site at ORNL, SWSA 6 continues to receive solid low-level waste that is buried using greater confinement disposal technologies such as concrete silos, steel-lined auger holes, and concrete vaults on a concrete pad.

Site characterization data has been collected as part of the RCRA Facility Investigation for WAG 6.[7] Tritium, ^{60}Co, ^{90}Sr, and ^{137}Cs were the principle radioactive contaminants found in samples of 35 ground-water wells. These same contaminants were found in surface water and in both surface and subsurface soil samples. Trace levels of TRU isotopes were also found in two wells and two surface samples. Trace levels (generally

below health criteria) of several metals and solvents were found in a few wells. Only trace levels of metals from organics were found in surface water of soil samples. Sampling of wells in burial trenches by ORNL staff has measured numerous radioisotopes, heavy metals, volatile organic compounds (VOCs), and nitrates in the leachate.

WAG 7. This grouping is located in Melton Valley about 1.6 km (1 mi) southwest of the main plant area. The primary Solid Waste Management Units in this WAG are seven pits and trenches used for disposal of liquid low-level waste from 1951 through 1966. WAG 7 also includes a decontamination facility, three leak sites, a storage area containing shielded transfer tanks and other equipment, and seven fuel wells containing the acid solutions of enriched uranium from Homogeneous Reactor Experiment fuel. WAG 7 drains through three unnamed drainage channels into White Oak Creek.

More than 1,100,000 Ci of liquid low-level waste, primarily ^{90}Sr, ^{106}Ru, and ^{137}Cs, was transferred to the waste pits and trenches; another 2000 Ci of ^{137}Cs was placed in the shielded transfer tanks, and nearly 4 kg of ^{235}U in liquid form was placed in the Homogeneous Reactor Experiment fuel disposal auger holes. Characterization studies suggest that WAG 7 has been a source of ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, chromium, and zinc.

WAG 8. Located in Melton Valley, south of the main plant area, WAG 8 consists of reactor facilities and associated tank and piping systems, six leak sites and an old transfer line, five surface impoundments, a contractor spoils area, and RCRA-permitted hazardous waste storage facilities. Liquid low-level waste and process wastes from the reactors and associated facilities are collected on site in tanks and then pumped to the main plant area for storage and treatment. Wastes from the Homogeneous Reactor Experiment (WAG 9) were pumped using the same transfer system. WAG 8 drains into Melton Branch.

There is no existing inventory on the contents of the low-level waste collection and storage tanks, which are still in active use. Historical data are insufficient to determine whether or not any contamination remains at the leak sites in WAG 8. Samples of the sludge in the impoundments were not hazardous based on the EP-toxicity test. There is probably less than 10 Ci of radioisotopes in these ponds. There is no indication that radioactive or hazardous wastes were ever introduced into the waste treatment facilities. Historical studies have identified WAG 8 as a major source of ^{60}Co to Melton Branch. The WAG has also been a source of ^{137}Cs, copper, chromium, and zinc. No data are available on organic contaminants. The WAG contributes negligible amounts of other radionuclides to the White Oak Creek system.

WAG 9. Located in Melton Valley about 1 km (0.6 mi) southeast of the main plant area, this WAG includes the Homogeneous Reactor Experiment, the Homogeneous Reactor Experiment pond, the low-level waste collection and storage tanks, a septic tank, waste evaporator and associated pit, and several miscellaneous sites. The Homogeneous Reactor Experiment pond was constructed in 1955 as a waste storage impoundment for condensate from the Homogeneous Reactor Experiment waste evaporator. In 1970 the pond was filled with soil and capped with asphalt. WAG 9 drains to upper Melton Branch.

About 750 Ci of gross beta activity is present in the sediments of the Homogeneous Reactor Experiment impoundment. Strontium-90 and ^{137}Cs were the primary isotopes contributing to this activity. The sediments passed the EP-toxicity test. Tritium and ^{90}Sr were found in ground water down-gradient from the Homogeneous Reactor Experiment impoundment, but only trace levels of metal and organics were found.[3]

WAG 10. This area consists of the injection wells and grout sheets from four injection sites, two of which were experimental sites used in the development of the hydrofracturing process at ORNL. The other two sites were operating facilities (now inactive) used to dispose of ORNL's liquid low-level waste. All four sites are located in Melton Valley; however, they are not adjacent to one another. WAG 10 is significantly different from the other WAGs in that the grout sheets are located at depths of 90 to 300 m (300 to 1,000 ft) below the ground surface.

About 12 million L of liquid-radioactive wastes were injected into the fractured shale at the two major hydrofracture sites. Except for ^{90}Sr, ^{137}Cs, ^{244}Cm, and TRU, little is known about the contaminants that may have been included in the grout mixtures. At the two experimental sites, radioactive tracers were used instead of actual waste.

WAG 11. This area is the White Wing Scrap Yard located at the west end of East Fork Ridge between State Highway 95 (White Wing Road) and the Oak Ridge Turnpike. The site is outside the White Oak Creek watershed. The site, which covers about 20 acres, was used to store contaminated materials from the three Oak Ridge facilities (ORNL, K-25 Site, and Y-12 Plant). Wastes (equipment, tanks, and trucks) were thought to have been stored aboveground, but additional investigations may prove otherwise. Much of the stored materials and contaminated soil was removed in 1966–1971; however, some scrap metal, concrete, and other waste remains. Contaminants of concern identified to date are gamma radiation, ^{137}Cs, ^{234}Th, ^{235}U, and PCBs.

WAG 13. This grouping consists of the ^{137}C Contaminated Field and the ^{137}C Erosion/Runoff Study Area. The contaminated field is located about 330 ft north of the Clinch River at Clinch River Mile 20.5. The 50-acre area was set aside to study simulated fallout of ^{137}Cs fused at high temperature to silica particles. After ~20 years (since contamination), about 5.2 Ci of activity should remain.

The Erosion/Runoff Study Area is located due north of the confluence of the White Oak Creek and the Clinch River. The purpose of this study area was to use the field contamination to study runoff, erosion, and infiltration of ^{137}Cs on a silt-loam soil. The unit was contaminated on October 20, 1964, and is still under study.

WAG 17. Located about 1.6 km (1.0 mi) east of the main plant area, this area is the major craft and machine shop area for ORNL and includes the shipping, receiving, shops, and garage operations. The sites in WAG 17 are all tanks, of which three are underground. These tanks have the capacity of 39,000 gal of domestic sewage, ~13,000 gal of waste oil, and 5,000 gal of photographic wastes. In addition to the Solid Waste Management Units, there are four underground tanks (capacity ~31,000 gal) used for diesel fuel and gasoline, and one 4,000-gal aboveground waste oil tank.

1.4 ORNL PROBLEM DEFINITION

Environmental contamination in the ORNL WAGs has been grouped according to source and media:

1. buried wastes,
2. pits and trenches,
3. tanks,
4. impoundments,
5. pipelines,
6. hydrofracture,
7. soil and sediments, and
8. ground water/surface water.

These groupings reflect the results of program planning (e.g., Life Cycle Baselines and WAG 5 Remedial Investigation) that have addressed RA activities through currently anticipated site remediation. The anticipated types of remediation are technology based and incorporate present understanding of the general types of contaminant releases from the ORNL WAGs. Considerable data exists from past research and monitoring of various WAGs, and the known contaminants are listed in Table 1.1. Limited data is available concerning the sources of contamination, especially in the burial grounds. Ongoing investigations are currently under way to define the nature and extent of the contamination at WAGs 1, 2, and 5. Table 1.2 correlates the WAGs previously identified with the problem areas.

Table 1.1. Contaminants known or suspected to have been released from each ORNL WAG[a]

WAG	Contaminants[b]
1	^{60}Cr, ^{90}Sr, ^{137}Cs, ^{15x}Eu, ^{232}Th, ^{23x}U, ^{23x}Pu, ^{241}Am, ^{244}Cm, other radionuclides, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Zn, trichloroethylene (TCE), polychlorinated biphenyls (PCBs), chlordane
3	^{3}H, ^{90}Sr, ^{137}Cs, TCE
4	^{3}H, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{137}Cs, ^{23x}Pu, other radionuclides, TCE
5	^{3}H, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{233}U, ^{23x}Pu, ^{241}Am, ^{244}Cm, other radionuclides, Cr, Hg, Ni, Pb, Zn, PCBs
6	^{3}H, ^{14}C, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{15x}Eu, ^{23x}U, Cr, Cu, Hg, Mo, Ni, Pb, Zn, volatile organic compounds, nitrates
7	^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{137}Cs, ^{233}U, Cr, Ni, Zn, nitrates
8	^{60}Co, ^{90}Sr, ^{137}Cs, Cr, Cu, Zn
9	^{60}Co, ^{90}Sr, ^{137}Cs, Cr, Zn
10	^{90}Sr, ^{137}Cs, ^{244}Cm, TRU isotopes
13	^{137}Cs
17	^{137}Cs, Cd, Cr, Cu, Zn, fuel-derived hydrocarbons, and solvents

[a]WAG = waste area grouping
[b]Based primarily on data in ORNL RCRA Facility Investigation (unpublished) and environmental data packages for each WAG.

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Table 1.2. Problem areas and their related waste area grouping

WAG[a]	Problem areas
1	Buried wastes, tanks, impoundments, pipelines, and soils/sediments.
2	Soils/sediments and ground water/surface water
3	Buried wastes, soils/sediments, and ground water/surface water
4	Buried wastes, pipelines, soils/sediments, and ground water/surface water
5	Buried wastes, tanks, impoundments, pipelines, soils/sediments, and ground water/surface water
6	Buried wastes, soils/sediments, and ground water/surface water
7	Pits and trenches, pipelines, and soils/sediments
8	Tanks, impoundments, pipelines, and ground water/surface water
9	Tanks, impoundments, and ground water/surface water
10	Hydrofracture and ground water/surface water
11	Soils/sediments and ground water/surface water
13	Soils/sediments
17	Tanks

[a]WAG = waste area grouping

1.4.1 Buried Waste

Between 1944 and the present, waste was buried in six SWSAs (see Table 1.3). Waste sources at ORNL included physical, chemical, and biological laboratories, reactors, radioisotope operations, particle accelerators, hot-cell operations, and analytical labs. The buried waste was disposed on site in sanitary landfill-type areas, unlined trenches, alpha trenches and auger holes. Waste was disposed in a variety of containers, including drums, bags, boxes, bales, casks, concrete containers, and steel containers.

Table 1.3. Summary of SWSAs[a] at ORNL

WAG[b]	SWSA	Operation	Acreage	Records
1	1	1944	1.5	None
1	2	1944–1946	3.5	None
3	3	1946–1951	7	None
4	4	1951–1959	23	None
5	5	1959–1973	33	Incomplete
6	6	1969–	68	Limited

[a]SWSA = solid waste storage area
[b]WAG = waste area grouping

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From 1955 to 1963, SWSAs 4 and 5 were designated as the Southern Regional Burial Grounds by the Atomic Energy Commission and received waste from more than 50 off-site facilities, including Argonne National Laboratory, Mound Laboratory, Knolls Atomic Power Laboratory, and General Electric. The limited records available for all disposal activities indicate that low-level radioactive wastes, TRU waste, organic chemicals, mixed wastes, and asbestos were buried at ORNL.

1.4.2 Pits and Trenches

Low-level liquid-radioactive waste seepage pits and trenches were used between 1951 and 1966 for the disposal of 42 million gal of liquid-radioactive waste.[8] The liquids and sludges were placed into seven shallow seepage pits that allowed excess water and some radionuclides (e.g., ^{106}Ru and ^{3}H) to disperse into ground water and surface water. Within the suspended sludge and proximate soils, large inventories of fission products (^{90}Sr and ^{137}Cs) were retained along with a variety of TRU isotopes ($^{239,240}Pu$, ^{244}Cm, and ^{233}U) and activation products (i.e. ^{60}Co). Over a million curies of radioactivity were disposed, and about half remain in the area (WAG 7).

Waste Pit 1 was constructed in 1951 to test the feasibility of the permanent disposal of liquid wastes into surface pits. To test the safety of the method, 100,000 gal of waste containing 100 Ci of activity were to be placed onto Waste Pit 1.

Waste Pit 1 began receiving waste in August 1951. Waste from the ORNL Main Plant South Tank Farm was hauled to the pit in two 500-gal capacity tanks attached to a Dempster Dumpster Truck. Tanks W-8 (containing radioactive metal waste supernate) and W-10 (containing chemical waste concentrate, located in the South Tank Farm) were the main sources of waste. Waste Pit 1 received a total of 122,200 gal of waste prior to termination of the transfer in early October 1951.

Waste Pits 2, 3, and 4 were operated collectively during their history but are physically separate from each other.

Waste Pit 2 was constructed in 1952 to implement the routine disposal of liquid-radioactive wastes. Waste Pits 3 and 4 were built as more disposal volume was required to meet the disposal needs of ORNL. Each of the pits is similar in design and at the ground surface measures about 200 x 100 ft. The pits are each 15 ft deep, have walls that slope at angles of 20 to 30 degrees, and have a volume of about 1 million gal at a fluid level of 12 ft.

Trenches were designed to increase the efficiency of the seepage method. This was accomplished by using elongated trenches perpendicular to the bedding planes of the underlying shale and the addition of an earthen cover that reduced rainfall infiltration. Trench 5 was 300 ft long and 10 ft across at the ground surface and 4 ft across at the trench bottom. The trench contained about 10 ft of limestone fill covered by a polyethylene film. An additional 6 ft of earth filled the rest of the trench and was mounded above the ground surface. The capacity of Waste Trench 5 was 64,000 gal at a level of 9 ft.

The design of Waste Trench 6 differed from Waste Trench 5 in that the trench was longer (425 ft) and had a pronounced curved shape that followed local topography.

Waste Trench 7 was designed to consist of three separate pit segments. At ground level the trench segments are each 100 ft long by about 10.5 ft wide and 16 ft deep. The total capacity of Waste Trench 7 was 50,000 gal.

Use of waste seepage pits and trenches was discontinued in 1966, after the hydrofracture method of disposal of low-level waste went into operation.

1.4.3 Tanks

Throughout the 50 years of ORNL operations, low-level radioactive wastes have been accumulated and stored in underground tanks. These wastes were neutralized to minimize corrosion and concentrated to conserve tank volume. Many of these tanks have leaked in the past, usually to an unknown extent. Liquids have been removed from many inactive older tanks and either treated for disposal by other means or concentrated into other and newer tanks. Radioactivity, however, usually remains in the tanks due to the pressure of residual sediments and sludges that could not be removed completely by the methods used to get the liquids from the tanks.

While tanks are located in WAGs 5, 8, 9, and 17, most of the tanks at ORNL are within WAG 1. There are 73 waste storage, processing, and chemical storage tanks within WAG 1, 69 of which have been used for the collection, treatment, and/or storage of liquid low-level waste. Of the remaining four, two are aboveground tanks used for temporary waste-oil accumulation and storage, and two are aboveground tanks formerly used for storage of acid and caustic liquids. Twenty-five of the tanks continue to receive waste; 48 were removed from service because they (1) were leaking, (2) were no longer needed, or (3) did not meet FFA criteria for leak detection and secondary containment and were not scheduled for replacement.

About 95% of the documented inventory of radionuclides within inactive liquid low-level waste tanks in WAG 1 are contained within the six large underground storage tanks in the South Tank Farm. About half of the South Tank Farm inventory is in Tank W-10. Each 170,000-gal-capacity tank is made of Gunite—which is a construction process in which a mixture of sand, portland cement, and water is sprayed in layers onto steel reinforcement bars and/or welded wire mesh. The major contaminants in these Gunite tanks, among the first constructed at ORNL in the 1940s, are isotopes of Sr, Cs, Th, U, Pu, and Cm. The total gross beta activity is estimated to be about 23,000 Ci, from ^{90}Sr and ^{137}Cs, and the total gross alpha activity is about 160 Ci, mostly from plutonium and curium.

The North Tank Farm contains inactive underground liquid low-level waste Gunite and steel tanks; the Gunite tanks are much smaller than those in the South Tank Farm. The inventory of alpha-emitting radionuclides among all the tanks is estimated to be 7 Ci, and the inventory of beta emitters is estimated to be about 1000 Ci.

Due to the failure potential of the dome of the Gunite tanks, the fact that an estimated 95% of the waste curies at ORNL are stored within the Gunite tanks, and the ongoing RA activities at the North/South Tank Farm, the focus in the TLD problem area will be on the Gunite tanks.

1.4.4 Impoundments

Unlined impoundments have been used at ORNL to collect, treat, and, in some cases, dispose of process wastewater and storm water. These impoundments, also called waste basins or ponds, represent the earliest form of WM at the laboratory. The majority of the impoundments are located in WAG 1, although several ponds are located in WAG 5 and a closed pond in WAG 9. The mode of operation and contaminants at individual impoundments varied; however, the primary contaminants of concern are radionuclides, primarily ^{90}Sr, ^{137}Cs, ^{60}Co, ^{154}Eu, and other gamma emitters. Many of the impoundments are located at low elevations and are therefore in direct contact with the ground water.

Most of the impoundments were operated as process wastewater–settling or –storage basins, resulting in the deposition of sediments or sludge in the impoundments. The majority of impoundments are inactive; however, several, including 3524, 3539, and 3540, are still active and receive process wastewaters. The Homogeneous Reactor Experiment pond, used for storage of condensate from the Homogeneous Reactor Experiment evaporator, was filled with soil and capped with asphalt in 1970.

The 7835 impoundment, located in WAG 5, was used to contain and settle process sludge produced at the ORNL process-waste treatment plant. The 7852A impoundment is inactive but was used to receive accidental wastes generated during operation of the Old Hydrofracture Facility. White Oak Lake is a surface impoundment for radioactive and other hazardous wastes that drain ORNL via the White Oak Creek watershed. It serves as a final settling basin for waste released from ORNL operations and storage areas.

1.4.5 Pipelines

The ORNL main plant and outlying facilities have an extensive system of waste-carrying pipelines and tanks. There are 96 tanks used for radioactive, hazardous, and mixed waste known to exist at ORNL. Forty-two of these are active, and 54 are out of service (this total does not include petroleum tanks). The waste-carrying pipelines are divided into two types: low-level waste and process ("suspect") waste.

Low-level waste lines (mostly 1-in. to 4-in. stainless steel) carry liquid-radioactive waste from "hot drains" within buildings to an evaporator facility within the main plant area, where volume reduction is performed. The concentrate remains in the low-level waste system and is piped through double-contained lines to the Melton Valley Storage Tanks. The liquid is piped from the evaporator to the Waste Water Treatment Plant for removal of radionuclides. The effluent from this process is collected in aboveground storage tanks. The waste is then treated at the Nonradioactive Wastewater Treatment Plant, and the treated effluent is released at a National Pollutant Discharges Elimination System, which is a permitted discharge point to White Oak Creek.

Many of the process-waste lines (mostly 4-in. to 6-in. vitreous clay pipe) have been relined in recent years. Some sections are no longer used (the waste is transported to the Waste Water Treatment Plant from holding tanks via tanker truck). However, many of the sections of process pipe located between the building drains and holding tanks have held the most concentrated (and therefore most corrosive) waste, and it is conceivable that waste may have leaked into the soil beneath these buildings. The process and low-level waste lines are buried between 3 ft and 20 ft deep and cross over many other pipelines. Leaks from waste-carrying pipes may have spread to the pipe backfills of other types of piping, which may be serving as conduits for the transport of contaminants. Remediation of contaminated soil, without destruction of the buildings and other pipelines, calls for the use of innovative methods. The methods used at other remediation sites (information resulting from a reference search) have consisted exclusively of either capping the pipes and/or filling them with grout and leaving the pipe and contaminated soil in place or excavating the soil and pipe and disposing of the soil and pipe material.

1.4.6 Hydrofracture

As part of waste disposal operations conducted at ORNL, wastes were injected into low-permeability shale about 300 m below ground. The process, known as hydrofracture injection, was conducted during the 1960s through the 1980s. Radioactive wastes were mixed with grout and other additives to form a slurry then pumped down injection wells

and into the Pumpkin Valley Shale formation. The waste mixture extended horizontally from the injection well to form a solid grout sheet 2-25 mm thick with a radius of 150–200 m. Additional injections were made into the shale formation at slightly shallower depths in order to dispose of the waste volumes. About 3.2 million gal of low-level radioactive wastes containing 1.4 million Ci of radioactivity were disposed of between 1959 and 1984 at depths between 225 and 340 m (Table 1.4).

The Hydrofracture Experiment Site 1 is located within the boundary of WAG 7 and was the site of the first experimental injection of grout (October 1959) as part of a testing program for observing the fracture pattern created in the shale and identifying potential operating problems. Waste injected was water-tagged with ^{137}Cs and ^{141}Ce. Grout consisted of diatomaceous earth and cement.

The Hydrofracture Experiment Site 2 is located about 0.5 mile south of the Homogeneous Reactor Experiment area in WAG 8. The second hydrofracture experiment was designed to duplicate, in scale, an actual disposal operation. However, radioactive tracers were used instead of actual waste. Water tagged with ^{137}Cs, cement, and bentonite was used in formulating the grout.

The Old Hydrofracture Facility is located in the southwest corner of WAG 5. The facility, commissioned in 1963, served as a pilot plant to demonstrate the feasibility of permanent disposal of liquid-radioactive waste in impermeable-shale formations by hydrofracture methods. Wastes used in the experiments included concentrated liquid low-level waste, ^{90}Sr, ^{137}Cs, ^{244}Cm, TRU, and other unidentified radionuclides.

The New Hydrofracture Facility is located 900 ft southwest of the Old Hydrofracture Facility on the south side of Melton Branch. The facility was constructed to replace the Old Hydrofracture Facility and serve as the operational liquid low-level waste disposal system for ORNL. Wastes used in the injections were concentrated liquid low-level waste and sludge removed from the Gunite tanks and included ^{90}Sr, ^{137}Cs, ^{244}Cm, TRU, and other nuclides.

The hydrofracture problem area includes only the underground component at the four sites. It consists of the wells, grout sheets and contaminated subsurface media, and about 150 observational wells. The latter were used to measure changes to the geology around the injection site, and most of these wells do not penetrate the grout sheets.

For the purposes of the TLD, the problem area was divided into two subproblems: the well bores and the grout sheets. The well bores, though not a waste site, present a potential pathway for vertical migration of any mobile waste from the grout sheets to aquifers above or below the grout sheets. The grout represents a potential waste site because the potential exists that some of the waste may not have been immobilized with the grout or that a phase separation of the grout mixture may have left a liquid slurry capable of leaching or migrating to an aquifer.

1.4.7 Soils and Sediment at ORNL

Soils and sediments act as receptors of contaminants released to the terrestrial environment. Predominate modes of contamination result from spills, leaks from waste storage tanks and associated transfer lines, and uncontrolled WM practices, such as disposal in unlined lagoons and burial trenches. The concentration and character of contamination vary widely (i.e., radionuclides, heavy metals, as well as hazardous- and toxic-organic compounds) and are largely dependent on the historical operations conducted at ORNL. For example, there is a potential for contamination by a spectrum of fission and neutron activation products because of the wide diversity in fission research conducted over the nearly 40 years at ORNL. This is unlike the other DOE Oak

Table 1.4. Summary of hydrofracture grout injections[a]

Injection type	Number of injections	Water plus			Primary waste constituents[b] (curies)					
		Waste volume (gal × 10^3)	Water volume (gal × 10^3)	Grout volume (gal × 10^3)	^{90}Sr	^{137}Cs	^{244}Cm	TRU[c]	Other	Total
HF1										
Experimental (1959)	1	N/A[d]	N/A	27	--	35	--	--	8.7 (^{141}Ce)	44
HF2										
Experimental (1960)	2	N/A	N/A	224	--	50	--	--	--	50
HF3 (OHF)										
Experimental (1963-1965	11	N/A	457	678	1,436	5,237	N/A	N/A	N/A	6,673
Operational (1966–1979)	18	969	1,200	1,650	38,640	603,881	233[d]	5.8[e]	N/A	642,760
HF4 (NHF)										
Experimental (1982)	1	N/A	66	98	--	--	--	--	20 (^{198}Au)	184
Operational (1982–1984)	13	2,240	2,540	2,873	644,505	83,765	7,464	2,125	13,314	751,173
Total	46			5,550						1.4×10^6

[a]Values are estimates of injected volumes only. Accurate determination of phase separation and bleed-back volumes cannot be made for many of the injections.

[b]Other radionuclides were present in waste in much smaller quantities, were in equilibrium with listed radionuclides, or were not analyzed prior to injection.

[c]TRU represents transuranic elements.

[d]Not analyzed.

[e]Totals here should be used with caution. Data on radionuclide content are not available for injections in this series.

Source: Modified from Myrick and Stow, *Remedial Action Plan for ORNL Hydrofracture Operation*, ORNL/RAP-9, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, 1987.

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Ridge Operations sites, where radioactive contamination is generally limited to U and ^{99}Tc in the uranium-enrichment and processing industry.

Due to the changing mission and needs of the laboratory, the management of liquid and solid wastes was generally one that involved considerable flexibility. In the early to late 1940s, high-level liquid wastes were treated with caustic and held in large Gunite tanks to allow for sludge settling and decay of short-lived radioisotopes. Supernatant from these tanks were diverted to settling basins and discharged to the White Oak Creek impoundment. In 1949, an evaporator was added to reduce the volume of liquid waste stored in the Gunite tanks. Storage space in Gunite tanks became limited, and in 1951 direct disposal of high-level liquid waste into disposal pits began. From 1951 to 1966 about 42 million gal of radioactive-liquid waste containing about 1.2 million curies were disposed in seven seepage pits and trenches. Much of the short-lived activity has decayed leaving an estimated 200,000 Ci of ^{90}Sr, 600,000 Ci of ^{137}Cs, and much smaller amounts of U and TRUs.[8] A limited and unknown portion of activity has leached from these pits and trenches contaminating soils and sediment of the White Oak Creek impoundment. Low-level solid and liquid wastes have also been disposed of in unlined waste pits, trenches, and lagoons, resulting in the contamination of underlying soils as well as the floodplain soils and sediments of the White Oak Creek impoundment. To roughly estimate the quantity and characteristics of contaminated soils and sediments present at ORNL, each area containing potentially contaminated soil and/or sediment is discussed below.

1.4.7.1 Contaminated Soils in Low-Level Solid Waste Burial Grounds

Soils contaminated as a result of low-level solid waste disposal operations are predominately those in contact and adjacent to the unlined burial trenches. Treatment of these soils may be required if wastes from these trenches are removed off site. This scenario is being considered but is unlikely to take place in the next 10–20 years. Seven sites at ORNL have been used for disposal of low-level solid wastes. All but one (SWSA 6) are closed to active burial operations. The total surface area for all seven is about 130 acres.[9] If one assumes about one-half of that area contains trenches (14 ft by 40 ft and 15 ft deep with 6 ft by 12 ft between trenches), then an estimate for the total number of burial trenches is about 1800. The contaminated soil surrounding these trenches would be on the order of 2.2×10^5 yd^3, assuming contamination is confined to within 3 ft of the trench. Obviously, such an estimate is subject to a large error (by factors of 10–100), depending on cleanup levels and accessibility of contaminated soil after removing the waste forms. The main point to keep in mind is that large volumes of soil will likely require treatment if wastes are removed from these burial grounds.

1.4.7.2 Contaminated Soils Surrounding ORNL Seepage Pits and Trenches

Large quantities of radioactive-liquid wastes have been disposed of in the ORNL waste pits and trenches (~ 42×10^6 gal containing ~ 1.2×10^6 Ci of activity).[8] However, a direct association between levels of ^{90}Sr, ^{60}Co, and ^{137}Cs observed in stream-bed sediment and discharge from the waste pits and trenches was difficult to ascertain. Pit 1 and Trench 6 are the only identifiable sources of ^{90}Sr contamination in stream-bed sediment.[10] Concentrations of ^{90}Sr on stream-bed gravels routinely measured >220 pCi/g in the streams draining these two sources. Very large concentrations of ^{60}Co (>4.5×10^3 pCi/g) were measured in stream-bed gravels immediately to the east of Trench 7. These concentrations of ^{60}Co likely reflect transport of ^{60}Co observed by Duguid in ground-

water seeps east of Trench 7 (concentrations >100 pCi/mL).[11] Concentrations of ^{60}Co or ^{90}Sr in surface soils or relict-contaminated subsurface soils adjacent to Trench 7 have not been reported. Thus, it is difficult to determine the extent of contamination so that estimates relating to the quantities of contaminated soils in these areas can be determined. Because of the high affinity of ^{137}Cs to become irreversibly sorbed to the illicitic soil clays native to this area, ^{137}Cs contaminated surface soils are rarely observed.[12] The one exception appears to be soils and stream gravels immediately downstream from Trench 6. This trench was constructed in 1961 in the absence of geologic advice or preconstruction coring and water-table monitoring. It was U-shaped, and only small portions of it were perpendicular to the geologic strike as prescribed in the Trench 5 design. Its use was discontinued about one month after it received its first waste. Significant seepage containing ^{90}Sr and ^{137}Cs (~20 mr/h) was detected south of the trench indicating serious leakage through open fissures. Concentrations of radioactivity in soil or estimated quantities of soil contaminated by the seepage was not reported in Spalding's 1987 report.[8]

The need for remediation of soils and sediments within the ORNL seepage pit and trench waste grouping area will depend on two major factors: (1) the approach used to remediate the pits and trenches and (2) levels of cleanup established for soils and sediments. Obviously the most important remediation effort will be directed at the waste pits and trenches per se; however, ground water, as well as surface water contamination, will likely continue until relict-contaminated subsurface soils immediately adjacent to these waste disposal sites are remediated. The quantity of contaminated soil, as well as the level or forms of contamination, are not clearly understood.

1.4.7.3 Contaminated Soils Under Waste Impoundments

Unlined impoundments have been used at ORNL to collect, treat, and in some instances, dispose of liquid wastes. These impoundments, also called waste basins or ponds, represent the earliest form of WM at the laboratory. ORNL has used at least 11 waste impoundments to collect liquid low-level radioactive wastes.[13] These include the 3513, 3524, 3539, and 3540 impoundments located in WAG 1; the 7905, 7906, 7907, and 7908 impoundments located in Melton Valley for the collection of liquid waste from the High Flux Isotope Reactor and Transuranium Process Plan; the 7835 impoundment located in WAG 5; the 7852A or the Old Hydrofracture Facility impoundment (the Old Hydrofracture holding pond); and the Homogeneous Reactor Experiment impoundment (Homogeneous Reactor Experiment No. 2) located just south of Melton Valley Drive. The two largest impoundments are 3513 and 3524 (design capacity of 2×10^9 gal and 1×10^9 gal, respectively). The bottoms of these impoundments are very near the limestone bedrock (usually within 2 ft, and in the case of the 3524 impoundment on bedrock at the west end). Thus, soil contamination is predominately that soil making up the berms of the impoundments and the surface soil between the impoundments and the White Oak Creek. The surface area within this complex (less the area of the impoundments) is ~1.3×10^5 ft^2 (3 acres). If one assumes a soil depth of 15 ft to bedrock, the total volume of contaminated soil in this area would be about 7.2×10^4 yd^3. The dominant contaminant, judging from concentrations in ground-water monitoring wells, would be ^{90}Sr. There may be unacceptable levels of mercury in some of the soil—sediment in the 3513 pond contained EP toxic levels of extractable mercury.[14] Thus, sediment in the 3513 impoundment will likely be classified as a mixed waste. Characterization of sediment contained in all of the ponds was completed before promulgation of the Toxicity Characteristic Leaching Procedure to identify toxicity of

organic compounds in wastes: thus, it is likely that all the sediment from these impoundments (and possibly the soils below and adjacent to the impoundments) will require classification by the Toxicity Characteristic Leaching Procedure test.

The impoundments at the High Flux Isotope Reactor and TRU sites (7905, 7906, 7907, 7908) are relatively small (total capacity < 8.5×10^5 gal) and have < 2 Ci of activity in the sludge of sediment contained in the bottom of the impoundments. Total volume of contaminated soil after remediation of the sludge in the impoundments is expected to be $<10^3$ yd^3 and, judging from the concentrations of radionuclides in the sludge, concentrations of radionuclides would also be low.

The 7834 impoundment was used to contain and settle process-waste sludge generated at the ORNL Process Waste Treatment Plant. The impoundment (85 × 80 × 8 ft deep) was constructed in 1976 and taken out of service in 1981. Characterization by Francis and Sealand[13] showed the impoundment contained ~20 Ci of activity (predominately ^{90}Sr, ^{137}Cs with ~1 Ci of ^{60}Co) in a very low-density sediment (dominated by an organic resin).[9] If one assumes soil contamination is limited to a distance of 4 ft around and below the impoundment, the volume of potentially contaminated soil would be on the order of 2.5×10^3 yd^3. The Homogeneous Reactor Experiment impoundment was drained and backfilled with soil and partially weathered shale in 1970. The ground water has been monitored, and the sludge/sediment has been characterized as to concentration of radionuclides and metals and its EP toxicity characteristics.[14, 15] The radionuclide inventory was ~90 Ci (~ 75 and 15 Ci of ^{90}Sr and ^{137}Cs, respectively, with traces of plutonium isotopes) with some samples containing 5.4×10^4 and 3.9×10^5 pCi/g of ^{137}Cs and ^{90}Sr, respectively. The volume of contaminated soil/sediment within the original pond area would be about 10^3 yd^3 and about 6 times that if soil under the asphalt cap were removed to a depth of 10 ft.

The Old Hydrofracture Facility impoundment contains the largest radionuclide inventory of the ORNL impoundments. The estimated inventory is ~150 Ci and the sludge/sediment (on a dry-weight basis) would be classified as a Class C waste under Nuclear Regulatory Commission (NRC) regulations.[13,16] High levels of ^{90}Sr (3.8×10^4 pCi/L) in ground water sampled from the well in the northwest berm indicate that considerable contamination is moving out of the impoundment. Surface soils down-gradient, as well as those between the pump house and impoundment, showed elevated rad levels, indicating considerable contamination of soils at this impoundment.[16] These data indicate that estimates of surface-soil contamination may range to as high as 1.5×10^3 yd^3 and about 0.5×10^3 yd^3 of contaminated soil beneath the contaminated sludge contained in the impoundment.

1.4.7.4 Contaminated Sediments and Floodplain Soils

Most of the contaminated sediments in the ORNL area are in the Intermediate Pond, both White Oak Creek and Melton Branch weirs, White Oak Lake, and White Oak Lake Embayment of the White Oak Creek watershed. Contaminated floodplain soils are also located along tributaries of White Oak Creek.

The contaminated sediments and soils belong to WAG 2. The White Oak Creek drainage system has been exposed to a diversity of contaminants as a result of operation and waste disposal activities at ORNL during the past 47 years.

The Intermediate Pond was to serve as a settling basin for radionuclide-contaminated sediments released from ORNL and traveling down White Oak Creek toward White Oak Lake. The bed of the Intermediate Pond covers an area of about 8.3 acres, and the average depth of contaminated sediment is 1.6 ft.[6] The volume of contaminated sediment

in the pond is about 2.1×10^4 yd^3. Seven sediment samples taken at the area have ^{90}Sr (59–680 pCi/g), ^{60}Co (15–460 pCi/g), ^{137}Cs (68–8.1×10^7 pCi/g), and minor amounts of ^{125}Sb (0.0–8.2 pCi/g) and TRU radionuclides.

The estimated area of contaminated sediments deposit above the White Oak Creek and Melton Branch weirs is 0.6 acres. The volume of contaminated sediments in the weirs is 2.9×10^3 yd^3. Loar presented data from common radiological contaminants for the White Oak Creek and Melton Branch weirs.[6] The average concentration of ^{137}Cs, ^{60}Co, and ^{90}Sr was 3.6×10^3, 61.0, 177 pCi/g, respectively, in the White Oak Creek weir; and 50, 1.0×10^3, 17.0 Pci/g, respectively, in the Melton Branch weir.

The current estimated surface area of White Oak Lake is 17 acres.[17] The calculated volume of contaminated sediments in the lake is 5.6×10^4 yd^3. Oakes et al., 1982, estimated the radiological contaminants in the White Oak Lake: 14.6 Ci ^{90}Sr, 152 Ci ^{60}Co, 704 Ci ^{137}Cs, and 1038 Ci ^{106}Ru.[18]

The area of the embayment at the summer pool level is about 8.3 acres. The estimated volume of contaminated sediments in the embayment is 5.2×10^3 yd^3. The estimated inventory of radionuclides was 6.6 Ci ^{137}Cs and 0.06 Ci ^{60}Co with small amounts of ^{90}Sr, ^{241}Am, ^{244}Cm, $^{238,240}Pu$, and $^{234,235,238}U$.[19]

Contaminated soils in the floodplain occupied an area of ~ 40 acres. The estimated volume of contaminated soil in the area is 6.3×10^4 yd^3. Average activities of ^{137}Cs was 3×10^3 pCi/g.

The estimated total volume of contaminated sediments and floodplain soils is 1.5×10^5 yd^3. The weight of the total sediment and soils is 3.3×10^8 lb. Inventory of sediment and soil weight was calculated by assuming a bulk density of 1.3 g/cm^3.

1.4.8 Ground Water/Surface Water

This problem area includes all ground water and surface water within ORNL. Ground water includes the freshwater aquifer and deeper-saline aquifer systems for Bethel and Melton valleys. Surface water includes White Oak Creek and Melton Branch and their tributaries, White Oak Lake, and the embayment. Ground-water seeps, surface and subsurface storm flow, and water in the unsaturated zone are also included in this problem area.

Three WAGs are located within Bethel Valley: WAGs 1, 3, and 17; Melton Valley encloses WAGs 4, 5, 6, 7, 8, 9, and 10. WAG 2 surface water lies in both Bethel and Melton Valleys.

In addition to natural drainage, White Oak Creek has received treated and untreated effluents and reactor-cooling water from ORNL activities since 1943. Controlled releases include those from the Nonradioactive Wastewater Treatment Facility, the Sewage Treatment Plant, and a variety of process-waste holding ponds throughout the main plant area. It also receives ground-water discharge and surface drainage from WAGs 3, 4, 5, 6, 7, 8, 9, and 17. Major contaminants in White Oak Creek are ^{90}Sr, ^{60}Co, ^{137}Cs, ^{3}H, and metals (e.g., mercury, zinc, and chromium).

White Oak Lake is a surface impoundment for radioactive and other hazardous wastes that drain ORNL via the White Oak Creek watershed. It also serves as a final settling basin for wastes released from ORNL operations and waste storage areas.

Ground water and surface water are contaminated from contact and leaching with subsurface wastes. The types and concentrations of contaminants vary; a summary list of contaminants is presented in Table 1.1.

The limited interaction between the freshwater/saline water interface is evidenced by the chemical ($CaCo_3$, $NaHCO_3$, and NaCl) stratification with depth. Additional

confirmation of limited interaction is the variation of tritium concentration with depth. Preliminary data shows that tritium is confined primarily to the shallow system.

1.4.9 Priorities

Priorities for remediating the site problem areas discussed in the preceding sections are presented in Table 1.5. The priorities were assigned on the basis of the potential for releases of contaminants to the environment. For the tanks soils/sediment, and ground water/surface water problem areas, two priorities were assigned to account for differences in the potential for release within a specific problem area.

Table 1.5. Remedial action site problem priorities

Site Problem	Priority[a]	Comments
Buried waste	5	Primary source of releases
Pits and trenches	3	Releases already happened, contaminants locked up
Low-level waste tanks		
Gunite	5	Structural integrity questionable
Steel	3	Smaller volume/tanks intact
Soils and sediments		
Sediments	4	Moving off site
Soils	2	Remain in place
Ground water/surface water		
Seeps	5	Hot spots identified
Balance	2	
Buried pipelines	1	Not mobile or a major pathway
Impoundments	4	Some leaking contaminants
Hydrofracture Grout sheets/ injection wells	1	Migration not an issue

[a]Highest priority designated by "5"

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1.5.1 Introduction

The *Strategic Roadmap for the Oak Ridge Reservation* is a generalized planning document that identifies broad categories of issues that keep ORNL outside full compliance with the law and other legally binding agreements.[20] The *Strategic Roadmap for the Oak Ridge Reservation* identifies possible generic paths to compliance, issues, and the schedule for resolution of the issues. The role of the *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) is then to identify specific site issues (problems), identify specific technologies that can be brought to bear on the issues, and assess the current status and readiness of these remediation technologies within the constraints of the schedule commitment.

Regulatory requirements and commitments contained in the *Strategic Roadmap for the Oak Ridge Reservation* are also included in the TLD as constraints to the application of immature technological solutions. Some otherwise attractive technological solutions may not be employed because they may not be deployable on the schedule enumerated in the regulatory agreements. Conversely, negotiators in the process of defining regulatory agreements may fruitfully take cognizance of the TLD assessments in order to schedule remediation milestones that allow the use of cheaper, faster, better, or safer technologies.

The roadmap for ORNL includes a list of comprehensive logic diagrams for RA of low-level, radioactive-mixed, hazardous, sanitary and industrial, and TRU wastes at the ORNL WAGs. The roadmapping process gives comparisons of the installation as it exists to the way the installation should exist under full compliance. The goal of roadmapping allows accurate and timely formulation of activities. The following information is excerpted from the *Strategic Roadmap for the Oak Ridge Reservation*.[20]

1.5.2 Roadmapping Methodology

The roadmapping methodology is divided into nine steps and covers three phases—assessment, analysis, and issue resolution.

The assessment phase identifies the current status and background of the installation. This phase is accomplished in four steps: (1) identifying installation assumptions that provide for the conduct of environmental management (EM) activities; (2) identifying regulations and codes at federal, state, and local levels, DOE orders, and other agreements that DOE is responsible to comply with; (3) describing those DOE commitments, which include Inter-Agency Agreements and FFAs; and (4) preparing a schedule that includes all commitments with all currently budgeted and forecasted activities.

The analysis phase identifies key issues and actions needed for resolution. This phase is accomplished in four steps: (1) identifying issues that prevent the installation from accomplishing EM objectives; (2) analyzing issues to determine the root causes; (3) converting issues to needs for the resolution of issues and the identification of activities that satisfy those needs; and (4) preparing the schedule for the desired activities.

The issue-resolution phase merges the issue-resolution activities with ongoing and planned activities as the ninth and final step. Specific recommendations for modifications, additions, or deletions to current plans are formulated and captured in Activity Data Sheets or are forwarded to DOE Headquarters for resolution.

A "Revised Roadmap Methodology Document" was issued in May 1993.

000221

1.6 ORNL RA STRATEGY

The ORNL ER program addresses environmental contamination problems at ORNL consistent with the *Oak Ridge Reservation Site Management Plan for the Environmental Restoration Program.*[21] The plan identifies approaches to meet the requirements of the FFA for the ORR. The approach promotes early remedy selections, flexibility for RA, and contingencies to react to new information discovered during investigations and is based on the following premises:

1. Operable units (OUs) consisting of remediation unit groupings have been initially identified for ORR. These OUs will proceed through the formal CERCLA process encompassing investigation field activities, the selection of the appropriate RAs, design and construction, and unit-monitoring activities. During the performance of the remedial investigation phase, the initial OUs may be further subdivided into additional OUs or combined to best expedite the identification and implementation of the remediation alternatives.
2. Removal actions will be undertaken to protect human health and the environment from an imminent threat in the short term (i.e., the planning period prior to initiation of action is less than 6 months). Interim RAs may also be taken to stabilize a site, prevent further degradation, or achieve significant risk reduction quickly [i.e., while the remedial investigation/feasibility study to support interim or final remedy selection is under way].
3. Unit characterization will be planned on the basis of optimizing field sampling and maximizing use of available data. In cases where sufficient historical data exist to support or eliminate potential remedies, these data on the OUs will be used to converge early on RAs based on probable unit conditions. Measures will be implemented to effectively manage the uncertainties where the unit has not been fully characterized.
4. A preliminary assessment/site inspection will be performed on units newly discovered or not already included in one of the existing OUs. Following the preliminary assessment/site inspection, these units will be classified as requiring no further investigation, requiring immediate action to stabilize the area and provide controlled access, or requiring further investigation (remedial investigation/feasibility study). Units requiring further investigation may be added to an existing OU or combined with other units to create a new OU.
5. Remediation of many ORR waste sites poses challenges unlike those encountered in cleanup of typical Superfund sites. For example, many of the sites have radioactive as well as hazardous contamination, which limits the commercially available treatment methods used at other Superfund sites. Excavating and treating some radioactive wastes may pose unacceptable risk, leading to the frequent use of consolidation and containment remedies. Thus, final remediation schedules will most likely be longer than those encountered at other Superfund sites and involve interim actions to reduce the risk to human health and the environment until the final remediation.

The current RA strategy at ORNL is oriented toward WAGs, which are consistent with OUs. The activities for each of these WAGs provide for

- a remedial investigation/feasibility study,
- interim corrective measures or removal actions, Record of Decision/Interim Record of Decision, and
- final site remediation for the WAG.

The remedial investigation/feasibility study process represents the methodology for characterizing the nature and extent of risks posed by WAGs and for evaluating potential remedial options. This approach is a dynamic, flexible process tailored to the specific circumstances of each of the WAGs. Due to the uncertainties inherent with each of the WAGs (e.g., site hydrogeology, extent of contamination), an "observational approach" workshop was conducted for each WAG. The observation approach workshop is a technique for recognizing and managing uncertainty and includes

- obtaining WAG data sufficiency rather than data completeness;
- focusing characterization efforts to support or eliminate potential remedies;
- converging early on RA alternative(s) based on probable conditions;
- identifying reasonable deviations from the RA alternative(s);
- preparing contingency plans; and
- monitoring the effectiveness of the RAs to protect the human health and environment.

Scoping is the initial-planning phase of the remedial investigation process, and begins with the collection of existing site data. Typical scoping activities include

- review and analysis of existing data for each of the WAGs;
- determining the RA objectives and identifying the data and other information needed to support those objectives;
- preparing the work plan, the sampling and analysis plan, and other project documentation; and
- determining overall project management strategy with the governmental agencies (e.g., EPA, TDEC, and DOE).

A scoping meeting will be held with the regulators prior to initiation of the remedial investigation to agree upon the sampling and analysis plan.

Site characterization activities are then initiated soon after, including field sampling and analysis. This data will be used to

- characterize the WAG,
- prepare a risk assessment that identifies the existing or potential risk posed to human health and the environment, and
- evaluate potential RA alternatives.

These alternatives are developed to address the contaminated medium (e.g., ground water), a specific area of the site (e.g., a waste lagoon or hot spot), or the entire WAG.

After the RA alternatives have been developed and assessed, the feasibility study and associated NEPA documentation will be prepared. During the feasibility study, the development of remedial alternatives are more fully analyzed and screened. The screening

process is based on the short- and long-term aspects of three broad criteria: effectiveness, implementability, and cost. The Proposed Remedial Action Plan and the Record of Decision are also prepared during the feasibility study.

Due to the size and complexity of these WAGs, they may be divided into OUs at the completion of the initial site characterization. Each OU will move through a remedial investigation (if required), a feasibility study, Record of Decision, and remediation as separate units. Coordination between OUs will be maintained at the WAG level so that remediation strategies for OUs will be compatible with remediation objectives for the WAG as a whole.

Prior to completion of final site remediation interim corrective measures or removal actions will be conducted if required to protect human health and the environment. Contamination resulting from releases of hazardous constituents from contaminated sites in the WAGs will be contained, removed, or treated.

Final site remediation activities for a WAG, if required, will include

- preliminary engineering,
- remedial design,
- RA,
- verification,
- long-term monitoring, and
- operation and maintenance.

1.6.1 Status of RA Activities at ORNL

ER activities for inactive contaminated sites at ORNL were initiated in 1985 under the auspices of the Remedial Action Program.[4] As determined by the EPA, the regulatory driver for the RA Program was RCRA. RCRA requires implementation of (1) a compliance monitoring program, (2) a corrective action program, or (3) a detection monitoring as appropriate [40 Code of Federal Regulations (CFR), Part 264, Subpart F]. Consequently, the RA Program developed an approach that was consistent with RCRA yet reflected the uniqueness of the problems and physical setting of ORNL.

Initially, the RA Program established a strategy that was consistent with the various federal and state laws and regulations and DOE orders relevant to the remediation of contaminated sites at ORNL.[4] Activities were initiated with a RCRA Facilities Assessment for ORNL followed by the development of the remedial feasibility investigation or the remedial investigation plan for each WAG established at ORNL. By 1989, most of the remedial feasibility investigations or the remedial investigation plans had been completed and submitted to EPA for approval. The remedial investigation Plans for WAGs 11 and 13 were completed and submitted to EPA in December 1990.

Subsequent activities affected the RA Program. First, DOE established a national ER Program, which was mirrored by Energy Systems' establishment of a centralized ER Program and the concurrent creation of an ORNL ER Program. The ORNL ER Program replaced the ORNL RA Program. The second activity was the establishment of an FFA between DOE, EPA, and TDEC effective January 1, 1992. This document formalized a procedural framework for developing, implementing, and monitoring appropriate response actions in accordance with CERCLA, the National Contingency Plan,[5] RCRA, the NEPA, Tennessee State law, and appropriate guidance and policy. The framework for response actions at contaminated sites incorporates a range of potential activities identified in Section 1.5. Also, the FFA contains specific requirements for the low-level radioactive tank systems at ORNL.

A remedial investigation was performed for WAG 1 following EPA guidance developed to meet the requirements of CERCLA. Phase I field activities were initiated in December 1989 and three reports (Site Characterization Summary Report, Preliminary Risk Assessment Report, and Operable Unit Strategy Document) were submitted to EPA and TDEC for review and comment in September 1992.[22] Based on these documents, a number of OUs have been identified, including the Gunite and associated tanks OU, the surface impoundment OU and the shallow ground water OU. Remedial alternatives will be developed for the Gunite and associated tanks OU and the surface impoundments OU. Because of their high priority, appropriate technologies are needed to address the current problems associated with these two OUs.

WAG 2, composed of White Oak Creek and its tributaries and associated floodplains, acts as a conduit for contaminants from up-gradient WAGs. Consequently, the WAG 2 Remedial Investigation Plan[6] was developed and approval by EPA and TDEC that is based on short-term monitoring activities, followed by final remediation after the up-gradient areas or WAGs have been remediated. The objectives for the short term are as follows:

1. preliminary surveys and sampling to determine hot spots (discrete areas of significant contamination that may need interim corrective measures to protect the public or environment), identify areas where additional data are needed, fill data gaps for the first round of risk assessment, and clearly delineate the boundary of WAG 2; and
2. implementation of a multimedia environmental monitoring and characterization program to (a) define and monitor the input of contaminants from adjacent WAGs, (b) characterize the hydrology of the White Oak Creek system and support a mass-balance approach to determining sources, sinks and transport of contaminants in WAG 2, and (c) establish the basis for determining long-term trends in contaminant levels.

Long-term objectives of the WAG 2 remedial investigation include

1. definition of the nature and extent of contamination in WAG 2,
2. quantification of any risk to human health and the environment resulting from the contamination, and
3. preliminary evaluations of potential corrective measures and RA alternatives for the OUs in WAG 2.

A remedial feasibility investigation was implemented for WAG 6 to meet the RCRA Corrective Action Program schedule agreed upon by DOE, EPA, and TDEC for the remediation of WAG 6.[7] The schedule called for completion of the remedial feasibility investigation by September 1991 and closure and final remediation of WAG 6 by 1997. Field activities for the remedial feasibility investigation commenced in December 1988 and were completed during the summer of 1990. The remedial feasibility investigation report was submitted for regulator review in September, 1991. Subsequently, a feasibility study/environmental assessment was prepared and accepted by EPA and TDEC. During a public hearing on the proposed remediation, strong objections were received related to the cost and temporary nature of the action. As a result, remedial activities have been delayed and a monitoring plan is being developed to monitor contaminant discharges in ground water from the WAG. Additionally, the development of technologies needed to address the remediation of buried wastes in WAG 6 have been expedited.

Except for the initial remedial investigation plan completed in 1988, ER remediation activities have not been scheduled for WAG 7. A technology demonstration of in situ

vitrification (ISV) is planned for a part of Pit 1 and a Treatability Study Work Plan is being prepared for submittal to EPA and TDEC.

The initial Remedial Investigation Implementation Plan for the WAG 10 remedial investigation was prepared in March 1990. The Sampling and Analysis Plan component of the Remedial Investigation Implementation Plan was revised based on regulatory review comments and resubmitted to EPA and TDEC in June 1992. Responses to regulatory comments on the revised Sampling and Analysis Plan were prepared and submitted in June 1993. The near term objective for the WAG 10 remedial investigation involves characterization of existing hydrofracture wells and bore holes. Information collected through this characterization work will be used to develop plugging and abandonment techniques for the various WAG 10 wells and bore holes.

A Remedial Investigation Work Plan was completed and submitted to EPA and TDEC for approval in 1990 for WAG 11. An interim RA has been implemented to collect, segregate, containerize, and remove the contaminated surface debris from the WAG. This action will be finalized with the issuance of a postconstruction report. At some time in the future, the remedial investigation leading to the final RA for the site will be initiated.

The Remedial Investigation Work Plan for WAG 13 was completed and submitted to EPA and TDEC in 1990. This WAG includes 13 cesium treatment plots used to simulate nuclear weapons fallout and four of the plots have been determined to emit elevated levels of gamma radiation, which poses a potential threat to human health and the environment. Consequently, an interim RA is being initiated to excavate cesium-contaminated soil and transport it to WAG 6. The final remediation of WAG 13 will be implemented at some time in the future.

1.6.2 Summary of Major Committed Milestones

ER milestones are negotiated annually with the regulators based upon DOE funding and priority considerations. These milestones reflect activities initiated in the past and support activities planned for the long-term. Major negotiated milestones for fiscal years 1994 and 1995 are shown in Table 1.6. Milestones are identified by site OUs and include monitoring plans, remedial investigation/feasibility study reports, designs, and postconstruction reports. The relationship between these milestones and remedial activities at the WAGs are discussed in Sect. 1.6.1.

Table 1.6. Fiscal year milestones negotiated with TDEC[a] and EPA[b] through FFA[c]

Site/OU[d]	Deliverable	Date
	1994	
WAG[e] 1	RI/FS[f] Gunite and associated tanks OU	05/02/94
	Shallow GW[g] Monitoring Plan (RIWP[h] Addendum)	TBD
WAG 2	Annual monitoring (ERMA[i] Report)	09/30/94
	Site Sampling and Analysis Plan (Addendum)	09/30/94
WAG 6	Monitoring plan	TBD
WAG 7	Treatability study	TBD
WAG 11	Postconstruction report	05/31/94
WAG 13	Postconstruction report	02/28/94
Ground water	RI work plan	01/30/94
Active LLLW[j] tanks	Secondary containment design cat. B	03/31/94
	Status report	09/30/94
	1995	
WAG 1	Proposed plan Gunite and associated tanks OU	04/19/95
	RI/FS surface impoundments OU	02/11/95
WAG 2	Annual monitoring (ERMA Report)	09/30/95
	Site Sampling and Analysis Plan (Addendum)	09/30/95
WAG 5	RI report	03/31/95
	Feasibility study	09/27/95
WAG 6	Annual monitoring report	06/30/95
		09/30/95
Active LLLW Tanks	Struct. integ. assess. cat. C tanks	09/30/95
	Struct. integ. assess. cat. C pipelines	09/30/95
	Status report	09/30/95

[a] TDEC = Tennessee Department of Environment and Conservation
[b] EPA = U.S. Environmental Protection Agency
[c] FFA = Federal Facilities Agreement
[d] OU = operable unit
[e] WAG = waste area grouping
[f] RI/FS = remedial investigation/feasibility study
[g] GW = ground water
[h] RIWP = remedial investigation work plan
[i] ERMA = environmental restoration monitoring and assessment
[j] LLLW = liquid low-level waste

000227

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000228

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2. Description of the Technology Logic Diagram

2. DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM

- 7751

2.1 PURPOSE AND SCOPE

The purpose of the TLD is to provide a planning document for DOE, DOE operating contractors, and private industry that relates the Environmental Restoration/Waste Management (ER/WM) problems at ORNL to the technologies that can be used to remediate these problems. In doing so, the status of each potential remediation technology is evaluated. This is a significant focus of the diagram preparation.

Several important aspects impacting implementation of each technology are folded into the evaluation so that the appropriateness of each technology can be evaluated:

1. Potential efficacy of the technology—how successful will its application be to the site problem?
2. Level of maturity of the technology—when can it be applied to site problems?
3. Level of WM required for the technology—what wastes are generated as a result of the use of the technology?

The TLD addresses the enforceable compliance and cleanup agreements that have designated timetables for ameliorating the specific site problems. For potentially attractive but immature technologies, or those for which improvement paths (which make them faster, better, safer, and cheaper) are visualized, priorities are assigned to technology development activities.

Because of enforceable compliance agreements, DOE is bound by Executive Order 12088, which requires the Secretary of the Department of Energy to submit a plan and request sufficient funding each year to comply with federal pollution control standards. This document will aid in the annual planning and budget submittals.

This document will address all RA problems that have been identified at ORNL. The technology listings in the diagrams were judged to have some reasonable prospect for application at ORNL. In a few cases the prospects are limited, however.

The K-25 Site TLD has been used whenever possible.

000231

2.2 STAFFING FOR THE TLD

The formulation of the ORNL TLD was led by the same teams that formulated and published the *Oak Ridge K-25 Site Technology Logic Diagram*,[1] with participation from across ORR. Although a number of ORNL personnel were involved, about half of the team was selected from other Energy Systems organizations in Oak Ridge, such as the K-25 Site, the Y-12 Plant, Central Engineering, and other DOE contractors. The personnel from these organizations represent input from personnel associated with programs under the DOE Deputy Assistant Secretaries of Waste Management (EM-30), Environmental Restoration (EM-40), and Technology Development (EM-50), as well as professionals not associated with these programs. Figure 2.1 shows a staffing plan for the ORNL TLD Team.

Specialists worked as members of each team formed for the *subelement* categories. Representatives from each team served on a coordinating committee, which functioned as a common communication forum for the TLD. More than 100 specialists were involved in this effort. The teams (1) compiled the site problems in terms that were applicable to each team; (2) identified and evaluated technologies that could be applied to remediate the problems; (3) furnished, through the technology evaluation, information on the opportunities that were evident for development and improvement in each technology; and (4) furnished the requirements for deployment of these developed and improved technologies.

Technology evaluation was a significant component of the TLD effort. Team members identified potential technologies, but it was not necessary for the technology evaluation experts to become familiar with the concepts of the TLD before their evaluations. The data sheets allowed the evaluations to be performed on a systematic basis. The data sheets (Vol. 3, Pts. A, B, and C) provide detailed information and the basis upon which the diagram (Vol. 2, Pts. A, B, and C) was devised.

The TLD provides several benefits to the DOE community. The diagram identifies technologies that can be used for EM programs. It serves as a vehicle to identify the deficiencies in technologies that otherwise have potential to (1) foster faster remediation; (2) allow safer project activities; (3) result in better remediation efforts; and (4) allow these projects to be accomplished at a lower cost to DOE and the United States. Improving existing technologies, demonstrating the applicability of promising technologies, developing immature technologies, and supporting fundamental technology investigations are options that DOE can pursue to deploy technologies necessary for successful EM of DOE facilities. The diagram will highlight areas for private industry and university involvement in EM.

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Fig. 2.1. The ORNL Technology Logic Diagram Team.

2.3 TECHNICAL APPROACH

This section describes the overall layout and development of the TLD. The logical progression flows from (DOE) EM Goal → EM Problem → ORNL Problem → Problem Area (Target Constituent) → Reference Requirements → Subelement → Alternative (Generic Technology) → Technology → Technology Status → Science/Technology Need → Implementation Need.

Three different levels of information are provided. First, the technologies are evaluated and ranked in Vol. 1, Pts. A, B, and C. Second, more detailed diagrams are provided in Vol. 2, Pts. A, B, and C. Although each large sheet contains the entire logic path, several sheets are necessary to describe each evaluation area. Finally, each single logic path is published as a technology data sheet. These sheets are the most detailed source of information about each technology and are provided in Vol. 3, Pts. A, B, and C.

The information found under each logic element is described below.

EM Goal has three components: clean up legacy waste, prevent future insult, and develop environmental stewardship. These problems are shared by all elements of the DOE complex to varying extents.

EM Problem contains problem areas agreed upon by EM/DOE such as decommissioning of facilities; cleanup of soils, ground water, and surface water (RA); and WM from inception to final disposition.

ORNL Problem describes the problem areas identified at ORNL. These problem areas have been defined by D&D, ER and WM staff. The magnitudes of the site problems will be indicated in terms of floor areas, estimated metal tonnages, etc.

Problem Area/Constituent addresses a subelement-specific (see below) list of problems, all of which are traceable directly to the ORNL problems.

Reference Requirements refers the reader to the final chapters of Vol. 1, Pts. A, B, and C. Requirements can only be determined after consideration of detailed site-, waste-, and technology-specific characteristics.

Subelement specifies the different components that must be addressed to solve the problem. All D&D activities have been categorized into the following subelement groups: characterization; decontamination; dismantlement; robotics/automation; materials disposition; and regulatory compliance.[2] The subelements for RA are characterization; treatment and fixation; retrieval; robotics/automation; materials disposition; and regulatory compliance. The subelements for WM are waste retrieval; characterization; processing; stabilization; minimization; packaging, handling, and transportation; disposal; and regulatory compliance. Table 2.1 lists these various subelements for D&D, RA, and WM.

Alternative defines the general technology approaches that may be applied to the problem.

Technology identifies specific technologies that may be applied to remediate the problem.

000234

Table 2.1. Subelement categories in the Technology Logic Diagram

Area of environmental management	Subelements (or "Universe" of Activities)					
Decontamination and decommissioning	Characterization	Decontamination	Dismantlement	Robotics/ automation	Materials disposition	Regulatory compliance
Remedial action	Characterization	1. Treatment 2. Fixation	Retrieval	Robotics/ automation	Materials disposition	Regulatory compliance
Waste management	Characterization	1. Processing 2. Stabilization 3. Minimization	1. Transportation 2. Retrieval 3. Disposal	Robotics/ automation	Materials disposition	Regulatory compliance
	Crosscutting			Crosscutting	Crosscutting	Crosscutting

000235

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Status provides information on the status of the technologies identified in the previous column using the standard categories.

Some accepted technologies are *fully developed* or *commercially available* and if so are noted. These terms are used to denote slightly different meanings. *Fully developed* means that both the basis of the technology and the methods for designing remediation equipment or operations using the method are well known and covered in public literature. *Commercially available* means that the technology is offered by one or more commercial firms, but the data, design methods, or experience needed to assess the technology are not fully available to the public. The only difference in these two categories is that the public's ability to assess the performance and reliability of the technology is restricted for commercial technology. It suggests an unknown degree of risk in the commercially available technologies that cannot be fully evaluated with generally available information (even though the amount of risk may be negligible).

- *In Use*—technology is presently being used to remediate the identified problem.
- *Accepted*—demonstrated technology exists for use at ORNL and is accepted by site personnel.
- *Demonstration*—technology is available but is not demonstrated and/or accepted for the problem at ORNL.
- *Predemonstration*—technology is under laboratory-, bench-, or pilot-scale testing.
- *Evolving Technology*—technology status is at a conceptual or preconceptual stage.
  - *Conceptual*—a scientific or knowledge basis for the technology exists.
  - *Preconceptual*—only a partial scientific or knowledge basis of the technology exists.

These classifications should provide indirect, relevant information on the present view of the short-term or long-term availability of technologies.

Several different areas are specifically addressed to further clarify the status designations chosen above.

- *Efficacy*—the effectiveness of the technology in remediating the problem is addressed. Normally, quantitative measures are given for the technology's performance in standard practice, such as, estimating the final dpm/cm^2 of surface contamination for a decontamination technology; the time to cut a 24-in. pipe for a dismantlement technology; the analysis time and lower detection limit for a characterization technology.
- *Waste*—output from the technology. This describes the nature and volume of both the waste and the potentially useful materials.

Science and Technology Needs are perceived needs, where support or development is needed for an immature technology. Science and technology needs are related to the fundamental understanding of the scientific phenomena that form the basis for the technology. These needs are typically for laboratory or bench-scale experiments. Technology development needs identify areas where work is necessary to successfully implement scientific principles that will lead to a technology. Technology improvement needs suggest improvements that will make a current technology more economical to apply, safer, and more effective or efficient. The demonstration of a technology on a site-specific problem is classified as a technology improvement need.

If scientific needs are specified, it should be understood that the needs of scientific technology development or improvement are necessary to implement newly developed

scientific understanding. Likewise, testing a technology development opportunity implies that technology improvements are also likely to be needed.

DOE funding for a project that addresses the technology deficits is indicated by a Technical Task Plan (TTP) number, Activity Data Sheet number, or other reference number. Other work related to the technology area may also be referenced.

Most new technologies that are not in common use will require a large-scale test or demonstration to show that they are capable of achieving expected results on the site-specific problem. These tests demonstrate that a suitable and workable process or facility can be designed, built, and operated successfully. They show that no unknown condition prevents the process or facility from functioning as it was designed and that the equipment can last an acceptable lifetime. Demonstrations are intended to provide final tests of all aspects of a technology. If, however, particular questions remain about the technology, these are specifically mentioned on the diagram.

Implementation Needs or specialized needs were evaluated for both development of a technology and deployment of a mature technology. These needs were evaluated in the areas of (1) resources, such as financial or personnel; (2) hardware, such as process equipment, development equipment, and computers; (3) software, such as models, procedures, computer programs; (4) facilities, such as labs, shops, and buildings; and (5) education, such as training classes or degreed personnel. An estimate of the cost of the process and any potential cost payback are also given. Only extraordinary needs are highlighted (i.e., those needs that would require long lead time or unusual procurements, such as line items for facility construction).

The cost of applying the technology and the payback cost potential has been estimated. There are many reasons for payback, such as reducing the waste volume compared to a reference process, the sale of useable products, and the reduction of labor compared to a reference technology.

When standard laboratory facilities are sufficient, facility needs are not identified. Since the facilities on ORR are relatively extensive—including the K-25 Site, ORNL, and the Y-12 Plant—the diagram does not address needs for standard facilities but focuses on unique facility needs.

However, additional conventional facilities may be needed to meet the technology needs for RA at ORNL because the available facilities may not provide adequate capacity for testing the various technologies. To assess the availability of standard facilities for these programs, it will be necessary to know (1) the rate at which technology development in Oak Ridge will proceed and (2) the extent at which other programs will compete for the facilities.

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Throughout the technology evaluation a method of conveying information about the priority and status of each technology and its application is used to communicate separate information about the following:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low.
- Significance of site problem to which the technology is applied (1-5 is the scale of lowest importance to highest importance).
- Time required to bring the technology to the state of acceptable for application at large scale (commercial or mature state) at the site. This is expressed in number of years and depends on the state of its development.
- The cost for bringing the technology from its present state to acceptable for use commercially or at large scale. The costs are presented as $M or $K, which indicates the number of millions or thousands of dollars without escalation.
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate). This includes annual ranking costs for software.

An example of a ranking follows:

H-5-5 ($3.5M:N)

This means that this technology has a high overall usefulness; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

2.4.1 Overall Assessment

Following are the criteria used to determine the overall assessment of a technology and its application.

- *Waste Generation Reduction*—ability of the technology to minimize additional waste generation (1-no confidence, 5-complete confidence).
- *Compliance with Requirements [Applicable or Relevant and Appropriate Requirements (ARARs)]*—confidence that the technology will comply with applicable, relevant, and appropriate requirements (1-no confidence, 5-complete).
- *Environmental, Safety, and Health (ES&H)*—ability of the technology to meet the requirements of ES&H (1-no confidence, 5-complete).
- *Versatility*—ability of the technology to meet a wide range of requirements and to adapt to changes in requirements (1-no confidence, 5-complete).
- *Complexity*—ability of the technology to be deployed without requirements for extraordinary levels of expertise, training, and oversight (1-very high level of requirements, 5-low level of requirements).
- *Technical Risk*—confidence that the technology will work at the site(s) being evaluated (1- no confidence, 5-complete confidence).

000238

- *Technical Maturity*—readiness of the technology relative to final application at large (commercial) scale (1–very immature idea for research, 5–ready for commercial application).
- *Development Required*—relative amount of time required to bring the technology to commercial application (1–all research, development, and demonstration steps required, 5–now commercial/no tests required).
- *Development Cost*—relative cost of bringing the technology to commercial application (1–highest cost for development of a technology within a technical area, 5–no costs, not even field testing).
- *Process Cost*—relative cost of process in terms of unit production costs in application (1–prohibitively expensive relative to other methods, 5–very inexpensive compared with other methods).

After scoring the criteria, the scores were averaged and the overall assessment rating was determined by the scale in Table 2.2.

Table 2.2. Scale for overall assessment rating

Assessment code	Code meaning	Score	Meaning
E	Essential	Any score	No other processes or technology available for essential requirement
H	High	3.67 to 5	High potential for application
M	Medium	2.33 to <3.67	Medium potential for application
L	Low	<2.33	Low potential for application

2.4.2 Status of Technology

The development state for technology was assessed using the scale provided in Table 2.3.

Table 2.3. Scale for status of technology

State of Technology	Score
Accepted	5
Demonstration needed	4
Predemonstration—evolving	3
Conceptual	2
Preconceptual	1

2.4.3 Estimates for Time to Maturity

Definitions for progress of development and time periods, which were used as guidelines for estimating the total period required to bring technology to the state of large-scale application (state of acceptance), are provided in Table 2.4.

Table 2.4. Definitions for progress of development and time periods

Step in development	Definition of step	Years
	New technology	
Applied research	Work required to define scientific feasibility	1–3
Development	Bench or engineering scale to define scaling of the technology	2–3
Pilot	Integrated test of process or technology at less than full scale	3–4
Prototype demonstration	Integrated demonstration at full scale	3–5
Commercialization or mature application	Application of the technology at large scale	1–2
	Adaptation of existing technology (existing at mature state)	
Synthesis demonstration	Combining existing technologies to meet requirement—demonstrate at pilot scale	2–3
Field test	Testing on the exact site problems and configuration	1–3

These stages of development correspond to the state of the technology and are shown in Table 2.5.

Table 2.5. Correspondence of terms for state of the technology

Status of technology	Score	Development period expressed by time	Development stages
Accepted	5	Available	Mature
Demonstration	4	Short range	Field test
Predemonstration	3	Medium range	Development, pilot, prototype, or synthesis of technology
Evolving—conceptual	2	Long range	Development
Evolving—preconceptual	1	Unknown	Applied research

000240

2.5 REFERENCES

1. *Oak Ridge K-25 Site Technology Logic Diagram*. K-2073, Martin Marietta Energy Systems, Inc., K-25 Site, February 26, 1993.

2. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge National Laboratory, October 29, 1992.

3. Characterization

3. CHARACTERIZATION

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3.1 INTRODUCTION

RA problem areas require several types of characterization to answer the following questions:

1. What contaminants are present?
2. How concentrated are the contaminants?
3. Where are they?
4. How far have they spread?

In some cases, identification of the chemical form of the contaminant is also needed to design treatment schemes. Characterization technologies are used to locate buried wastes and contaminated ground-water seeps and to define contaminant migration boundaries in soils and sediments in burial grounds and outside of tanks, pipelines, buildings, and other structures. It is required to meet regulatory requirements, to permit risk assessment, and to guide remedial treatments. The technologies involve, for the most part, the analysis of soils, sediments, sludges, water, and air in the field and laboratory. The main contaminant groups of concern are radioactive elements, heavy metals, and organic compounds or mixtures of organic compounds (e.g., PCBs or fuels). Pathogenic organisms also are screened.

This chapter presents the characterization technologies required to support RA at ORNL, brief overviews of the science and technology needs to bring the technologies to a useable level, implementation needs to deploy these technologies, and rankings of these technologies for RA.

000243

3.2.1 Characterization Technology Options

Characterization technology options for RA at ORNL are listed in Table 3.1 of Sect. 3.5, along with their rankings. All technologies are not required for each EM problem, and many of the technologies for a given constituent are optional. Many of these technologies are broadly applicable to a variety of constituents and RA problem areas, and they are listed in Vol. 2 under a "general" problem category. This reflects the applicability of a technology to more than one group of constituents (e.g., radioactive elements and metals) and to more than one problem area (e.g., buried waste, soils and sediments, impoundments, and pits and trenches). Under this general heading, the technologies are grouped as the following alternatives: sampling design, sample collection, sample preparation, detection and measurement—field methods, and detection and measurement—laboratory methods. Technologies specific to a group of constituents are then listed in the TLD under a specific alternative: radioactive elements (which includes both specific radionuclides and radioactivity), inorganic constituents (cations, anions, and elemental metals such as mercury), organic constituents, physical characteristics, and pathogens. These constituent-specific technologies are subdivided by their deployment in the field or laboratory. Technologies for in situ and ex situ determinations are included in the field and laboratory classifications. Simple and highly common characterization technologies, such as for pH measurements are omitted for simplicity in this compilation. Following these general listings are specific ORNL problems to which technologies are particularly relevant.

3.2.1.1 Sampling Design

The main technologies needed under this alternative are statistical designs or approaches for planning sample collection. For example, the large number of samples called for by a conventional full-factorial sampling design applied to burial grounds can be reduced to a more manageable number by statistical considerations without sacrificing information value.

3.2.1.2 Sample Collection

Sample collection methods exist for most of the RA problems at ORNL, but many are inadequate or expensive, and technology improvements are needed. Examples are the collection of soils and sediments by EPA methodology for VOCs analysis and the collection of representative samples from liquids and sludges from underground nuclear waste storage tanks. The constraints of handling radioactive materials or working in radioactive fields severely hamper sampling methods. The DOE as low as reasonably achievable (ALARA) principle is the guiding factor for adaptation and development of such technologies. Solid-phase in situ sampling or extraction technologies are an attractive alternative to current methods.

Perhaps the most difficult sample collection problem is the collection of truly representative samples from heterogenous wastes. This would include many of the wastes buried in drums and boxes in the burial grounds. The contents of the former may range from bottles, gloves, wipes, and shoe covers to broken, damaged, or contaminated equipment and apparatus. Technology needs include not only statistical designs for directing the sample collection but also the physical means for obtaining the samples.

3.2.1.3 Sample Preparation

One of the largest technology needs is the adaptation of conventional sample preparation methods to the special requirements of radioactive samples where containment in a radiochemical hood (low activities of alpha, beta, or gamma emitting samples) or glove box (primarily for samples with alpha activities of 10^6 disintegrations per minute and greater) or shielding in a hot cell (generally, samples with beta/gamma radiation fields of 500 mR/h or greater) may be required. This includes upgrading organic and inorganic preparation methods and regulatory leaching procedures. Current methodologies have not been able to meet regulatory requirements in some applications. High-pressure ashing methods are critically needed to prepare samples for inorganic radiochemical analyses.

3.2.1.4 Detection and Measurement—Field Methods

Measurement technologies for field use are needed to define areas and boundaries of contamination or to locate buried waste. They can also screen samples in the field so that only those with appreciable contamination are returned to the laboratory for more extensive and expensive characterization. Field-method technologies are also discussed below under specific contaminant group alternatives. In this alternative, major technology needs are fieldable technologies for locating buried waste by seismic, magnetic, ultrasonic, tomographic, or other methods. Deployment of these measurement technologies with robotics and automation is an important crosscutting area that promises to streamline and reduce costs of such surveys. Please refer to the robotics and automation chapter (Chap. 5) of this volume.

3.2.1.5 Detection and Measurement—Laboratory Methods

Laboratory-based technologies capable of inorganic and organic component determinations are listed in the general alternative, while constituent group-specific technologies are presented under the specific alternatives. A technology need general to laboratory measurements is contamination control of the analytical equipment. This need goes hand-in-hand with adaptation of the sample preparation technologies for radioactive samples.

3.2.1.6 Data Analysis and Management

A wide range of information management and data analysis technologies will be needed, perhaps in some cases required, to support the level of tracking and accounting necessary to assure compliance with environmental laws and guidelines for conduct of activities. Configuration-management support will be needed to meet the demands of working in a highly regulated environment, especially in dealing with hazardous

materials. Decision aids, including simulation models, data bases, full-text information retrieval applications, and expert systems will be needed to assist with planning. Statistical analysis, graphical display, and geographical information system support will be needed to assist with analysis and interpretation of data. Large amounts of information and data will need to be transferred between the various groups of people working on the various aspects of the ER effort. Quick, reliable access to data or information distributed among many different organizations will be needed. All of these areas of support are best taken care of using computer networks. Network-communications support then becomes yet another area of technology that must be included. The demands on project management and support made by environmental legislation, requirements for safe handling and processing of very hazardous materials, and having adequate resources to deal with problems on the large scales that are involved make use of automation and networked computing capabilities essential or highly important.

3.2.1.7 Radioactive Elements—Field Methods

Fieldable technologies are needed to define areas of radiological contamination and to quantify radionuclides or radiation fields. They can reduce the sample load (and thus costs) for laboratory analyses and ensure that only the most important contaminated samples are sent to the laboratory for detailed analysis.

3.2.1.8 Radioactive Elements—Laboratory Methods

A general technology need is the upgrading of radiochemical laboratory procedures and equipment to make them more rapid and efficient and to reduce the generation of secondary laboratory wastes. This is important in view of the greatly increased sample load anticipated from RA programs and the need to minimize costs and wastes. A particularly important technology need is the development and validation of inductively coupled plasma—mass spectrometry (ICP-MS) methods for determining long-lived, low-specific activity radionuclides. Traditional chemical separation and counting methods are labor intensive and require long counting periods to meet sensitivity requirements. ICP-MS can also determine nonradioactive metals.

3.2.1.9 Inorganics—Field Methods

Technologies for determining inorganic composition in the field are needed for the same reasons as described above for fieldable methods for radioactive elements. Promising technologies include X-ray fluorescence, which is especially useful for quickly measuring surface contamination by heavy metals. Glow discharge ionization mass spectroscopy may also be fieldable, with some development work.

3.2.1.10 Inorganics—Laboratory Methods

There are many established, accepted laboratory methods for inorganic analyses. Adapting and upgrading these technologies to meet the special requirements of radioactive samples is required. A particularly useful technology is ICP-MS.

3.2.1.11 Organics—Field Methods

Fieldable methods for organic compounds will be required for numerous deployments in large numbers. The technologies require development to make them more rugged and reliable in the field, simpler to operate so that the technical expertise required to use them is reduced. Fieldable gas chromatography and also immunoassay-based field test kits for selected organic compounds or mixtures such as PCBs are high-priority technologies.

3.2.1.12 Organics—Laboratory Methods

Technologies that determine regulated organic and DOE-unique (e.g., chelators or chelated radionuclides) compounds are required. Improvements that reduce secondary waste generation, increase analytical speed and efficiency, or to address DOE-unique compounds (e.g., chelators) are needed. Supercritical fluid extraction as a virtually waste-free sample preparation method and liquid chromatography-mass-spectrometry for nonvolatile analytes are examples of technologies whose development and deployment would greatly support site remediation.

3.2.1.13 Physical—Field Methods

Technologies for locating contaminated ground-water seeps and determining ground-water flows and directions are needed.

3.2.1.14 Physical—Laboratory Methods

Characterization of particles and other materials is a small technology need.

3.2.1.15 Pathogens—Laboratory Methods

Remediation of biological wastes will require surveillance for pathogenic organisms as a part of worker protection as well as waste treatment.

3.2.2 Crosscutting Technologies

An important area of technology crosscutting is robotics and automation. This is particularly relevant in three areas of characterization: sample collection in situations too hazardous or remote for direct human participation (as during the retrieval and sampling of highly radioactive buried wastes), preparation of highly radioactive samples for analysis (as for nuclear wastes), and robotic automation of measurements (as in radiation surveys of large areas such as burial grounds). These crosscutting technologies are discussed in Chap. 5 of this volume.

3.3 SCIENCE AND TECHNOLOGY NEEDS

The basic R&D needs for characterization technologies range from none to considerable. Many characterization technologies are already mature and available on site. Examples of such technologies are gas chromatography-mass spectrometry for identification and quantification of regulated organic compounds and inductively coupled plasma-emission spectroscopy for metals. Some technologies may require some development work, such as the determination of extractants or chelators by derivatization-gas chromatography.

Other technologies will require basic R&D. The specific needs are explained in the data sheets that are included in Vol. 3, Pt. A. For example, basic advances in technology are needed for sampling heterogeneous wastes, both in sampling strategy as well as in the physical method and equipment used to take the representative sample(s).

3.4 IMPLEMENTATION NEEDS

Implementation needs, like science and technology needs, range from none to considerable. Instruments and protocols already exist for the determination of many regulated organics and inorganics using EPA protocols. These technologies have essentially no implementation needs and are ready as is for samples that can be handled in nonzoned laboratories. Other mature technologies are available on site, but some work is needed to deploy them. This work may entail calibration for the specific constituents and/or sample matrices or adaptation for deployment in certain locations, such as fieldable-gas chromatography or radiation sensors. Performance validation of field and laboratory analytical technologies is a part of the technology quality assurance and is included in the implementation costs. Other technologies are not available on site and will require greater effort to obtain them and implement them at ORNL.

Some facility upgrades at ORNL are also required to handle the anticipated sample load. This is particularly true for radioactive samples and mixed wastes that require shielding or containment and for which current facilities are inadequate.

3.5 TECHNOLOGY RANKINGS

The rankings assigned to the characterization technologies for RA at ORNL are included in the last column of Table 3.1. The ranking system is essentially the same as that explained in Sect. 2.3 of Chap. 2 in this volume.

Table 3.1. Rankings of characterization technologies for remedial action

Alternative	Data sheet code numbers	Technology	Ranking[a]
General applicability to all remedial action problems			
Sampling design	CHAR-252-OL	Sequential sampling plans	M-3-.5 ($.1M;$0.5Kam[b])
	CHAR-71-OL	Optimization of sampling designs	H-5-.5 ($.1M;N)
	CHAR-228-OL	Sampling program configuration management system	E-5-1 ($0.5M;$50Kam)
Sampling collection	CHAR-270-OL	Sampling of heterogeneous wastes	H-5-3 ($2.8M;N)
	CHAR-210-OL	In situ solid phase microextraction of organics	H-5-1 ($.25M;$200)
	CHAR-81-OL	Sampling and mixing methods	E-5-1 ($.25M;N)
	CHAR-256-OL	Soil/sediment sampling for volatile organics analysis	H-4-1 ($.1M;$50)
	CHAR-257-OL	Sampling underground storage tanks for volatile organics	H-5-1 ($.26M;$500)
	CHAR-254-OL	Solid sorbent sampling for airborne organics	H-5-1 ($.2M;$50)
	CHAR-55-OL	Membranes for sample collection and concentration	M-5-1 ($.25M;$50)
	CHAR-276-OL	Sediment sampling from restricted access locations	M-5-2 ($.45M;N)
	CHAR-64-OL	Multiangle drilling for depth profiling of contaminants	M-4-1 ($.2M;N)
Sample preparation	CHAR-205-OL	Radioactive sample preparation	H-4-1 ($.1M;N)
	CHAR-208-OL	Supercritical fluid extraction of organics	M-5-1 ($.33M;$100)
	CHAR-201-OL	Supercritical fluid extraction of inorganics	M-3-2 ($.2M;N)
	CHAR-209-OL	Adaptation of the EPA[c] toxicity characteristic leaching process for use with radioactive samples	E-5-1 ($.45M;N)
	CHAR-19-OL	Microwave digestion	H-5-1 ($.2M;$100)
	CHAR-67-OL	Metallographic sectioning and preparation	M-4-0 ($0M;<$500)
	CHAR-203-OL	High-pressure ashing for sample preparation	H-4-1 ($1M;N)
Detection/measurement —field methods	CHAR-25-OL	Fiber-optic chemical sensors	H-5-1 ($1M;$10)
	CHAR-264-OL	Ion mobility mass spectrometry	M-5-2 ($1M;$50)

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Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking[a]
Detection/measurement —field methods *(continued)*	CHAR-23-OL	Immunoassay detection	H-5-3 ($1M;$50)
	CHAR-84-OL	Portable Raman spectrometer	M-5-2 ($1M;$10)
	CHAR-27-OL	Optical absorption spectroscopy	H-5-1 ($.6M;$50)
	CHAR-59-OL	Air monitoring	E-5-0 ($.25M;$500)
	CHAR-18-OL	Infrared spectroscopy (wavelength dispersion)	M-5-1 ($.5M;$100)
	CHAR-52-OL	Personnel monitoring	H-5-1 ($.2M;N)
	CHAR-60-OL	Tomographic seismic monitoring	M-5-N (N;N)
	CHAR-123-OL	Ultrasonic ranging and data system	H-5-0 ($0;N)
	CHAR-124-OL	Ground-penetrating radar	H-5-0 ($.03M;N)
	CHAR-125-OL	Electrical and electromagnetic detection of ground and geologic features	H-5-1 ($.2M;N)
	CHAR-126-OL	Seismic methods (refraction, profiling, reflection)	M-5-1 ($.2M;N)
	CHAR-127-OL	Microgravity methods	M-5-1 ($.2M;N)
	CHAR-128-OL	Magnetics	M-5-1 ($.2M;N)
	CHAR-92-OL	Portable luminescence detection	M-5-1 ($.5M;$10)
	CHAR-10-OL	Electrochemical methods	M-4-2 ($.5M;$100)
Detection/measurement —laboratory methods	CHAR-204-OL	Contamination control—analytical equipment	H-5-2 ($.5M;N)
	CHAR-8-OL	Fourier transform infrared spectroscopy	M-5-1 ($.2M;$50–$500)
	CHAR-48-OL	Isotopic dilution mass spectrometry	M-5-0 ($0M;$100–$1000)
	CHAR-11-OL	Nuclear magnetic resonance	M-5-1 ($.2M;$200–$500)
	CHAR-3-OL	Secondary ion mass spectroscopy	H-5-0 ($0M;$400)
	CHAR-9-OL	Ultraviolet/visible spectroscopy	H-5-0 (<$.1M;$50–$200)

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Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking[a]
Detection/measurement —laboratory methods *(continued)*	CHAR-4-OL	Laser ionization mass spectrometry	M-5-0 ($0M;$300-$500)
Data analysis/ management	DISM-151-OL	Project information access services	E-5-1 ($.5M;$100Kam)
	DISM-152-OL	Network architecture with integrated workstations	E-5-1 ($5M;$60Kam)
	DISM-153-OL	Client/server access to standards and regulatory guidelines	E-5-0.5 ($.25M;$25Kam)
	DISM-154-OL	Data access services	E-5-1 ($.5M;$200Kam)
	DISM-181-OL	Geographic information system for DOE sites	E-5-1 ($1M;$200Kam)
	DISM-155-OL	Automated scanning and conversion of engineering drawings	E-5-2 ($2M;$300Kam)
	CHAR-233-OL	Hazard analysis expert system	E-5-2 ($.5M;$150Kam)
	CHAR-234-OL	Application of approximate reasoning to data analysis/evaluation	E 5-2 ($.5M;$150Kam)
	DISM-171-OL	Simulated walk-through facility for robotics task sequence analysis	E-5-1 ($.3M;$60Kam)
	DISM-191-OL	Computer-based training systems	E-5-1 ($.3M;$100Kam)
	DISM-172-OL	Computer-aided task analysis and procedure preparation	E-5-1 ($.5M;$150Kam)
	DISM-157-OL	Client/server/architecture for data base access	E-5-1 ($.5M;$200Kam)
	DISM-158-OL	Hypertext information systems	E-5-1 ($.3M;$150Kam)
	CHAR-253-OL	Spatial sample and data analysis plans	H-3-.5 ($.1M;$.5Kam)
	CHAR-251-OL	Statistical methods for the analysis of large data sets	M-3-3 ($.5M;$.5Kam)
	CHAR-250-OL	Quality control for measurement processes	E-4-.25 ($.05M;$.5Kam)
	CHAR-249-OL	Analysis of censored data	H-4-.25 ($.05M;$.5Kam)
	CHAR-44-OL	Criticality indices	L-2-1 ($.25M;N)
	CHAR-53-OL	Modeling of volatile organic compounds migration in porous materials	M-4-1 ($.2M;N)
	CHAR-241-OL	Task scheduling aids	E-5-1 ($.5M;$80Kam)

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Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking[a]
Data analysis/ management	CHAR-222-OL	Multisensor fusion measurement systems	H-3-1 ($.5M;$.25/ measurement)
	CHAR-223-OL	Detection and measurement systems with feature extraction	M-4-2 ($1M;$1/image scanned
	CHAR-225-OL	Fractals used to select models for material transport in porous media	M-2-2 ($.5M;$20Kam)
	CHAR-229-OL	Configuration management system	E-5-1 ($.5M;$50Kam)
	CHAR-242-OL	Stored material neural net identification system	E-5-2 ($1M;$100/ container analyzed)
	CHAR-45-OL	Subsurface complexation model	
	CHAR-255-OL	Dynamic modeling of material transport	H-5-2 ($.3M;$10Kam)
	DISM-159-OL	Electronic catalog descriptions and source locations of site historical data	E-5-2 ($2M;$150Kam)
Radioactive elements—field methods	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 ($.1M;$100)
	CHAR-102-OL	Passive monitors for weak beta radionuclides	M-4-2 ($.6M;$20)
	CHAR-103-OL	Thermoluminescence dosimeter array for spatial characterization of alpha contamination	M-4-3 ($.6M;$20)
	CHAR-65-OL	Long-range alpha detector	M-4-1 ($.4M;$100)
	CHAR-216-OL	Bubble dosimeters for neutron flux	M-4-1 ($.2M;$15)
	CHAR-269-OL	Advanced radiation monitors	M-4-2 ($.4M;$50)
	CHAR-95-OL	Electret passive surface alpha monitor	H-4-1 ($.3M;$15)
	CHAR-96-OL	Alpha track etch detectors for surface alpha contamination	H-4-1 ($.4M;$10)
	CHAR-263-OL	Portable gamma-ray scintillometers	H-4-0 ($0M;$100)

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Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking[a]
Radioactive elements—laboratory methods	CHAR-107-OL	Neutron activation	H-4-1 ($.2M;$300)
	CHAR-106-OL	Sodium iodine-germanium gamma spectroscopy	H-4-0 ($0M;N)
	CHAR-202-OL	Radioanalytical procedures	H-4-2 ($1M;N)
	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 ($.1M;$100)
	CHAR-266-OL	Neutron activation analysis	H-4-1 ($.2M;$300)
	CHAR-268-OL	Gamma-ray spectrometry	H-5-0 ($.1M;$100)
	CHAR-267-OL	Liquid scintillation counting	H-5-0 ($.1M;$100)
Inorganics—field methods	CHAR-76-OL	Atomic emission spectroscopy	M-5-1 ($.2M;$N)
	CHAR-6-OL and CHAR-219-OL	Portable X-ray fluorescence	H-5-1 ($.2M;$25)
Inorganics—laboratory methods	CHAR-78-OL	Inductively coupled plasma—mass spectroscopy	H-4-2 ($1M;$200)
	CHAR-77-OL	Inductively coupled plasma spectroscopy	H-4-0 ($1M;$200)
	CHAR-76-OL	Atomic emission spectroscopy	H-4-0 ($1M;$200)
	CHAR-50-OL	Ion chromatography	H-4-0 ($.1M;$100)
	CHAR-37-OL	Electron diffraction	M-4-0 ($0M;$100)
	CHAR-36-OL	Wavelength dispersive X-ray spectroscopy	M-4-0 ($0M;$100)
	CHAR-35-OL	Energy dispersive X-ray spectroscopy	M-4-0 ($0M;$100)
	CHAR-34-OL	Transmission electron microscopy	M-4-0 ($0M;$100)
	CHAR-33-OL	Scanning electron microscopy	M-4-0 ($0M;$100)
	CHAR-17-OL	Particle-induced X-ray emission	M-4-0 ($0M;$100)
	CHAR-56-OL	Glow discharge ionization mass spectroscopy	H-4-1 ($.5M;N)

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Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking[a]
Inorganics—laboratory methods *(continued)*	CHAR-24-OL	Cold vapor (mercury) analysis	H-4-0 ($0M;$100)
	CHAR-266-OL	Neutron activation analysis	H-4-1 ($.2M;$200)
	CHAR-31-OL	Powder X-ray diffraction	M-4-0 ($0M;>$100)
	CHAR-1-OL	Electron spectroscopy for chemical analysis	M-4-0 ($0M;$200-$600)
	CHAR-2-OL	Auger electron spectroscopy	M-4-0 ($0M;$300-$800)
Organics—field methods	CHAR-100-OL	Portable gas chromatograph/electron capture detection for analyzing PCBs[d]	H-4-0 ($.25M;$50)
	CHAR-5-OL	Portable volatile organic compound detectors	H-5-0 ($.25M;$10)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-5-2 ($.2M;$50)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-4-1 ($.2M;<$50)
	CHAR-262-OL	Gas chromatography in the field	H-5-0 ($.25M;$50)
Organics—laboratory methods	CHAR-206-OL	Analytical methods for chelators and decontamination agents	H-5-1 ($.25M;$500-$1000)
	CHAR-207-OL	Capillary zone electrophoresis	M-5-1 ($.25M;$300)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-5-1 ($.25M;$300)
	CHAR-66-OL	Gas chromatography-Fourier transform infrared spectroscopy	H-5-2 ($.5M;$400)
	CHAR-89-OL	Liquid chromatography—mass spectrometry	H-5-1 ($.34M;$500)
	CHAR-88-OL	Gas chromatography—mass spectrometry	E-5-0 ($0M;$200-$800)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-5-1 ($.2M;$10)
	CHAR-94-OL	Gas chromatography	E-5-0 M;$0M;$300)

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Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking[a]
Organics—laboratory methods *(continued)*	CHAR-211-OL	Solid phase microextraction analysis method	H-5-1 ($.3M;$500)
	CHAR-258-OL	In situ ground-water flow meter	H-5-0 ($.4M;$1–3K)
	CHAR-259-OL	Ground-water discharge location	H-5-0 ($0M;$50K)
Physical—laboratory methods	CHAR-26-OL	Particle size analysis	M-5-0 ($0M;$1000)
	CHAR-32-OL	Optical microscopy	H-5-0 ($0M;$100–$800)
Pathogens—laboratory method	CHAR-215-OL	Pathogen surveillance	E-5-1 ($.25M;$50–$250)
Buried waste remedial action problem only			
Sample collection and field methods	CHAR-273-OL	SEAMIST inverted membrane	H-5-1 ($.6M;$15K)
	CHAR-25-OL	Fiber-optic chemical sensors	H-5-1 ($1M;$3.3M)
Hydrofracture remedial action problem only			
Sample collection and field methods	CHAR-274-OL	Hydrofracture ground-water monitoring	H-1-2 ($.5M;$3.3M)

[a] The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b] Kam = thousands of dollars annual maintenance.

[c] EPA = Environmental Protection Agency.

[d] PCBs = polychlorinated biphenyls.

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3.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the characterization technologies listed in Table 3.1. Table 3.2 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with the complete set of characterization technologies listed in the TLD, Vol. 1, Pts. A, B, and C. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding characterization technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Characterization technologies for which no matches were found are omitted from the table. When many matches were found, specific TTPs may or may not be cited but it is noted that many exist. The relevance column indicates the degree of overlap between the technologies listed in Vol. 1, Pts. A, B, and C, and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 3.2. Characterization technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Auger electron spectroscopy (AES)	CHAR-2-OL	OR121115	M	Uses energy dispersive X ray for U analysis
Laser ionization mass spectroscopy	CHAR-4-OL	CH101101		Laser ablated inductively coupled plasma (ICP)
Portable volatile organic compound detectors	CHAR-5-OL	CH101104	H	Portable VOC analyzer
Portable X-ray fluorescence	CHAR-6-OL	RL321114	H	Field-portable XRF
		RL321113	H	Develop field-portable XRF
Fourier transform infrared spectroscopy	CHAR-8-OL	AL221108	M	Uses FTIR for chromium
		AL239002	L	Uses in package tests
		CH111203	M	Integration demo: sensors, monitoring
		CH131001	H	FTIR analysis of waste
Ultraviolet/visible spectroscopy	CHAR-9-OL	OR121101	H	In situ fiber-optic probe development
		OR101101	H	In situ fiber-optic derivative UV spectroscopy
		CH101101	H	Mobile ICP atomic emission spectroscopy
		AL213204	M	Robotics to include AES
		AL221108	M	Uses AES for chromium
		CH114101	M	Center for Advanced Technical Development and Toxicology Information Program: sensors, monitors
Electrochemical methods	CHAR-10-OL	RL321112	H	Stripping voltametry
Nuclear magnetic resonance	CHAR-11-OL	RL132002	M	Using technique on polymers
Laser photoacoustic spectroscopy	CHAR-15-OL	AL113101	M	Technology studies
		AL121122	M	Use on Fernald soil samples
		CH101104	M	Portable VOC analyzer
		CH131001	M	Photoacoustic Spect
Infrared spectroscopy	CHAR-18-OL	CH101104	L	FTIR (but not atmospheric)
Microwave digestion	CHAR-19-OL	AL132006	H	Microwave detoxification of mixed waste
		OR123101	H	Lead lab for EPA SW-846 mixed waste adaptation
		AL123101	H	EPA SW-846 for mixed waste
Ultrasonic extraction	CHAR-20-OL	RF121204	L	Ultrasonic cleaning at Rocky Flats Plant

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Fiber-optic chemical sensors	CHAR-25-OL	OR101101	H	Fiber-optic derivative UV spectrometry
		ID111701	M	Innovative technology development
		SF211203	H	Fiber-optic raman system development
		SR132003	H	IR fiber-optic spectrophotometer
		Many more		Widely pursued technology
Optical absorption spectroscopy	CHAR-27-OL	OR101101	M	Fiber-optic version
		SF211203	H	Fiber-optic differential abs spectrometer
Scanning electron microscopy	CHAR-33-OL	OR121115	M	One example of widely used technology
		Many More		
Transmission electron microscopy	CHAR-34-OL	OR121115	M	Example. Mature tech. needs careful sample preparation
Energy dispersive X-ray spectroscopy	CHAR-35-OL	AL221108	M	Using on Cr mobility study
Electron diffraction	CHAR-37-OL	AL121120	H	Site geochemistry characterization use
		AL121122	H	Site geochemistry characterization use
		AL221108	H	Cr mobility studies
		OR121115	H	Uranium solubility in soil study
Inorganic cementitious matrix composites model	CHAR-39-OL	CH331001	L	Cement matrix grout development and application
Computer tomography	CHAR-41-OL	AL221123	M	Electromag. tomography (esp water) of underground sites
		SF223203	H	Developing CT for waste drum inspection
Subsurface complexation model	CHAR-45-OL	AL031102	L	Geochemistry: Monticello, Utah
		ID111701	L	Chelation: lanthanides, actinides
		RL331002	L	Chemical barriers in ground
Ion chromatography	CHAR-50-OL	Many		Accepted and widely used
Modeling of volatile organic compounds migration in porous materials	CHAR-53-OL	None except soil	NA	Much work directed at soil
Membranes for sample collection and concentration	CHAR-55-OL	OR111204	M	High-efficiency particulate air filter
		AL131007	M	VOC in air sampling
		AL221107	L	Borehole membrane liner
		SR121106	L	Membrane use
Glow discharge ionization mass spectroscopy	CHAR-56-OL	AL131007	M	Membrane sampling ion-trap mass spectrometry

Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Magnetic resonance imaging	CHAR-58-OL	RL132002	M	Using technique on polymers
Air monitoring	CHAR-59-OL	Many		Widely used. Tailor to application need
Tomographic seismic monitoring	CHAR-60-OL	AL201101	H	Seismic tomography development, use Savannah River Integrated Demonstration (SRID)
		AL221123	M	Underground imaging (resistance)
		CH221101	M	Seismic wave measurement of clay at Savannah River (SR)
		SF121101	H	High-resolution seismic imaging
		SF121102	M	Underground imaging (resistance)
		AL921102	M	Seismic survey and analysis
Modeling of heterogeneous materials sampling	CHAR-61-OL	SR132003	L	Chemometric models tank waste spectrophotometry
In situ solvent-extraction methods	CHAR-62-OL	SR121107	L	Vacuum extraction of VOC from soil at SRID
		Many more	L	
Long-range alpha detector	CHAR-65-OL	AL131002	H	LRAD developed, used at Fernald
Atomic emission spectroscopy	CHAR-76-OL	Many		Widely used technique
ICP spectroscopy	CHAR-77-OL	CH101101	H	Mobile ICP AES development
		Many		Widely used technology
ICP—mass spectroscopy	CHAR-78-OL	OR111105	M	Direct sampling ion-trap mass spectrometer
		AL113101	M	Covered in field screening project
Sampling and mixing methods	CHAR-81-OL	AL131003	H	Use on Fernald soil
		NV031001	H	Use on Nevada Test Site soil
Portable Raman spectrometer	CHAR-84-OL	OR121101	H	Fiber-optic raman sensor development
		OR101101	H	Employ sensor on aromatic hydrocarbons
		RL401206	M	Use raman sensing in hot cell
		SF211203	H	Development raman sensor for RL401206
IR absorption (laser-based source)	CHAR-85-OL	RL401206	M	Near IR absorption
		SF211203	H	Near IR raman with diode laser
Laser ablation for sample collection	CHAR-86-OL	CH101101	H	Laser ablation ICP development
Gas chromatography—mass spectrometry	CHAR-88-OL	Many	NA	Widely used

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Liquid chromatography—mass spectrometry	CHAR-89-OL	AL113101	M	Considered in field screening
		ID101301	H	Used on halogenated organic compounds (HOCs)
		SR132002	H	Used on cesium extraction project
Direct sampling ion-trap mass spectrometry	CHAR-90-OL	OR101102	H	Development
		OR101103	H	Development and application
		OR101105	H	Use with army toxic materials
		OR121103	H	Use at SRID Project
		Others		
Portable luminescence detection	CHAR-92-OL	OR121201	H	Luminescence spot test for PCBs
Laser ablation organic mass spectrometry	CHAR-93-OL	CH101101	H	Laser ablation ICP
Gas chromatography	CHAR-94-OL	Many		Widely used
Photon electron rejecting alpha liquid scintillation	CHAR-97-OL	ORNL-DOSAR Facility	H	Evaluate uranium resuspension at Weldon Springs cleanup
Portable gas chromatograph/electron capture detection for analyzing PCBs	CHAR-100-OL	RL321101	M	HOC monitoring off-gas treatment project VOC non-Arid
Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	CHAR-101-OL	OR121101	H	In situ fiber-optic probe development
Sodium iodide-germanium gamma spectroscopy	CHAR-106-OL	AL131004	M	Gamma detector used in project
		AL931001	M	Gamma detector used in project
Neutron activation	CHAR-107-OL	AL911201	M	Neutron activated fission for detection of uranium
		AL921101	M	Prompt fission neutron logging
		AL931001	M	Neutron activated fission
Fluorescence diagnosis of contaminated surfaces	CHAR-110-OL	OR121101	M	In situ fiber optic probe development
Laser ablation; ICP; AES	CHAR-111-OL	CH101101	H	Laser ablation ICP
		CH501301	H	Field test, Fernald
On-line supercritical fluid extraction—multidetector gas chromatography	CHAR-115-OL	AL123101	M	Use for SW-846 methods
		ID4231010	M	Use for SW-846 methods
Ground-penetrating radar	CHAR-124-OL	AL921102	H	Used on mixed waste landfill
		NV001102	M	Airborne tests
		RL313203	H	Tested on landfill

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Electrical and electromagnetic detection of ground and geologic fractures	CHAR-125-OL	SF121102	H	Underground imaging (resistance)
Seismic methods (refraction, profiling, reflection)	CHAR-126-OL	AL201101	H	Seismic tomography development, use SRID
		CH221101	M	Seismic wave measurement of clay at SR
		SF121101	H	High-resolution seismic imaging
		AL921102	M	Seismic survey and analysis
Magnetics	CHAR-128-OL	AL011201	H	Tensor magnetic gradiometer
		AL921102	M	Landfill characterization
		ID132003	H	Use for site characterization
Supercritical fluid extraction of inorganics	CHAR-201-OL	ID111701	H	Lanthanides and actinides with lariat crown ethers
Radioanalytical procedures	CHAR-202-OL	CH013102	L	Environmental management (EM) analytical laboratories performance evaluation
Contamination control—analytical equipment	CHAR-204-OL	AL213203	L	Characterization automation
Radioactive sample preparation	CHAR-205-OL	OR123101	M	Adapted SW-486 methods for rad. mixed waste analysis
Analytical methods for chelators and decontamination agents	CHAR-206-OL	AL132002	M	Polymers for Pu and Am concentration for wastewater
Capillary zone electrophoresis	CHAR-207-OL	SF213203	M	Robotic cross cutting advanced technology
Supercritical fluid extraction of organics	CHAR-208-OL	ID111701	L	Lantanides and actinides with lariate crown ethers
Adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples	CHAR-209-OL	RF101205	L	Incineration alternatives
Fissile material locator/profiler	CHAR-212-OL	NV021701	H	Associated particle imaging
		AL931001	L	Multispectral neutron logging
XRF for in situ monitoring of toxic heavy metals	CHAR-219-OL	RL321114	H	Field portable XRF
		RL321113	H	Field portable XRF development
Sampling program configuration management system	CHAR-228-OL	Many	H	Used at many other sites
Configuration management system	CHAR-229-OL	Many	H	Used at many other sites
Fiber-optic systems for measuring multiple physical variables	CHAR-248-OL	SF213203	H	Microsensor systems development

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Quality control for measurement processes	CHAR-250-OL	CH013101	H	Analytical management-quality assessment program (Environmental Measurements Laboratory)
Sequential sampling plans	CHAR-252-OL	Many	H	Accepted and widely used
Spatial sample and data analysis plans	CHAR-253-OL	Many	H	Accepted and widely used
Solid sorbent sampling for airborne organics	CHAR-254-OL	AL113101	M	Field screening study
Soil/sediment sampling for volatile organics	CHAR-256-OL	Many	H	Widely found
In situ ground-water flow meter	CHAR-258-OL	OR121104	H	Colloidal bore scope
Ground water discharge location	CHAR-259-OL	Many	H	Accepted and widely used
Waste drum gamma activity monitor	CHAR-261-OL	SF223203	H	Waste facilities operation & sorting technology
		SR113201	H	SR robotics, waste facilities operations
Gas chromatography in the field	CHAR-262-OL	ALTTPMSA	M	Mobile sample analysis laboratory
Portable gamma-ray scintillometers	CHAR-263-OL	AL112101	L	Field screening studies
		SF223203	M	Used in waste facilities operations
Surface-enhanced Raman scattering	CHAR-265-OL	OR121101	H	Spectroelectrochemical sensors
		SF211203	M	Adv. fiber-optic spectroscopy for inorganic contaminants
Neutron activation analysis	CHAR-266-OL	AL131004	M	Multispectral neutron logging
		AL931001	H	Multispectral neutron logging
Liquid scintillation counting	CHAR-267-OL	AL931102	L	Chemical barriers demonstration
		ORNL-DOSAR Facility	H	Uranium resuspension evaluation
Gamma-ray spectrometry	CHAR-268-OL	RL132002	M	Polymer concentration of U and Pu (gamma technique)
Advanced radiation monitors	CHAR-269-OL	AL121218	M	Real time emission monitor
		ID111701	M	Fiber-optic thermoluminescence dosimeter monitor development
		ID121210	M	BWID contamination control
Sampling of heterogeneous wastes	CHAR-270-OL	AL123101	M	Adapted SW-846 methods for mixed waste analysis

Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Sampling interface system for surface contamination by organics	CHAR-271-OL	CH101101	H	Laser ablated ICP mass spectrometer
SEAMIST inverted membrane	CHAR-273-OL	AL221107	H	Landfill characterization system
Hydrofracture ground-water monitoring	CHAR-274-OL	Many	H	Accepted and widely used
Isotope dilution ICP mass spectrometry	CHAR-275-OL	CH101103	M	ICP/mass spectrometry dev.
Sediment sampling	CHAR-276-OL	OR113203	H	Robotics advanced technologies

[a]TTP = Technical Task Plan identifier.
[b]The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

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4. Remedial Action

4. REMEDIAL ACTION

4.1 INTRODUCTION

In Chap. 1, environmental contamination at ORNL was grouped according to source and media into the following site problem areas:

1. buried wastes,
2. tanks,
3. pits and trenches,
4. soils and sediments,
5. buried pipelines,
6. impoundments,
7. hydrofracture, and
8. ground water and surface water.

A technical team was organized to assess the RA needs and technologies for each problem area. Each team conducted an initial workshop with multiorganizational and multidisciplinary experts to define the problem area and identify candidate remedial technologies. Each team focused on defining the status, science and technology needs, and implementation needs of the identified technologies. Each team then gave rankings for development of the identified technologies (see Chap. 2 explanation). The approach taken by most teams was to identify technologies for the RA subelements: containment and isolation, in situ treatment, retrieval, and ex situ treatment. Technical teams coordinated activities and cross-referenced data sheets (Vol. 2). In several instances it was necessary to prepare more than one data sheet for an individual technology due to differences in the status of development and needs associated with individual problem areas (e.g., ISV).

This chapter is organized into sections discussing the technologies considered, science and technology needs, implementation needs, and technology rankings. Each section is in turn subdivided into the individual site problem areas.

4.2 DESCRIPTION OF TECHNOLOGIES CONSIDERED

4.2.1 Introduction

Technologies considered in each area are described and listed below. In all, this included more than 120 technologies, but even this is not a complete list. The list is the result of a selection by the experts who work in each area. The list includes technologies for interim, as well as permanent solutions, to the problem in each area. Some technologies may play an important role but may not be able to solve entire problems by themselves. For instance, some technologies can remove or destroy only one contaminant, and other technologies are only useful for retrieval of contaminated soil, wastes, etc. New technologies are likely to be conceived and developed in the future that are not covered.

4.2.2 Buried Wastes

Systematic evaluation of alternatives for buried waste sites resulted in three systems approaches: in situ hydrologic isolation or containment, in situ treatment, and retrieval followed by treatment. Each of the three systems entails a series of interrelated activities (see Fig. 4.1), each of which is essential for the success of the system. The in situ isolation/containment system includes definition of the design basis, which encompasses the design life, health/safety standards, structural criteria, environmental parameters, waste-form requirements, and cost limitations; site characterization; structural stabilization; actual isolation technologies; monitoring; and support activities (transportation, health & safety, decontamination of equipment, etc.). The in situ treatment system includes definition of the design basis; characterization of waste and site, and treatment technologies; verification of treatment effectiveness; site closure and monitoring; and support activities. The retrieval system includes definition of the design basis; waste and site characterization; retrieval; staging/storage; segregation/sorting/packaging; treatment/recycle/recovery/decontamination; disposal or recycle of residue; and support activities. Since other sections of the TLD examine technology development and support needs for characterization and monitoring, waste storage, site closure, and disposition of treatment residues, this section focuses on technology needs to support structural stabilization, containment and isolation, in situ treatment, retrieval, segregation/sorting/repackaging, and ex situ treatment.

Specific technologies that were evaluated for application to ORNL's buried waste problems are listed, along with their ranking, in Table 4.1 of Sect. 4.5. Data sheets for these technologies are available in Vol. 3, Pt. B.

Many of the technologies applicable to buried waste (e.g., barrier technologies) were also considered for remediation of contaminated solid and sediments and impoundments. In addition, many decontamination techniques (e.g., CO_2 blasting) could potentially be applied to retrieved waste.

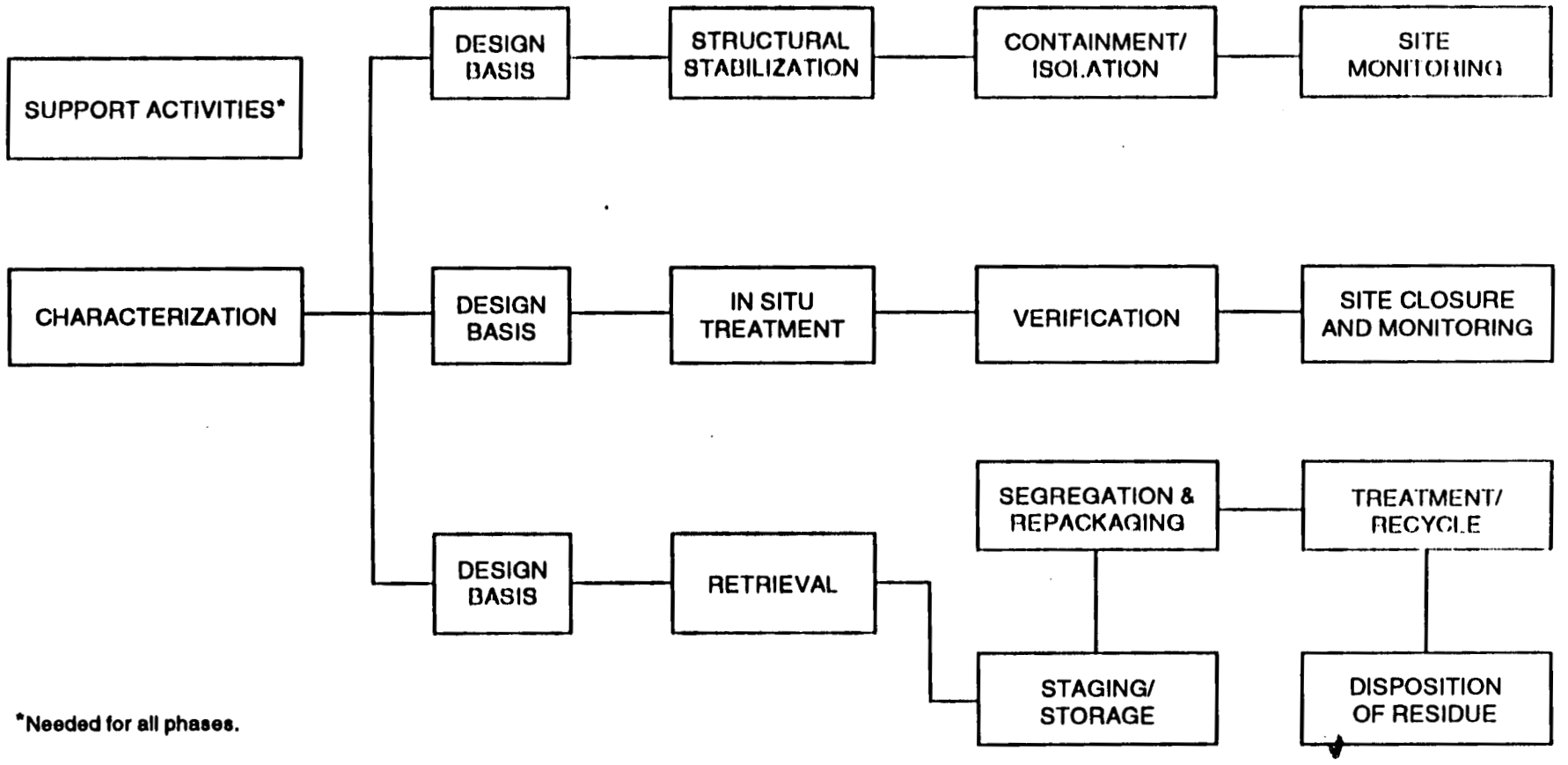

Fig. 4.1. Potential buried waste remediation systems.

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4.2.3 Low-Level Waste Tanks

Remedial alternatives considered for the inactive low-level waste tanks include removal of the tank contents, in situ treatment via fixation or sorption, removal of the tank shells, hydrogeologic containment or isolation of the tanks, and treatment of the tank contents via chemical methods. Data sheets are available for the technologies that accomplish the first two alternatives. Technologies supporting the last three alternatives are covered in other core groups and are discussed in more detail below.

- *Removal of the tank contents (liquid alone, or both liquid and sludge)*—Specific technologies included in this alternative are mechanical excavation, pneumatic removal, and hydraulic removal (sluicing/slurry pumping). The use of cryogenics to freeze and thereby facilitate removal of the contents has been suggested; however, this technology was not pursued further because of concern over potential for cracking or breaching the tank shells.
- *In situ treatment of tank contents*—Specific fixation technologies include cement grouting, silicate-based stabilization, vitrification, chemical grouting, and thermoplastic encapsulation; in situ sorption was also discussed as a physical separation treatment.
- *Removal of the tank shells (Gunite and steel)*—Specific technologies are discussed by the dismantlement team in Vol. 1, Pt. A, Chap. 4.
- *Hydrogeologic containment or isolation of the tanks using walls or barriers or combinations of capping and drains*—Examples of wall or barrier technologies are grout curtains, slurry walls, sheet-pile walls, and cryogenic barriers. Examples of capping are intruder barriers and multilayer caps, and examples of drains are french drains and horizontal wells. Specific technologies are discussed in Sect. 4.2.2.
- *Treatment via chemical methods*—Examples of chemical treatments are dissolution, neutralization, and radiochemical separation and recovery. Specific ex situ chemical treatment technologies are discussed in Vol. 1, Pt. C, and Vol. 3, Pt. C. Potential in situ chemical treatments have not been identified nor referenced.

For many of these alternatives, access to the inside of the tanks with special equipment will be necessary. However, due to the radiation hazard inside the tanks, the remediation equipment that enters the tanks must be operated remotely. The robotics and automation (see Chap. 5) addresses the different types of equipment that can be used remotely in hazardous environments.

4.2.4 Pits and Trenches

Remedial alternatives considered for the pits and trenches include containment, in situ treatment, retrieval, ex situ treatment, and disposal. Data sheets are available for the following technologies: capping/barrier overview—containment; ISV, grouting, and extraction—in situ treatment; remote excavation—retrieval.

Ex situ treatment and disposal technologies are available in other RA problem areas and the WM Volumes. Additional containment technologies (such as cryogenic barriers and slurry walls) and in situ technologies (such as freezing and heating) are available in other RA problem areas.

4.2.5 Soils and Sediments

Technologies considered for the management of ORNL contaminated soils and sediments are broadly divided into containment and isolation and treatment processes. Because the contamination of soils and sediments at ORNL often includes a variety of contaminants (organic compounds, toxic metals, and an almost unlimited list of radionuclides), the application of both types of processes to many of the soils may be required. For example, the prevailing ORNL management strategy for contaminated soils is containment in low-level radioactive waste burial grounds. One alternative would be treatment to achieve volume reduction, which would lower containment costs. The selection of a technology for the management of contaminated soils and sediments is highly dependent on the type of contaminant(s), its distribution in the soils and sediments (both in terms of depth within the profile and distribution among particle-size fractions), and its chemical form. Knowledge of these properties requires extensive characterization. Because of the lack of characterization data and the potential presence of a wide variety of contaminants in many of the soils and sediments of ORNL, the descriptions of treatment technologies are also varied.

Contaminated soils and sediments must be managed at ORNL because of one of two actions: (1) soils and sediments accumulated from construction, facilities already in need of remediation (e.g., leaking pipelines, impoundments, waste area), or of other activities, and (2) soil and sediment remediation projects already specified. In the near term, most of the needs for the development, demonstration, and implementation of the required technologies will center on the soil and sediments generated from actions other than soils and sediments remediation *per sec*. For example, remediation of underground storage tanks, leaking pipelines, and waste lagoons commands higher priority than soils and sediments. These facilities are generally the source term of soil contamination. The careless selection of technologies to remediate these facilities could generate large volumes of soils and sediments requiring remediation. From this stand point, an important soil remediation technology is one that does not generate contaminated soil and sediment.

In the near term, soil remediation needs at ORNL will be directly associated with remediation of pipelines and waste tanks (most of which contain radioactive wastes). From this standpoint, the major objective is volume reduction of soils and sediments to lower the need for containment in a burial ground. In the long term, specific areas may require remediation, such as sediments of White Oak Lake, residual soils resulting from the excavation of waste lagoons or waste burial grounds, and surface soils, where spills of hazardous/radioactive wastes have contaminated soils. The technologies required to address near- and long-term needs in soil and sediment remediation are often similar; however, their priorities in implementation differ due to their degrees of maturity and confidence in expected deliverables. Because near-term needs are related primarily to contaminated soils resulting from remediation of pipelines and waste tanks, the emphasis was placed on the description of technologies involving ex situ treatment over containment. In the case of long-term needs, the emphasis on in situ treatment and containment technologies generally prevailed.

The following technologies were evaluated:

Treatment

- *Soil washing/extraction*—Soil washing/extraction is a broad term that involves size segregation of soil fractions using water as solvent to selectively extract specific contaminants (organic compounds, metals, and/or radionuclides) and using a variety of chemical leaching media. The major objective is volume reduction, when water is used, and the transfer of contaminants from the soil phase to a liquid phase, when specifically designed extraction media are used.
- *Thermal desorption*—For soils containing VOCs, ex situ vapor-extraction techniques or thermal desorption processes could be readily applied. These technologies would be beneficial in the removal of RCRA volatile compounds from mixed wastes prior to containment in a burial ground.
- *Stabilization/fixation by grouting*—The primary purpose in the grouting of soils is to stabilize and reduce the mobility of contaminants in soil scheduled for disposal in landfills. The major detriment of grouting soils for disposal is the added volume. For most soils, grouting would be conducted using particulate-based grouting materials in commercially available mixers and blenders. Portland cements, because of their low cost, would be the predominant cementing agent. In certain instances, additives would be used for sorption or complexation of specific contaminants, depending on the mobility characteristics of the contaminant. In special cases, chemical-based grouting materials might be preferred because they do not add substantially to the volume of soil to be disposed of. However, their higher costs will generally preclude widespread use unless some low-cost chemical grouting materials are developed.
- *Soil-Vapor Extraction*—For soils containing VOCs, in situ soil-vapor extraction, thermally enhanced soil-vapor extraction, and soil-vapor extraction with radio frequency (RF) heating were evaluated. The latter two technologies are enhancements of soil-vapor extraction.
- *High-Temperature Destruction*—Several technologies (including incineration, molten glass combustor, chem char process, plasma arc furnace, and cement kiln incineration) were considered for destruction of organic compounds in soil and sediments.
- *Chemical Separation*—Solvent extraction, chemical oxidation/reduction and electrokinetics were considered for removal of organics, metals, and radionuclides from soils and sediments.
- *In Situ Vitrification*—Encapsulation of metals and radionuclides in a durable glass and crystalline product by extreme heat.
- *Biotreatment*—This technology includes a wide range of biological processing options that rely on microbial transformation of organic compounds to remediate soils and sediments.

Retrieval

- *Entombed Clamshell*—Modified clamshell bucket used to dredge contaminated sediments.

Containment

- *Capping/barrier installation*—This technology involves the placement of a hydraulic barrier over and around contaminated soil. Materials used in this technology vary from flexible membrane liners to clay grouts. The major objective is to stop infiltrating rainwater and ground water and inhibit the intrusion of plant roots and burrowing animals.

4.2.6 Buried Pipelines

Buried pipes exist throughout the ORNL area, many in the main laboratory area. Some of these pipes have carried radioactive wastes to underground storage tanks or to treatment facilities in the past. Many of the pipes have deteriorated, and most are no longer in use. Most pipes are relatively near the surface, and the levels of radioactivity and other hazards do not appear excessively hazardous. Only two technologies were considered for treating the pipes themselves—excavation and fixation (probably with cement-based grout). Where the pipes have leaked considerably, there may be significant amounts of contaminated soil around pipes. Although such contamination may have to be removed or contained, treatment of contaminated soils around piping will be covered by soils and sediments core groups.

4.2.7 Impoundments

Impoundments are areas where contaminated waters have been discharged into ponds or diked areas that prevent run-off. The soil in impoundments often can be treated with technologies discussed in Sect. 4.2.5, Soils and Sediments, but the localized concentration in impoundments requires special technologies. These special technologies, not the more general soil treatment technologies, are discussed below.

Containment and Isolation

- *Capping*—This technology involves the placement of a hydraulic barrier over and around the contaminated impoundment.
- *Drains*—French drains, biopolymer drains, and horizontal wells aid in hydraulic isolation of the impoundments.
- *Walls/Barriers*—Grout Curtains, slurry walls, sheet pile walls, clay bentonite additives and cryogenic barriers were considered for hydraulic isolation of the impoundments.

Treatment

- *Physical Separation*—Soil washing and in situ soil flushing were considered for removal of metals and radionuclides from impoundments. Sludge drying was also considered for removal of water from impoundment sediments as a pretreatment for storage/disposal.
- *Fixation*—In situ fixation using silicates, cements or polymers and ISV were considered for immobilizing contaminants in impoundment sediments.

Retrieval

- *Excavation*—Mechanical excavation, vacuum loading, and dredging to retrieve contaminated impoundment sediments were considered.

Note that some technologies (sludge drying and soil washing) are ex situ treatment technologies that require mechanical excavation or vacuum loaders (technologies listed for waste retrieval), prior to processing. Similarly, cryogenic barriers are an in situ treatment that retain the contamination temporarily (perhaps for relatively long times) until radioactivity has decayed or until permanent treatment plans are complete.

Several technologies aim to restrict the entry of water into the impoundment area. These include slurry walls, sheet-pile walls, grout curtains, french drains, capping, and biopolymer drains. These may be considered permanent or temporary solutions, depending upon the lifetime of the retention and the lifetime of the contaminant. These technologies can also be useful for preventing pollutant migration while the contaminated region is being treated.

Other impoundment technologies are in situ treatment for permanent solutions to the problems. These technologies may be of more interest for impoundments than for most soil contamination because impoundments are more likely to contain high local concentrations of contaminants that can be immobilized by solidification of relatively small volumes of soil.

4.2.8 Hydrofracture

Due to the depths and lateral extent of the injected wastes, only containment alternatives were considered for remediation of the hydrofracture problem area. Plugging and abandonment was considered for the well bores. Three containment technologies—water proofing cave with hydraulic cage, deep rock drainage curtain, and chemical grout—were considered for the grout sheets. A brief description of each technology follows.

- *Plug and abandon*—Conventional plugging of well bores using drilling rigs to place concrete plugs above and below injection zones in the well bore.
- *Water proofing cave with hydraulic cage*—Deep-rock hydraulic curtain at the periphery of the contamination zone. The contaminated zone is surrounded by a series of interconnected wells that equalize the pressure in the rock mass, thereby reducing any seepage to less than 1% of the original flow through the rock mass.
- *Deep rock drainage curtain*—A circular array of vertical drill holes serve as a drainage gallery for any mobile wastes in the contaminated zone.
- *Chemical grouting*—Polymer is injected to fill in any cracks or fissures in the host rock at the edge of the contaminated zone.

4.2.9 Ground Water and Surface Water

Processes for removal of contaminants from ground water and surface waters can be carried out in either of two general methods: in situ or aboveground. Some of the technologies considered have been practiced widely in the chemical process industries and can be designed with confidence for aboveground application. When such technologies (e.g., ion exchange) are considered for in situ application, uncertainties arise concerning the control of flow distribution and rate and monitoring concentrations and

associating them with flow rates so that mass balances are closed properly. No experience is available to indicate efficiencies that may be expected when such materials must be replaced.

For radionuclides and heavy metals, the technologies evaluated were adsorption, ion exchange, precipitation, and artificial wetlands. For hydrocarbons, VOCs, and PCBs, the technologies evaluated were adsorption, biological oxidation, chemical oxidation, artificial wetlands, and air and steam stripping. For nitrates, the technologies evaluated were biological denitrification and artificial wetlands.

Adsorption requires that the water be contacted intimately with a solid sorbent, such as activated carbon, so that the containment distributes preferentially onto the solid phase. Usually such contacting is done in a tower filled with the sorbent (in the form of small pellets), providing a large surface area for mass transfer. Sorbents have been prepared from immobilized algae, which are said to be highly specific for certain contaminants. After the sorbent bed is fully loaded (exhausted), it may or may not be regenerated for reuse depending on process economics. Ion-exchange operations are quite similar to adsorption except that the contaminant must be an ionized species that replaces another ion carried by the fresh exchanger in the solid phase.

Precipitation of heavy metals and radionuclides can be enhanced by various reagents, iron hydroxide and aluminum hydroxide being the most common. Precipitation is carried out in the ORNL Process Waste Treatment Plant and is an accepted technology. Artificial wetlands have been used for treating domestic sewage and coal mine runoff. Therefore, this technology has the potential to destroy organics and immobilize heavy metals. Application to ORNL ground water and surface waters would require development work.

Biological oxidation is used routinely to degrade water-soluble organics, as in the ORNL Storage Treatment Plant. More refractory contaminants, such as chlorinated solvents, may require specially designed treatment systems. Laboratory-scale tests have shown that higher-chlorinated PCBs can be dechlorinated anaerobically, and that lower-chlorinated PCBs can be dechlorinated aerobically. Chemical oxidation of organic contaminants has been demonstrated with potassium permanganate, ozone, and hydrogen peroxide.

For VOCs in water, air stripping has been promulgated a "best available technology." The operation is usually done by passing the water down a packed-column countercurrent to a rising air stream. The effluent air carrying organics may require treatment. The use of steam rather than air is a well-established industrial technology. The advantage of steam is that it can be condensed, which eliminates the problem of treating the effluent gas.

4.3 SCIENCE AND TECHNOLOGY NEEDS

4.3.1 Introduction

This section highlights some of the R&D needed to make the technologies available for RA at ORNL. For accepted technologies and even for some demonstrated technologies, there may be no science and technology needs. However, the soils and other conditions at Oak Ridge are unusually complex, and some testing, perhaps only treatability studies, may be needed, even for technologies that have been in common use elsewhere.

4.3.2 Buried Wastes

The majority of the structural stabilization technologies have been demonstrated and are available. Science and technology needs include testing to determine material compatibility for structural caps and solidification. Other needs include field tests with full-scale dynamic compaction equipment.

Needs for isolation/containment technologies include methods to minimize waste generation during application, guidance systems for grout injection/tunnelling, and development of waste-resistant materials for capping.

The applicability of thermal destruction technologies for buried wastes and the characteristics of the treated residue need to be determined. Methods for treating off-gas from thermal destruction are also needed.

Science and technology needs for fixation technologies include development of new chemical mixtures and application/injection equipment. This is especially critical to ensure and verify that containers are ruptured and grout/polymer has mixed with contents for in situ technologies. The development of compaction methods is needed to prevent flashing/overpressurization of waste during ISV.

Testing is needed to estimate the effectiveness and identify additives for freeze purification and thermal desorption. Soil simulation methods to promote conductivity for fracted air stripping are needed.

Methods are needed to safely and effectively segregate buried waste during and after retrieval. The development of remotely controlled/robotic retrieval technologies needs to be continued.

4.3.3 Low-Level Waste Tanks

With regard to tank contents removal (particularly sludge removal), the principal science and technology needs are the development of retrieval and transport devices or systems. Retrieval equipment must be capable of removing hard salt cake, sludges of varying consistencies, tank hardware, and foreign objects. Conveyance systems must be capable of handling dislodged or mobilized wastes and tank hardware, and, in some cases, it must be capable of transporting the slurry over long distances with negligible solids separation or in-line clogging. Special emphasis is being placed in the Integrated Demonstration projects of DOE's Office of Technology Development on robotics-integrated retrieval equipment (e.g., articulated and remotely operated mechanical arms). Because the equipment must be versatile, this work is technically difficult. If scheduled implementation time is short, large expenditures in terms of dollars and manpower will be needed for development.

Another principal science and technology need is for a detailed characterization of the waste matrix that will determine the suitability of the solidifying agent for specific tanks. This is a necessary first step in development of in situ fixation methods. Better understanding of immobilization mechanisms and the chemistry of these solidified waste forms can lead to improved performance and better predictions about their durability. It is important also to note that high confidence in the long-term effectiveness of these fixation techniques is not universal. More careful demonstrations and operations are needed to create a higher level of confidence in the long-term performance of the fixation techniques. Long-term assessments of the ability of the fixation technologies to retain and contain the contamination would be useful. The assessments would address, for example, whether the cement grout and silicate-based formulations maintain the pH necessary to prevent migration and whether the polymer grout and thermoplastic formulations retain their stability in high-radiation environments.

One of the most promising in situ fixation methods is vitrification. ISV needs two significant technology developments to make it acceptable for ORNL underground storage tanks. The problem of off-gas pressurization and splattering during ISV of underground tanks seems to be caused by the absence of lateral and subsurface porosity when the tank is sealed on top by molten material of high temperature. As an ISV melt proceeds, molten glass can pressurize confined gas or liquids within the underground tank resulting in the rapid burping of off-gas and associated splattering. This problem could be largely overcome by in situ compaction of the tank prior to ISV or by filling the tank space with earthen material (or other contaminated soil or waste) that would be incorporated into the final product. Specific tank contaminants and materials would need to be tested for compatibility with such earthen materials during vitrification.

4.3.4 Pits and Trenches

For long-term containment of pits and trenches, radionuclide source-term identification and long-term performance testing of materials and construction methods are needed.

A principal science and technology need for in situ grouting is the development of delivery, mixing, and dispersion systems. Grout-waste compatibility, as well as long-term performance modeling under field weathering, would also need to be determined.

In situ extraction requires the development of fluid extractants that could mobilize the radionuclides of concern. Technology for injection, disposal, and recovery of extractants in the pits and trenches would also be needed.

In situ vitrification is the most promising technology for the pits and trenches. The most significant technology need is the modification of off-gas handling techniques to deal with volatilization of cesium during vitrification.

4.3.5 Soils and Sediments

One of the most important science and technology needs is an accurate and complete characterization of the contaminated soils and sediments. It is a gamble selecting the most appropriate remediation technology if properties of the contaminant and the soils and sediments are unknown. In many instances, the distribution and chemical form of the contaminant within particle-size fractions of the soils and sediments is important in determining the success or failure of a specific technology.

Near-term science and technology needs at ORNL should be directed at determining how to reduce the volume of contaminated soils being disposed of in ORNL's low-level

radioactive waste burial grounds. Bench-scale studies should be initiated to investigate the potential advantages of volume reduction methods such as size classification and soil washing/extraction, using soils presently on hand and stored at SWSA 5 but designated for burial in SWSA 6. Other near-term science and technology needs include investigations relating to how much more efficiently vapor extraction of VOCs from ORNL impermeable soils can be conducted. The effectiveness of chemical oxidation processes to destroy organic contaminants in these same high-silty and -clayey soils also needs to be investigated.

Long-term science and technology needs at ORNL involve the identification and testing of methods to remediate large volumes of soil that contain relatively low levels of radionuclides and/or other hazardous contaminants. These include sediments contained in White Oak Lake and adjacent to many of the waste lagoons at ORNL and the contaminated soils along waste lines and in the low-level burial grounds. The first need is to thoroughly characterize these soils and sediments and evaluate the potential environmental and health risk associated with a "no remediation action" scenario. If an unacceptable risk is involved, bench-scale studies should be aggressively pursued. However, because of the time involved in making a risk analysis and in obtaining a regulatory approval of "no remediation action," it may be beneficial to start up (on a limited scale) some bench-scale testing of the more promising technologies.

4.3.6 Buried Pipelines

Both of the previously described technologies considered for treated buried piping are considered accepted, and there are not believed to be significant science and technology development needs. Only in the unexpected event that radioactivity or toxic hazard is sufficient to prevent direct participation of personnel with protective clothing would robotic or other new equipment be required.

4.3.7 Impoundments

All of these technologies are accepted or have been demonstrated on somewhat similar sites. Usually the most important science and technology need is a sufficient understanding of the soil properties in the impoundment. In situ vitrification, in particular, needs an understanding of the behavior of all components during high-temperature treatment, such as volatilization, decomposition of organic compounds, and leachability of contaminants from the product glass. Although there is more experience with fixation of contaminants with cement-based grouts, this technology also needs treatability testing to confirm that all contaminants of interest are adequately contained within the grout.

Most of the in situ technologies, including the different types of barrier construction, have been used or demonstrated in soils that are far less complex than those in the Oak Ridge area. For instance, the complex flow patterns in the highly fractured soils at Oak Ridge make placement of barriers more complicated than in simpler and more nearly homogeneous sandy soils.

4.3.8 Hydrofracture

The circulating fluid used for conventional well plugging and abandonment could become contaminated and pose a potential health risk to workers during plugging and abandonment. Technology to develop remotely controlled equipment is needed to minimize worker health risk.

The geologic and hydrologic characteristics of the rock formations need to be characterized for both the deep rock drainage curtain and water proofing cave with hydraulic cage technologies. Modeling is also needed to evaluate the sensitivity of waste movement to pore pressures. Because deep-drilling costs are a key to the economic viability of these technologies, cost-effective drilling techniques are needed.

The impact of radioisotopes and saline ground water on the long-term properties of cured polymers is needed to evaluate the feasibility of chemical grouting of the hydrofracture grout sheets.

4.3.9 Ground Water and Surface Water

Chemical process operations are normally fine-tuned to operate at optimal conditions on the feed stream. A primary consideration concerning ground water and surface water treatment is the variation in flow rates and contaminant concentrations that may be encountered. These variations are presently unknown, and determining them is a key factor in minimizing treatment costs. For aboveground treatment, consideration should be give to accumulating a feed reservoir to average out fluctuations in flow rates and concentrations.

For in situ technologies, the extent of the contaminated ground water and its variation with climatological conditions must be identified, and this flow must be directed through the treatment zone. Subsurface structures to control ground-water flow must be demonstrated and costs established. Instrumentation for monitoring flow rates and contaminant levels for in situ applications is needed.

4.4.1 Introduction

This section highlights some of the problems that must be overcome to use the technologies at ORNL. These could include establishment of treatment limits and regulatory acceptance of the final treatment product. Some technologies do not solve the problems completely but are important single steps in the solution. In these cases, it will be necessary to have the other technologies available to complete the job. One particular group of technologies does not provide permanent solutions to the problems but provides containment of the pollutant, sometimes for long periods. Use of such technologies requires regulatory acceptance of delayed permanent treatment and development (perhaps future development) of permanent treatment technologies.

4.4.2 Buried Wastes

Dynamic compaction and surcharging need to be demonstrated for the soil and hydraulic conditions at ORNL prior to implementation. Field tests are needed to determine the long-term effectiveness of different materials for use as barrier walls or in fixation applications. Cold-test facilities are needed to check guidance systems for grout delivery prior to implementation.

Significant permitting and trial burn efforts are needed to establish the effectiveness of thermal destruction technologies and to obtain regulatory approval for implementation. Safety, product-quality, and field-process operations all need to be established.

Field testing of retrieval technologies under actual conditions is needed to demonstrate safety and precision.

4.4.3 Low-Level Waste Tanks

If the contents are removed from the tanks (removal of either the liquid alone or the liquid and sludge), facilities will be needed to receive the waste. Review of the waste in the inactive low-level waste tanks indicates that the supernates (liquid) could generally be transferred to the active liquid low-level waste system. This means that the liquid would probably be concentrated in the liquid low-level waste evaporator and then transferred to the Melton Valley Storage Tanks for long-term storage. Two tanks are known to contain significant organic layers and could not be sent directly to the active liquid low-level waste system. Additional studies will be required before recommendations can be made for these tanks. Only a small percentage of the supernates (~1%) could be discharged directly to the Process Waste Treatment Plant. The other 99% of the supernates exceed the Process Waste Treatment Plant waste acceptance criteria for such indicators as cesium, strontium, and gross beta, and sometimes for cobalt and gross alpha (Th, U, and Pu). A fairly complicated pretreatment system (e.g., mixed-bed ion-exchange columns, zeolite ion-exchange columns, and precipitation) would be necessary to treat these waste acceptance criteria-exceeding supernates for discharge to the Process Waste Treatment Plant. The time required to perform development studies and build such a pretreatment facility precludes considering this as a viable option for the near future.

The storage volume currently available in the Melton Valley Storage Tanks is limited and is insufficient for all of the tank supernatants. Periodic campaigns to solidify a portion of the supernatant have allowed continued operation of the liquid low-level waste system in the past, but this is undesirable in many ways and is only a temporary

000280

measure. DOE and ORNL's WM group is working together to acquire and implement additional storage tanks and/or treatment facilities. Long-term options for liquid low-level waste storage and treatment generally include building the Waste Handling and Packaging Plant at ORNL to process and repackage liquid low-level waste for eventual disposal at the planned Waste Isolation Pilot Plant in New Mexico.

The tank supernatants are non-TRU, while about two-thirds of the tank sludges are TRU waste. After the liquids are removed from the tanks, the sludges may also be removed to the active liquid low-level waste system or processed in other ways, such as in situ treatment. According to DOE Order 5820.2A, stored TRU sludges must be removed from the tanks and disposed of at the Waste Isolation Pilot Plant unless another alternative is fully justified. If the TRU sludges are solidified and stabilized in situ, the treatment would probably be temporary, and final disposition of the tank contents may be required at a later date. The degree to which in situ fixation options facilitate final disposition of the tank contents should be analyzed carefully. For example, significant cement grouting of the tanks may make final contents disposition difficult. An option would be to partially fill a tank with grout so tank accessibility is not limited.

Basic implementation needs for both retrieval or in situ fixation alternatives include the following:

- Support platforms that straddle tanks. Because the structural strengths of the Gunite tank domes are suspect, all equipment to be mounted above the tanks should be supported on a platform that straddles the tanks.
- Access to the tanks for in situ solidification or retrieval of the contents.
- Use of minimal in-tank equipment (i.e., ancillary equipment should be located outside the tank) to improve system reliability and accessibility.
- Specially designed remote equipment. ES&H considerations may mandate that in-tank equipment be remotely operated; such equipment may need to be specially designed.
- Closed-circuit TV and remote control equipment.
- Areas to provide for wash-down, minor maintenance, and waste load-out in preparation for equipment relocation.

With regard to the in situ treatments, the necessary equipment and expertise are needed to properly blend and mix the constituents and manage the operation. This is especially true for polymer grouting, where some of the grouting polymers are toxic. It is important that the polymers react with the tank contents; if they do not react and instead become free liquids in the tanks, they become future candidates for migration. Processing controls are necessary to ensure that the grouting and tank contents are mixed correctly and proportionately to promote solidification of the mixture.

A critical implementation need for ISV is field-scale tests to demonstrate that off-gas pressurization and splattering problems can be eliminated via compaction or by filling the void spaces with an appropriate material. Existing pilot-scale ISV equipment could be used to perform demonstrations that would require about two years and an estimated three million dollars to complete. Successful deployment of the ISV technology for underground tanks would then require fabrication of site-dedicated hardware (about 6 million dollars and two years of effort) and contractual arrangements with a private sector corporation to operate that equipment. All underground tanks at ORNL would require many years to treat by ISV, but only a few years (i.e., three) would be required to treat selected higher-activity units that present the greatest risk for exhumation and redisposal.

4.4.4 Pits and Trenches

Capping implementation needs center on characterizing of the site to determine the exact areas to be contained and identifying potential lateral and subsurface recharge areas that would require hydrologic separation. In situ grouting implementation needs include establishing grout mixing and compatibility at a projected field scale. Due to the relatively higher-radiation fields at the pits and trenches, remote operations, including auger change, repair, and abandonment within the waste, would likely be required during in situ grouting.

In situ vitrification implementation needs center only on providing a field-scale operation to demonstrate implementability. In situ extraction implementation needs are largely indeterminate because the specific in situ process and extractants cannot be identified.

4.4.5 Soils and Sediments

Pilot-scale testing of soil remediation technologies is needed before full-scale use. Presently, ORNL does not have facilities to conduct pilot-scale tests for soil remediation technologies, such as soil washing/extraction, chemical oxidation/reduction, thermal desorption, or incineration. Because of the potential to contaminate private vendor's equipment, contracting pilot-scale studies is not a cost-effective option. Contracting often restricts flexibility in design of experiments and in many cases does not offer a total systems approach. For example, many of the soil remediation technologies are based on separation processes of a contaminant from the soil (e.g., soil-vapor extraction, thermal desorption, soil washing/extraction, and electrokinetics) and treatment of the contaminant (using a destruction or containment process) is addressed separately. Accessibility to pilot-scale facilities at ORNL would be cost effective, provide greater utility in technology evaluation, and ensure the correct scale-up to full-fledged treatment facilities.

To meet long-term science and technology objectives in soil remediation at ORNL, a determined program that evaluates potential environmental and health risks associated with large bodies of soils and sediments that contain relatively low levels of radionuclides and/or toxic hazardous constituents, needs to be implemented. This program should include a major task in soil characterization that determines fate and transport of contaminants contained in the soils and sediments of concern. The program should be formed in such a manner so that the EPA and state of Tennessee regulatory agencies can actively participate. Goals should be established with a realistic timetable, dealing with expected dates of promulgation and cleanup levels. Implementation of a successful program along these lines would aid significantly (in cost as well as time) in the selection of the most appropriate soil remediation technology for ORNL sites.

4.4.6 Buried Pipelines

Both of these technologies and the expected means of application are accepted. No unusual implementation needs are expected.

4.4.7 Impoundments

Since some technologies considered for impoundments are temporary measures, their implementation obviously requires methods and plans for subsequent permanent treatment. Although short half-life radioactivity may decay during the retention period, other contaminants may remain. The potential temporary measures include most of the barrier concepts. The ability to leave the contaminants in-place but contained may depend upon an agreement of the regulators to accept institutional control of the site for several years. In a similar manner, excavation methods depend upon the availability of ex situ treatment methods.

Other technologies considered produce a solid mass that retains the contamination. It is acceptable to leave a solidified mass in place. Although this mass would not support plant life as the original soil, it would be more like large rocks.

4.4.8 Hydrofracture

Field demonstration sites and flow modeling are needed for the deep rock drainage curtain and water proofing cave with hydraulic cage. Facilities for leachate treatment from these deep-rock drainage curtains are also needed.

Laboratory testing, to determine the site-specific impacts of radioisotopes/saline water on the chemical grout, is needed.

4.4.9 Ground Water and Surface Water

Ion-exchange and adsorption operations carried out aboveground have been done on a large scale for many years. Costs for these operations can be estimated with considerable confidence. In commercial applications a range of $1–$2/1000 gal of water treated would be typical. For applications that treat water containing nuclear materials, the cost is much higher because of the required nuclear waste storage, additional permitting, etc., and $5–$10/1000 gal is a better estimate.

In situ adsorption and ion exchange operations and the control of ground water have not been demonstrated. Materials must be contained so that they are accessible to ground water but removable after exhaustion. These same ground-water control considerations apply to other in situ operations that might be done using a trench-and-fill concept, such as precipitation and chemical oxidation.

Costs for aboveground precipitation for heavy metals, cesium and strontium should cost about $100/1000 gal of water and about $1000/1000 gal for cobalt and technetium. Cost for aboveground biological oxidation of organics are about $10/1000 gal, typical of storage treatment plants. For chemical oxidation, costs are expected to be about $100/1000 gal. For nitrate destruction, biological denitrification is expected to cost less than $200/1000 gal.

Separation of volatile organics by air stripping aboveground will cost between $0.60 and $4.10/1000 gal, depending on the scale of operation and whether the organics are recovered from the air. Steam stripping would cost about $8/1000 gal.

4.5 TECHNOLOGY RANKINGS

4.5.1 Introduction

The rankings of RA technologies are presented in the following sections. The criteria listed in Chap. 2, Sect. 2.4, were used to rank the technologies. It should be noted that the development and projected unit operating costs are rough order-of-magnitude estimates. Their validity is limited to the relative comparison of costs between technologies.

4.5.2 Buried Wastes

Table 4.1 summarizes the rankings of each technology addressed by the buried waste group. The rankings are briefly discussed by systems approach in the following sections.

4.5.2.1 Containment and Isolation Technologies

Challenges to hydrologic isolation of buried waste in the ORNL setting have been ranked in this study with direct-surface infiltration having the highest impact, near-surface storm-water flow of secondary impact, and deeper ground-water flow of least impact. Accordingly, technologies to prevent direct infiltration were ranked higher than technologies providing isolation from deeper ground water.

Among the structural stabilization technologies, dynamic compaction was ranked high, partly due to its effectiveness of surface caps at relatively low cost and its applicability to many trench areas at ORNL. High ranking was also assigned to horizontal-mixing-in-place technology, due to its potential for penetration of containers, which effectively stabilized nonhomogeneous wastes. While this technology has been demonstrated for contaminated soil, the effectiveness of the delivery system for buried waste needs further evaluation and demonstration.

In the evaluation of isolation technologies, vertical barriers were determined ineffective in Oak Ridge's geology, which does not provide an impermeable bottom seal. Higher priority was assigned to caps that prevent direct infiltration, and drains that divert shallow storm flow from buried waste areas. An exception was the high ranking of the slurry wall with HDPE screen, which can serve as a leachate collection/drainage/leak-detection system or possibly as a hydrobarrier to prevent contaminant migration through the wall down-gradient of contaminants.

4.5.2.2 In Situ Treatment

High priority was assigned to ISV, due primarily to its robustness and potential effectiveness in converting radionuclides to an excellent waste form, while destroying all organic hazards and combustible materials. Although ISV has been successfully demonstrated for contaminated soil, the challenges of off-gas pressurization and fluid pressurization within ambient containers must be addressed (possibly by in situ compaction) prior to application of this technology to buried waste.

Table 4.1. Rankings of remedial action technologies

Alternative	Data sheet code number	Technology	Contaminants	Ranking[a]
Buried waste group				
Containment and isolation				
Structural stabilization	REMA-1	Dynamic compaction	LLW[b], organics, metals	H-5-1 ($0.5M;$1.50/ft^2)
	REMA-81	Horizontal mixed in-place	LLW, organics, metals	H-5-2 ($1.5M;$275/yd^3)
	REMA-96	Structural caps	LLW, organics, metals	M-5-1 ($.5M;$1M/acre)
	REMA-82	Surcharge	LLW, organics, metals	M-5-1 ($0.25M;$25/yd^3)
	REMA-5	In situ solidification	LLW, organics, metals	M-5-2 ($0.5M;$150/yd)
	REMA-97	Thermal set resin impregnation	LLW, organics, metals	L-5-10 (>$1M;<$50/ton)
Capping	REMA-94	Intruder barriers	LLW, organics, metals	H-5-1 (≤$.5M;$0.5M–$7M/acre)
	REMA-46	Capping	LLW, organics, metals	H-5-1 (≤$.5M;$0.5M–$7M/acre)
Bottom seals	REMA-87	Vibrated plastic tube bottom seal	LLW, organics, metals	L-5-3 ($0.5M;$200–$300/ft^2)
	REMA-86	Microtunneled high-density polyethylene liner	LLW, organics, metals	L-5-5 ($3M;>$500/ft^2)
	REMA-85	Jet grouting	LLW, organics, metals	L-5-1 ($0.8M;$150–$300/ft^2)
Barriers	REMA-58	Cryogenic barriers	LLW, organics, metals	L-5-3 (≤$1M;~$100/ft^2)
Drains	REMA-44	Biopolymer drains	LLW, organics, metals	H-5-1 (≤$1M;$15–$20/ft^2)
	REMA-43	French drains	LLW, organics, metals	H-5-1 (≤$1;$50–$100/ft^2)
	REMA-45	Horizontal wells	LLW, organics, metals	H-5-1 (≤$1M;$150/ft)
Walls	REMA-84	Hydromill	LLW, organics, metals	M-5-3 (≤$1M;$30/ft^2)
	REMA-42	Grout curtains	LLW, organics, metals	M-5-1 (≤$1M;$30–$40/ft^2)
	REMA-40	Slurry walls	LLW, organics, metals	M-5-1 (≤$1M;$15–$20/ft^2)
	REMA-83	Slurry walls with high-density polyethylene insert	LLW, organics, metals	H-5-2 ($2M–$3M;~$40/ft^2)
	REMA-41	Sheet pile walls	LLW, organics, metals	M-5-2 (≤$1M;$30–$40/ft^2)
	REMA-88	Soil saw	LLW, organics, metals	L-5-2 ($0.8M;$70–$80/ft^2)

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Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking[a]
		In situ treatment		
Destruction	REMA-99	In situ heating	Organics	L-5-8 (>$1M;<$50/ton)
	REMA-110	In situ biodegradation (buried waste)	Organics	L-5-5 (≤$1M;<$50/ton)
Fixation	REMA-3	In situ particulate grouting	LLW, organics, metals	M-5-2 (>$1M;$40-$60/yd^3)
	REMA-2	In situ chemical grouting	LLW, organics, metals	M-5-2 (≤$1M;$60-$100/yd^3)
	REMA-100	In situ vitrification (buried waste)	LLW, organics, metals	H-5-5 ($3M;$60-$100/yd^3)
Separation	REMA-89	Fracted air stripping	Organics	M-5-4 ($2M;$50-$75/ton)
		Retrieval		
Excavation	REMA-123	Overshot drilling	HFIR[c] control plates	H-5-4 ($5M/6 HFIR[b] holes)
	REMA-126	Bulk item exhumation	Large equipment	H-5-2 (≤$1M;<$50/ton)
	REMA-125	Wireline basket recovery	HFIR control plates	H-5-4 ($8M/6 HFIR holes)
	REMA-101	Vacuum loader (buried waste)		L-5-2 (≤$1M;<$50/ton)
	REMA-4	Borehole mining (super soil stabilization management)	LLW, organics, metals	L-5-3 (≤$1M;$50-$100/yd^3)
	REMA-10	Solidify and mine (freeze and mine)	LLW, organics, metals	L-5-8 (≤$1M;<$50/ton)
	REMA-90	Precision excavation	LLW, organics, metals	H-5-1 (≤$.5M;<$50/ton)
	REMA-122	Modular excavation	LLW, organics, metals	M-5-8 (>$1M;<$50-$100/ton)
	REMA-38	Remote excavation	LLW, organics, metals	H-5-2 (≤$.5M;$203-$244/ft^3)
		Ex situ treatment		
Separation	REMA-93	Shredding and magnetic separation	LLW, metals	L-5-1 ($1M;$0.2M/yr/system)
	REMA-121	Physical sorting	LLW, metals	M-5-1 (N;N)
	REMA-92	Thermal desorption	Organics	L-5-3 (≤$1M;$35-$120/ton)
	REMA-91	Freeze purification	LLW, organics, metals	L-5-5 (≤$.5M;<$50/ton)
	REMA-8	Gravity sorting	LLW, metals	L-5-3 (≤$1M;$0.35-$1/lb)

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Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking[a]
		Ex situ treatment (continued)		
Separation (continued)	REMA-55	Soil washing (contaminated soil/sediment)	LLW, organics, metals	L-5-3 (≤$.5M;$70–$150/ton)
Fixation	REMA-9	Cementitious solidification	LLW, organics, metals	H-5-3 (≤$.5M;$200–$300/yd^3)
	REMA-112	Thermoplastic encapsulation	LLW, organics, metals	H-5-3 (≤$.5M;$25/ft^3)
	REMA-113	Thermoset encapsulation	LLW, organics, metals	H-5-3 (≤$1M;$30/ft^3)
	REMA-114	Sulfur polymer cement encapsulation	LLW, organics, metals	H-5-10 (≤$1M;$25/yd^3)
	REMA-115	Polymer-impregnated concrete/polymer-modified concrete	LLW, organics, metals	M-5-8 (>$1M;<$50/ton)
	REMA-117	Vitrification	LLW, organics, metals	M-5-6 (>$1M;$400–$500/ton)
	REMA-116	Ceramic encapsulation	LLW, organics, metals	L-5-10 (N;N)
Destruction	REMA-95	Incineration	Organics, metals	H-5-1 (≤$1M;>$100/ton)
	REMA-98	Calcining/sintering	LLW, organics, metals	L-5-10 (>$1M;<$50/ton)
	REMA-7	Low-temperature ashing	LLW, organics, metals	H-5-6 (>$1M;<$50/ton)
Recovery/ conversion	WPRO-111	Smelting	Metals	M-5-1 ($3M;$2/lb.)
	REMA-127	Transmutation	LLW, TRU[d]	M-5-4 (≤$1M;<$50–$100/ton)
		Tanks core group		
Contents removal	REMA-27	Tank contents removal using mechanical mining		H-5-3 (>$4M;N)
	REMA-28	Tank contents removal using pneumatic techniques		H-5-0 ($4M;N)
	REMA-29	Tank contents removal using hydraulic techniques		H-5-0 (>$4M;N)
Fixation	REMA-25	In situ solidification using cement-based grouting		M-5-2 (>$5M;>$70/m^3)

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Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking[a]
Tanks core group (continued)				
Fixation (continued)	REMA-26	In situ solidification using silicate-based formulations		M-5-2 (>$5M;>$70/m^3)
	REMA-30	In situ treatment using in situ vitrification		M-5-2 ($3M;<$50–$100/ton)
	REMA-32	In situ solidification using polymer grouting		M-5-2 (>$5M;>$100/m^3)
	REMA-33	In situ solidification using thermoplastic techniques		L-5-3 (>$5M;>$70/m^3)
Physical separation	REMA-31	In situ solidification using sorbents		M-5-1 (>$1M;>$50/m^3)
Pits and trenches				
Containment	REMA-36	Capping (pits/trenches)		H-3-1 (L, $0.5–$7M/acre)
In situ treatment	REMA-35	In situ vitrification (pits/trenches)		H-3-1 (>$1M;$25/ft^3)
	REMA-37	In situ grouting (pits/trenches)		M-3-2 (≤$1M;$75/ft^3)
	REMA-39	In situ extraction		L-3-10 (>$1M;$244/ft^3)
Retrieval	REMA-38	Remote excavation		M-3-2 (≤$.5M;$203–$244/ft^3)
Soils and sediments				
Containment	REMA-46	Capping	LLW, organics, metals	M-4-1 (≤$.5M;$0.5–$7M/acre)
	REMA-58	Cryogenic barriers	LLW, organics, metals	M-4-3 (≤$1M;$200–$300/ft^2)
Physical separation	REMA-55	Soil washing (contaminated soils/sediments)	LLW, organics, metals	H-4-2 (≤$.5M;$70–$150/ton)
	REMA-13	Low-temperature thermal treatment	Volatile organics	M-4-2 ($1M;$100–$800/ton)
	REMA-11	Vapor extraction with radio frequency heating	Volatile organics	H-2-4 (≤$1M;<$100/ton)
	REMA-16	Thermal desorption	Volatile organics	H-2-2 (≤$1M;$35–$120/ton)
	REMA-78	Soil vapor extraction	Volatile organics	H-2-3 (≤$1M;$50–$75/ton)
	REMA-80	Thermally enhanced soil vapor extraction	Volatile organics	H-2-3 (≤$1M;$50–$100/ton)
Chemical separation	REMA-119	Soils treatment using solvent extraction	Organics, metals	M-2-3 ($3M–$5M;$200–$300/ton)
	REMA-120	Soils treatment using oxidation or reduction	Organics, metals	M-2-3 ($3M–$5M;$100–$200/ton)
	REMA-19	Electrokinetic removal	Organics, metals	L-2-4 ($1M–$10M;>$100/ton)

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Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking[a]
Soils and sediments (continued)				
Destruction	REMA-118	Soils treatment using bioremediation	Organics	M-2-3 ($3M-$5M;$100-$200/ton)
	REMA-12	Incineration	Organics	M-4-2 ($1M-$2M;$100-$800/ton)
	REMA-15	Molten glass combustor	Organics, PCBs[f]	M-2-3 (≤$1M;>$200/ton)
	REMA-20	Chem char process	Organics, PCBs	L-2-4 ($1M;<$50-$100/ton)
	REMA-17	Plasma arc furnace	Organics, PCBs	M-2-3 ($10M;<$50-$100/ton)
	REMA-14	Incineration, cement kiln	Organics, PCBs	M-2-3 (≤$1M;<$50/ton)
Fixation	REMA-18	In situ vitrification	LLW, organics, metals	M-4-3 (≤$.5M;$390/ton)
	REMA-59	In situ vitrification (impoundments)	LLW, organics, metals	M-4-2 (≤$1M;$75/ft^3)
Retrieval	REMA-124	Entombed clamshell	LLW, organics, metals	H-4-0 (≤$.5M;<$25–$50/yd^3)
Pipeline group				
Excavation	REMA-53	Pipeline excavation	LLW	H-1-0 ($0;>$25/yd^3)
Fixation	REMA-52	In situ grouting (pipeline)	LLW	H-1-1 ($0;~$25–$70/yd^3)
Hydrofracture group				
Containment —well bores	REMA-22	Well plugging and abandonment		H-1-2 ($0;$10–$20M total cost)
Containment —grout sheets	REMA-21	Waterproofing cave with hydraulic cage		M-1-5 ($3M;$30–$40M total cost)
	REMA-24	Deep rock drainage curtain		M-1-4 ($3M;$30–$40M total cost)
	REMA-23	Hydrofracture grouting		L-1-2 ($3M;$30–$40M total cost)
Impoundments				
Capping	REMA-46	Capping	LLW, organics	H-4-1 (≤$.5M;$0.5–$7M acre)
Drains	REMA-43	French drains	LLW, organics	H-4-1 (≤$1M;$50–$100/ft^2)
	REMA-44	Biopolymer drains	LLW, organics	H-4-2 (≤$1M;$15–$20/ft^2)
	REMA-45	Horizontal wells	LLW, organics	H-4-3 (≤$.5M;~$150/ft^2)
Walls/ barriers	REMA-58	Cryogenic barriers	LLW, organics	M-4-3 (≤$1M;$200-$300/ft^2)

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Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking[a]
Impoundments (continued)				
Walls/ barriers (continued)	REMA-42	Grout curtain	LLW, organics	M-4-2 (≤$1M;$30–$40/ft^2)
	REMA-40	Slurry walls	LLW, organics	M-4-3 (≤$1M;$15–$20/ft^2)
	REMA-41	Sheet pile walls	LLW, organics	M-4-2 (≤$1M;$30–$40/ft^2)
	REMA-60	Clay/bentonite additives	LLW, organics	L-4-1 (≤$.5M;$0.55/ft^2)
Physical separation	REMA-51	Soil washing (impoundments)	LLW, organics, metals	M-4-2 (≤$.5M;$70–$150/ton)
	REMA-47	In situ soil flushing	LLW, organics, metals	M-4-3(≤$.5M;<$50/ton)
	REMA-56	Sludge drying	Organics	M-4-3(≤$1M;<$50/ton)
Fixation	REMA-57	In situ fixation	LLW, organics, metals	H-4-1 (≤$1M;$50–$75/yd^3)
	REMA-59	In situ vitrification (impoundments)	LLW, organics, metals	M-4-3 (≤$.5M;$25/yd^3)
Excavation	REMA-50	Mechanical excavation	LLW, organics, metals	H-4-1 (≤$.5M;<$50/ton)
	REMA-49	Vacuum loaders	LLW, organics, metals	H-4-1 (≤$.5M;<$50/ton)
	REMA-48	Dredging	LLW, organics, metals	H-4-1 (≤$.5M;<$50/ton)
Ground water and surface water				
Physical separation	REMA-65	Ion exchange	Radionuclides, inorganics	H-5-1 ($1M;$5–$10/1000 gal)
	REMA-34	Precipitation	Radionuclides, inorganics	M-5-1 ($1M;$100–$1000/1000 gal)
	REMA-73	Adsorption on biomedia	Inorganics	M-2-2 ($2M;N)
	REMA-66	Activated carbon	Organics, inorganics	H-2-1 ($1M;$5–$10/1000 gal)
	REMA-76	Air stripping	VOCs[b]	H-2-0 ($0;$.6–$4.10/1000 gal)
	REMA-77	Steam stripping	VOCs	H-2-0 ($0;$8/1000 gal)
Destruction	REMA-68	Biological oxidation	Organics	H-2-1 ($1M;$10/1000 gal)
	REMA-72	Chemical oxidation	Organics	M-2-2 ($2M;$100/1000 gal)
	REMA-69	Anaerobic dechlorination	PCBs	L-2-5 ($5M;N)
	REMA-75	Biological denitrification	Nitrates	M-2-1 ($1M;$200/1000 gal)

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Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking[a]
		In situ processes		
Physical separation	REMA-64	In situ ion exchange	Radionuclides, inorganics	L-5-3 ($3M;N)
	REMA-62	In situ precipitation	Radionuclides, inorganics	L-5-3 ($3M;N)
	REMA-74	In situ biomedia adsorption	Inorganics	L-2-3 ($3M;N)
	REMA-67	In situ activated carbon	Organics, inorganics	L-2-3 ($3M;N)
	REMA-70	In situ biological oxidation		M-2-3 ($2M;N)
Fixation	REMA-63	Artificial wetlands	Organics, inorganics	M-2-3 ($3M;N)
	REMA-79	Cryogenic immobilization		H-5-2 ($2M;N)
Destruction	REMA-61	In situ chemical oxidation	Organics	M-2-2 ($2M; a few$/1000 gal)
	REMA-71	In situ anaerobic dechlorination	PCBs	M-2-5 ($5M;N)
	REMA-75	In situ biological denitrification	Nitrates	M-2-3 ($3M;N)

[a] The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b] LLW = low-level waste
[c] HFIR = High Flux Isotope Reactor
[d] TRU = transuranic
[e] RFH = radio frequency heating
[f] PCBs = polychlorinated biphenyls
[g] VOCs = volatile organic compounds

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4.5.2.3 Retrieval and Ex Situ Treatment

Three technologies were ranked in waste retrieval. Excavation technologies, including precision excavation, were selected because they are already highly developed and readily adaptable to retrieval of low-activity waste. The development/demonstration needs for precision excavation focus on contamination control. Also given a high ranking for development/demonstration was bulk item exhumation because of the need to remove large buried objects safely. Overshot drilling for high-activity applications, such as the retrieval of reactor plates for auger holes, is also given a high ranking.

Segregation/sorting technologies ranked lower than other subelements for two reasons. First, the need for segregation will be driven by the primary treatment technology, which is undefined. Second, the buried waste is not characterized well enough to determine relative proportions of different treatment groups (e.g., metals). The highest ranking technology in this area was physical sorting, because it is already used for newly generated waste and because it provides for segregation into a larger number of treatment categories.

A group of thermal treatment technologies and a group of solidification technologies were ranked high in ultimate treatment. Incineration, vitrification, and low-temperature ashing were selected because of their effectiveness, robustness, and tremendous waste-reduction effects. Low-temperature ashing has the potential of providing better control of semi-volatile contaminants. Technology development/demonstration needs focus on off-gas treatment and development of a final waste form. High-ranking solidification technologies included cement solidification, thermoplastic encapsulation, thermoset encapsulation, and sulfur polymer cement encapsulation.

4.5.3 Low-Level Waste Tanks

Table 4.1 also summarizes the rankings for each technology addressed in the tank's core group. Those technologies with the highest ranking (mechanical excavation, pneumatic removal, and hydraulic removal or sluicing) were identified for the contents removal alternative. One of the reasons for the high ranking for the contents removal technologies is that they comply in part with DOE policy of TRU wastes removal. Two of the technologies, pneumatic and hydraulic removal, are technically mature and well demonstrated at ORNL and Hanford. However, based on lessons learned from past experience with these two technologies, their removal efficiency (historically up to 90%) could be improved by upgrading the in-tank equipment and through careful selection of tools appropriate for the particular tank waste. The technology with the potential for the highest removal efficiency, at least for the Gunite tanks, may be mechanical excavation. DOE's Office of Technology Development is already helping develop this technology through its Integrated Demonstration Programs for robotics and the underground storage tanks. The parallel robotics developments are useful because robotics is a crosscutting technology that enables remote deployment of equipment, tools, and sensors in the hazardous-tank environment.

4.5.4 Pits and Trenches

The rankings for each technology addressed by the pits and trenches group are in Table 4.1. In situ vitrification and capping were the highest ranked technologies. Both technologies have been demonstrated and shown effective. In situ grouting was ranked

as a medium priority because of uncertainties of its effectiveness and its implementation costs/schedule. Although remote excavation does not require significant development, it was ranked medium because of uncertainty in the disposal of excavated material. In situ extraction was ranked low due to the lack of an extractant, uncertainties in implementability/effectiveness, and need for delivery/recovery systems.

4.5.5 Soils and Sediments

Table 4.1 provides rankings of soils and sediments technologies. Soil washing was ranked a high priority because of its demonstrated ability to selectively remove radionuclides, the major contaminant of concern. Other physical separation technologies, such as thermal desorption and soil-vapor extraction (including thermally enhanced and RF heating), were also given high priority. It should be noted, however, that since the effectiveness of these technologies is limited to volatile and semi-volatile organics, their site-problem ranking is lower.

The rankings in the systems approach for soil remediation technologies are expected to change over time. Near-term priorities focus on ex situ treatment because of the early implementation in important remediation projects, such as the removal of leaking tanks and pipelines and the remediation of spills. Longer-term priorities are expected to focus on in situ treatments and containment for large volumes of contaminated sediments and soils, such as those contained in White Oak Lake and the burial grounds.

4.5.6 Buried Pipelines

Both technologies evaluated for remediation of buried pipelines were given high rankings (see Table 4.1). Both technologies are currently used for remediation of buried pipelines and their effectiveness at ORNL has been demonstrated.

4.5.7 Impoundments

Technologies receiving the highest rankings (see Table 4.1) included all excavation and capping and drainage technologies since these are likely to be the most critical for remediation of impoundments. In situ fixation was also rated high, primarily for its demonstrated ability to immobilize wastes. The other technologies were ranked lower due to their limited applicability and limited effectiveness for the site conditions at ORNL.

4.5.8 Hydrofracture

Plug and abandon was ranked the highest since it has been demonstrated as effective and is versatile and will not require a long development period or cost. The deep-rock drainage curtain was ranked as medium since it is a well-established technique for seepage control below high-head dams. Chemical grouting and water proofing cave with hydraulic cage were ranked low, primarily due to the development required and uncertainty of the effectiveness. Due to the nature of the problem, all technologies (with the exception of plug and abandon) were estimated to be of high cost ($\geq$\$100M) to develop and implement.

4.5.9 Ground Water and Surface Water

The technology receiving the highest rankings for inorganics (e.g., heavy metals) and radionuclides was aboveground ion exchange. For organics and inorganics the highest ranked were aboveground adsorption on activated carbon. Aboveground biological oxidation, for organics; aboveground air or steam stripping, for VOCs; and cryogenic immobilization, for tritium, were given high rankings as well.

4.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the RA technologies listed in Table 4.1. A search of available information on programs funded in FY 1992 and FY 1993 was performed to identify possible matches with this list of RA technologies. The results of this search are presented in Table 4.2. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding RA technology code and TTP number. When no FY 1993 matches were found and the searchers (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. RA technologies for which no matches were found are omitted from the table. The relevance column indicates the degree of overlap between the listed RA technologies and active TTP projects. The TTP's comprising the search data base are listed in the appendix.

Table 4.2. Remedial action technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
In situ chemical grouting	REMA-2-OL	AL231008	H	In situ containment
		CH321101	H	In situ containment
		RL331002	H	In situ containment
In situ particulate grouting	REMA-3-OL	CH321101		
In situ solidification	REMA-5-OL	RL311103	L	In situ remediation
Soil washing	REMA-6-OL	CH331002	M	Cost-to-benefit analysis
		NV031001	M	Plutonium separation
		PE031001	H	Centrifugal jig
		SR121105	M	Extraction/leaching
Cementitious solidification	REMA-9-OL	ID132012	L	Acceptance criteria
Solidify and mine (freeze and mine)	REMA-10-OL	ID121203	M	Ground freezing
		SR121104	H	Integrated demonstration
Vapor extraction with radio frequency (RF) heating	REMA-11-OL	AL221121	H	RF heating
		RL311104	M	In situ soil heating
		SF211104	H	RF heating
		SR121106	M	RF heating
		SR121107	M	Integrated demonstration
		ID121701	M	Biofiltration
		SR121104	H	Integrated demonstration
		SR131001	H	In situ heating
Incineration	REMA-12-OL	ID132011	M	Arc melter vitrification
		RL321211	L	Plasma torch and furnace
Low-temperature thermal treatment	REMA-13-OL	AL221121	H	Vapor extraction system
		RL311103	L	In situ heating
		RL311104	H	Six-phase soil heating
		RL331003	H	Six-phase soil heating
		SR131001	H	In situ heating
Thermal desorption	REMA-16-OL	ID121114	H	Volatile organic compound (VOC) recycle and recovery
Plasma arc furnace	REMA-17-OL	ID132011	H	Arc melter vitrification
		PE033502	H	Plasma centrifugal furnace
		RL321211	H	Direct Current (DC) arc plasma furnace

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Table 4.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
In situ vitrification (ISV)	REMA-18-OL	ID132010	H	Thermal kinetic processes
		RL332000	H	Pilot-scale ISV system
		OR101201	M	Data and engineering analyses
Electrokinetic removal	REMA-19-OL	AL221122	M	Electrokinetic remediation
		AL231000	M	Electrokinetic remediation
		ID121211	M	Electrokinetic remediation
Water proofing cave with hydraulic cage	REMA-21-OL	AL223305	M	International Technology Exchange Program (ITEP) activities
		AL231008	M	Flowable grout technologies
Tank contents removal using hydraulic techniques	REMA-29-OL	RL332006	H	Waste dislodging and conveyance
In situ treatment using in situ vitrification	REMA-30-OL	ID132010	H	Thermal kinetic processes
In situ solidification using polymer grouting	REMA-32-OL	CH321201	H	Polyethylene encapsulation
In situ solidification using thermoplastic techniques	REMA-33-OL	CH321201	H	Polyethylene encapsulation
Precipitation	REMA-34-OL	ID121204	L	Biological destruction
		RL431001	M	In situ chemical treatment
In situ vitrification - pits and trenches	REMA-35-OL	OR101201	H	Pilot-scale demonstration
Capping - pits and trenches	REMA-36-OL	AL121125	L	Postclosure monitoring
		AL131001	L	Barrier selection software
In situ grouting - pits and trenches	REMA-37-OL	AL121125	L	Postclosure monitoring
Remote excavation	REMA-38-OL	AL232006	M	Buried Waste Integrated Demonstration (BWID)
		ID121203	H	BWID waste retrieval demo
		ID121210	M	BWID contamination control
		ID132007	M	BWID retrieval technologies
		ID332004	H	BWID remote excavation demo
		ID413200	M	Robotics technology
		ID431001	H	Uranium in Soils Integrated Demonstration (USID) remote excavation demo
		SF213205	M	Robotics technology
		OR113202	M	Robotics technology
Slurry walls	REMA-40-OL	AL121125	L	Barrier evaluations

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Table 4.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Sheet pile walls	REMA-41-OL	ID132007	M	BWID retrieval technologies
Horizontal wells	REMA-45-OL	AL221114	M	Moisture logging system
		RL421103	H	Drilling technology development
		SR121106	M	Air stripping
		SR134101	L	Air stripping
Capping	REMA-46-OL	AL221111	H	Effects on contaminant transport
		AL321002	H	Air-enhanced dry barrier
		CH331001	M	Subterranean vertical barrier
In situ soil flushing	REMA-47-OL	AL201101	M	Ground-water flow sensor
		RL311103	M	In situ soil flushing
Mechanical excavation	REMA-50-OL	NO031001	L	Rotomill excavator testing
Soil washing	REMA-51-OL	AL1312R1	M	Heap leaching
		NV031001	M	Plutonium separation
		SR121105	M	Extraction/leaching
Stabilization/fixation by grouting	REMA-54-OL	CH321101	H	Advanced grouting materials
Soil washing	REMA-55-OL	CH331002	M	Cost-to-benefit analysis
		NV031001	M	Plutonium separation
		PE031001	H	Centrifugal jig
		SR121105	M	Extraction/leaching
In situ fixation	REMA-57-OL	CH321101	H	Advanced grouting materials
Cryogenic barriers	REMA-58-OL	AL121125	M	Barrier evaluation
		ID132007	M	Ground freezing
In situ vitrification - impoundments	REMA-59-OL	RF101201	L	Microwave solidification
		RL332009	M	Vitrification studies
Clay/bentonite additives	REMA-60-OL	AL231008	L	Bentonite-paraffin material
In situ chemical oxidation	REMA-61-OL	ID121217	L	Supercritical water oxidation
		OR121206	M	Supercritical water oxidation
In situ precipitation	REMA-62-OL	RL331002	L	Chemically enhanced barriers
		RL431001	M	In situ chemical treatment
In situ ion exchange	REMA-64-OL	PE021104	L	Technology screening
		RL321204	M	Inorganic sorbent exchangers

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Table 4.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Ion exchange	REMA-65-OL	AL232004	M	Titanate ion exchangers
		OR111102	L	Liquid-phase decontamination
		OR111203	L	$NaNO_3$ + radioactivity
		PE021104	L	Resource recovery
		RL321203	M	Cesium recovery on resin
		RL421102	L	Decontaminated ground water
Biological oxidation	REMA-68-OL	ID111701	H	Methanotropic biofiltration
Anaerobic dechlorination	REMA-69-OL	RL321102	H	Bimolecular probe analysis
		OR121110	H	Bioremediation of PCBs
In situ biological oxidation	REMA-70-OL	RF101205	L	Incineration alternatives
In situ anaerobic oxidation	REMA-71-OL	SR121106	H	Methane monooxygenase treatment
Biological denitrification	REMA-75-OL	ID121204	L	Destruction of tank wastes
		OR111203	L	Destruction of tank wastes
Air stripping	REMA-76-OL	RF121204	M	Feasibility study
Thermally enhanced soil vapor extraction	REMA-80-OL	AL221121	H	Extraction system
		RI311104	H	Six-phase soil heating
Jet grouting	REMA-85-OL	AL231004	H	Linear and rotating jet grouting
Shredding and magnetic separation	REMA-93-OL	AL124103	H	Magnetic separation Cooperative Research and Development Agreement (CRADA)
Calcining/sintering	REMA-98-OL	RL421216	H	Tank waste treatment
		RL432004	H	Calcine residue leaching
In situ vitrification (buried waste)	REMA-100-OL	ID132010	H	Thermal kinetic processes
		ID132011	H	Arc melter vitrification
		OR101201	H	Issues evaluation
In situ biodegradation	REMA-110-OL	OR123302	H	Biodegradation
		SR121104	H	Integrated demonstration
In situ biological denitrification	REMA-111-OL	OR111203	L	Aqueous sodium nitrate
Thermoplastic encapsulation	REMA-112-OL	RF111203	H	Polymer development
Thermoset encapsulation	REMA-113-OL	RF111203	H	Polymer development
Sulfur polymer cement encapsulation	REMA-114-OL	CH331001	L	Bench-scale evaluations
		ID132012	L	Performance criteria

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Table 4.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Sensors for monitoring entombment integrity	REMA-118-OL	CH111203	M	Sensor technology implementation plan
Solvent extraction	REMA-119-OL	RL322101	M	Development of advanced processes
		OR121204	H	TRUEX® extraction process
Concrete-based solidification/stabilization	REMA-120-OL	CH321101	M	Advanced grouting materials

[a]TTP = Technical Task Plan identifier.

[b]The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

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5. Robotics and Automation

5. ROBOTICS AND AUTOMATION

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5.1 INTRODUCTION

There are a number of reasons why robotics/automation would be used for RA activities, including (1) to perform a task more efficiently than by direct human involvement or (2) to remove the humans from the hazardous environment and minimize the danger level to the humans. Both of these reasons are encountered in RA activities.

For the purpose of identifying the robotics/automation technologies applicable to RA, the RA activities have been grouped into six problem areas, as follows:

- buried waste,
- low-level waste tanks,
- impoundment,
- soils,
- ground water, and
- buried pipes.

Some of these problem areas will require very little involvement by robotics/automation while others may require extensive involvement, at least until the hazard level associated with the activity has been better defined. Further, each of these problem areas requires a somewhat different mix of robotics/automation technologies. It should also be noted that, in general, robotics/automation supports those other technological activities—including characterization, retrieval, and treatment—necessary to perform the actual remediation tasks.

000302

5.2 TECHNOLOGY OPTIONS

The robotics/automation technologies that are applicable to RA activities are listed in Table 5.1 (an X indicates which technologies are applicable to specific RA problem areas). As shown in the table, the robotics/automation technologies are grouped into nine functional categories. The technologies listed for RA tasks are primarily those required (1) to locate, characterize, and retrieve buried wastes, including buried pipes, (2) to sample and remove contaminated soil, and (3) to sample and remove the wastes from low-level waste storage tanks. Robotics/automation will have fewer applications in impoundment or ground-water treatment applications.

Generally, it will be necessary to combine a number of these robotics/automation technologies into integrated systems before a particular RA task can be performed effectively. For example, having a remotely operable vehicle (ROBA-2-OL) available to locate or characterize buried waste would not be particularly useful unless appropriate detection sensors (ROBA-47-OL), operator interfaces (ROBA-38-OL), and data/signal transmission devices (ROBA-13-OL) are also available. In setting priorities for needed R&D, consideration was also given to integrated robotics/automation systems.

Table 5.1. Relationship of robotics/automation technologies to remedial action problems

Data sheet code number	Remedial action problem area					
	Buried waste	LLW[a] tanks	Impound-ment	Soil	Ground water	Buried pipes
Mechanical—mobility						
ROBA-1-OL	X[a]		X	X	X	X
ROBA-7-OL			X			
ROBA-9-OL		X				
ROBA-10-OL	X		X	X	X	X
ROBA-11-OL	X			X		
ROBA-12-OL	X			X		X
ROBA-13-OL	X		X	X	X	X
Mechanical—manipulation						
ROBA-16-OL	X	X				X
ROBA-19-OL	X	X				X
Mechanical—mechanisms						
ROBA-21-OL		X				X
ROBA-22-OL	X	X				X
Mechanical—end-of-arm tooling						
ROBA-23-OL	X	X				X
ROBA-24-OL	X	X				X
ROBA-25-OL	X	X				X
ROBA-26-OL	X	X				X
Controls—algorithms						
ROBA-27-OL	X	X		X		X
ROBA-28-OL	X			X		X
ROBA-29-OL	X			X		X
ROBA-30-OL	X	X				X
ROBA-31-OL		X				
ROBA-32-OL	X	X		X		X
ROBA-33-OL		X				
ROBA-34-OL	X	X				X
ROBA-35-OL	X	X		X		X
ROBA-37-OL	X	X	X	X	X	X

Table 5.1 (continued)

Data sheet code number	Remedial action problem area					
	Buried waste	LLW[a] tanks	Impound-ment	Soil	Ground water	Buried pipes
Controls—human/machine interface						
ROBA-38-OL	X	X	X	X	X	X
ROBA-39-OL	X	X		X		X
ROBA-40-OL	X	X		X		X
ROBA-41-OL		X				X
ROBA-42-OL	X	X	X	X	X	X
Sensors—perception						
ROBA-43-OL	X	X	X	X	X	X
ROBA-44-OL		X				
ROBA-45-OL		X				
ROBA-46-OL	X	X		X		X
ROBA-47-OL	X			X		X
Sensors—control						
ROBA-48-OL	X	X		X		X
ROBA-50-OL	X	X				X
ROBA-51-OL		X				
ROBA-52-OL	X	X		X		X
Other technologies						
ROBA-53-OL	X	X	X	X	X	X
ROBA-54-OL	X	X				X
ROBA-55-OL	X	X	X	X	X	X
ROBA-56-OL	X	X	X	X	X	X
ROBA-57-OL	X	X	X	X	X	X
ROBA-58-OL	X	X	X	X	X	X
ROBA-59-OL	X	X	X	X	X	X

[a]LLW = low-level waste
[b]An X indicates that a technology is applicable to an RA problem area.

000305

5.3 SCIENCE AND TECHNOLOGY NEEDS

Specific needs, with short explanations of the reasons why additional R&D is required, are given below for each of the RA problem areas.

5.3.1 Buried Wastes and Buried Pipes

Many of the records showing the location and the contents of buried-waste fields have either been lost or destroyed, or accurate records were never kept. Similar problems exist for some of the buried pipes that have carried radioactive fluids in the past. Also, since the hazards associated with these waste fields are not well defined and may exceed those to which humans can be exposed, the surveys necessary to characterize these burial grounds will be performed remotely using teleoperated or robotic vehicles to deploy the detection sensors. Needs related to this activity are included in the following sections:

5.3.1.1 Remotely Deployable, Nonintrusive Sensors (ROBA-47-OL)

Present sensors have limited usefulness. Ground-penetrating radar has limited range in the soil encountered on ORR, particularly if clay caps have been placed on the waste field. Conductivity probes can be disrupted by the metallic signature of the robotic vehicle used to deploy the probes. Radioactivity meters and organic gas detectors cannot indicate the burial depth or the quantity of buried materials. Efforts to improve the capabilities of sensors are required, and it is assumed this technology need will be addressed by characterization programs. The integration of these various types of sensors onto a remotely deployed vehicle is also a technology need that requires additional R&D. Addressing this need will minimize potential interference between the sensors and other systems on the deployment vehicle.

5.3.1.2 Low-Metallic Content, Remotely Driven Vehicle (ROBA-1-OL)

A vehicle of this type is needed to minimize interference with the detection sensors carried by the vehicle. Some work in this area is presently being conducted by the Office of Technology Development Robotics Program, with a technical demonstration planned for later in this calendar year.

5.3.1.3 Tool Caddies (ROBA-21-OL)

Methods of stowing various tools where they are easily accessible to a manipulator arm is a technology need that has not been adequately addressed in previous robotics/automation programs. The present approach is to move the manipulator away from the work site to a tool storage area when tool changes are necessary. Having an on-board tool caddie would greatly increase the efficiency of the remote operations and would be particularly useful in the repair or replacement of buried pipes where frequent tool changes may be necessary.

5.3.1.4 Navigation of Robotics Vehicles on Waste Sites (ROBA-29-OL)

In the surveying of waste sites, relatively precise information on the position of the vehicles conducting the survey is required to relate data from the detection instruments to burial site location. Although several instruments to provide this information are available commercially (e.g., Ultrasonic Ranging and Data System), they generally require line-of-sight between the detectors and the vehicle and may not be applicable to many of the terrains encountered on the ORNL waste sites.

5.3.2 Low-Level Waste Storage Tanks

The condition of storage tanks at ORNL varies from active tanks that are in reasonably good shape but nearing capacity (Melton Valley Storage Tanks) to storage tanks in which the domes are in danger of collapsing (Gunite storage tanks). Generally, the radioactivity levels in these tanks are sufficiently high. Therefore, remediation tasks will have to be performed remotely using robotics/automation technologies. The highest priority science and technology needs to perform these tasks are summarized in the following sections.

5.3.2.1 Long-Arm Deployed Robotic Platforms (ROBA-9-OL)

Many of the storage tanks are quite large and have limited penetrations, making the remediation activities difficult. A reasonably compact, long-reach arm capable of entering the existing top-of-the-tank penetrations and accessing the lower periphery of the vessel is a high priority. The length of the arm and its inherent flexibility present control and stability problems that must be addressed in the R&D program.

5.3.2.2 Support and Stabilization Platforms (ROBA-22-OL)

Methods of supporting long-arm deployed robotic platforms, particularly for the remediation of deteriorated tanks, where no additional load can be placed on the dome of the vessel, is a technology need that is only recently being addressed in other programs. Ideally this platform could be used on a variety of vessels, regardless of their size.

5.3.2.3 Force-Limiting and Compliant End-of-Arm Mechanisms (ROBA-26-OL)

The development of a method of remotely adjusting and limiting the force that an arm or tool can exert on a surface, such as a tank wall, is also a technology need for robotics/automation. Although force reflecting manipulators are commercially available, these units depend on the ability of an operator to sense forces transmitted back through the control system and are not sufficient to prevent damage during remote operations.

5.3.3 Soils

Rather large quantities of contaminated soils are present at ORNL. Although surface soils probably are not sufficiently contaminated to require remote operations, soils adjacent to buried wastes, buried and leaking pipes, and leaking low-level waste storage tanks may be highly contaminated and will require removal by remote means. There is also an economic incentive to minimize the amount of soil removed for treatment or waste

disposal. The science and technology needs required for robotics/automation for soil remediation are summarized below.

5.3.3.1 Front-End Loaders and Backhoes for Minimum Soil Removal (ROBA-2-OL)

A remotely operated, heavy-duty vehicle with sufficient sensors to control the depth of soil removal is a high priority science and technology need for robotics/automation. There is presently a jointly funded Department of Defense and DOE Office of Technology Development Robotics Program to develop the first prototype of a vehicle with these capabilities, and a technical demonstration is planned for late in calendar year 1993. This program should be continued to the point so that the technology can be turned over to a private company for commercial deployment.

5.3.4 Impoundment

At the present time confinement of contaminants in sediments has been effectively controlled by coffer dams. In the future, however, if migration of the contaminants occurs, it may be necessary to consider techniques to remove the sediments from the impoundment areas.

5.3.4.1 Specialized Robotic Deployment Platforms (ROBA-7-OL)

Use of available techniques for sediment removal (e.g. surface dredging) would result in a significantly greater release of contaminants during the treatment period. Methods of deploying equipment to remove sediments with minimal disturbance of the surrounding material are required. Underwater deployment of sediment removal equipment, using remotely operated submersibles, would be one method of accomplishing this task.

Remotely operated submersibles have been used for some time for off-shore oil rigs and ocean exploration. However, for shallow water operations in freshwater impoundments, experience has shown that the primary difficulty is the limited visibility. This is particularly true when the bottom sediment is being disturbed or, during warm weather months, when algae growth is at a maximum. In addition to specialized robotic deployment platforms, specialized sensors (ROBA-43, -44, and -45-OL) may also be required for these robotic applications.

5.4 IMPLEMENTATION NEEDS

For RA activities high-priority implementation needs are cold-test beds where the effectiveness of robotic systems to detect, characterize, sample, and remove buried wastes, buried pipes and soils can be demonstrated prior to performing the actual remediation effort. Similar facilities are needed for the development and testing of the robotic devices that would be used to recover residual wastes from low-level waste tanks.

An additional implementation need is quantitative information on the anticipated physical and radiological characteristics of the various waste materials, particularly those that are likely to be encountered in buried waste sites and as residual materials in the low-level waste tanks. Without this information, it will be very difficult to determine the required capabilities of the robotic systems used to deploy the sensors and tools needed for the remediation efforts.

5.5 TECHNOLOGY RANKINGS

The rankings of the robotics/automation technologies required for RA activities are given in Table 5.2. It should be noted that the criteria used for ranking are biased toward those technologies that are commercially available. Hence, a one-for-one comparison between the rankings and the science and technology needs identified in Sect. 5.3 is not possible (i.e. commercially available devices generally require little additional R&D). It should also be noted that several of the criteria suggested for ranking were not considered applicable to robotics/automation. These include (1) compliance with requirements or regulations, (2) ES&H requirements, and (3) unit processing costs. Others of the criteria have limited applicability to robotics/automation.

A number of the technologies were considered essential. However, many of these technologies also had a high ranking, which meant they were commercially available. The essential technologies were usually associated with highly ranked site problems also.

The development costs identified in Table 5.2 should be considered rough order-of-magnitude estimates. They have more validity in the comparison of relative costs between various robotics/automation technologies (i.e. they are internally consistent), than they do in their absolute magnitude.

Table 5.2. Rankings of robotics/automation technologies for remedial action

Data sheet code number	Technology	Ranking[a]
	Mechanical—mobility	
ROBA-1-OL	Wheeled/tracked vehicles	E-5-2 ($3M;N)
ROBA-7-OL	Specialized robotic deployment platforms	M-4-3 ($5M;N)
ROBA-9-OL	Long-arm deployed robotic platform	M-5-3 ($5M;N)
ROBA-10-OL	Power sources for mobile platforms	E-5-1 ($0.5M;N)
ROBA-11-OL	Failure recovery systems for mobile platforms	E-5-1 ($0.5M;N)
ROBA-12-OL	Transportation methods for mobile platforms	M-3-1 ($0.5M;N)
ROBA-13-OL	Data/signal transmission	E-5-1 ($0.5M;N)
	Mechanical—manipulation	
ROBA-16-OL	Dexterous manipulators	E-5-1 ($1M;N)
ROBA-19-OL	Compact, high-capacity manipulators	H-5-1 ($1M;N)
	Mechanical—mechanisms	
ROBA-21-OL	Tool caddies	H-4-1 ($0.5M;N)
ROBA-22-OL	Stabilization/support mechanisms or booms	M-3-1 ($0.5M;N)
	Mechanical—end-of-arm tooling	
ROBA-23-OL	End effectors/alternatives	E-5-2 ($1M;N)
ROBA-24-OL	End-effector changeout mechanisms	M-3-1 ($0.5M;N)
ROBA-25-OL	General gripper/tool interface	H-4-1 ($0.5M;N)
ROBA-26-OL	Force limiting/compliant mechanisms	M-3-1 ($0.5M;N)
	Controls—algorithms	
ROBA-27-OL	Control modes	E-5-N ($N;N)
ROBA-28-OL	Vehicle/mobility driving	E-5-1 ($0.5M;N)
ROBA-29-OL	Vehicle/mobility navigation	H-4-1 ($0.5M;N)
ROBA-30-OL	Manipulation (joint control)	H-4-1 ($0.5M;N)
ROBA-31-OL	Manipulation (Cartesian control)	H-4-1 ($1M;N)
ROBA-32-OL	Manipulation (special purpose control)	H-4-2 ($1.5M;N)
ROBA-33-OL	Manipulation (redundancy control)	M-3-2 ($2M;N)
ROBA-34-OL	Combined mobility/manipulation	M-2-2 ($1M;N)
ROBA-35-OL	Safety (collision avoidance)	H-4-1 ($1M;N)
ROBA-36-OL	Safety (load/rate limiting)	H-3-1 ($0.5M;N)
ROBA-37-OL	Emergency shutdown	E-4-1 ($0.5M;N)
	Controls—human/machine interface	
ROBA-38-OL	Console (fixed/mobile/suitcase)	E-5-1 ($0.5M;N)
ROBA-39-OL	Console (data handling methods)	M-3-1 ($1M;N)
ROBA-40-OL	Operator interface (command input)	H-3-1 ($0.5M;N)

000311

Table 5.2 (continued)

Data sheet code number	Technology	Ranking[a]
	Controls—human/machine interface (continued)	
ROBA-41-OL	Operator interface (operator assistance)	H-3-2 ($1.5M:N)
ROBA-42-OL	Operator interface (status/alert system)	E-5-1 ($0.5M:N)
	Sensors—perception	
ROBA-43-OL	Visual/aural systems	E-5-1 ($1M:N)
ROBA-44-OL	Range finders	M-3-2 ($1.5M:N)
ROBA-45-OL	Proximity probes	M-2-2 ($1M:N)
ROBA-46-OL	Force/torque (sensors)	M-2-1 ($0.5M:N)
	Sensors—control	
ROBA-48-OL	Position/velocity sensors	E-5-1 ($0.5M:N)
ROBA-50-OL	Force/torque	H-3-1 ($0.5M:N)
ROBA-51-OL	Proximity probes as control sensors	H-3-1 ($1M:N)
ROBA-52-OL	Tooling sensors	H-3-1 ($0.5M:N)
	Other technologies	
ROBA-53-OL	Field hardening	E-5-1 ($0.5M:N)
ROBA-54-OL	Radiation hardening	M-3-2 ($2M:N)
ROBA-55-OL	Integrated automated analytical laboratory	E-5-2 ($3M:N)
ROBA-56-OL	Information management for sample handling	E-5-1 ($1M:N)
ROBA-57-OL	Sample collection	E-5-1 ($1.5M:N)
ROBA-58-OL	Characterization sensor integration	M-5-2 ($1M:N)
ROBA-59-OL	Sample preparation	E-5-1 ($1M:N)

[a] The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M:N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

000312

5.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the robotics/automation technologies listed in Table 5.2. A search of available information on programs funded in FY 1992 and FY 1993 was performed to identify possible matches with the complete set of robotics/automation technologies listed in the TLD, Vol. 1, Pts. A, B, and C. The results of this search as presented in Table 5.3 include, but are not limited to, robotics/automation technologies listed in Table 5.2. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding robotics/automation technology code by TTP number. When no FY 1993 matches were found and the searchers (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Robotics/automation technologies for which no match was found are omitted from the table. When many matches were found only one or two were cited. The relevance column indicates the degree of overlap between the technologies listed in Vol. 1, Pts. A, B, and C, and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 5.3. Robotics/automation technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Wheeled/tracked vehicles	ROBA-1-OL	OR113202	M	Robotics for buried waste
		OR113203	H	Crosscutting and advanced technology
		OR113206	H	Demonstr. of telerobotic dismantlement
		SR123201	H	Robotics for decontamination and decommissioning (D&D)
Pipe/duct crawler (internal)	ROBA-5-OL	AL213204	L	Miniature robotics
		SF213203	L	Remote microsensor technology
Pipe/duct crawler (external)	ROBA-6-OL	AL223201	H	Robotic external pipe decontamination
		OR113206	H	Robotic asbestos removal
		SR123201	H	Robotic asbestos bagging
Specialized robotic development	ROBA-7-OL	AL213204	H	Crosscutting and advanced technology
		SF213203	H	Crosscutting and advanced technology
		SF223203	H	Robotics technology development
		OR113203	H	Crosscutting and advanced technology
Transportation methods of mobile platforms	ROBA-12-OL	AL213205	M	Remote drum handling equipment
Data/signal transmission	ROBA-13-OL	AL213204	H	High-bandwidth long cable, harsh env.
		AL322002	H	Data acquisition modules
		SF213205	H	Data and video telemetry
Long-reach manipulator (light duty)	ROBA-14-OL	RL313202	H	Long-arm, light duty manipulator for underground tanks
Long-reach manipulator (heavy duty)	ROBA-15-OL	OR113206	H	Demonstration arm collision avoidance
		AL213204	H	Development high payload long-arm
Dexterous manipulators	ROBA-16-OL	OR113202	H	Robotics for buried waste
		AL213201	H	Robotics for buried waste
		AL213202	H	Robotics for buried waste
Precise programmable motions	ROBA-20-OL	AL213204	M	Programmed robotic motion
		SR113201	M	Programmed teleoperated control
		RL332004	M	Short-reach dexterous manipulator
End effectors/alternatives	ROBA-23-OL	AL213201	H	End-effector development
		AL213207	H	End-effector development
		RL332004	H	End-effector development
End-effector change out mechanisms	ROBA-24-OL	SR123201	M	Robotics for D&D

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Table 5.3 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Vehicle/mobility navigation	ROBA-29-OL	OR113203 OR113205 RL313203	L L L	Crosscutting and advanced technology Crosscutting and advanced technology Robotics for buried waste
Manipulation (joint control)	ROBA-30-OL	AL213201	M	Joint failure reconfiguration
Manipulation (special purpose control)	ROBA-32-OL	AL221205	L	In-tank hardware removal
Manipulation (redundancy control)	ROBA-33-OL	AL213104	M	Kinematic redundancy of controls in crosscutting
Safety (collision avoidance)	ROBA-35-OL	AL213201 (Many)	M	Robotics for storage tanks (No new methods developed)
Console (data handling methods)	ROBA-39-OL	AL232002	L	Computer interface/end effector
Operator interface (command input)	ROBA-40-OL	RL313203 OR113202	L L	Robotics for buried waste Robotics for buried waste
Operator interface (operator assistance)	ROBA-41-OL	OR113203 AL213204	L L	Crosscutting and advanced technology Crosscutting and advanced technology
Operator interface (status/alert system)	ROBA-42-OL	OR113203 AL213204	L L	Crosscutting and advanced technology Crosscutting and advanced technology
Range finders	ROBA-44-OL	OR113201 (Many)	L	Robotics storage tanks
Proximity probes	ROBA-45-OL	OR113203 AL213204	L L	Crosscutting and advanced technology Crosscutting and advanced technology
Force/torque sensors	ROBA-46-OL	OR113203 RL313205	H H	Crosscutting and advanced technology Crosscutting and advanced technology
Detection instruments	ROBA-47-OL	OR113203	M	Crosscutting and advanced technology
Force/torque	ROBA-50-OL	OR113203 AL213204	H H	Crosscutting and advanced technology Crosscutting and advanced technology
Tooling sensors	ROBA-52-OL	SR123201	M	Robotics for D&D
Field hardening	ROBA-53-OL	AL213204 (Many)	L	Crosscutting and advanced technology
Radiation hardening	ROBA-54-OL	AL213204 (Many)	M	Crosscutting and advanced technology

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Table 5.3 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Integrated automated analytical laboratory	ROBA-55-OL	AL213203	H	Robotic contaminant analysis automation
Information management for sample handling	ROBA-56-OL	AL213203	H	Robotic contaminant analysis automation
Sample collection	ROBA-57-OL	AL213203	H	Robotic contaminant analysis automation
Characterization sensor integration	ROBA-58-OL	AL213204	H	Crosscutting and advanced technology

[a]TTP = Technical Task Plan identifier.

[b]The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

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6. Regulatory Compliance

6. REGULATORY COMPLIANCE

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6.1 INTRODUCTION

Many government-owned facilities that supported the early nuclear energy research and defense programs have no current use and have been retired. Some of these DOE facilities have residual radioactive or chemical contamination levels that require cleanup. ER of these facilities is currently focusing on D&D of facilities and RA for contaminated soils, ground water, and surface water. A related issue is WM of any wastes generated by these activities, as well as those wastes related to daily performance.

ORR was proposed by the EPA for placement on the National Priorities List under CERCLA on July 14, 1989 [54 *Federal Register (FR)* 29820], with final National Priorities Listing on Nov. 21, 1989, effective Dec. 21, 1989 (54 *FR* 48184). As a result of this listing, DOE, EPA, and TDEC (formerly the Tennessee Department of Health and Environment) have signed an FFA for the ER ORR (effective Jan. 1, 1992). This FFA is an Interagency Agreement required by §120 of CERCLA. FFA §IV discusses the coordination between RCRA and CERCLA, and states that corrective actions previously established under DOE's current RCRA permit [Hazardous and Solid Waste Amendments (HSWA) of 1984 TN 001] and the TDEC RCRA permit (TN1 890 090 003) will be supplemented with response actions under CERCLA to ensure comprehensive remediation ORR. Because ORR is on the National Priorities List, most RA activities and technologies will be legally subject to CERCLA regulation, and the FFA will govern the scheduling and character of such activities.

An effort is under way to incorporate into the FFA all inactive facilities that are known or suspected to contain significant quantities of residual hazardous materials. These facilities would be added to project lists under the FFA, and would subsequently undergo remediation pursuant to CERCLA or RCRA. Facilities that remain listed as D&D activities would be closed under the D&D program, subject to the regulatory drivers detailed in Vol. 1, Pt. A, Chap. 7. The scope of this chapter will address regulatory drivers for remedial activities proceeding under RCRA and CERCLA.

Further, DOE has entered into a number of signed agreements with state and federal parties, as well as appraisals and audits that define committed milestones for ER and WM activities. Some of these major committed milestones impacting ORNL RA activities include the *FFA for the ORR*, the *Tennessee/DOE Monitoring and Oversight Agreement (TOA)*, and the *Compliance Agreement Between the U.S. DOE - Oak Ridge Reservation and the EPA, Region IV (LDR-FFCA/ORR)*.

The FFA among DOE, EPA Region IV, and TDEC focuses on resolving compliance issues associated with ER ORR. The agreement sets up a procedural framework and schedule for developing, implementing, and monitoring response actions conducted in compliance with RCRA, CERCLA, NEPA, Tennessee laws/regulations, and other applicable and appropriate requirements.

The TOA details the obligations and agreements between DOE and TDEC with respect to the DOE provision for technical and financial support of state environmental activities. These activities include participation in the FFA, covering ER ORR, oversight, monitoring, accessing, and emergency response initiatives. Such activities are designed to ensure compliance with applicable federal, state, and local laws and regulations concerning ORR and its environs.

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The LDR-FFCA/ORR was signed June 12, 1992 in order to bring mixed-waste generation and storage facilities at ORR into compliance with the RCRA land disposal restrictions (LDRs) for mixed waste. The LDR-FFCA/ORR allows DOE ORR facilities to continue to generate and store mixed wastes while addressing LDR mixed-waste compliance issues. The mixed wastes covered under the LDR-FFCA/ORR include flammable and corrosive liquids, solvents, paint waste, waste oils and organics, and solid-mixed wastes. The LDR-FFCA/ORR is addressed in more detail in Sect. 6.4.2.

In addition to the above signed agreements, other agreements are pending, including one that would allow for the continued storage of PCBs at ORNL.

The Federal Facility Compliance Act (FFCA) of 1992 (Public Law 102-386, October 6, 1992) will also impact on committed milestones for RA activities. This Act amends §6001 of the Solid Waste Disposal Act (SWDA) to waive immunity of the United States with respect to substantive and procedural requirements regarding control, abatement, or management of solid or hazardous waste and is discussed in detail in Sect. 6.4.2.

DOE has also published its strategy for development of a national compliance plan for DOE mixed waste (57 *FR* 57170, December 3, 1992). DOE's National Compliance Plan will integrate ER and D&D activities with the development of appropriate mixed-waste treatment, storage and disposal capacity.

A second group of milestones, not considered commitments, are derived primarily from DOE's annual *Five Year Plan*, *Current Year Work Plans*, and *Activity Data Sheets*.

All of the above milestones, both committed and uncommitted, currently serve as regulatory drivers for RA activities in addition to applicable promulgated regulations triggered under CERCLA. This chapter will only define regulatory drivers for D&D and RA activities proceeding under CERCLA (i.e., FFA ER sites). These RA activities will address contaminated soil, ground water, burial grounds, point and line sources of contamination, and pond-waste sludges. Regulatory drivers for those D&D activities that only involve decontamination and dismantling of buildings or structural components (i.e., sites that will not be listed under the FFA as ER sites) are addressed in Vol. 1, Pt. A, Chap. 7.

In addition to regulatory issues pertaining to RA, any wastes generated under any regulatory umbrella must be managed according to prescribed WM procedures. Vol. 1, Pt. C, Chap. 7, will address federal, state, and local codes, DOE orders, Interagency Agreements and Federal Facility Compliance Agreements as they apply to WM practices at ORNL.

6.2 OVERVIEW OF ENVIRONMENTAL LAWS AFFECTING RA ACTIVITIES

As DOE begins RA at some of its ORNL facilities, special attention must be given to the environmental laws that will impact on these activities. These laws were promulgated to protect public health and the environment. The requirements of these environmental laws will dictate how the RA activities are to be carried out. This section gives a general overview of the major environmental regulations that will affect DOE RA activities.

The purpose of RCRA is to ensure the safe and environmentally acceptable management of hazardous and nonhazardous solid wastes. This law outlines the framework for national programs to achieve environmentally sound management of both hazardous and nonhazardous wastes. It is also concerned with the promotion of resource recovery techniques to reduce waste volume. The HSWA both expanded the scope of RCRA and increased the level of detail in many of its provisions.

CERCLA as amended by Superfund Amendments and Reauthorization Act (SARA) of 1986, was passed in response to a growing national concern about the release of hazardous substances into the environment. CERCLA provides for liability, compensation, clean up, and emergency response for hazardous substances released into the environment and the clean up of inactive hazardous-waste disposal sites. The intent of CERCLA is to provide for response to, and cleanup of, environmental problems that are not covered by the permit programs of the many other environmental laws.

CERCLA specifies that RA for clean up of hazardous substances must comply with requirements or standards under federal or more stringent state environmental laws that are applicable or relevant and appropriate to the hazardous substances or particular circumstances at a site. Inherent in the interpretation of ARARs is the assumption that protection of human health and the environment is ensured. The National Oil and Hazardous Substances Pollution Contingency Plan was amended to reflect changes made by SARA. In particular, Subpart E, "Hazardous Substance Response," contains a detailed plan of authorized activities involved in abating and remediating releases or threats of releases of hazardous substances, including compliance with all ARARs. If remedial activities proceed under RCRA, compliance with all legally applicable federal and state regulations must be assured; under CERCLA, compliance is also required with regulations that meet the definition of "relevant and appropriate" as defined in the National Contingency Plan.

Despite the completion of RAs to clean up a release of a hazardous substance, a natural resource such as land, fish, wildlife, biota, air, water, ground water, or drinking water supplies may suffer residual damages (i.e., the natural resource is not returned to the position it was in before the injury). In these situations, under the authority of CERCLA §122(j), a Natural Resource Trustee is authorized to conduct a natural resource damage assessment (NRDA). CERCLA authorized the Department of the Interior to promulgate regulations at 43 CFR 11 outlining the NRDA process. Because DOE caused the release, it becomes the responsible party and is liable to the Natural Resource Trustee(s) for financial compensation for the irreparable harm done to the natural resource. The NRDA process includes collecting, compiling, and analyzing information, statistics, or data through prescribed methodologies to determine damages for injuries to natural resources.

As a result of ORR's listing on the National Priorities List, DOE, EPA, and TDEC have signed a FFA for the ER ORR. This FFA is an Interagency Agreement required by §120 of CERCLA. FFA §IV discusses the coordination between RCRA and CERCLA, and states that corrective actions established under DOE's current RCRA permit and the TDEC

RCRA permit will be supplemented with response actions under CERCLA to ensure comprehensive remediation at ORR. Because ORR is on the National Priorities List, most RA activities and technologies will be legally subject to CERCLA regulation, and the FFA will govern the scheduling and character of such activities. Following is a summary of all federal laws and regulations that may be legally applicable to cleanup of ER sites that are grouped in the FFA under the umbrella of CERCLA.

The Clean Air Act (CAA) of 1970 is the major federal law regulating process and facility air emissions. The objectives of the CAA are to protect and enhance the quality of the nation's air resources and to protect public health and welfare, while fostering a beneficial productive capacity. This is accomplished through National Ambient Air Quality Standards, National Emission Standards for Hazardous Air Pollutants, air permits, and other standards and requirements set forth under the CAA. The CAA amendments of 1990 established a list of 189 hazardous-air pollutants for which technology-based emission standards must be set. Depending on the type of activity or technology proposed, RA might be subject to any one or all of these CAA standards.

The Clean Water Act of 1972 (CWA) is the major water-related statute affecting D&D activities. The objectives of CWA include prohibition of toxic discharges, protection of fish and wildlife, and availability of federal funds for public-waste treatment works. All DOE facilities that discharge wastewaters to either a surface-water body or a publicly owned treatment system must ensure compliance with the CWA.

The Safe Drinking Water Act (SDWA) of 1974 is an environmental statute that protects drinking water resources. Primary drinking water standards promulgated under the SDWA apply to drinking water "at the tap" as delivered by public water supply systems. As such, the standards are directly applicable to those DOE facilities that meet the definition of a public water supply system. Of equal significance to DOE is the fact that these drinking water standards are used to determine ground-water protection regulations under a number of other statutes.

The Atomic Energy Act (AEA) of 1954 delegates authority to DOE, NRC, and EPA to control nuclear energy. NRC has the authority to issue licenses for use of radioactive materials at certain types of facilities and can promulgate rules regulating that use. DOE is exempt from NRC's authority under the AEA. Although NRC regulations are not legally applicable to DOE sites, DOE addresses the regulation of radioactive materials in its DOE orders that are binding on all DOE sites. Standards outlined in the DOE orders reiterate, for the most part, the standards promulgated under NRC regulations.

The Toxic Substances Control Act (TSCA) of 1976 is a comprehensive act governing toxic substances. TSCA protects human health and the environment by requiring that specific chemicals be tested and that regulations restricting their processing and use be implemented. The objectives of TSCA include development of adequate data to determine the health and environmental effects of chemicals and control of any chemicals that present an unreasonable risk of injury. RA activities involving PCBs and asbestos-contaminated materials, in particular, would be regulated under this act.

The Hazardous Materials Transportation Act (HMTA) of 1975, as amended, is the major transportation-related statute affecting DOE. The objective of the HMTA is "to improve the regulatory and enforcement authority of the Secretary of Transportation to protect the nation adequately against risks to life and property which are inherent in the transportation of hazardous materials in commerce." Any transportation of hazardous or radioactive materials off site from an RA site would be regulated under HMTA.

The Occupational Safety and Health Act (OSHA) of 1970 is concerned with providing employees with a safe and healthy working environment. Under OSHA, rules have been promulgated to protect employees involved with cleanup operations at uncontrolled

hazardous-waste sites and to provide for worker protection during initial site characterization and analysis, monitoring activities, materials handling activities, training, and emergency response. All OSHA requirements apply to all DOE ER activities. DOE addresses occupational safety in DOE Orders 5480.11 (*Radiation Protection for Occupational Workers*), 5480.4 (*Environmental Protection, Safety, and Health Protection Standards*), 5483.1A (*Occupational Safety and Health Program for Contractors at Government-Owned, Contractor-Operated Facilities*), and 5480.9 (*Construction Safety and Health Program*), and it is understood that DOE will comply with these Orders. The DOE orders related to occupational safety are not addressed in this chapter unless they specifically apply to RAs.

NEPA establishes national policies and goals for protection of the environment. The purposes of NEPA include encouraging harmony between people and the environment, promoting efforts to prevent or eliminate damage to the environment and the biosphere, and encouraging the understanding of ecological systems and natural resources important to the country. NEPA ensures that federal agencies take into account the environmental impact of their actions through a procedure and detailed statement known as an Environmental Impact Statement. DOE Order 5440.1D (*National Environmental Policy Act Compliance Program*) mandates DOE compliance with the requirements of NEPA. Further, DOE Order 5400.4 [*Comprehensive Environmental Response, Compensation, and Liability Act Requirements* (CERCLA)] calls for integration of NEPA and CERCLA requirements for DOE RAs at CERCLA sites. This issue has been reaffirmed in the FFA §I(A)(3) and §III(A)(2) and Secretary of Energy Notice of Feb. 5, 1990 (SEN-15-90), which was issued to ensure that DOE's NEPA activities are carried out in a centralized and uniform manner.

The Endangered Species Act of 1973 and the Fish and Wildlife Coordination Act of 1958 are major federal statutes designed to protect plant and animal resources from adverse effects of development projects. Both acts require consultation with wildlife authorities before committing resources to certain types of projects. The Endangered Species Act provides for the designation and protection of invertebrates, wildlife, fish, and plant species that are in danger of becoming extinct and mandates conservation of the ecosystems on which such species depend. The Fish and Wildlife Coordination Act was enacted because the goals of water-related projects may at times conflict with the goal of conserving fish and wildlife resources. This act ensures that fish and wildlife resources receive equal consideration with other factors during the planning of development projects that affect water resources.

The Federal Insecticide, Fungicide, and Rodenticide Act of 1947 regulates pesticides. Its purpose is to control the use of pesticides by requiring that all pesticides be registered with the EPA. Under Federal Insecticide, Fungicide, and Rodenticide Act, EPA conducts inspections to ensure compliance with Federal Insecticide, Fungicide, and Rodenticide Act, (e.g., having pesticides labeled and stored properly). The act regulates the proper disposal of pesticides, which may impact on RA activities involving pesticides or pesticide-contaminated materials.

It should be noted that all the major environmental laws also specify designated test methods and detailed sampling and analysis protocols that must be followed when testing materials or substances or verifying the applicability of a particular law to a given situation, substance, or material.

DOE has issued orders, as discussed above, addressing many of the activities regulated under the above-mentioned environmental statutes. These DOE orders are binding between DOE and its contractors, in this case, Martin Marietta Energy Systems,

Inc., which operates the facilities in Oak Ridge, Tennessee. Pertinent DOE orders will be considered throughout the chapter as they relate to ER activities at DOE facilities.

Environmental laws enacted by the state of Tennessee generally correlate to their federal counterparts. The differences that arise between the state and federal laws will be pointed out throughout the chapter.

Specific requirements and standards promulgated under each of the above laws are discussed in detail in the following sections. This regulatory summary has been modified from the ER report *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation. A Compendium of Major Environmental Laws.*[1] Regulations are grouped into four major areas: (1) *chemical-specific* regulations—standards or limits based on the particular contaminant or pollutant present; (2) *radiation protection* standards—regulations governing radioactivity, promulgated to protect the public health and environment; (3) *action-specific* regulations—performance or design standards or restrictions that set limits or controls based on the kind of activity planned at a site or designed into a particular technology; and (4) *location-specific* regulations—restrictions placed on pollutant concentrations or activities solely because they are in a particular location.

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Chemical-specific regulations set health- or risk-based concentration limits or discharge limitations in various environmental media for specific hazardous substances, pollutants, or contaminants. These requirements generally set protective cleanup levels for the chemicals of concern in a designated medium or indicate a safe level of discharge that may be incorporated when considering a specific remedial activity.

Although limited in number, chemical-specific standards have been established under several statutes, including RCRA, SDWA, CWA, TSCA, OSHA, CERCLA, and the CAA. Designated test methods and sampling/analysis protocols are delineated under each regulation for determining applicability of chemical-specific standards. These methods and protocols must be followed exactly as outlined in the regulation.

6.3.1 Ground Water and Surface Water

Table 6.1 lists available chemical-specific standards that have been promulgated under federal law for ground water, surface water, and air. The regulations for air are listed in the table and described in Sect. 6.3.2.

All ground water at ORR is scheduled to be cleaned up under CERCLA as part of the ER Program. As stated in the National Contingency Plan (55 *FR* 8666, March 8, 1990), the goal of EPA's approach to cleanup of contaminated ground water is to return usable ground water to its beneficial use within a given time frame that is reasonable for the particular circumstances at a CERCLA site. Ground water at ORR has not been given an EPA classification. Although not legally applicable unless promulgated, EPA guidance on ground-water classification should be used to determine whether ground water at ORR falls within Class I, II, or III. Classes I and IIA represent current sources of drinking water of varying value, Class IIB represents potential sources of drinking water, and Class III ground water is not considered a potential source of drinking water and is of limited beneficial use. Restoration time periods vary, depending on the use classification of the ground water, and may range from 1 year to several decades.

In the National Contingency Plan, EPA states the preference for SDWA maximum contaminant levels (MCLs) and nonzero maximum contaminant level goals (MCLGs) or other health-based standards, criteria, or guidance for cleanup of Class I and Class II ground water at CERCLA sites (55 *FR* 8732). Alternate concentration limits may also be used when active restoration of the ground water to MCLs or nonzero MCLGs is not practicable (55 *FR* 8754). For Class III ground waters, EPA establishes remediation levels based on specific site conditions, the beneficial use of the ground water, and environmental receptors (55 *FR* 8732). Final determination of applicable standards for site-specific cleanup of ground water at ORR will depend on the chosen ground-water classification.

The state of Tennessee has issued draft ground-water classification rules that classify ground water as: (1) Class A—current or future sources of drinking water; (2) Class B—not a current or future source of drinking water but protected for other beneficial uses; (3) Class C—not protected for drinking water or for other beneficial uses; and (4) Surface Water Recharge—ground water that recharges surface waters.

Class A ground waters are listed by aquifers; two are identified for East Tennessee—Cambrian-Ordovician Carbonate Aquifer and Crystalline Rock Aquifer. Final promulgation of this ground-water classification rule is projected for mid-1993.[2]

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Table 6.1. Chemical-specific federal regulations for protection of human health[a]

Chemical	RCRA[b] MCLs[c] (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs[d] (µg/L)	Clean Air Act NAAQS[e] (µg/m³)
Acrylamide[f]		TT[g]	0	
Adipates [di(ethylhexyl)adipate][h]		400	400	
Alachlor[f]		2	0	
Aldicarb[i]		3	1	
Aldicarb sulfone[i]		2	1	
Aldicarb sulfoxide[i]		4	1	
Antimony[h]		6	6	
Arsenic[j]	50	50		
Asbestos (fibers >10µm)[f]		7[k]	7[k]	
Atrazine[f]		3	3	
Barium[l]	1,000	2,000	2,000	
Benzene[m]		5	0	
Benzo(a)pyrene[h]		0.2	0	
Beryllium[h]		4	4	
Cadmium[n]	10	5	5	
Carbofuran[f]		40	40	
Carbon monoxide				40,000 (1-h)[o] 10,000 (8-h)[o]
Carbon tetrachloride[m]		5	0	
Chlordane[f]		2	0	
Chromium (total)[n]	50	100	100	
Copper		TT[p]	1,300	
Cyanide[h]		200	200	
Dalapon[h]		200	200	
1,2-Dibromo-3-chloropropane[f]		0.2	0	
o-Dichlorobenzene[f]		600	600	

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Table 6.1 (continued)

Chemical	RCRA[b] MCLs[c] (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs[d] (µg/L)	Clean Air Act NAAQS[e] (µg/m³)
p-Dichlorobenzene[m]		75	75	
1,2-Dichloroethane[m]		5	0	
1,1-Dichloroethylene[m]		7	7	
cis-1,2-Dichloroethylene[f]		70	70	
trans-1,2-Dichloroethylene[f]		100	100	
Dichloromethane (methylene chloride)[h]		5	0	
2,4-Dichlorophenoxyacetic acid (2,4-D)[n]	100	70	70	
1,2-Dichloropropane[f]		5	0	
Dinoseb[h]		7	7	
Diquat[h]		20	20	
Endothall[h]		100	100	
Endrin[h]	0.2	2	2	
Epichlorohydrin[f]		TT[g]	0	
Ethylbenzene[f]		700	700	
Ethylene dibromide[f]		0.05	0	
Fluoride[q]		4,000	4,000	
Glyphosate[h]		700	700	
Heptachlor[f]		0.4	0	
Heptachlor epoxide[f]		0.2	0	
Hexachlorobenzene[h]		1	0	
Hexachlorocyclopentadiene[h]		50	50	
Lead	50	TT[p]	0	1.5 (90-day)[r]
Lindane (*gamma*-HCCH)[n]	4	0.2	0.2	
Mercury[n]	2	2	2	
Methoxychlor[n]	100	40	40	
Monochlorobenzene[f]		100	100	

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Table 6.1 (continued)

Chemical	RCRA[b] MCLs[c] (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs[d] (µg/L)	Clean Air Act NAAQS[e] (µg/m³)
Nickel[h]		100	100	
Nitrate (as N)[n]		10,000	10,000	
Nitrite (as N)[f]		1,000	1,000	
Nitrate + Nitrite (as N)[f]		10,000	10,000	
Nitrogen dioxide				100 (1-year)[s]
Ozone				235 (1-year)[o,t]
Oxamyl (Vydate)[h]		200	200	
Particulate matter				260 (24-h)[o] 75 (1-year)[u]
Pentachlorophenol[f]		1	0	
Phthalates [di(ethylhexyl)phthalate][h]		6	0	
Picloram[h]		500	500	
Polychlorinated biphenyls[f]		0.5	0	
Selenium[n]	10	50	50	
Silver[v]	50			
Simazine[h]		4	4	
Styrene[f]		100	100	
Sulfate[w]		400,000/500,000	400,000/500,000	
Sulfur oxides				365 (24-h)[o] 80 (1-year)[s]
Tetrachloroethylene[f]		5	0	
Thallium[h]		2	0.5	
2,3,7,8-Tetrachlorodibenzo-p-dioxin (Dioxin)[h]		0.00003	0	
Toluene[f]		1,000	1,000	
Toxaphene[n]	5	3	0	

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Table 6.1 (continued)

Chemical	RCRA[b] MCLs[c] (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs[d] (µg/L)	Clean Air Act NAAQS[e] (µg/m³)
1,2,4-Trichlorobenzene[h]		70	70	
1,1,1-Trichloroethane[m]		200	200	
1,1,2-Trichloroethane[h]		5	3	
Trichloroethylene[m]		5	0	
Trihalomethanes (total)[l,x]		100		
2,4,5-Trichlorophenoxy-propionic acid (2,4,5-TP)[n]	10	50	50	
Vinyl chloride[m]		2	0	
Xylenes (total)[f]		10,000	10,000	

[a]Federally promulgated regulations under RCRA, SDWA, and the CAA are included in this table. Clean Water Act regulations are listed in Tables 6.4 and 6.5. Tennessee state drinking water MCLs/MCLGs (Chap. 1200-5-1 of the Rules of the TDEC) are identical to the federal.

[b]RCRA = Resource Conservation and Recovery Act (40 *CFR* 264.94).

[c]MCL = maximum contaminant level; RCRA MCLs are properly termed "maximum concentration limits."

[d]MCLG = maximum contaminant level goal.

[e]NAAQS = National Ambient Air Quality Standards (40 *CFR* 50.4, 50.6, 50.8 and 50.9 50.12).

[f]56 *FR* 3526 (January 30, 1991). Effective July 30, 1992.

[g]TT = treatment technology.

[h]57 *FR* 31776 (July 17, 1992). Effective January 17, 1994 except for the MCL/MCLG for Endrin which becomes effective August 17, 1992.

[i]Effective date for aldicarb compounds, originally set for January 1, 1993, is postponed indefinitely pending further study (57 *FR* 22178, May 27, 1992).

[j]40 *FR* 59570 (December 24, 1975).

[k]Million fibers per liter.

[l]56 *FR* 30266 (July 1, 1991). Effective January 1, 1993.

[m]52 *FR* 25690 (July 8, 1987).

[n]The final MCL/MCLG was set for this chemical (56 *FR* 3526, January 30, 1991) and supersedes the original interim SDWA MCL. Effective July 30, 1992; interim MCLs remain in effect until that time.

[o]Maximum concentration not to be exceeded more than once per year.

[p]TT= treatment technology; 56 *FR* 26460 (June 7, 1991, effective December 7, 1992). When the "action level" of 15 or 1300 µg/L, for lead or copper, respectively, measured in the 90th percentile at the consumer's tap, is exceeded for lead or copper, corrosion control study and treatment requirements are triggered. However, an OSWER memorandum (dated June 21, 1990) recommends that a final cleanup level of 15 µg/L for lead in ground water usable for drinking water is protective of sensitive subpopulations; this is guidance, not an ARAR.

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2251

Table 6.1 (continued)

Chemical	RCRAb MCLsc (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGsd (µg/L)	Clean Air Act NAAQSe (µg/m³)

[q]MCL - 51 *FR* 11396 (April 2, 1986); applies to community water systems only. MCLG - 50 *FR* 47141 (November 14, 1985).
[r]Three-month maximum arithmetic mean concentration.
[s]Annual arithmetic mean concentration.
[t]Hydrocarbon emissions are controlled as part of the ozone NAAQS strategy.
[u]Annual geometric mean.
[v]The interim SDWA MCL was revoked for this chemical (56 *FR* 3526, January 30, 1991) and a secondary MCL established instead (see Table 6.2). Effective July 30, 1992; interim MCL of 50 µg/L remains in effect until that time.
[w]This is a *proposed* MCL/MCLG only (55 *FR* 30370, July 25, 1990). EPA has deferred setting a final MCL/MCLG for sulfate pending further study (57 *FR* 31776, July 17, 1992).
[x]Total trihalomethanes refers to the sum of the concentration of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.
Source: Etnier et al., 1993.

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7251

6.3.1.1 Resource Conservation and Recovery Act

Subtitle C of RCRA lists maximum concentration levels for 14 chemicals; the concentration of these chemicals in ground water at the plant boundary of a RCRA-permitted treatment, storage, and disposal facility may not exceed the stated maximum concentration level. In addition, background concentrations or alternate concentration limits are established in 40 CFR 264.94 as ground-water protection standards. Table 6.1 lists RCRA maximum concentration levels; however, as mentioned above, EPA has specified SDWA MCLs and nonzero MCLGs for cleanup of Class I and Class II ground-water and site-specific remediation levels for Class III ground waters. This approach is consistent with the substantive requirements of RCRA maximum concentration levels, alternate concentration limits, or background limits (53 *FR* 51433). The newly promulgated regulations for municipal landfills (56 *FR* 50978, October 9, 1991) establish all SDWA MCLs by reference, and alternate concentration limits, or background concentrations as ground-water protection standards (40 CFR 258.55). Although not legally applicable to RAs found at ORR, these regulations may prove relevant and appropriate for cleanup of ground water at some of the sites. Alternate concentration limits may be calculated for chemicals without an MCL, using a risk-based approach (56 *FR* 51026).

Under the present RCRA Subtitle C hazardous-waste identification regulations, solid wastes ("solid wastes," as defined under RCRA, can be solid, liquid, semisolid, or contain gaseous material) generated during the D&D process would be subject to RCRA regulation under the following conditions: (1) if they are identified as RCRA-listed or RCRA-characteristic hazardous wastes pursuant to 40 CFR Part 261; (2) if they are a "mixture" of solid waste and listed hazardous waste "derived from" a listed hazardous waste, or (3) if they have a listed hazardous waste "contained in" the waste (40 CFR 261.3). Wastes are "characteristically hazardous" under RCRA if they (1) exhibit ignitability, corrosivity, reactivity, or toxicity, (2) meet certain toxicity criteria, or (3) contain certain toxic constituents (40 CFR 261.10-24). Currently, listed wastes remain hazardous unless they are "delisted" according to procedures set forth in 40 CFR 260.20 and 260.22.

In an attempt to address instances where regulation of listed hazardous waste under the jurisdiction of RCRA Subtitle C would cease without the need for a delisting petition, EPA proposed two alternative approaches for identifying a waste as a RCRA hazardous waste ("Hazardous Waste Identification Rule," 57 *FR* 21450, May 20, 1992). However, this proposed rule was withdrawn due to a large number of policy and technical issues. Congress has charged EPA with promulgating rules to address the "derived from" and "mixture" issues by October 1994.[3]

6.3.1.2 Safe Drinking Water Act

EPA has promulgated primary and secondary drinking water regulations applicable to public water systems that have at least 15 service connections or serve an average of at least 25 people daily at least 60 days of the year. National Primary Drinking Water Standards are established in 40 CFR 141 and include MCLs and MCLGs. New drinking water standards promulgated for eight synthetic organic chemicals (52 *FR* 25690, July 8, 1987) added a new category of suppliers referred to as noncommunity, nontransient systems that regularly serve at least 25 people for 6 months of the year. Table 6.1 lists SDWA MCLs and MCLGs.

MCLs are enforceable standards that take into consideration human health effects, available treatment technologies, and costs of treatment. MCLGs are strictly health-based standards that disregard cost or treatment feasibility and are not legally enforceable. MCLs are legally applicable to water "at the tap" but are not applicable to cleanup of ground water or surface water. However, they may be considered as relevant and appropriate in situations where ground water or surface water may be used for drinking water. CERCLA §121(d)(2)(A) specifically mentions that RAs must require a level or standard of control that at least attains MCLGs and federal ambient water quality criteria (WQC) where such goals or criteria are relevant and appropriate under the circumstances of the release. Although MCLGs and WQC are nonenforceable guidelines, Congress elevated them to a higher status by specifically mentioning them in CERCLA. Therefore, promulgated MCLGs are listed in Table 6.1. At present, EPA is planning to use the SDWA MCLs for RA compliance for carcinogens that have an MCLG of zero and any nonzero MCLG for systemic toxicants (55 *FR* 8752).

EPA has revised its drinking water standards for lead and copper, eliminating the MCL and replacing it with a treatment technique requirement (56 *FR* 26460, June 7, 1991). If an "action level" of 15 or 1300 µg/L, for lead or copper, respectively, is exceeded at the tap, a state is required to analyze source water samples and to decide what treatment levels are necessary to minimize lead or copper levels delivered to users from the affected distribution system. In the instance of contaminated ground water, the action levels for lead and copper are neither legally applicable nor relevant and appropriate for cleanup; however, for copper, the MCLG of 1300 µg/L is relevant and appropriate. In addition, the EPA Office of Solid Waste and Emergency Response final cleanup level of 15 µg/L for lead in ground water usable for drinking water is protective of sensitive populations (Office of Solid Waste and Emergency Response memorandum dated June 21, 1990). This might be considered TBC guidance for remediation of lead-contaminated ground water (footnoted in Table 6.1) and will serve as guidance to ensure the precision of analytical detection limits. TDEC has proposed a cleanup criteria of 15 µg/L for lead in ground water (TDEC Rule 1200-1-13-.08, Table 8-2). When promulgated this criteria will be applicable to cleanup.

Chapter 1200-5-1 of the Rules of the TDEC lists MCLs for public water systems that are identical to the federal MCLs. Therefore, the state regulations are not repeated here.

National Secondary Drinking Water Standards regulate contaminants that affect the aesthetic qualities related to public acceptance of drinking water and are implemented in 40 CFR 143.3 as secondary maximum contaminant levels (SMCLs) (see Table 6.2). These regulations are not federally enforceable but are intended to serve as guidelines for use by states in regulating water supplies. Tennessee has promulgated SMCLs in Chap. 1200-5-1.12 of the Rules of the TDEC (see Table 6.2). These regulations are designed to provide water to the consumer, which is aesthetically pleasing, and they apply to all community water systems and to those noncommunity water systems "as may be deemed necessary" by TDEC. In that context, they would not be legally applicable to cleanup of ground water or surface water, but may be considered as relevant and appropriate in instances where these media may provide private drinking water sources. EPA has proposed National Secondary Drinking Water Standards for ten additional contaminants (54 *FR* 22062, May 22, 1989; 55 *FR* 30370 July 25, 1990); when these are promulgated, they will be incorporated into the TDEC secondary drinking water regulations.[4] Therefore, they are included in Table 6.2 for completeness. EPA has published a final National Secondary Drinking Water Standards for aluminum and silver (56 *FR* 3526, January 30, 1991).

Table 6.2. Federal and Tennessee secondary drinking water regulations

Chemical	Federal SMCL[a] (mg/L)	Tennessee SMCL[b] (mg/L)
Aluminum	0.05–0.2[c,d]	
Chloride	250	250
Color (color units)	15	15
Copper	1	1
o-Dichlorobenzene[e]	0.01	
p-Dichlorobenzene[e]	0.005	
Ethylbenzene[e]	0.03	
Fluoride	2.0	2.0
MBAS (methyl blue active substance)		0.5
Hexachlorocyclopentadiene[f]	0.008	
Iron	0.3	0.3
Manganese	0.05	0.05
Odor (threshold odor number)	3	3
Pentachlorophenol[e]	0.03	
pH	6.5–8.5	6.5–8.5
Silver	0.1[c]	
Styrene[e]	0.01	
Sulfate	250	250
Toluene[e]	0.04	
TDS (total dissolved solids)	500	500
Xylene[e]	0.02	0.02
Zinc	5	5

[a]Final rule [44 *FR* 42198 (July 19, 1979)]. National Secondary Drinking Water Standards (NSDWS) are included in this table for completeness because they will be incorporated into the TDEC secondary drinking water regulations when they are revised.

[b]Chapter 1200-5-1.12 of the Rules of the TDEC.

[c]NSDWS final rule [56 *FR* 3526 (January 30, 1991)]. Effective date July 30, 1992.

[d]Level recommended to prevent posttreatment precipitation in the distribution system.

[e]Proposed NSDWS (54 *FR* 22062, May 22, 1989). EPA has deferred setting final standards for these chemicals pending further study (56 *FR* 3572, January 30, 1991).

[f]Proposed NSDWS (55 *FR* 30370, July 25, 1990); EPA has deferred setting a final standard for this chemical pending further study (57 *FR* 31776, July 17, 1992).

6.3.1.3 Clean Water Act

CERCLA §121(d)(2)(A) specifically states that RAs shall at least attain federal ambient WQC established under the CWA if they are relevant and appropriate. In determining whether any WQC are relevant and appropriate, one must consider the "designated or potential use of the surface or ground water, the environmental media affected, the purposes for which the criteria were developed, and the latest information available" [CERCLA §121(d)(2)(B)]. Federal WQC are derived for the protection of freshwater aquatic organisms and for the protection of human health from the consumption of contaminated drinking water and/or aquatic organisms.

Table 6.3 lists federal ambient WQC for the protection of human health. EPA has derived WQC for ingestion of drinking water and aquatic organisms and for the ingestion of aquatic organisms alone. Since neither of these categories is relevant and appropriate for consideration of contaminated ground water, WQC derived for the ingestion of drinking water alone are also included in Table 6.3. The EPA Region IV Water Quality Standards Unit has adjusted WQC for human health based on recent human toxicity information [reference doses (RfDs) and carcinogen slope factors (CSFs)] obtained from the EPA *Integrated Risk Information System*[5]. The values presented in Table 6.3 reflect the EPA Region IV revised WQC and are current as of October 1991.[6] They are intended to supersede all previous WQC. Federal WQC are not promulgated standards. They are intended to serve as guidelines for individual states to use in promulgating state water quality standards. When a state adopts federal WQC and promulgates them in their state regulations, then they become legally enforceable under that state's law.

As part of the federal requirement for a triennial review of state water quality standards, the TDEC Division of Water Pollution Control has promulgated amendments to Chaps. 1200-4-3 and 1200-4-4 of the Rules of the TDEC. TDEC has revised its water quality standards and promulgated the federal SDWA MCLs as WQC for domestic water supplies (effective date Aug. 30, 1991). Included in this revision are criteria for protection of recreational uses. These criteria are human health criteria derived to protect the consumer from consumption of contaminated fish; these criteria are similar to the federal WQC for the protection of human health from consumption of fish alone. However, they are based on a risk of 10^{-5} rather than the 10^{-6} risk on which the federal WQC are based. Tennessee WQC for human health are listed in Table 6.4.

Chapter 1200-4-3 of the Rules of the TDEC lists seven use-designation categories for Tennessee's surface waters and ground waters. Specific water quality standards are promulgated for each use category. Under the Tennessee Water Quality Control Act, the Tennessee Water Quality Control Board has classified the Clinch River for domestic water supply, industrial water supply, fish and aquatic life, recreation, irrigation, and livestock watering and wildlife uses (Chap. 1200-4-4 of the Rules of the TDEC). The tributaries to the Clinch River have various use classifications, that need to be analyzed on a site-specific basis. The standards also state that "all other streams, named and unnamed, which have not been specifically noted shall be classified for fish and aquatic life, recreation, irrigation, and livestock watering and wildlife uses." TDEC has promulgated a change in the use classification that adds recreation as a category for all segments of rivers and streams that are not currently classified as such (effective August 1991).

Table 6.5 lists federal WQC for the protection of freshwater aquatic life. EPA Region IV has also revised these WQC based on current toxicity and bioaccumulation data for aquatic organisms, and these appear in Table 6.5 as well. When the designated use classification requires protection of aquatic life or when environmental factors are being considered at an RA site, a WQC for the protection of aquatic life that is more stringent than the SDWA MCL may be appropriate for cleanup. TDEC has promulgated WQC for the protection of aquatic organisms, effective Aug. 30, 1991; these are identical, for the most part, to the federal WQC and are listed in Table 6.4.

6.3.2 Air Standards

Primary National Ambient Air Quality Standards for six chemicals appear in 40 CFR 50; these standards are based on the direct health effects of those chemicals to sensitive groups, with no economic factors considered. The National Ambient Air Quality Standards take into consideration all sources of exposure to a given chemical and establish ceilings that are not to be exceeded in the United States. Only major new

Table 6.3. Federal ambient water quality criteria (WQC) for the protection of human health (µg/L)

Chemical	WQC for aquatic organisms and drinking water[a]	WQC for aquatic organisms alone[a]	WQC for drinking water alone[b]
Acenaphthene	20 (org)[c]	NA[d]	2,100
Acrolein	320	780	
Acrylonitrile	0 (0.059)	0 (0.67)	0 (0.065)
Aldrin	0 (1.3E-04)[e]	0 (1.4E-04)	0 (2.1E-03)
Anthracene	9,567.2	107,692	10,500
Antimony	14	4,308	14
Arsenic	0 (0.018)	0 (0.14)	0 (0.02)
Asbestos	0 (30,000 fibers/L)	NA	
Benzene	0 (1.18)	0 (71.28)	0 (1.2)
Benzidine	0 (1.2E-04)	0 (5.4E-04)	0 (1.5E-04)
Benzo(a)anthracene	0 (2.8E-03)	0 (0.031)	
Benzo(a)pyrene	0 (2.8E-03)	0 (0.031)	
Benzo(k)fluoranthene	0 (2.8E-03)	0 (0.031)	
3,4-Benzofluoranthene	0 (2.8E-03)	0 (0.031)	
Beryllium	0 (7.7E-03)	0 (0.13)	0 (8.1E-03)
Bromoform	0 (4.38)	0 (363.5)	0 (4.4)
Carbon tetrachloride	0 (0.254)	0 (4.42)	0 (0.27)
Chlordane	0 (5.8E-04)	0 (5.9E-04)	0 (0.03)
Chlorinated benzenes			
Monochlorobenzene	20 (org)	NA	700
1,2-Dichlorobenzene	2,667	17,432	3,150
1,3-Dichlorobenzene	400	2,600	
1,4-Dichlorobenzene	400	2,600	
1,2,4,5-Tetrachlorobenzene	38	48	
Pentachlorobenzene	74	85	
Hexachlorobenzene	0 (7.5E-04)	0 (7.7E-04)	
Chlorinated ethanes			
1,2-Dichloroethane	0 (0.38)	0 (98.6)	0 (0.38)
1,1,1-Trichloroethane	3,094	173,077	3,150
1,1,2-Trichloroethane	0 (0.605)	0 (41.99)	0 (0.61)
1,1,2,2-Tetrachloroethane	0 (0.172)	0 (10.8)	0 (0.175)
Hexachloroethane	0 (1.95)	0 (8.85)	0 (2.5)
Chlorinated phenols			
2-Chlorophenol	0.1 (org)	NA	175
2,4-Dichlorophenol	0.3 (org)	NA	105
2,4,5-Trichlorophenol	1.0 (org)	NA	
2,4,6-Trichlorophenol	0 (2.1)	0 (6.5)	0 (3.2)
Pentachlorophenol	0 (0.28)	0 (8.2)	0 (0.29)
3-Methyl-4-chlorophenol	3,000 (org)	NA	

000334

Table 6.3 (continued)

Chemical	WQC for aquatic organisms and drinking water[a]	WQC for aquatic organisms alone[a]	WQC for drinking water alone[b]
Chloroalkyl ethers			
bis-(Chloromethyl) ether	0 (1.6E-04)	0 (0.077)	0 (1.6E-04)
bis-(2-Chloroethyl) ether	0 (0.031)	0 (1.42)	0 (0.032)
bis-(2-Chloroisopropyl) ether	1,389	174,400	1,400
Chlorodibromomethane	0 (0.412)	0 (34.2)	0 (0.417)
Chloroform	0 (5.67)	0 (470.8)	0 (5.74)
Chromium (III)	33,300	673,077	35,000
Chrysene	0 (2.8E-03)	0 (0.031)	
Copper	1,000 (org)	NA	
DDD	0 (8.3E-04)	0 (8.3E-04)	0 (0.15)
DDE	0 (5.9E-04)	0 (5.9E-04)	0 (0.103)
DDT	0 (5.9E-04)	0 (5.9E-04)	0 (0.103)
Dibenz(a,h)anthracene	0 (2.8E-03)	0 (0.031)	
3,3'-Dichlorobenzidine	0 (0.04)	0 (0.77)	0 (0.078)
Dichlorobromomethane	0 (0.27)	0 (22.1)	0 (0.27)
Dichlorodifluoromethane	0 (5.67)	0 (470.8)	
1,1-Dichloroethylene	0 (0.06)	0 (3.2)	0 (0.058)
Dichloropropanes/Dichloropropenes			
cis-1,3-Dichloropropene	10.4	1,691	10.5
trans-1,3-Dichloropropene	10.4	1,691	10.5
Dieldrin	0 (1.4E-04)	0 (1.4E-04)	0 (2.2E-03)
2,4-Dimethylphenol	400 (org)	NA	200
2,4-Dinitrotoluene	0 (0.11)	0 (9.1)	
1,2-Diphenylhydrazine	0 (0.041)	0 (0.54)	0 (0.044)
Endosulfan(*a*-,*b*-)	0.932	1.99	1.8
Ethylbenzene	3,120	28,718	3,500
Fluoranthene	295.5	374.6	1,400
Fluorene	1,275.6	14,358.5	1,400
Halomethanes	0 (5.67)	0 (470.8)	
Heptachlor	0 (2.1E-04)	0 (2.1E-04)	0 (8.1E-03)
Heptachlor epoxide	0 (1.0E-04)	0 (1.0E-04)	0 (3.8E-03)
Hexachlorobutadiene	0 (0.45)	0 (49.7)	0 (0.45)
Hexachlorocyclohexanes (HC-CH)			
Alpha-HCCH	0 (0.004)	0 (0.013)	0 (5.5E-03)
Beta-HCCH	0 (0.014)	0 (0.046)	0 (0.02)
Gamma-HCCH	0 (0.019)	0 (0.063)	

000335

Table 6.3 (continued)

Chemical	WQC for aquatic organisms and drinking water[a]	WQC for aquatic organisms alone[a]	WQC for drinking water alone[b]
Hexachlorocyclopentadiene	1 (org)	NA	945
Indeno(1,2,3-cd)pyrene	0 (2.8E-03)	0 (0.031)	
Isophorone	0 (8.42)	0 (599.7)	0 (8.5)
Mercury	0.151	0.153	
Methyl bromide	48	4,020	49
Methyl chloride	0 (5.67)	0 (470.8)	
Methylene chloride	0 (4.65)	0 (1,578)	0 (4.7)
Nickel	607	4,584	700
Nitrobenzene	17.3	1,863	17.5
Nitrophenols			
2,4-Dinitrophenol	69.7	14,264	70
2,Methyl-4,6-dinitrophenol	13.4	765	
Nitrosamines			
n-Nitrosodimethylamine	0 (6.9E-04)	0 (8.12)	0 (6.8E-04)
n-Nitrosodiphenylamine	0 (4.95)	0 (16.2)	0 (7.1)
n-Nitrosopyrrolidine	0 (0.016)	0 (91.9)	
Pentachlorobenzene	74	85	
Phenol	300 (org)	4,615,385	21,000
Phthalate esters			
Butylbenzyl phthalate	2,984	5,202	7,000
Diethylphthalate	22,631	118,019	10,500
Dimethylphthalate	313,000	2,900,000	
Di-*n*-butylphthalate	2,715	12,100	3,500
Bis-2-ethylhexylphthalate	0 (1.8)	0 (5.9)	0 (2.5)
Polychlorinated biphenyls (1016, 1221, 1242, 1254, 1260)	0 (4.4E-05)	0 (4.5E-05)	0 (4.5E-03)
Polynuclear aromatic hydrocarbons	0 (2.8E-03)	0 (3.11E-02)	
Pyrene	956.7	10,769.2	1,500
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin	0 (1.3E-08)	0 (1.4E-08)	0 (2.2E-07)
1,2,4,5-Tetrachlorobenzene	38	48	
Tetrachloroethylene	0 (0.8)	0 (8.9)	
Thallium	13	48	
Toluene	6,764.8	201,294	70,000
Toxaphene	0 (7.3E-04)	0 (7.5E-04)	0 (0.032)
Trichloroethylene	0 (2.7)	0 (80.7)	
Trichlorofluoromethane	0 (5.67)	0 (470.8)	
Vinyl chloride	0 (2)	0 (525)	
Zinc	5,000 (org)	NA	

[a]The criterion value of zero for all potential carcinogens is listed in the table. Concentrations in parentheses for potential carcinogens correspond to a risk of 10^{-6}.

[b]These adjusted criteria, for drinking water ingestion only, are estimated using a reference dose or carcinogen potency factor and a body weight of 70 kg and water ingestion rate of 2 L/day.

[c]Criteria designated as organoleptic are based on taste and odor effects, not human health effects. Health-based WQC are not available for these chemicals.

[d]NA = not available.

[e]Read as 1.3×10^{-4}.

Source: U.S. Environmental Protection Agency, Region IV Criteria Charts, October 1991.

000336

Table 6.4. Tennessee water quality criteria for designated water uses (µg/L)[a]

Chemical	Domestic Water Supply	Recreation[b]	Fish and Aquatic Life	
			CMC[c]	CCC[d]
Acenaphthylene	NA[h]	0.3	NA	NA
Acrolein	NA	780	NA	NA
Acrylonitrile	NA	6.7	NA	NA
Aldrin	NA	0.0014	3	NA
Anthracene	NA	0.03	NA	NA
Antimony	NA	4310	NA	NA
Arsenic (III)	NA	NA	360	190
Arsenic (total)	50	NA	NA	NA
Benzene	5	710	NA	NA
Benzo(a)anthracene	NA	0.3	NA	NA
Benzo(a)pyrene	NA	0.3	NA	NA
3,4-Benzofluoranthene	NA	0.3	NA	NA
Benzo(k)fluoranthene	NA	0.3	NA	NA
Beryllium	NA	1.3	NA	NA
g-BHC (Lindane)	4	0.63	2	0.08
Bis(2-chloroethyl)ether	NA	14	NA	NA
Bis(2-ethylhexyl)phthalate	NA	59	NA	NA
Boron	NA	NA	NA	NA
Bromoform - (Tribromomethane)	NA	4700	NA	NA
Cadmium	10	NA	4[e]	1[e]
Carbon tetrachloride	5	44	NA	NA
Chlordane	NA	0.006	2.4	0.0043
Chloroform - (Trichloromethane)	NA	4700	NA	NA
Chromium (III)	NA	670,000	NA	NA
Chromium (hexavalent)	NA	NA	16	11
Chromium (total)	50	NA	NA	100
Chrysene	NA	0.03	NA	NA
Cobalt	NA	NA	NA	NA
Copper	NA	NA	18[e]	12[e]
Cyanide	NA	NA	22	5.2
4,4'-DDT	NA	0.006	1.1	0.001
4,4'-DDE	NA	0.006	NA	NA
4,4'-DDD	NA	0.008	NA	NA
1,2-Dichlorobenzene	NA	17,000	NA	NA
1,3-Dichlorobenzene	NA	2600	NA	NA
1,4-Dichlorobenzene-(*para*-Dichlorobenzene)	75	2,600	NA	NA
Dichlorobromomethane	NA	4700	NA	NA

Table 6.4 (continued)

Chemical	Domestic Water Supply	Recreation[b]	Fish and Aquatic Life	
			CMC[c]	CCC[d]
1,2-Dichloroethane	5	990	NA	NA
1,1-Dichloroethylene	7	32	NA	NA
1,3-Dichloropropylene	NA	1700	NA	NA
Dieldrin	NA	0.0014	2.5	0.0019
Diethyl phthalate	NA	120,000	NA	NA
Dimethyl phthalate	NA	2,900,000	NA	NA
Di-n-butyl phthalate	NA	12,000	NA	NA
2,4-Dinitrophenol	NA	14,000	NA	NA
2,4-Dinitrotoluene	NA	42	NA	NA
Dioxin	NA	0.000001	NA	NA
a-Endosulfan	NA	2.0	0.22	0.056
b-Endosulfan	NA	2.0	0.22	0.056
Endrin	0.2	NA	0.18	0.0023
Ethylbenzene	NA	29,000	NA	NA
Fluoranthene	NA	54	NA	NA
Fluorene	NA	0.03	NA	NA
Heptachlor	NA	0.002	0.52	0.0038
Heptachlor epoxide	NA	0.001	0.52	0.0038
Hexachlorobenzene	NA	0.007	NA	NA
Hexachlorobutadiene	NA	500	NA	NA
Hexachlorocyclo-pentadiene	NA	NA	NA	NA
Hexachloroethane	NA	89	NA	NA
Lead	50	NA	82[e]	3[e]
Lindane (*g*-BHC)	4	0.63	2	0.08
Lithium	NA	NA	NA	NA
Manganese	50[f]	NA	NA	NA
Mercury	2	0.15	2.4	0.012
Methyl chloride - (Chloromethane)	NA	4700	NA	NA
2-Methyl-4,6-dinitro-phenol (4,6-Dinitro-*o*-cresol)	NA	765	NA	NA
Methylene chloride - (Dichloromethane)	NA	16,000	NA	NA
n-Butylbenzyl phthalate	NA	NA	NA	NA
Nickel	NA	4600	1400	160
Nitrobenzene	NA	1900	NA	NA
Pentachlorophenol	NA	NA	20[g]	13[g]
Phenanthrene	NA	0.03	NA	NA

000338

Table 6.4 (continued)

Chemical	Domestic Water Supply	Recreation[b]	Fish and Aquatic Life	
			CMC[c]	CCC[d]
Polychlorinated biphenyls				
PCB-1242	NA	0.0005	NA	NA
PCB-1254	NA	0.0005	NA	NA
PCB-1221	NA	0.0005	NA	NA
PCB-1232	NA	0.0005	NA	NA
PCB-1248	NA	0.0005	NA	NA
PCB-1260	NA	0.0005	NA	NA
PCB-1016	NA	0.0005	NA	NA
PCBs (total)	NA	0.001	NA	0.001
Pyrene	NA	0.03	NA	NA
Selenium	10	NA	20	5
Silver	50	NA	4[e]	NA
1,1,2,2-Tetrachloroethane	NA	110	NA	NA
Tetrachloroethylene	NA	88	NA	NA
Toluene	NA	300,000	NA	NA
Toxaphene	5	0.008	0.73	0.0002
1,1,1-Trichloroethane	200	170,000	NA	NA
1,1,2-Trichloroethane	NA	420	NA	NA
Trichloroethylene	5	807	NA	NA
2,4,6-Trichlorophenol	NA	6.5	NA	NA
Vanadium	NA	NA	NA	NA
Vinyl chloride	2	5250	NA	NA
Zinc	5000[f]	NA	117[e]	106[e]

[a]Rules of the TDEC, Chap. 1200-4-3.
[b]Based on a 10^{-5} risk level for carcinogens.
[c]CMC = criterion maximum concentration.
[d]CCC = criterion continuous concentration.
[e]Calculated for a water hardness of 100 mg/L, the approximate average hardness of the Clinch River.
[f]Secondary MCL: Rules of the TDEC, Chap. 1200-5-1.12.
[g]At pH = 7.8.
[h]NA = not available.

000339

Table 6.5. Federal ambient water quality criteria for the protection of freshwater organisms

Chemical	Maximum (µg/L)[a]	24-h (µg/L)[b]
Aldrin	3	NA[i]
Aluminum	750[c]	87[c]
Ammonia	Concentrations are temperature and pH dependent	
Arsenic (III)	360	190
Cadmium	1.8[d]	0.66[d]
Chlordane	2.4	4.3E-03[e,f]
Chloride	860,000	230,000
Chlorine	19	11
Chlorpyrifos	0.083	0.041
Chromium (VI)	16	11
(III)	984[d]	117[d]
Copper	9.22[d]	6.54[d]
Cyanide	22	5.2
Dichlorodiphenyl-trichloroethane (DDT)	1.1	1.0E-03[g]
Demeton	NA	0.1
Dieldrin	2.5	1.9E-03[f]
Endosulfan	0.22	0.056
Endrin	0.18	2.3E-03[f]
Guthion	NA	0.01
Heptachlor	0.52	3.8E-03[f]
Heptachlor epoxide	0.52	3.8E-03[f]
Hexachlorocyclohexanes (HCCH) gamma-HCCH (Lindane)	2	0.08
Hydrogen sulfide	NA	2
Iron	NA	1,000
Lead	33.8[d]	1.32[d]
Malathion	NA	0.1
Mercury	2.4	0.012[f]
Methoxychlor	NA	0.03
Mirex	NA	1.0E-03
Nickel	789[d]	88[d]
Parathion	0.065	0.013
Pentachlorophenol	3.32[h]	2.1[h]
pH	NA	6.5–9
Polychlorinated biphenyls	NA	0.014[g]
Selenium (inorganic selenite)	20	5
Silver	1.23[d]	NA
Sulfides	NA	2
Zinc	65[d]	59[d]

[a]One-hour average concentration not to be exceeded more than once every 3 years.
[b]Four-day average concentration not to be exceeded more than once every 3 years.
[c]pH 6.5–9.0.
[d]Water hardness dependent criteria (50 mg/L as $CaCO_3$).
[e]Read as 4.3×10^{-3}.
[f]Based on marketability of fish.
[g]Final residue value based on wildlife feeding study.
[h]pH dependent criteria.
[i]NA = not available.

Source: U.S. Environmental Protection Agency, Region IV Criteria Chart, October 1991.

000340

sources, or major modifications to existing sources, must ensure regional attainment of National Ambient Air Quality Standards. Although ORR is in a Tennessee state "attainment" area, it is unlikely that any emissions from RA cleanup will be considered a "major" source under present federal law. EPA has, however, listed "site remediation" as a major source category under Section 112(c) of the CAA (57 *FR* 31576, July 16, 1992). A regulatory schedule was issued in September 1992 for promulgating emission standards under Section 112(e) of the CAA for these newly-listed major source categories.

National Ambient Air Quality Standards are established as the criteria state and local governments must plan to achieve and, thus, are not directly enforceable. Under §110 of the CAA, states are required to implement regulations to achieve the National Ambient Air Quality Standards. The ambient air quality standards established by the TDEC Division of Air Pollution Control appear in Chap. 1200-3-3 of the Rules of the TDEC and are identical to the federal primary National Ambient Air Quality Standards (see Table 6.1). The ambient standards of 1200-3-3 are translated into source-specific emission limitations (Rules of the TDEC, Chaps. 1200-3-4 to 1200-3-21) that must be considered legally applicable if they apply to any of the remedial activities selected. Tennessee state air emission standards are considered "hybrid" regulations and will be summarized as action-specific regulations in Sect. 6.5.3; they would have to be analyzed on a site-specific basis depending on the type of RA planned for a site.

National Emission Standards for Hazardous Air Pollutants for various industrial sources that emit one of several pollutants are established in 40 CFR 61. Most of the National Emission Standards for Hazardous Air Pollutants are generally not legally applicable to cleanup at CERCLA sites because they regulate particular types of sources that would not be expected to be found at these sites. However, the National Emission Standards for Hazardous Air Pollutants for asbestos and radionuclides should be considered as potential "hybrid" regulations on a site- specific basis depending on the RAs planned at a site. The National Emission Standards for Hazardous Air Pollutants for radionuclides is discussed in Sect. 6.4.2.

The CAA Amendments of 1990 establish a list of 189 additional hazardous air pollutants for which technology-based standards must be promulgated. These will be applicable to categories of emission sources rather than to the substances emitted. A draft schedule has been published for promulgation of these technology-based standards (57 *FR* 44147).

6.3.3 Soil Regulations

Very little legislation or guidance is available governing cleanup criteria for contaminated soils. RCRA has addressed land disposal of treated hazardous wastes in its LDRs (40 CFR 268), and these are addressed as action-specific regulations in Sect. 6.5.2. If a site is identified as a RCRA Sect. 3004(u) solid waste management unit, or if RCRA-characteristic or RCRA-listed hazardous waste as defined in 40 CFR 261 is present at the site, it is subject to RCRA corrective action regulations. The proposed RCRA corrective action regulations address risk-based cleanup standards for soils (55 *FR* 30798); these are briefly discussed in Sect. 6.5.2. Treatment standards for contaminated soil and debris at CERCLA sites are discussed in Sect. 6.5.2.

The regulations found in the TSCA contain storage, disposal, and cleanup requirements for materials contaminated with PCBs. These regulations limit concentrations of PCBs disposed of in soil to 50 ppm and require that any soils containing concentrations of PCBs greater than 50 ppm (40 CFR 761.60) be incinerated (40 CFR 761.70) or stored in a chemical waste landfill (40 CFR 761.75). TSCA also specifies requirements that must be achieved for PCBs disposed of by incineration

(40 CFR 761.70), in a chemical waste landfill (40 CFR 761.75), or by other disposal methods [40 CFR 761.60(a)(5)(iii)]. A further discussion of the TSCA requirements appears in Sect. 6.5.6.

6.3.4 Nonregulatory Guidance

EPA has suggested cleanup values for lead in soils based on studies of blood-lead levels in exposed children. The EPA Office of Solid Waste and Emergency Response Directive 9355.4-02 (dated Sept. 7, 1989) recommends a cleanup level for soils of 500–1000 ppm lead.

Although not a legal standard, EPA has published a TSCA PCB spill cleanup policy (52 *FR* 10688) that recommends cleanup standards for PCBs of 25–50 ppm for sites with restricted access; a 10-ppm cleanup level is recommended for residential and unrestricted access rural areas. In this latter case, a 10-inch cap of clean soil must cover the site. In the EPA guidance report for RAs at Superfund sites containing PCBs, preliminary remediation goals are set at 1 ppm for residential land use (a risk of 10^{-5}) and between 10 and 25 ppm for industrial and/or remote areas (a risk of 10^{-4}).[7] Alternatives should reduce concentrations to these levels or limit exposures. EPA also presents an approach to deriving cleanup levels of PCBs in sediments.[7] This approach results in "sediment quality criteria" as a function of organic carbon concentrations and is meant to protect wildlife consumers of freshwater benthic species.

In the absence of federally or state-promulgated standards, or in the case where standards are not adequately protective, EPA states a preference for RfDs or reference concentrations (RfCs) for systemic toxicants, and CSFs for carcinogens or Office of Drinking Water Health Advisories for drinking water contaminants.[8] The RfDs, RfCs, and CSFs are available through the *Integrated Risk Information System* and the EPA *Health Effects Assessment Summary Tables*.[5, 9]

The EPA Office of Drinking Water has developed nonregulatory health advisories for concentrations of noncarcinogenic contaminants in drinking water at which no adverse health effects would be expected to occur. EPA uses the lifetime HA (for noncarcinogens only) to develop MCLs and MCLGs; health advisories will most likely represent future MCL proposals.

Very few standards are available that are legally applicable to the cleanup of radioactively contaminated media at ORNL RA sites. The AEA and its amendments delegated authority for control of nuclear energy to DOE, NRC, and EPA. In addition, certain states have regulatory authority and programs for radioactive waste. The EPA's regulations are derived from several other statutes as well, and cover many types of activities and all types of radioactive materials, including naturally occurring and accelerator-produced radioactive material (NARM). NRC licenses the possession and use of various types of radioactive materials at certain types of facilities. Tennessee is an NRC-agreement state and, as such, has its own authority and licensing regulations. In addition, Tennessee enforces NARM standards.

DOE is authorized to control all types of nuclear materials at sites under its jurisdiction and is exempt from NRC licensing and regulatory requirements; therefore, NRC regulations are not considered to be legally applicable to RA activities at DOE facilities. DOE regulations for handling and cleanup of radioactive materials are outlined in a series of internal DOE orders that are binding to DOE contractors.

Because a complete characterization of the identity and quantity of radioactive waste at ORNL RA sites has not been completed, all of the available EPA regulations will be presented here, as well as the numerical NRC values. The proper definition of "mixed low-level waste and hazardous waste" has caused considerable debate with regard to dual jurisdiction by EPA and NRC. However, EPA has published a clarification of the problem (53 *FR* 37045, Sept. 23, 1988), as did DOE previously [52 *FR* 15937, May 1, 1987 and DOE Order 5400.3 (*Hazardous and Radioactive Mixed Waste Program*, dated Feb. 22, 1989)]. In effect, mixed wastes are those containing a RCRA hazardous waste as defined in 40 CFR 261 and a radioactive waste subject to the AEA. RCRA regulations apply to the hazardous component of the waste, and AEA regulations apply to the radioactive component. When the application of both standards is conflicting or inconsistent, RCRA yields to the AEA. Tennessee received final authorization to regulate radioactive mixed waste on July 3, 1986 (53 *FR* 37045, Sept. 23, 1988); however, the state has not implemented any regulations or guidance related to the handling of mixed waste.[10]

6.4.1 Generic Below Regulatory Concern Levels for Radioactive Wastes

The NRC has developed the concept of a risk threshold to distinguish those radioactive materials that do not warrant regulation to the same degree as other radioactive materials to ensure adequate protection of the public and the environment. The low levels of risk posed by these radioactive materials have been termed below regulatory concern (BRC). The NRC published a policy statement (55 *FR* 27522, July 3, 1990) to guide its decisions on exemptions of BRC materials from the full scope of the NRC's regulatory program.

The BRC policy was established, in part, to ensure adequate and consistent decisions on acceptable risks posed by decontaminated and decommissioned nuclear facilities. The BRC concept is based on the premise that risk from doses to individuals for practices that are under consideration for exemption are comparable to the voluntary and involuntary risks commonly accepted by the general public from radiation exposures in their daily lives (i.e., natural background radiation, which results in risks corresponding to doses on the order of 5–10 mrem/year or an annual risk of about 10^{-6}). This level of risk is within the risk-based guidelines of 10^{-4} to 10^{-7} established by the EPA.

000343

Based on these considerations, the NRC policy states that the average dose to individuals in a critical group should be less than 10 mrem/year (a hypothetical incremental annual risk of 5×10^{-6}) for each exempted practice. In addition, for such practices that result in widespread distribution of radioactive materials (e.g., consumer products or recycled materials), the NRC recommends an interim dose criterion for individuals in the critical group of 1 mrem/year (a risk of 5×10^{-7}). These individual annual doses translate to a lifetime risk from continuing annual exposures in the order of 10^{-4} and 10^{-5}, respectively.

The adoption of the BRC policy generated widespread public concern over its implications and a general dissatisfaction with the process the NRC used to develop the BRC policy. Because of these concerns, the NRC declared a moratorium on implementation of the BRC policy and initiated a consensus process to provide advice to the NRC on the full range of issues related to the BRC policy (56 *FR* 36068, July 30, 1991).

EPA utilizes a similar policy in setting *de minimis* risk-based levels for exemption of hazardous chemicals from RCRA Subtitle C regulation (57 *FR* 21450, May 20, 1992). Health-based exemption levels are proposed for systemic toxicants and carcinogens based on RfDs and risk-specific doses, respectively. EPA has proposed a risk level of 10^{-6} to establish exemption criteria for Groups A, B, and C carcinogens (see 51 *FR* 33992, September 24, 1986, for a discussion of EPA's carcinogen classification scheme).

As of September 1992, the NRC has been unable to reach consensus on a BRC policy acceptable to the general public and has no plans to pursue further action on this initiative, nor does it plan to enforce the BRC policy issued in July 1990. Instead, it will focus on developing waste-stream- and media-specific risk-based BRC levels, similar to EPA's *de minimis* levels, through a series of individual rule makings. Until these individual rules are promulgated, the lack of a generic BRC policy for radioactive wastes that would guide cleanup and release of radioactive components at RA sites has hampered RA activities at DOE facilities. At present, internal DOE orders (see Sect. 6.4.5) provide the only guidance for such cleanup activities.

6.4.2 Federal Agreements and Legislation

DOE has entered into a number of signed agreements with state and federal parties that define committed milestones and impact the handling of radioactive wastes at ORNL RA sites. In addition, recent Congressional legislation, and DOE action in response to it, will also have an impact.

In June 1992, EPA and DOE signed the LDR-FFCA/ORR to bring mixed waste generation and storage facilities on the reservation into compliance with environmental law. Under the agreement, effective immediately, DOE-OR will submit plans that will include treatment and storage options for LDR mixed wastes to meet the requirements of RCRA. The plans, to be prepared by DOE, will include proposals for waste minimization, treatment studies, technology development, facility construction, and schedules for future treatment. The LDR-FFCA/ORR allows DOE ORR facilities to continue to generate and store mixed wastes while addressing LDR mixed waste compliance issues. The mixed wastes covered under the LDR-FFCA/ORR include flammable and corrosive liquids, solvents, paint waste, waste oils and organics, and solid mixed wastes.

On May 26, 1992, EPA published (57 *FR* 22024) a notice, proposing to find that DOE has made all but one of the demonstrations required in its application, under RCRA rules in 40 CFR 268.5, for a one-year, case-by-case extension of the May 8, 1992, effective date

of the LDRs applicable to certain mixed wastes generated or stored at 31 DOE facilities. Comments were due back to EPA by July 27, 1992, and no official final action has been taken on this proposal as yet.

The FFCA of 1992 (Public Law 102-386, October 6, 1992) amends §6001 of the SWDA to waive immunity of the United States with respect to substantive and procedural requirements regarding control, abatement, or management of solid or hazardous waste. This waiver of immunity includes injunctive relief, administrative order, or civil or administrative penalties or fines, and subjects the federal government to the full range of available enforcement tools to penalize isolated, intermittent, or continuing violations. A delayed effective date of three years from enactment of the FFCA of 1992 is applied to the waiver of sovereign immunity for mixed waste regulated under SWDA §3004(j) so long as that waste is managed in accordance with other applicable requirements. Further, DOE is expressly exempt from the three year effective date for mixed waste in violation of SWDA of §3004(j) so long as DOE has in effect a plan that has been submitted and approved pursuant to SWDA §3021(b), and an order requiring compliance with such plan has been issued pursuant to SWDA §3021(b).

Even though the waiver is not delayed for DOE facilities that are subject to an existing agreement, permit, administrative or judicial order addressing compliance with the LDR storage prohibition for mixed wastes, the waiver will not apply to DOE as long as DOE meets certain conditions specified in the Act [FFCA of 1992, Sect. 102(c)(3)]. Specifically, the waiver shall not apply to DOE for mixed waste violations of §3004(j) of SWDA for as long as DOE has submitted, has in effect, and is in compliance with, a plan pursuant to §3021(b) of SWDA, and is in compliance with an order issued pursuant to SWDA §3021(b) requiring compliance with such plan.

Further sections of the Act regulate mixed waste inventory reports and plans required to be submitted by DOE within 180 days of the enactment of the FFCA of 1992. DOE has published its strategy for development of a national compliance plan for DOE mixed waste (57 *FR* 57170, December 3, 1992). DOE's National Compliance Plan will integrate ER and D&D activities with the development of appropriate mixed-waste treatment, storage and disposal capacity.

6.4.3 EPA Regulations

EPA has promulgated MCLs for radionuclides in community water systems (see Table 6.6). These MCLs appear in two forms—concentration limits for certain alpha-emitting radionuclides (40 CFR 141.15) and an annual dose limit for the ingestion of certain beta- and gamma-emitting radionuclides (40 CFR 141.16). MCLs and MCLGs were proposed for radon and uranium and reproposed for ^{226}Ra and ^{228}Ra, beta emitters, and photon emitters on July 18, 1991, and are included in Table 6.6. Final promulgation of the concentration limits was scheduled for April 1993, but Congress voted to delay promulgation until the end of 1993. EPA plans to propose a schedule extension and issue a final rule in 1994.[3] As with the chemical-specific MCLs, these concentration limits may be relevant and appropriate for cleanup of contaminated ground water at ORR.

Table 6.7 lists EPA and DOE radiation protection standards that are described below. Subpart H of 40 CFR 61 addresses atmospheric radionuclide emissions from DOE facilities and may be applicable to airborne emissions during RA activities at ORNL. EPA has issued a final National Emission Standards for Hazardous Air Pollutants rule (54 *FR* 51654, Dec. 15, 1989) that limits emissions of radionuclides to the ambient air from DOE facilities to amounts that would not cause any member of the public to receive an effective dose equivalent of 10 mrem/year (40 CFR 61.92).

Table 6.6. Radionuclide-specific standards under the SDWA for ground water and surface water contamination at the Oak Ridge Reservation

Radionuclide	Current SDWA MCLs[a]	Proposed SDWA MCLs[b]
Radium[c]	5 pCi/L	20 pCi/L
Gross alpha[d]	15 pCi/L	15 pCi/L
Gross beta	4 mrem/year	4 mrem/year
Natural uranium		20 μg/L[e]
Radon-222		300 pCi/L
Strontium-90[f]	8 pCi/L	52 pCi/L
Tritium[f]	20,000 pCi/L	60,900 pCi/L
All other manmade radionuclides	4 mrem/year[f]	4 mrem/year[g]

[a] SDWA MCL = Safe Drinking Water Act maximum contaminant level.
[b] Proposed rule, July 18, 1991 (56 *FR* 33050); final rule expected 1994.
[c] The present MCL applies to combined ^{226}Ra and ^{228}Ra; the proposed MCL applies to each separately.
[d] The present MCL excludes radon and uranium but includes ^{226}Ra; the proposed MCL excludes all three radionuclides.
[e] Approximately equal to 30 pCi/L.
[f] These values are not MCLs; rather they are concentrations that result in the effective dose equivalent (EDE) of 4 mrem/year, the MCL for gross beta emissions.
[g] If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ shall not exceed 4 mrem/year.

Source: E. L. Etnier, E. P. McDonald and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation. A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

Environmental protection standards for the management, storage, and disposal of spent nuclear fuel, high-level wastes, and TRU wastes are found in 40 CFR 191. Management and storage must be conducted so as to provide a reasonable assurance that no member of the public in the general environment will receive a combined annual dose equivalent or greater than 25 mrem to the whole body and 75 mrem to any organ (40 CFR 191.03). The standards for disposal systems, originally listed in Subpart B of 40 CFR 191, were vacated by a federal appeals court decision in 1987. These standards stated that disposal systems for the wastes defined above must be designed "to provide a reasonable expectation that, for 1000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 mrem to the whole body and 75 mrem to any critical organ." All potential pathways must be considered (40 CFR 191.15). These vacated disposal standards thus could not be considered legally applicable to RA activities, but could provide some guidance. In 40 CFR 191.04, alternative standards are established for DOE facilities if EPA determines that such standards prevent any member of the public from receiving a continuous exposure of more than 100 mrem/year effective dose equivalent or an infrequent

Table 6.7. Radiation protection standards that may be applicable to Oak Ridge Reservation D&D activities

Regulation	Applicability	Exposure conditions	Standard
40 CFR 61	National Emission Standards for Hazardous Air Pollutants for DOE facilities	Public exposure, airborne emissions	10 mrem/year
40 CFR 141	Drinking water maximum contaminant levels	Community water systems, gross beta	4 mrem/year
40 CFR 191	Spent nuclear fuel, high-level and transuranic wastes	Public exposure, all sources	25 mrem/year (total body) 75 mrem/year (thyroid)
DOE Order 5400.5[a]	Radiation Protection of the Public and the Environment	Public exposure, all sources	100 mrem/year
		Temporary exemption, maximum limit	500 mrem/year
		Aquatic organism exposure, absorbed dose	1 rad/d
DOE Order 5820.2A	Radioactive Waste Management	Public exposure, all sources, excluding air	25 mrem/year
		Public exposure, atmospheric releases	10 mrem/year
DOE Order 5480.11[b]	Radiation Protection for Occupational Workers	Worker exposure limits, continuous exposure	5 rem/year, cancer effects 50 rem/year, noncancer effects, any organ or tissue
		Public exposures, controlled areas, effective dose equivalent	100 mrem/year

[a] Proposed as 10 CFR 834 (58 *FR* 16268, March 25, 1993); final rule expected March 1994.
[b] Proposed as 10 CFR 835 (56 *FR* 64334, Dec. 9, 1991); final rule expected July 1993.

Source: E. L. Etnier, E. P. McDonald and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation. A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

exposure of more than 500 mrem/year effective dose equivalent from all sources, excluding natural background, and medical exposures. EPA has proposed to revise its standards to create a new Subpart B and promulgate generally applicable environmental standards to establish limits for the release of radioactive materials to the environment (58 *FR* 7924, February 10, 1993); a final rule is expected by February 1994. When promulgated, these standards will supersede those mentioned above as legally applicable standards.

EPA intends to develop environmental radiation protection standards for the disposal of low-level waste (possibly including NARM) under 40 CFR 193 and 764. The intent of

these standards will be to protect the public health and general environment from potential adverse effects from low-level waste disposal. These proposed regulations may provide guidance for cleanup of the RA sites when promulgated. The proposed rule is scheduled for September 1993, final rule September 1994.[3]

In addition, EPA intends to develop public health and environmental radiation protection criteria for cleanup of residual radioactive materials at decommissioned DOE, Department of Defense and NRC-licensed sites, as well as others. These criteria may provide useful guidance for RA activities at ORR. However, there is no schedule for action for these criteria.[3]

6.4.4 Department of Transportation Regulations

The Department of Transportation Regulations for Hazardous Materials list general requirements for shipping and packaging at 49 CFR 172 and 173, and for requirements for carriage by public highway at 49 CFR 177. General requirements for shipping of hazardous materials are defined in 49 CFR 172, with specific marking, labeling, and placarding regulations for radioactive materials in 49 CFR 172.310, 172.403, and 172.556, respectively. These regulations would be applicable to any off-site shipments of hazardous or radioactive materials from RA activities.

49 CFR 173, Subpart I, lists requirements for packaging and shipping radioactive materials. General package design requirements are given in 49 CFR 173.411, with specific design requirements for Type A and B packaging found in 49 CFR 173.412 and 173.413, respectively. Activity limits for normal form radioactive material (termed A_2 limits) are listed in 49 CFR 173.435 for various radionuclides. Type A packaging is authorized for shipment if each package does not exceed the A_2 value (49 CFR 173.431). If package quantities exceed the A_2 value, Type B packaging is required (49 CFR 173.431). In addition, each package of radioactive materials must be designed and prepared for shipment such that under normal conditions, the radiation level does not exceed 200 mrem/h at any external point on the package (49 CFR 173 .441). Small quantities of solid radioactive materials are exempt from the packaging and shipping requirements of this part if the materials package limit is less than 10^{-3} A_2 (49 CFR 173.4 and 173.423).

Standards for the packaging and shipment of NRC-licensed material are found in 10 CFR 71. These are not legally applicable to DOE activities. However, DOE Order 5480.3 (*Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes*) specifies the Type A packaging requirements, which are given in 49 CFR 173.411 and 412. Type B packages shall be in compliance with requirements found in 10 CFR 71. Reference is made to 10 CFR 71.41 *et seq.* for general standards for all packages and special requirements for Type B packages [DOE Order 5480.3(8)].

Regulations governing transportation of hazardous materials by public highway are found in 49 CFR 177, and specific loading and unloading requirements for radioactive materials are in 49 CFR 177.842. The number of packages in any one motor vehicle must be limited so that the total transport index number does not exceed 50. The total transport index is described as the sum of the numbers expressing the maximum radiation level in mrem/h at 1 meter (3.3 ft) from the external surface of each package (49 CFR 173.403bb).

6.4.5 DOE Orders

DOE orders are not promulgated regulations and thus are not considered to be legally binding by EPA. They are, however, binding between DOE and Martin Marietta Energy Systems, Inc., because of contractual agreements. The radiation exposure limits for members of the public from management and storage of TRU waste defined in DOE Order 5400.5 (*Radiation Protection of the Public and the Environment*, February 8, 1990) are: (1) an effective dose equivalent of 25 mrem/year to the whole body, or (2) 75 mrem/year to a single organ [5400.5(II.1c)]. The basic dose limit for routine DOE activities, including RA monitoring, cleanup, and control of residual radioactive material is 100 mrem/year. In addition, guidelines are given for levels of residual surface contamination that shall not be exceeded if a RA is to be considered completed and property released to the public without restrictions on use [5400.5(II.5a)]. These levels are listed for specific isotopes and beta-gamma emitters in general. In all instances, the overriding principle of the DOE order is that all releases of radioactive material shall be ALARA. Chapter IV of the order lists guidelines for cleanup of radioactive real and personal property, management of the resulting wastes and residues, and release of property. Information on application of the guidelines and requirements presented in the order, including procedures for deriving specific property guidelines for allowable levels of residual radioactive material from basic dose limits, is contained in DOE/CH 8901, "A Manual for Implementing Residual Radioactive Material Guidelines, A Supplement to the U.S. Department of Energy Guidelines for Residual Radioactive Material at FUSRAP and SFMP Sites," June 1989 [5400.5(IV.2)]. Table 6.8 summarizes the contents of DOE Order 5400.5 with respect to RAs. DOE proposed for codification as 10 CFR 834 the contents of DOE Order 5400.5 as radiation protection requirements for the public and the environment for DOE and DOE Contractor operations (58 *FR* 16268, March 25, 1993).

DOE Order 5820.2A (*Radioactive Waste Management*, Sept. 9, 1988) states that the management of low-level waste must ensure that external exposure to the waste and concentrations of radioactive material that may be released into surface water and soil does not exceed 25 mrem/year to any member of the public. Releases to the atmosphere shall not exceed 10 mrem/year (Table 6.7). Reasonable effort should be made to maintain releases to the environment to ALARA levels. The order pertains to the management of radioactive waste and contains closure and post-closure care requirements. Table 6.9 summarizes the substantive requirements of this DOE order.

DOE Order 5480.11 (*Radiation Protection for Occupational Workers*) contains guidelines for worker protection, which are similar to those of 10 CFR 20 [i.e., 5 rem/year and 50 rem/year annual effective dose equivalent for stochastic (cancer) and nonstochastic (systemic) effects, respectively, from both internal and external sources for continuous exposures]. Also included in the order are standards for the general public when entering a controlled area. Exposures to the public are limited to an effective dose equivalent of 100 mrem/year (Table 6.7). As with the other DOE orders, the ALARA principle prevails. Remediation of radionuclide-contaminated soils must ensure that exposures to on-site workers or public intruders shall not exceed these standards. DOE has proposed for codification in 10 CFR 835 the primary standards for radiation protection of occupational workers from normal operation of DOE facilities (56 *FR* 64334, Dec. 9, 1991). A final rule is expected in July 1993. When promulgated, these standards will then be legally applicable for RA activities at ORNL.

Table 6.8. DOE Order 5400.5, "Radiation Protection of the Public and the Environment"

Action	Requirement	Chapter
Planning and performance of all DOE activities	DOE will carry out all DOE activities to ensure that radiation doses to individuals will be as low as reasonably achievable (ALARA).	I.4
Routine DOE activities including remedial action	DOE must comply with all legally applicable requirements of 40 CFR 61 (NESHAPS[a] for DOE Facilities) and 40 CFR 191 (spent nuclear fuel, high-level, and transuranic wastes).	I
	Exposures to members of the public from all radiation sources shall not cause an effective dose equivalent to be greater than 100 mrem (1 mSv) per year.	II.1a
	Exposures to members of the public from all radiation sources released into the atmosphere shall not cause an effective dose equivalent to be greater than 10 mrem (0.1 mSv) per year.	II.1b
Management and storage of spent nuclear fuel, high-level or transuranic waste at a disposal facility that is not regulated by the NRC[b]	Members of the public shall not receive an effective dose equivalent greater than 25 mrem (0.25 mSv) to the whole body or 75 mrem (0.75 mSv) to a single organ per year.	II.1c
	Radioactive materials released into public drinking water supplies shall not cause an effective dose equivalent to be greater than 4 mrem (0.4 mSv) to an individual per year. Gross alpha activity shall not exceed 1.5×10^{-8} µCi/ml.	II.1d
	Liquid effluents shall not cause private or public drinking water systems downstream of the facility to exceed the MCL(s) of 40 CFR 141.	II.1d(3)
Discharge of liquid waste containing radionuclides to surface water	Implementation of best available technology (BAT) treatment required if discharge is at an annual average concentration greater than the derived concentration guide (DCG) level.	II.3a(1)

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Table 6.8 (continued)

Action	Requirement	Chapter
Discharge of liquid waste containing radionuclides to surface water (continued)	Discharge of liquid waste containing radionuclides to surface water at an annual average concentration less than the DCG level does not require the implementation of BAT treatment.	II.3a(2)
	The absorbed dose to native aquatic animal organisms shall not exceed 1 rad/day from exposure to liquid wastes discharged to natural waterways.	II.3a(5)
	Liquid wastes containing concentrations of radioactive materials greater than 5 times the DCG(s) may be discharged to a federal sanitary sewerage system that provides liquid waste treatment prior to discharge to surface water according to II.3a(1). ALARA process considerations are required.	II.3d(3)
	If a waste stream contains multiple radionuclides, then the DCG shall be the sum of the fractional DCG values.	II.3a(3)
Management of low-level radioactive solid waste containing no RCRA[c] constituents	Design, operational, and monitoring requirements are found in DOE Order 5820.2A (Radioactive Waste Management).	II.4
Demonstration of compliance with the dose limits	DOE shall make appropriate documentation containing information about compliance with dose limits for members of the public in the immediate vicinity and within 80 km of the site.	II.6
Conduct of radiological environmental protection programs	DCGs for water ingestion, air inhalation, and immersion in a gaseous cloud are provided as reference values. These DCGs are based on a committed effective dose equivalent of 100 mrem for the radionuclide taken into the body by ingestion or inhalation during one year.	III.2
	The DCG values apply to only one mode of exposure (i.e., either ingestion or inhalation).	III.2a

000351

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Table 6.8 (continued)

Action	Requirement	Chapter
Conduct of radiological environmental protection program (continued)	For known mixtures of radionuclides the sum of the ratios of the observed concentration of each radionuclides to its corresponding DCG must not exceed 1.0.	III.2c
Cleanup of residual radioactive material and management of resulting wastes or residues	DOE facilities shall develop plans and protocols for the implementation of this guidance.	IV.1 & 2
	These guidelines are for levels of residual radioactive material that is acceptable for public use of property without restrictions because of residual radioactive material.	IV.2c
	Generic guidelines are taken from existing radiation protection standards.	IV.2c(1)
	Authorized limits are levels of residual radioactive material that shall not be exceeded if the remedial action is to be considered completed and the property is to be released without restrictions on use.	IV.2d
	Monitoring, cleanup, and control of residual radioactive material are subject to the ALARA policy.	IV.2e
	The basic dose limits for exposure to residual radioactive material is 100 mrem (1 mSv) annually.	IV.3a
	Under unusual circumstances, the dose limit for exposure to residual radioactive material is increased from 100 mrem (1 mSv) to 500 mrem (5 mSv) annually.	IV.3b
	Residual radioactive material in soil are those concentrations in excess of background concentrations averaged over an area of 100 m^2. These derivations are obtained by means of environmental pathway analysis and basic dose limits.	IV.4a

000352
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Table 6.8 (continued)

Action	Requirement	Chapter
Cleanup of residual radioactive material and management of resulting wastes or residues (continued)	Residual concentrations of radionuclides in the air and water shall not exceed 100 mrem (1 mSv) per year.	IV.4c
	Limits for hot spots shall be developed in cases where the average concentration in any surface or below surface area equal to or less than 25 m^2 exceeds the limit or guidelines by a factor of $(100/A)^{0.5}$. Reasonable effort must be made to remove any radionuclide source that exceeds 30 times the limit.	IV.4a(1)
	The generic guidelines for ^{226}Ra, ^{228}Ra, ^{230}Th, and ^{232}Th are 5 pCi/g averaged over the first 15 cm of soil or 15 pCi/g averaged over 15-cm-thick layers of soil below the first 15 cm.	IV.4a(2)
Management of residual radioactivity above the guidelines specified in IV.1-4	Interim storage control and stabilization features shall be planned to have a minimum life of 25 years and, if reasonably achievable, an effective life of 50 years.	IV.6b(1)
	Control features must be designed so that radionuclide concentration in the ground water shall not exceed applicable federal and state standards.	IV.6b(3)
	If residual radioactive material is in inaccessible locations and would be unreasonably costly to remove and when residual radioactive material exceeds guideline values, an interim management plan may be arranged to maintain the property.	IV.6c(1)
	Administrative controls shall include (but are not limited to): · periodic monitoring as appropriate, · appropriate shielding, · physical barriers to prevent access, and · appropriate radiological safety measures.	IV.6c(2)

000353

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Table 6.8 (continued)

Action	Requirement	Chapter
Management of residual radioactivity above the guidelines specified in IV.1-4 (continued)	Control and stabilization for uranium, thorium, and their decay products must be designed to last at a minimum of 200 years and if reasonably achievable have an effective life of 1000 years.	IV.6d(1)(a)
	In accordance with legally applicable federal and state standards, DOE facilities shall protect ground water.	IV.6d(1)(d)
	Use of and access to residual radioactive material shall be controlled through appropriate administrative and physical controls.	IV.6d(1)(e)
	Long-term management of other radionuclides shall be controlled by applicable requirements in Chapters II, III, and IV of DOE 5820.2A.	IV.6d(2)

[a]NESHAPS = National Emission Standards for Hazardous Air Polluting Substances.
[b]NRC = Nuclear Regulatory Commission.
[c]RCRA = Resource Conservation and Recovery Act.

Source: E. L. Etnier, E. P. McDonald and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

000354

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Table 6.9. DOE Order 5820.2A, "Radioactive Waste Management"

Action	Requirement	Chapter
Management of low-level radioactive waste	Development of site-specific comprehensive closure plans shall address: · Disposal sites' closure after the site has been filled for 5 years and · National Environmental Policy Act (NEPA) requirements.	III.3j(1)
	Residual radioactivity levels for surface soil will comply with DOE decommissioning guidelines (DOE Order 5400.5).	III.3j(2)
	The Oak Ridge Reservation must correct problems that could jeopardize the attainment of this order's performance objectives.	III.3j(3)
	All disposal sites and units shall be maintained to conform with RCRA[a], CERCLA[b], and SARA[c] standards.	III.3j(4)
	An appropriate field organization shall review and approve any closure plans for new and existing low-level waste disposal sites.	III.3j(5)
	An analysis of site performance will be the basis for terminating the monitoring and maintenance activity at closed facilities or sites at the end of the institutional control period.	III.3j(6)
Management of buried transuranic waste	All disposal sites and units shall be maintained to conform with CERCLA and SARA standards.	II.1
	Transuranic waste shall be managed to protect the health and safety of the public and the workers at the site.	II.2
	Each DOE facility will develop a site closure plan which will include: · NEPA requirements; · Applicable federal, state, and local regulations; · Permits required; · Selected closure strategy and justification; and · Postclosure monitoring and control.	II.3i(4)

[a]RCRA = Resource Conservation and Recovery Act.
[b]CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act.
[c]SARA = Superfund Amendments and Reauthorization Act.

Source: E. L. Etnier, E. P. McDonald and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

000355

6.5 ACTION-SPECIFIC REGULATIONS

Performance, design, or other action-specific requirements set controls or restrictions on particular kinds of activities related to the management of hazardous waste. Certain RAs at a site may invoke the appropriate action-specific regulations that specify particular performance standards or technologies, as well as specific environmental levels for discharged or residual chemicals. Action-specific regulations are established under RCRA, CERCLA, CAA, CWA, SDWA, TSCA, Federal Insecticide, Fungicide, and Rodenticide Act, and OSHA.

6.5.1 Comprehensive Environmental Response, Compensation, and Liability Act

The intent of CERCLA as amended by SARA is to provide for the cleanup of inactive hazardous waste disposal sites and to provide for response to, and cleanup of, environmental problems that are not covered adequately by the permit programs of other environmental laws. RA activities that have been incorporated into the FFA would be subject to CERCLA regulations.

The administrative requirements of RCRA (e.g., permitting, reporting, and record keeping) or any other federal or state regulations are not required for on-site RA if a facility is being cleaned up under CERCLA [CERCLA §121(e) and FFA §XXII(A)]. However, under CERCLA §121(d)(3) and FFA §XXII(B), any removal or RA involving the off-site transfer of hazardous substances, pollutants, or contaminants must involve a facility in compliance with all RCRA substantive and administrative requirements. CERCLA response actions will be coordinated with, and supplement, the corrective measures required and conducted by DOE under its current RCRA permit [FFA §IV(A)].

6.5.2 Resource Conservation and Recovery Act

RCRA has nine distinct sections (subtitles) that regulate various aspects of hazardous waste. Three of these, Subtitle C "Hazardous Waste Management," Subtitle D "Solid Waste Management," and Subtitle I "Regulation of Underground Storage Tanks," provide the regulatory guidance for CERCLA actions and will be considered for regulations for on-site RA activities and cleanup at ORNL.

Minimum national standards for acceptable management of hazardous waste appear in RCRA, although Tennessee has been authorized by EPA to administer and enforce its own standards in lieu of the federal RCRA regulations. Federally authorized state RCRA programs relate only to RCRA standards before HSWA.

Tennessee's promulgated RCRA requirements supersede federal regulations as legally applicable. However, Tennessee's substantive RCRA regulations are identical for the most part to the federal RCRA regulations.[11] New regulations imposed in 1984 by HSWA are to be considered applicable under federal law in all states until each authorized state promulgates its own HSWA-related standards. Although the Tennessee Solid Waste Disposal Control Board has promulgated many of the HSWA regulations, EPA has not yet authorized the program.[12]

6.5.2.1 RCRA Subtitle C regulations

RCRA Subtitle C regulates the generation, transportation, treatment, storage, and disposal of hazardous waste. Standards for the management of hazardous waste at

RCRA-permitted treatment, storage, and disposal facilities were promulgated July 26, 1982, and appear as 40 CFR 264. Standards for interim treatment, storage, and disposal facilities are found in 40 CFR 265.

In general, this text will address the Part 264 rather than the Part 265 standards as they are the more stringent. Table 6.10 lists the pertinent subparts of the permitted and interim standards and the equivalent section of the TDEC hazardous WM regulations.

As discussed in Sect. 6.2, D&D activities that generate RCRA hazardous wastes but are not incorporated as CERCLA Sites into the FFA would be subject to regulation under RCRA. In contrast to CERCLA, D&D activities subject to RCRA would be subject to the administrative as well as the substantive requirements of the law, including all the applicable permitting requirements.

The RCRA Subtitle C Part 264 regulations apply to particular WM processes (e.g., capping or incineration) or to general procedures (e.g., treatment, disposal, or closure), and it may be necessary to combine the two types of categories to adequately address the action-specific regulations for a particular remedial activity.

6.5.2.2 Land Disposal Restrictions

If RCRA-listed or -characteristic waste is generated/identified during the RA process, these wastes would be subject to the RCRA LDRs. For each hazardous waste, EPA has established treatment standards that are protective of human health and the environment when the wastes are land disposed. Land disposal includes, but is not limited to placement in a landfill, surface impoundment, waste pile, and land treatment facility. In the final National Contingency Plan, EPA reaffirms that movement of waste within a unit does not constitute "land disposal" for purposes of application of the RCRA LDRs; however, waste consolidation from different units at a CERCLA site are subject to the restrictions (55 *FR* 8759).

These LDRs apply only to RCRA hazardous waste placed after the effective prohibition date. Wastes may be land disposed if they have been treated with the best demonstrated available technology (BDAT) set by EPA and meet the treatment standards. A final rule listing provisions for specific treatment standards and prohibiting land disposal of the following wastes has appeared. Table 6.11 lists the waste categories for which LDRs have been promulgated, the *Federal Register* citation, and the corresponding section in 40 CFR 268. Tennessee Rule 1200-1-11-.10 contains the state LDRs, which are similar to the RCRA LDRs. A final rule for corrective action at RCRA sites and CERCLA sites contaminated with RCRA hazardous waste regulates wastes generated for the purpose of implementing RAs, and exempts designated sites from the LDRs and minimum technology requirements (MTRs) under 40 CFR 268 (see "Correction Action Requirements" below).

EPA has determined that the RCRA treatment standards are generally inappropriate or infeasible when applied to contaminated soil or debris (55 *FR* 8760). Therefore, EPA is proposing separate rule makings to establish treatment standards for disposal of such contaminated soil and debris. The advance notice of proposed rule making (ANPRM) for debris appeared in 56 *FR* 24444, May 30, 1991, the notice of proposed rule making (NPRM) on Jan. 9, 1992 (57 *FR* 958) and the final rule on August 18, 1992 (57 *FR* 37194). The rule requires contaminated debris to be treated before land disposal using extraction, destruction, or immobilization technologies. Six different categories of debris and ten different categories of contaminants are specified in the rule. As with mixed waste, debris contaminated with both hazardous and radioactive waste must

Table 6.10. RCRA[a] Subtitle C—standards for the treatment, storage, and disposal of hazardous waste

Federal	Tennessee	Category
40 CFR Part 264	*1200-1-11-.06*[b]	
Subpart I	Section 9	Containers
Subpart J	Section 10	Tanks
Subpart K	Section 11	Surface impoundments
Subpart L	Section 12	Waste piles
Subpart M	Section 13	Land treatment
Subpart N	Section 14	Landfills
Subpart O	Section 15	Incinerators
Subpart X	Section 19	Miscellaneous treatment units
40 CFR Part 265	*1200-1-11-.05*	
Subparts I-O	Sections 9-15	As listed above
Subpart P	Section 16	Thermal treatment
Subpart Q	Section 17	Chemical, physical, and biological treatment

[a]RCRA = Resource Conservation and Recovery Act.
[b]Rule 1200 of the Tennessee Department of Environment and Conservation Hazardous Waste Management Regulations.

Table 6.11. Federal RCRA[a] land disposal regulations

Waste category	Citation	40 CFR Part
Spent-solvent and dioxin-containing wastes	51 *FR* 40572 (Nov. 7, 1986)	268.30 268.31
"California List" wastes	52 *FR* 25760 (July 8, 1987)	268.32
First Third wastes[b]	54 *FR* 31138 (Aug. 17, 1988)	268.33
Second Third wastes[b]	54 *FR* 26594 (June 23, 1989)	268.34
Final Third wastes[b]	55 *FR* 22520 (June 1, 1990)	268.35

[a]RCRA = Resource Conservation and Recovery Act.
[b]All listed hazardous wastes identified under 40 CFR 261.

000358

comply with the treatability standards for contaminated debris as well as those under the AEA. Disposal of treated debris and resultant wastes are discussed in the rule.

In the debris rule, EPA established a new treatment unit for treating contaminated debris: a "containment building" has been added to the definitions of 40 CFR 260.10 to provide for storage and treatment of contaminated debris that does not contain free liquids and is not amenable to treatment in tanks or containers (57 *FR* 979, January 9, 1992). Performance standards for the design and operation of such containment buildings are promulgated for a new Subpart DD to 40 CFR 264 and 265 for permitted facilities and interim status facilities, respectively. All containment buildings, permitted or unpermitted must comply with the same level of performance. These standards would be legally applicable to any RA activities involving dismantlement of structures and subsequent decontamination in a building. Physical extraction technologies such as abrasive blasting or spalling used to treat debris in place, but that is intended for discard (e.g., treatment of a contaminated building prior to demolition), are subject to the permit standards of 40 CFR 264, Subpart X for miscellaneous units or the interim status standards for chemical, physical, or biological treatment in 40 CFR 265, Subpart Q (preamble to the final debris rule).

The ANPRM for soil appeared Oct. 24, 1991 (56 *FR* 55160); NPRM expected August, 1993, final rule August 1994.[3] In the interim, EPA has developed guidance for obtaining and complying with a treatability variance for soil and debris that are contaminated with RCRA hazardous wastes for which treatment standards have already been set (Office of Solid Waste and Emergency Response Directive 9347.3-06FS, July 1989). Alternate treatment levels are presented for structural functional groups of organics and for ten inorganics based on actual treatment of soil and best management practices (BMPs) for debris. These should be considered as guidance when RA activities are scheduled that may contaminate or deal with contaminated soil. In addition, EPA has granted an extension of the generic national capacity variance from the LDRs for certain soils and debris and radioactive mixed wastes until May 8, 1993 (57 *FR* 20766, May 15, 1992).

6.5.2.3 Corrective action requirements

Several sections of RCRA require promulgation of corrective action regulations; when finalized, these requirements will most likely be legally applicable to RA sites where there is RCRA hazardous waste contamination. Currently, only the 40 CFR 264 Subpart F regulations on ground-water protection at RCRA-regulated units are potentially applicable to RA activities within facility boundaries and these include ground-water protection standards (40 CFR 264.92 and 40 CFR 264.94) and ground-water monitoring requirements (40 CFR 264.97). The corrective action standards developed under RCRA §3004(u) will be applicable to any D&D or RA cleanup site that is also an active or a formerly active RCRA facility with an active solid waste management unit; thus, the standards will also be applicable to a D&D or RA site where disposal is currently occurring. In addition, RCRA §3004(v) authorizes cleanup beyond facility boundaries.

Requirements for corrective action for RCRA solid waste management units have been proposed (55 *FR* 30798, July 27, 1990). A final rule is expected to appear in December 1993. EPA proposes a risk-based approach to establish media cleanup standards for surface water, ground water, soil, and air. These standards are to be established at concentrations that ensure protection of human health and the environment and are to be set for each media of concern during the remedy selection process. RCRA corrective action levels are not intended to be used as cleanup levels; they are intended only to "trigger" the corrective action process when exceeded. Target cleanup levels may initially

be set at these RCRA action levels but must be modified as appropriate to reflect site-specific exposure assumptions (55 *FR* 30826). Appendix A of the proposed rule lists proposed action levels for 165 compounds (55 *FR* 30865), and Appendix E gives governing equations for calculating action levels (55 *FR* 30870).

A portion of the proposed Subpart S rule was promulgated as a final rule for corrective action at Corrective Action Management Units (CAMUs) and Temporary Units (TUs). This rule establishes two sections in Subpart S *(Corrective Action for Solid Waste Management Units)*: 40 CFR 264.552 (CAMUs) and 40 CFR 264.553 (TUs) (58 *FR* 8658, February 16, 1993). Both of these units function solely to manage wastes that are generated at a RCRA facility for the purpose of implementing RA (i.e., remediation wastes). As a result of this rule, regulatory requirements for remediation wastes will differ from those for "as-generated" wastes regulated under Subtitle C, particularly the LDRs and MTRs. The CAMU or TU designations must be made by EPA or the authorized state, and such designations would be subject to the public review and comment process as part of a remedy selection. These designations would be incorporated into permit modifications for a facility and would include specifications of applicable design, operating, and closure requirements that may be less stringent than the appropriate 40 CFR 264 standards.

Under the CAMU provisions, movement and consolidation of remediation wastes within a designated CAMU will not be subject to LDRs or other hazardous waste land disposal requirements. CAMUs would also not be subject to MTRs, since they are not classified as landfills, surface impoundments, or waste piles. Placement of remediation wastes into a CAMU from an area at a facility but outside the CAMU, or from one CAMU into another CAMU will not trigger LDRs or MTRs, nor will excavation, treatment outside the CAMU, and replacement back in the CAMU. However, movement of wastes from a CAMU to another area in a facility not designated a CAMU would trigger the appropriate LDRs or MTRs.

The EPA Regional Administrator may designate tanks and container storage units used for treatment or storage of remediation wastes as TUs. Permit specifications for TUs must include design, operating, and closure requirements. These may be less stringent than the 40 CFR 264 requirements as long as they are protective of human health and the environment and comply with statutory requirements.

The substantive requirements of this rule are expected to be legally applicable to RAs at CERCLA RA sites that involve the management of RCRA hazardous waste. In this context, CAMU designations would be incorporated into CERCLA decision documents.

6.5.2.4 RCRA Subtitle I Regulations

RCRA §9003 requires promulgation of regulations pertaining to detection, prevention, and correction of releases from underground storage tanks; implementing regulations appear in 40 CFR 280.50 ("Release Reporting, Investigation, and Confirmation"), 280.60 ("Release Response and Corrective Action for Underground Storage Tank Systems Containing Petroleum or Hazardous Substances"), and 280.70 ("Out-of-Service Underground Storage Tank Systems and Closure") and should be considered as regulations for cleanup of any Underground Storage Tanks located at RA sites. 40 CFR 280.66 specifies that corrective action plans designed to protect human health and the environment must be submitted to the "implementing agency" (TDEC Underground Storage Tank Division) for approval. The state must be notified of permanent closure plans not taken in response to corrective action (40 CFR 280.71); suggested cleaning and closure procedures are recommended in 40 CFR 280.71 and may be considered guidance for closure of any tanks at RA sites.

Tennessee Code Annotated (TCA) §68-53-101 *et seq.* authorized the Underground Storage Tank Board to promulgate regulations on July 1, 1988. The implementing regulations for release response and corrective action were promulgated April 15, 1990, and are found in TDEC Rules Chaps. 1200-1-15-.05 to 1200-1-15-.07. These regulations closely parallel the 40 CFR 280 regulations, although the state regulations only apply to Underground Storage Tanks containing petroleum products.

6.5.2.5 RCRA Subtitle D Regulations

EPA has promulgated a final rule establishing a new 40 CFR Part 258, which sets forth revised minimum federal criteria for municipal solid waste landfills (56 *FR* 50978, Oct. 9, 1991). These criteria include closure and postclosure care requirements (40 CFR 258.60 and 258.61).

In addition, the Tennessee (Rules of the TDEC Chap. 1200-1-7) and federal RCRA regulations governing solid WM facilities may regulate RA activities. Specifically, 40 CFR 257.3-3 prohibits nonpoint source contamination of surface waters from solid WM facilities. 40 CFR 257.3-3 also prohibits point source discharges of pollutants into surface waters that are in violation of the requirements of the National Pollutant Discharge Elimination System. 40 CFR 257.3-.4 prohibits contamination of an underground drinking water source above SDWA MCLs.

6.5.3 Clean Air Act

Chapter 25, "Air Pollution Control," of the TCA provides for the purity of the air resources of the state "consistent with the protection of normal health, general welfare and physical property of the people, maximum employment and the full industrial development of the state." Implementing these objectives are the Tennessee ambient air quality standards established by the TDEC Division of Air Pollution Control, which appear in Chap. 1200-3-3 of the Rules of the TDEC and are identical to the federal primary National Ambient Air Quality Standards (see Sect. 6.3.2 and Table 6.1). The ambient standards of Chap. 1200-3-3 are translated into source-specific emission limitations (Rules of the TDEC, Chaps. 1200-3-4 to 1200-3-21) that must be considered legally applicable if they apply to any of the RA sites. Table 6.12 lists sections of the Tennessee air emission standards that should be analyzed on a site-specific basis for each remedial alternative.

The CAA (§111) requires EPA to promulgate standards for new sources of air emissions. This requirement has been implemented in 40 CFR 60 through the New Source Performance Standards that are based on the BDAT and set minimum federal emission limitations on classes of facilities. The National Emission Standards for Hazardous Air Pollutants have been discussed as potential "hybrid" regulations (see Sects. 6.2 and 6.4.1), which should be considered as remedial alternatives are selected.

Certain on-site construction and/or excavation activities may be necessary to prepare a site for remediation. Airborne pollutants may result from these construction activities. The primary concern is elevation of particulate concentrations resulting from earth-moving and site-grading activities. The TDEC, Division of Air Pollution Control has promulgated regulations governing fugitive dust emissions (Rules of the TDEC, Chap. 1200-3-8-.010). An operator must take reasonable precautions to prevent particulate matter from becoming airborne. In addition, fugitive dust may not be emitted as visible emissions beyond property boundary lines for more than 5 min/h or 20 min/day.

Table 6.12. Rules of the TDEC[a] Bureau of Environment Division of Air Pollution Control

Chapter	Subject
1200-3-1	General provisions
1200-3-2	Definitions
1200-3-4	Open burning
1200-3-5	Visible emissions
1200-3-6	Nonprocess emission standards
1200-3-7	Process emission standards
1200-3-8	Fugitive dust
1200-3-11	Hazardous air contaminants
1200-3-14	Control of sulfur dioxide emissions
1200-3-16	New source performance standards
1200-3-18	Volatile organic compounds
1200-3-21	General alternate emission standards
1200-3-22	Lead emission standards
1200-3-23	Visibility protection
1200-3-24	Stack height regulations

[a]TDEC = Tennessee Department of Environment and Conservation.

6.5.4 Clean Water Act

The regulatory aspects of the CWA include site-specific pollutant limitations and performance standards designed to restore and maintain the chemical, physical, and biological integrity of the nation's surface waters. The National Pollutant Discharge Elimination System permit program includes applicable effluent standards, monitoring requirements, and conditions for discharge. Tennessee has an EPA-authorized state program that is equivalent to the federal program. Various National Pollutant Discharge Elimination System permits regulate discharges from ORR to the Clinch River and its tributaries. The effluent limitations and monitoring requirements found in the National Pollutant Discharge Elimination System permits should be analyzed on a site-specific basis for any cleanup at RA sites that would include discharge of pollutants to surface waters.

Direct discharge of dredge-and-fill material into navigable waters is regulated under CWA §404 and implemented through 33 CFR 320-330 and 40 CFR 230. Actions that may be considered dredge-and-fill activities include dredging of sediments from contaminated water bodies, disposal of contaminated soil or materials in surface water, capping of a site, building berms and levees to contain wastes, excavation for the containment of effluent, and dewatering of a site to obtain adequate flow.[8]

The U. S. Army Corps of Engineers issues dredge-and-fill permits for activities regulated under §10 of the Rivers and Harbors Act and §404 of the CWA; in addition, the Tennessee Valley Authority Act §26A approval application for streambed sediment removal may be necessary. Permits may be required by the Corps of Engineers for RA activities at ORNL because the Clinch River and portions of Poplar Creek are designated as "navigable waters" by the Corps of Engineers. All of the CWA §404 requirements for protection of wetlands from fill operations are potentially applicable to remedial activities at ORNL that would impact wetland communities (see Sect. 6.6.3 and Table 6.13 for a further discussion of these issues). CERCLA §121(e) stipulates that permits are not

Table 6.13. Action-specific regulations applicable to remedial action activities at the Oak Ridge Reservation[a]

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Air emissions	Standards for control of emissions of volatile organics. These are based on CAA[f,g], emission standards found in 40 CFR 60.480 60.489.	Emissions from process vents and equipment leaks at treatment, storage, and disposal (TSD) facilities handling or recycling hazardous waste containing 10% or more volatile organics	55 *FR* 25454 (June 21, 1990)	
	EPA is *proposing* to require organic emission controls be installed and operated on tanks, surface impoundments, containers, and certain miscellaneous treatment units if any hazardous waste having a volatile organic concentration equal to or greater than 500 ppm by weight is placed in the unit.	*Proposed* rule, not yet an ARAR[u]	*Proposed* rule, 56 *FR* 33490, July 22, 1991; Final rule expected October 1993	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Capping	Placement of a cap over waste (e.g., closing a landfill, or closing a surface impoundment or waste pile as a landfill, or similar action) requires a cover designed and constructed to: · Provide long-term minimization of migration of liquids through the capped area; · Function with minimum maintenance; · Promote drainage and minimize erosion or abrasion of the cover; · Accommodate settling and subsidence so that the cover's integrity is maintained; and · Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.	RCRA[h,i] hazardous waste placed at site after Nov. 19, 1980, or placement of hazardous waste into another unit will make requirements applicable when the waste is being covered with a cap for the purpose of leaving it behind after the remedy is completed. Capping without such placement will not make requirements applicable, but technical requirements are likely to be relevant and appropriate	40 CFR 264.228(a) (Surface impoundments) 40 CFR 264.258(b) (Waste piles) 40 CFR 264.310(a) (Landfills)	1200-1-11-.06(11)(i) 1200-1-11-.06(12)(i) 1200-1-11-.06(14)(k)
	Restrict postclosure use of property as necessary to prevent damage to the cover.	Final closure of a RCRA hazardous waste facility with some hazardous materials or residues left in place	40 CFR 264.117(c)	1200-1-11-.06(7)(h)
	Prevent run-on and run-off from damaging the final cover.	Postclosure care	40 CFR 264.228 (b) 40 CFR 264.310(b)	1200-1-11-.06(11)(i) 1200-1-11-.06(14)(k)
	Protect and maintain surveyed benchmarks used to locate waste cells (landfills, waste piles).	Postclosure care	40 CFR 264.310 (b)	1200-1-11-.06(14)(k)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Clean closure (e.g., closure with no post-closure care)	*Closure and postclosure standards*	Applicable to land-based unit containing hazardous waste[d]. Applicable to RCRA hazardous waste (listed or characteristic) placed at site after Nov. 19, 1980, or placement of hazardous waste into another unit	40 CFR 264.110-120 (Subpart G)	1200-1-11-.06(7)(a)-(k)
	General performance standard requires elimination of need for further maintenance and control; elimination of postclosure escape of hazardous waste, hazardous constituents, leachate, contaminated runoff, or hazardous waste decomposition products to ground water, surface water, or the environment.	Not applicable to material undisturbed since Nov. 19, 1980, or if treated in situ or consolidated within area of contamination	40 CFR 264.111	1200-1-11-.06(7)(b)
		Designed for cleanup that will not require long-term management; designed for cleanup to health-based standards.		
	Removal or decontamination of waste residues, contaminated containment system components (e.g., liners and dikes), contaminated subsoils, and structures and equipment contaminated with waste and leachate, and management of them as hazardous waste.		40 CFR 264.114 40 CFR 264.178 40 CFR 264.197 40 CFR 264.228 40 CFR 264.258	1200-1-11-.06(9)(c) 1200-1-11-.06(11)(l) 1200-1-11-.06(12)(c) 1200-1-11-.06(13)(l) 1200-1-11-.06(14)(l)
	Must protect human health and the environment.		40 CFR 264.111(b)	1200-1-11-.06(7)(b)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Closure with waste in place (capping)	Eliminate free liquids by removal or solidification.	Applicable to land based unit containing RCRA hazardous waste[d]	40 CFR 264.228(a)(2) (Surface impoundments)	1200-1-11-.06(11)(i)
	Stabilization of remaining waste and waste residues to support cover.		40 CFR 264.258(b) (Waste piles)	1200-1-11-.06(12)(i)
			40 CFR 264.310(a) (Landfills)	1200-1-11-.06(16)(k)
	Installation of final cover to provide long-term minimization of infiltration (see "capping" for further restrictions).		40 CFR 264.310	1200-1-11-.06(14)(k)
			40 CFR 264.310	1200-1-11-.06(14)(k)
	Postclosure care and ground-water monitoring.[j]			
Consolidation between units	Placement on or in land outside unit boundary or area of contamination will trigger land disposal requirements and restrictions.	Placement of RCRA hazardous wastes subject to land disposal restrictions	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
		Movement of hazardous waste (listed or characteristic) from one unit or area of contamination into another		
		Consolidation within a unit or area of contamination does not trigger applicability[d,k]		

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Container storage (on site)	Containers of hazardous waste must be: · Maintained in good condition; · Compatible with hazardous waste to be stored; and · Closed during storage (except to add or remove waste). Inspect container storage areas weekly for deterioration. Place containers on a sloped, crack-free base, and protect from contact with accumulated liquid. Provide containment system with a capacity of 10% of the volume of containers. Remove spilled or leaked waste in a timely manner to prevent overflow to the containment system.	Storage of RCRA hazardous waste (listed or characteristic) not meeting small quantity generator criteria held for a temporary period before treatment, disposal, or storage elsewhere, in a container (i.e., any portable device in which a material is stored, transported, disposed of, or handled) A generator who accumulates or stores hazardous waste on site for 90 days or less in compliance with 40 CFR 262.34 (a)(1-4) is not subject to full RCRA storage requirements.	40 CFR 264 (Subpart I) 40 CFR 264.171 40 CFR 264.172 40 CFR 264.173 40 CFR 264.174 40 CFR 264.175	1200-1-11-.06(9) 1200-1-11-.06(9)(b) 1200-1-11-.06(9)(c) 1200-1-11-.06(9)(d) 1200-1-11-.06(9)(e) 1200-1-11-.06(9)(f)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Container storage (on site) (continued)	Keep containers of ignitable or reactive waste at least 50 ft from the facility's property line.		40 CFR 264.176	1200-1-11-.06(9)(g)
	Keep incompatible materials separate. Separate incompatible materials stored near each other by a dike or other barrier.		40 CFR 264.177	1200-1-11-.06(9)(h)
	At closure, remove all hazardous waste and residues from the containment system, and decontaminate or remove all containers, liners.		40 CFR 264.178	1200-1-11-.06(9)(i)
	Storage of banned wastes must be in accordance with 40 CFR 268. When such storage occurs beyond one year, the owner/operator bears the burden of proving that such storage is solely for the purpose of accumulating sufficient quantities to allow for proper recovery, treatment, and disposal.		40 CFR 268.50	1200-1-11-.10(1)(e)
Dike construction	Design and operate facility to prevent overtopping from overfilling; wind and wave action; rainfall; run-on; malfunctions of level controllers, alarms, and other equipment; and human error.	Existing surface impoundment containing hazardous waste, or creation of new surface impoundment	40 CFR 264.221	1200-1-11-.06(11)(b)
	Construct dikes with sufficient structural integrity to prevent massive failure.		40 CFR 264.221	1200-1-11-.06(11)(b)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Dike construction (continued)	Ensure that the dike, including that portion which provides freeboard, has structural integrity that will withstand stress of pressures from added wastes and will not fail due to scouring or piping.	Following a period of six months or greater when an impoundment has been out of service	40 CFR 264.226(c)	1200-1-11-.06(13)(g)3
	Inspect weekly for proper operation and integrity of the containment devices.		40 CFR 264.226	1200-1-11-.06(11)(g)
	Remove surface impoundment from operation if the dike leaks or there is a sudden drop in liquid level.		40 CFR 264.227	1200-1-11-.06(11)(h)
	U.S. Army Corps of Engineer permit approval may be required.	Structures or work in, or affecting, navigable waters of the U.S.	§§9 and 10, Rivers and Harbors Act.	
Direct discharge of treatment system effluent	*National Pollutant Discharge Elimination System (NPDES) Permitting Program*		40 CFR 122 (Clean Water Act)[o]	1200-4-5
	Use of best available technology economically achievable is required to control toxic and nonconventional pollutants. Use of best conventional pollutant control technology is required to control conventional pollutants. Technology-based limitations may be determined on a case-by-case basis.	Point source discharge to waters of the United States[m, n]	40 CFR 122.44(a)	
	The discharge must comply with applicable federal water quality requirements and more stringent state requirements under the Clean Water Act (CWA)[p].		40 CFR 122.44(d) and state regulations approved under 40 CFR 131	1200-4-3-.03

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Direct discharge of treatment system effluent (continued)	The discharge must be consistent with the requirements of a Water Quality Management plan approved by EPA under CWA §208(b).		40 CFR 122.44(d)	
	Discharge limitations must be established for all toxic pollutants that are or may be discharged at levels greater than that which can be achieved by technology-based standards.		40 CFR 122.44(e)	
	Develop and implement a best management practice (BMP) program and incorporate in the NPDES permit to prevent the release of toxic constituents to surface waters.		40 CFR 125.100	
	Criteria and standards for NPDES		40 CFR 125	1200-4-5
	The BMP program must: • Establish specific procedures for the control of toxic and hazardous pollutant spills; • Include a prediction of direction, rate of flow, and total quantity of toxic pollutants where experience indicates a reasonable potential for equipment failure; • Ensure proper management of solid and hazardous waste in accordance with regulations promulgated under RCRA.	Discharge to waters of the United States[n]	40 CFR 125.104	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Direct discharge of treatment system effluent (continued)	To ensure compliance, discharge must be monitored for: · The mass of each pollutant; · The volume of effluent; · Frequency of discharge and other measurements as appropriate.		40 CFR 122.44(i)	
	Approved test methods must be followed for monitored waste constituents. Detailed requirements for analytical procedures and quality control are provided.		40 CFR 136.1-136.3(e)	
	Comply with additional permit conditions such as: · Duty to mitigate any adverse effects of any discharge; and · Proper operation and maintenance of treatment systems.	Off-site discharges	40 CFR 122.41(d,e)	
Discharge of dredge and fill material to navigable waters	The four conditions that must be satisfied before dredge and fill is an allowable alternative are: · There must be no practicable alternative. · Discharge of dredge or fill material must not cause a violation of state water quality standards, violate any applicable toxic effluent standards, jeopardize an endangered species, or injure a marine sanctuary.		40 CFR 230.10 (Marine Protection, Research, and Sanctuaries Act)	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Discharge of dredge and fill material to navigable waters (continued)	· No discharge shall be permitted that will cause or contribute to significant degradation of the water. · Appropriate steps to minimize adverse effects must be taken.			
	Determine long- and short-term effects on physical, chemical, and biological components of the aquatic ecosystems.		33 CFR 320-330 (Clean Water Act)	
	Comply with additional substantive conditions such as: · Duty to mitigate any adverse effects of any discharge; and · Proper operation and maintenance of treatment systems.		40 CFR 122.41(l)	
	Monitor and report results as required by permit (minimum of at least annually).	Off-site discharges	40 CFR 122.44(l)	
Dredging	Removal of all contaminated soil.	RCRA hazardous waste placed at site after Nov. 19, 1980, or movement of hazardous waste from one unit, area of contamination or location into another unit or area of concentration	40 CFR 264.228 (surface impoundments) 40 CFR 264.258 (waste piles)	1200-1-11-.06(11)(l) 1200-1-11-.06(11)(l)
	Prohibits construction of any structures, or work in or affecting navigable waters, without approval of the U.S. Corps of Engineers.	Work performed in navigable waters of U.S.	§§ 9 and 10, Rivers and Harbors Act.	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Excavation	Site excavations must be shored or sloped to prevent accidental collapse in accordance with Subpart P of 29 CFR 1926.	Occupational Safety and Health Act (OSHA) regulations for workers at hazardous waste sites	29 CFR 1926, 54 *FR* 45894 (Nov. 31, 1989)	
	Movement of excavated materials to new location and placement in or on land will trigger land disposal restrictions for the excavated waste or closure requirements for the unit in which the waste is placed.	Materials containing RCRA hazardous wastes subject to land disposal restrictions are placed in another unit	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
	Total suspended particulates (TSP) must be maintained below National Ambient Air Quality Standards	Nonpoint source contribution to fugitive dust emissions	40 CFR 50.6	1200-3-3-.03
	Control of fugitive dust emissions may be required under state air quality regulations.			
Gas collection	Standards for control of emissions of volatile organics. These are based on CAA emission standards found in 40 CFR 60.480-60.489.	Emissions from process vents and equipment leaks at TSD facilities handling or recycling hazardous waste containing 10% or more volatile organics	55 *FR* 25454 (June 21, 1990)	
Ground-water diversion	Excavation of soil for construction of slurry wall may trigger closure or land disposal restrictions.	Materials containing RCRA hazardous waste subject to land disposal restrictions if moved to another unit	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
	Site excavations must be shored or sloped to prevent accidental collapse in accordance with Subpart P of 29 CFR 1926.	OSHA regulations for workers at waste sites	54 *FR* 9294 (March 3, 1989)	
Incineration (on site)	Analyze the waste feed.	RCRA hazardous waste	40 CFR 264.341	1200-1-11-.06(15)(b)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Incineration (on site) (continued)	Dispose of all hazardous waste and residues, including ash, scrubber water, and scrubber sludge.			
	No further requirements apply to incinerators that only burn wastes listed as hazardous solely by virtue of combination, and if the waste analysis shows that no Appendix VIII constituent is present that might reasonably be expected to be present.			
	Performance standards for incinerators:			
	· Achieve a destruction and removal efficiency of 99.99% for each principal organic hazardous constituent in the waste feed and 99.999% for dioxins;		40 CFR 264.343(a)	1200-1-11-.06(15)(d)
	· Reduce hydrogen chloride emissions to 1.8 kg/h or 1% of the HCl in the stack gases before entering any pollution control devices; and		40 CFR 264.343(b)	1200-1-11-.06(15)(d)
	· Limit emissions of particulate matter.		40 CFR 264.343(c)	1200-1-11-.06(15)(d)
	EPA is *proposing* to amend the hazardous waste incinerator regulations to improve control of toxic metals, hydrogen chloride, and organic emissions.	*Proposed* rule, not yet ARAR	55 *FR* 17862 (April 27, 1990)	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Incineration (on site) (continued)	Monitoring of various parameters during operation of the incinerator is required. These parameters include: · Combustion temperature; · Waste feed rate; · An indicator of combustion gas velocity; and · Carbon monoxide		40 CFR 264.347	1200-1-11-.06(15)(g)
	Control fugitive emissions either by: · Keeping combustion zone sealed; or · Maintaining combustion zone pressure lower than atmospheric pressure.		40 CFR 264.345(d)	1200-1-11-.06(15)(f)
	Utilize automatic cutoff system to stop waste feed when operating conditions deviate.		40 CFR 264.345(e)	1200-1-11-.06(15)(f)
	Special performance standards for incineration of polychlorinated biphenyls		40 CFR 761.70(b) (Total Substances Control Act)[r]	
	New source performance standards for incinerators.	Incinerators with a charge rate greater than 45 metric tons/day	40 CFR 60.50-60.54 (Clean Air Act)	
Land treatment	Ensure hazardous constituents are degraded, transformed, or immobilized within the treatment zone.	RCRA hazardous waste being treated or placed into another unit	40 CFR 264.271(a)	1200-1-11-.06(13)(b)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[a] Rules, Chapter
Land treatment (continued)	Maximum depth of treatment zone must be no more than 1.5 meters (5 ft) from the initial soil surface; and more than 1 meter (3 ft) above the seasonal high-water table.		40 CFR 264.271(c)	1200-1-11-.06(13)(b)
	Minimize run-off of hazardous constituents.		40 CFR 264.273(b)	1200-1-11-.06(13)(d)
	Maintain run-on/run-off control and management system.		40 CFR 264.273(c)	1200-1-11-.06(13)(d)
	Special application conditions if food-chain crops grown in or on treatment zone.		40 CFR 264.276	1200-1-11-.06(13)(g)
	Unsaturated zone monitoring program required.		40 CFR 264.278	1200-1-11-.06(13)(i)
	Special requirements for ignitable or reactive waste.		40 CFR 264.281	1200-1-11-.06(13)(l)
	Special requirements for incompatible waste.		40 CFR 264.282	1200-1-11-.06(13)(m)
	Special requirements for RCRA hazardous wastes.	RCRA waste FO20, FO21, FO22, FO23, FO26, FO27, (dioxin-containing wastes) May be superseded by new land ban regulations.	40 CFR 264.283	1200-1-11-.06(13)(n)
	Prior to land disposal, waste must be treated to BDAT levels or meet a "no migration" standard.	RCRA hazardous waste being disposed of in another unit	40 CFR 268 (Part D)	1200-1-11-.10(3)
	Treatment standards and land disposal restrictions apply to: spent solvent wastes, dioxin-containing wastes, California-list wastes, and all RCRA hazardous waste (see Treatment).		52 *FR* 25760 (July 8, 1987) RCRA 3004(d)	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Operation and maintenance	30-year postclosure care to ensure that site is maintained and monitored.	Closure of hazardous waste management units	40 CFR 264.117	1200-1-11-.06(7)(h)
Placement of liquid waste in landfill	No bulk or noncontainerized liquid hazardous waste or hazardous waste containing free liquids may be disposed of in landfills. Containers holding free liquid may not be placed in a landfill unless the liquid is mixed with an absorbent or solidified.	Placement of a bulk or noncontainerized RCRA waste in a landfill	40 CFR 264.314(b)	1200-1-11-.06(14)(o)
Placement of waste in land disposal unit	Attain land disposal treatment standards to comply with "land ban" restrictions (see Treatment)	Placement of RCRA hazardous waste in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground cave or mine	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
Slurry wall	Excavation of soil for construction of slurry wall may trigger cleanup or land disposal restrictions.	RCRA hazardous waste placed at site after Nov. 19, 1980, or movement of hazardous waste from one unit into another unit or area of contamination	40 CFR 268 (Part D) See also Consolidation, Excavation, and Treatment regulations	1200-1-11-.10(3)
Surface-water control	Prevent run-on and control and collect run-off from at least the amount of water volume resulting from a 24-h, 25-year storm (waste piles, land treatment facilities, landfills).	RCRA hazardous waste treated, stored, or disposed at a site after Nov. 19, 1980	40 CFR 264.251(c,d); 40 CFR 264.273(c,d); 40 CFR 264.301(c,d)	1200-1-11-.06(12)(b) 1200-1-11-.06(13)(d) 1200-1-11-.06(14)(b)
	Prevent over-topping of surface impoundment.		40 CFR 264.221(c)	1200-1-11-.06(11)(b)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Surface-water control (continued)	Monitor surface water to ensure compliance with state water quality standards.	Discharge of wastes to adjacent streams or other surface water bodies	40 CFR 122	1200-4-3
Tank storage (on site)	Existing and new tanks must have sufficient structural strength, compatible with the waste, and corrosion protection to ensure that they do not collapse or rupture.	Storage of RCRA hazardous waste (listed or characteristic) not meeting small quantity generator criteria held for a temporary period greater than 90 days before treatment, disposal, or storage elsewhere, in a tank (i.e., any portable device in which a material is stored, transported, disposed of, or handled) A generator who accumulates or stores hazardous waste on site for 90 days or less in compliance with 40 CFR 262.34 (a)(1-4) is not subject to full RCRA storage requirements	40 CFR 264.191-192	1200-1-11-.06(10)(b)-(c)
	Waste must not be incompatible with the tank material unless the tank is protected by a liner or by other means.		40 CFR 264.191	1200-1-11-.06(10)(b)
	Tanks must be provided with secondary containment and controls to prevent overfilling, and sufficient freeboard maintained in open tanks to prevent overtopping by wave action or precipitation.		40 CFR 264.193-194	1200-1-11-.06(10)(d)-(e)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Tank storage (on site) (continued)	Prevent the migration of spills or leaks to soils or surface water. Remove and dispose of any visible containment of soils or surface water.	Leaks or spills from tanks or secondary containment systems containing RCRA hazardous waste	40 CFR 264.196(c)	1200-1-11-.06(12)(d)3
	Remove tank from service; remove waste from tank or secondary containment system.		40 CFR 264.196(a,b)	1200-1-11-.06(12)(d)3
	Repair any corrosion, crack, or leak.		40 CFR 264.196(c)	1200-1-11-.06(12)(d)3
	Notify pursuant to 40 CFR 302 if spill or leak is above a reportable quantity		40 CFR 264.196(d)	1200-1-11-.06(12)(d)3
	Inspect the following: overfilling control; control equipment, monitoring data, waste level (for uncovered tanks), tank condition, aboveground portions of tanks (to assess their structural integrity), and the area surrounding the tank (to identify signs of leakage).		40 CFR 264.195	1200-1-11-.06(10)(f)
	At closure, remove all hazardous waste and hazardous waste residues from tanks, discharge control equipment, and discharge confinement structures.		40 CFR 264.197	1200-1-11-.06(10)(h)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Tank storage (on site) (continued)	Store ignitable and reactive waste so as to prevent the waste from igniting or reacting. Ignitable or reactive wastes in covered tanks must comply with buffer zone requirements in "Flammable and Combustible Liquids Code," Tables 2-1 through 2-6 (National Fire Protection Association 1976, 1981).		40 CFR 264.198	1200-1-11-.06(10)(l)
	Storage of banned wastes must be in accordance with 40 CFR 268. When such storage exceeds one year, the owner/operator bears the burden of proving that the storage is solely for the purpose of accumulating sufficient quantities to allow for proper recovery, treatment, and disposal.		40 CFR 268.50	1200-1-11-.10(4)(a)
Transportation	Compliance with the RCRA manifest and pretransportation regulations must be achieved.	Transportation of RCRA waste to an off-site treatment, storage, or disposal facility	40 CFR 262	1200-1-11-.03
	Compliance with Department of Transportation (DOT) packaging, labeling, marking, and placarding requirements must be achieved (49 CFR 172-179)		40 CFR 262	1200-1-11-.03
Treatment (in a unit)	Design and operating standards for units in which hazardous waste is treated must ensure protection of human health and the environment.	Treatment of RCRA hazardous waste in a unit	40 CFR 264.601 (Miscellaneous treatment units)	1200-1-11-.06(10)(b)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Treatment (in a unit) (continued)	Prevention of any releases that may have adverse effects on human health or the environment due to migration of waste constituents			
	Specific considerations must be made to prevent adverse effects in: · the ground water or subsurface environment. · surface water, or wetlands, or the soil surface. · or the air.		40 CFR 264.601(a)	1200-1-11-.06(19)(b)
Treatment (chemical, physical, or biological	Hazardous wastes or treatment reagents must not be placed in the treatment process or equipment if they could cause the treatment process or equipment to rupture, leak, corrode, or otherwise fail before the end of its intended life.		40 CFR 265.401	1200-1-11-.05(17)
	Where hazardous waste is continuously fed into a treatment process or equipment, the process or equipment must be equipped with a means to stop the inflow.		40 CFR 265.401	1200-1-11-.05(17)
	Special requirements for ignitive, reactive, or incompatible wastes.		40 CFR 265.17	1200-1-11-.05(2)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Treatment in a containment building	Owners or operators of containment buildings designed and operated under the requirements of §268.1101 are not subject to the definition of land disposal in RCRA 3004(k) given certain provisions outlined in §268.1100.		40 CFR 264.1100	
	Design and operating standards are intended to assure containment of managed wastes and to prevent exposure to the elements via precipitation, wind, run-on, etc.		40 CFR 264.1101(a)	
	Maintain primary barrier to be free of significant cracks, gaps, corrosion, or other deterioration that could cause release of hazardous substances.		40 CFR 268.1101(c)(1)	
	Take measures to prevent the tracking of hazardous waste outside of the unit by the personnel or equipment.			
	Take measures to control fugitive dust emissions.			
	Obtain certification by a qualified registered professional engineer that the building design meets the requirements of §268.1101.		40 CFR 264.1101(c)(2)	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Treatment in a containment building (continued)	Any condition that could lead to the release of a hazardous substance must be repaired promptly in accordance with prescribed procedures.		40 CFR 264.1101(c)(3)	
	Inspect at least weekly, and keep a log book of the facility's operating record.		40 CFR 264.1101(c)(4)	
	Secondary containment requirements are listed for management of hazardous wastes containing free liquids or treated with free liquids.		40 CFR 264.1101(b); 40 CFR 264.1101(d)	
	At closure, remove or decontaminate all waste residues, contaminated containment system components, contaminated subsoils, and structures or equipment contaminated with waste and leachate, and manage them as hazardous waste. The closure plan, etc., must meet all the requirements of 40 CFR 264 Subparts G and H.		40 CFR 264.1102(a)	
	If not all contaminated subsoils can be removed from the structure, it must be closed in accordance with the landfill closure and postclosure requirements of 40 CFR 264.310.		40 CFR 264.1101(b)	

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Treatment	Treatment of wastes subject to ban on land disposal must attain levels achievable by BDAT for each hazardous constituent in each listed waste if residual is to be land disposed. If residual is to be further treated, initial treatment and any subsequent treatment that produces residual to be treated need not be BDAT if it does not exceed the value in the Constituent Concentration in Waste Extract Table for each applicable wastewater	The following wastes have been prohibited from land disposal without treatment:	40 CFR 268 (Part D)	1200-1-11-.10(3)
		· Spent solvent wastes and dioxin-containing wastes.	51 *FR* 40572 (Nov. 7, 1986)	
		· "California List" wastes	52 *FR* 25760 (July 8, 1987)	
		All ranked and listed hazardous wastes identified under 40 CFR Part 261:		
		· First third	40 CFR 268.33	
		· Second third	40 CFR 268.34	
		· Final third, and mixed radioactive hazardous waste	40 CFR 268.35	
		· Newly listed wastes and contaminated debris	40 CFR 268.36; 40 CFR 268.45	
	No-migration variance for restricted hazardous waste land disposal	*Proposed* ARAR. Land disposal of untreated hazardous waste that has been restricted from land disposal	40 CFR 268 (Part D) Notice of Proposed Rule Making (NPRM) Aug. 1992; Final rule expected August 1994	1200-1-11-.10(3)
	Treatment and disposal of hazardous soil	EPA will propose treatment standards for contaminated soil	40 CFR 268 (Part D) NPRM (soil) August 1993; Final rule expected August 1994	1200-1-11-.10(3)

000384

Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Treatment (continued)		Effective Nov. 8, 1990, disposal of contaminated soil or debris resulting from CERCLA[s] response actions or RCRA corrective actions is subject to land disposal prohibitions and/or treatment standards established for spent solvent wastes, dioxin-containing wastes, and "California List" wastes Disposal of soil and debris contaminated with RCRA hazardous waste for which the treatment standard is incineration is not subject to the land disposal restrictions until Aug. 1990, July 1991, and Nov. 1991, for the three thirds, respectively Mixed radioactive waste is included in the final third capacity national capacity variance schedule		
Underground injection of wastes and treated ground water	Underground Injection Control (UIC) program prohibits:		40 CFR 144 (Safe Drinking Water Act)[f]	1200-4-6
	• Injection activities that allow movement of contaminants into underground sources of drinking water (USDW) and results in violation of MCLs or adversely affects health[u].		40 CFR 144.12	1200-4-6-.04

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Underground injection of wastes and treated ground water (continued)	· Construction of new Class IV wells, and operation and maintenance of existing wells.	Excludes Class IV wells used to reinject contaminated ground water that has been treated if part of a CERCLA or RCRA remedial action	40 CFR 144.13	1200-4-6-.13
	Subsurface emplacement of waste fluids into ground water in area of regional rock deformation of the magnitude that occurs in east Tennessee	Class I wells		1200-4-6-.10(1)(c)
	All hazardous waste injection wells must also comply with the RCRA Part 264 permitting requirements.		40 CFR 144.14	
	Use or operation of unpermitted injection wells			1200-4-6-.03
	General standards and methods			
	Owners and operators must:		40 CFR 144.26	1200-4-6-.09
	· Submit inventory information to the director of the UIC program for the state; including hydrogeologic data for wells, construction record, nature or composition of injected fluids, injection rate and pressure, and ground-water monitoring data.		40 CFR 144.27	1200-4-6-.08(13)(j)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Underground injection of wastes and treated ground water (continued)	· Report noncompliance orally within 24 hours.	Class I wells	40 CFR 144.28(b)	1200-4-6-.08(13)(l)
	· Prepare, maintain, and comply with plugging and abandonment plan.		40 CFR 144.28(c)	1200-4-6-.09(6)
	Monitor Class I wells by:	Class I wells are used to inject hazardous waste beneath the lowermost formation containing, within one quarter mile, a USDW	40 CFR 144.28(g)(1)	1200-4-6-.10(4)(f)
	· Frequent analysis of injection fluid; · Continuous monitoring of injection pressure, flow rate and volume; and · Installation and monitoring of ground-water monitoring wells.			
	Applicants for Class I permits must:			
	· Identify all injection wells within the area of review;		40 CFR 144.55	1200-4-6-.10(3)(b)
	· Take action as necessary to ensure that such wells are properly sealed, completed, or abandoned to prevent contamination of USDW.		40 CFR 146.4	1200-4-6-.10(5)
	Case and cement all Class I wells to prevent movement of fluids into USDW, taking into consideration well depth, injection pressure, hole size, composition of injected waste, and other factors.		40 CFR 146.12(a)(b)	1200-4-6-.10(3)(d)(2) 1200-4-6-.10(3)(f)
	Appropriate logs shall be recorded and other tests conducted during construction and a descriptive report prepared and submitted to the UIC program director.		40 CFR 146.12(d)	1200-4-6-.10(f)

000387

Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Underground injection of wastes and treated ground water (continued)	Injection pressure may not exceed a maximum level designed to ensure that injection does not initiate new fractures or propagate existing ones and cause the movement of fluids into a USDW.		40 CFR 146.13(b)	1200-4-6-.10(4)(b)(1) 1200-4-6-.10(4)(b)(2)
	Continuous monitoring of injection pressure, flow rate and volume, and annual pressure, if required.		40 CFR 146.13(a)	1200-4-6-.10(4)(e) 1200-4-6-.10(4)(f) 1200-4-6-.10(4)(g)
	Demonstration of mechanical integrity is required every 3 years.		40 CFR 146.12(a)(b)	1200-4-6-.10(4)(e)(6)
	Criteria for determining whether an aquifer may be an exempted aquifer include current and future use, yield, and water quality characteristics.			
	Ground-water monitoring may also be required.		40 CFR 146.13(b)	1200-4-6-.10(4)(e) 1200-4-6-.10(4)(f)
	Prohibits underground injection of hazardous wastes (solvents and dioxins) in Class I wells; amendments to existing UIC regulations.	Class I injection wells	53 *FR* 28118 (July 26, 1988)	1200-4-6-.10(1)
Underground storage tanks (UST) temporary closure	Continuous monitoring for leaks; leave vent lines open and functioning; cap and secure all other lines, pumps, man ways and ancillary equipment; notify implementing agency of return to service or permanent closure.	Pertains to releases of CERCLA hazardous substances from any one or a combination of tanks the volume of which is 10% or more beneath the surface of the ground (including pipes). Tanks that have been out of service for 3-24 months	53 *FR* 37082 (Sept. 23, 1988) 40 CFR Part 280.80(-a)(b)	

000388

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter
Underground storage tanks permanent closure	Removal requires removing all flammable liquids from the UST, removing all pipes from the UST, and purging the UST of all hazardous vapors before removal and disposal.	Pertains to releases of CERCLA hazardous substances from any one or a combination of tanks the volume of which is 10% or more beneath the surface of the ground (including pipes). Tanks that have been out of service for 3-24 months	53 *FR* 37082 (Sept. 23, 1988) 40 CFR Part 280.80(c-f)	
	Closure requires removal of all flammable liquids from the UST, disconnect or cap all pipes, fill tank system with an inert solid material		52 *FR* 12662 (April 17, 19870	
Waste pile	Use liner and leachate collection and removal system.	RCRA hazardous waste, noncontainerized accumulation of solid, nonflammable hazardous waste that is used for treatment or storage in piles	40 CFR 264.25(a)	
	Operate and maintain run-on and run-off control systems for at least the amount of water resulting from a 14-h, 25-year storm.		40 CFR 264.251 (c)(d)	1200 1-11-.06(12)(b)
	Pile must be managed to control wind erosion.		40 CFR 264.251(f)	1200-1-11-.06(12)(b)
	Pile must be monitored and inspected.		40 CFR 264.254	1200-1-11-.06(12)(e)
Waste pile	Closure and postclosure care required.		40 CFR 264.258	1200-1-11-.06(12)(i)

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter

[a]Adapted from EPA (1989). Currently only RCRA, CWA, and Safe Drinking Water Act requirements are included. Additional action-specific requirements will be added as additional statutes are analyzed.

[b]Action alternatives from the Record of Decision keyword index, *FY 1986 Record of Decision Annual Report*. January 1987, Hazardous Site Control Division, EPA.

[c]Requirements have been proposed but not promulgated for various remedial actions. When these regulations are promulgated, they will be included in the matrix.

[d]Some action-specific requirements listed may be relevant and appropriate even if RCRA definitions of storage, disposal, or hazardous waste are not met (40 CFR 260.10), or if the waste at the site is similar to but not identifiable as a RCRA hazardous waste.

[e]TDEC = Tennessee Department of Environment and Conservation.

[f]CAA = Clean Air Act.

[g]Title I of the CAA covers Air Pollution Prevention and Control, and implementing regulations are found in 40 CFR Parts 50-99.

[h]RCRA = Resource Conservation and Recovery Act.

[i]Subtitle C of RCRA governs hazardous waste management (§3001-3020). Implementing regulations appear in 40 CFR Parts 260-268, 270, 271, 280, and 124.

[j]Regional administrator may revise length of postclosure care period (40 CFR 264.117).

[k]In many cases there are no defined "units" at a CERCLA site. Instead, there are areas of contamination with differing concentration levels (including hot spots) of hazardous substances, pollutants, or contaminants. When RCRA hazardous wastes are moved into or out of an area of contamination, RCRA disposal requirements are applicable to the waste being managed and certain treatment, storage, or disposal requirements (such as for closure) are applicable to the area where the waste is received.

[l]Landfill units meeting the requirements of 40 CFR 264.301(f) are not subject to RCRA minimum technology requirements.

[m]The term "Waters of the U.S." is defined broadly in 40 CFR 122.2 and includes essentially any water body and wetland.

[n]Section 121 of the Superfund Amendments and Reauthorization Act of 1986 (SARA) exempts on-site CERCLA activities from obtaining permits. However, the substantive requirements of a law or regulation must be met. In particular, on-site discharges to surface waters are exempt from procedural NPDES permit requirements. Off-site dischargers would be required to apply for and obtain an NPDES permit.

[o]Titles III and IV of the CWA cover Standards and Enforcement, and Permits and Licenses, respectively. Implementing regulations appear in 40 CFR Parts 110, 112, 116, 117, 122, 124, 125, 131, and 136. 40 CFR Subchapter N sets forth effluent guidelines for various point source categories.

[p]Federal Water Quality Criteria (WQC) may be relevant and appropriate depending on the designated or potential use of the water, the media affected, the purposes of the criteria, and current information [SARA §121(d)(2)(B)(i)]. Federal WQC for the protection of aquatic life will be relevant and appropriate when environmental factors (e.g., protection of aquatic organisms) are being considered (55 *FR* 8755, March 8, 1990).

[q]Discharge to publicly owned treatment works (POTWs) is considered an off-site activity. Off-site actions must comply with all legally applicable requirements, both substantive and administrative. The concept of "relevant and appropriate" is not available for off-site actions.

[r]Implementing regulations for the Toxic Substance Control Act of importance to cleanup at CERCLA sites are 40 CFR Parts 717 and 761.

[s]CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act

[t]Title IV of the Safe Drinking Water Act covers Safety of Public Water Systems. Implementing regulations are found in 40 CFR Parts 124 and 141-147.

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Table 6.13 (continued)

Actions[b]	Requirements	Prerequisites[c,d]	Federal citation	TDEC[e] Rules, Chapter

[d]Underground sources of drinking water (USDW) is a nonexempted aquifer or its portion which: (1) supplies any public water system, or (2) contains sufficient quantity of ground water to supply a public water system and currently supplies drinking water for human consumption or contains fewer than 10,000 mg/L total dissolved solids (40 CFR 144.3).

[e]ARAR = applicable or relevant and appropriate requirements

Source: E. L. Etnier, E. P. McDonald and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

000391

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required for on-site CERCLA cleanup; however, the applicability of these regulations for on- or off-site RA activities should be addressed on a site-specific basis.

Storm water discharges from activities at industrial sites involving construction operations that result in the disturbance of five acres total land have been included in the final rule for National Pollutant Discharge Elimination System permits for storm water discharges (40 CFR 122). Consultation with TDEC is required to ensure compliance with the substantive requirements of the National Pollutant Discharge Elimination System permitting process for storm water discharges during construction activities for CERCLA sites (Chap. 1200-4-10-.05 of the Rules of the TDEC). For RA activities not operating under CERCLA, compliance with the full storm water permitting process is required. In either case, implementation of good site planning and BMPs to control storm water discharges is required.

6.5.5 Safe Drinking Water Act

Part C of Title XIV of the SDWA authorizes the establishment of an underground injection control permit program designed to prevent contamination of underground sources of drinking water. Any RA activities involving discharge by way of underground injection wells would be subject to these regulations. An underground drinking water source is defined in the underground injection control regulations (40 CFR 146.3) as an aquifer or its portion that supplies drinking water for human consumption, contains a sufficient supply of ground water to supply a public water system, and contains fewer than 10,000 mg total dissolved solids per liter of water. Tennessee has a underground injection control program (Chap. 1200-4-6 of the Rules of the Water Control Board) that classifies all ground water as useful for domestic water supply unless certain exemption criteria apply. Aquifers are exempted for various reasons, including economic or technical impracticality (1) in recovery because of depth or location or (2) in successful treatment of contaminated water for drinking water purposes.

6.5.6 Toxic Substances Control Act

Specific TSCA standards exist for incineration or alternate disposal of liquid and nonliquid waste and for articles and soils containing PCBs. TSCA storage requirements for PCBs (40 CFR 761.65) specify that PCBs and PCB-containing items at concentrations of greater than 50 ppm must be disposed of within one year after being placed in storage for disposal. A federal facilities agreement is pending which would allow the continued storage of PCBs at ORNL. There are also structural requirements for facilities and containers used for storage of PCBs. These requirements, too detailed to be listed here, are delineated in 40 CFR 761.65(b) for facilities and 40 CFR 761.65(c) for containers. PCB WM is discussed further in Vol. 1, Pt. C, Chap. 7, which deals with WM regulations.

6.5.7 Federal Insecticide, Fungicide, and Rodenticide Act

The Federal Insecticide, Fungicide, and Rodenticide Act delegates authority to EPA to regulate the disposal and storage of excess pesticides and pesticide containers. To that end, EPA has published nonregulatory procedures for disposal of pesticides in 40 CFR 165, Subpart C. These recommendations might provide guidance for cleanup of pesticides and pesticide containers at RA sites and should be analyzed on a site-specific basis. EPA is currently updating these guidelines to make them consistent with current

regulations and technologies. Regulatory initiatives for 40 CFR 165 will be published in three phases. An NPRM for Phase I, concerning suspended and canceled pesticides, was published May 5, 1993 (58 *FR* 26856). The NPRM for Phase II, concerning container design, residue removal storage, containment, and excess, is due in July 1993, and the Phase III NPRM is due in 1994.[3]

6.5.8 Occupational Safety and Health Administration

Title I, §126(b) of CERCLA mandated that Occupational Safety and Health Administration (OSHA) promulgate standards for regulation of employee health and safety during hazardous waste operations at RCRA or CERCLA sites and during emergency response to hazardous substance releases. The final regulations for *Hazardous Waste Operations and Emergency Response* (29 CFR 1910) have appeared in 54 *FR* 9294 (Final Rule, March 6, 1989; effective date, March 1990). These regulations are designed to protect workers involved in cleanup operations at uncontrolled hazardous waste sites and to provide for worker protection during initial site characterization and analysis, monitoring activities, materials handling activities, training, and emergency response. These regulations do not apply to those workers who would not be exposed. Federal construction activities involving no potential for hazardous substance exposure are covered by the OSHA standards in 29 CFR 1926, *Federal Service Contracts*.

Standards for the protection of workers involved in construction, demolition, alteration, or repair activities involving asbestos-containing materials are listed in 29 CFR 1926.58 and would be applicable to RA activities involving asbestos-containing materials.

CERCLA provides in §126(b) that the OSHA regulations address certain worker protection provisions; however, employers would have to continue to comply with other pertinent OSHA standards found in 29 CFR 1910 (*General Industry*) as well. Air contaminant Permissible Exposure Limits for general industry for 212 substances were revised and updated on Jan. 19, 1989 (54 *FR* 2332), effective March 1, 1989, and are listed in Tables Z-1, Z-2, and Z-3 of the final rule. On July 7, 1992, a U.S. Circuit Court of Appeals vacated and remanded this final rule. The Clinton administration has decided not to appeal this ruling; this means the standards revert back to those in effect before 1989. In the case of conflict or overlap of worker protection standards and general industry standards, the more restrictive provisions apply. DOE orders related to occupational safety, as well as the regulations promulgated by OSHA, are usually addressed in the site-specific Health and Safety Plan for each RA site.

6.5.9 Federal and State Regulations

Table 6.13 gives a preliminary list of federal and state action-specific regulations established under RCRA and various other statutes discussed above. Action alternatives are listed alphabetically, followed by a summary of the requirements found in the particular statute cited. The prerequisites for applicability are also given; however, the regulations must be related to site-specific conditions to determine whether the regulation cited is legally applicable. This table does not represent a complete listing of action-specific regulations; analysis of the regulations on a site-specific basis would be necessary to ensure a comprehensive summary.

6.6 LOCATION-SPECIFIC REGULATIONS

Location-specific requirements set restrictions upon the concentration of hazardous substances or the conduct of activities solely because they are in special locations. In determining the use of location-specific regulations for actions at RA sites, one must investigate the jurisdictional prerequisites of each of the regulations. Basic definitions and exemptions should be analyzed on a site-specific basis to confirm the correct application of the requirements. Table 6.14 lists the major federal and state location-specific regulations that might be pertinent to RA actions at ORNL.

6.6.1 Caves, Salt-Dome Formations, Salt-Bed Formations, and Underground Mines

ORR, located in the Valley and Ridge Physiographic Province of eastern Tennessee, is characterized by gently to moderately sloping ridges and valleys.[13] A variety of geologic formations of sedimentary origin underlie ORR. The most important formations are the Rome Formation and the Conasauga, Knox, and Chicamauga Groups. There are no indications of salt-dome formations, salt-bed formations, or underground mines on or near the ORNL sites.[14] If any caves are located in areas where remedial activities might occur, the regulations found in RCRA [40 CFR 264.18(c)], which prohibit the placement of noncontainerized or bulk liquid hazardous waste in caves, might be applicable (Table 6.14).

6.6.2 Faults

The White Oak Mountain and Copper Creek thrust faults transect ORR; the faults on ORR are ancient (pre-Holocene) and are stable.[15] The possibility of fault movement is considered extremely unlikely.[16]

ORNL is exempted from compliance with the RCRA seismic requirements of 40 CFR 264.18 because 40 CFR 264.18(a) stipulates that all facilities located within political jurisdictions other than those listed in Appendix VI of 40 CFR 264.18 are assumed to be in compliance for location of new treatment, storage, and disposal facilities. Tennessee is not listed in the appendix.

6.6.3 Wetlands and Floodplains

ORNL is located within the Clinch River drainage basin and is bound on the south and west by the Clinch River; ORNL is located in a sub-basin of the Clinch River. Portions of ORNL are located within 100- and 500-year floodplain of the Clinch River.[17]

There are a number of wetlands located in and around ORNL. A draft report of a recent wetlands survey was released in March 1991.[18] Before any RA is taken, this report should be consulted and a survey conducted of the particular site to determine whether there are wetlands present that could be impacted by RA activities. If any RA activities are selected that would impact floodplains, the requirements found in Executive Order (EO 11988, 40 CFR 264.18(b), 40 CFR 6.302(b), 40 CFR 6 (Appendix A), and 10 CFR 1022 would provide applicable requirements for ORNL. If wetlands are affected, consideration should be given to EO 11990, 40 CFR 6.302(a), 40 CFR 6 (Appendix A), 10 CFR 1022, CWA §404, 40 CFR 230, and 33 CFR 320-330 for applicable requirements.

Table 6.14. Location-specific regulations applicable to remedial action activities at the Oak Ridge Reservation

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
	Faults		
With displacement in Holocene time	New treatment, storage or disposal facility RCRA[a]-defined listed or characteristic hazardous waste (40 CFR 261) *-or-* RCRA-permitted facility	Portions of new facilities must not be within 61 meters (200 ft) of such fault	40 CFR 264.18(a)
	Salt-dome formations, salt-bed formations, underground mines or caves		
	RCRA-defined listed or characteristic hazardous waste (40 CFR 261) *-or-* RCRA- permitted facility	Placement of noncontainerized or bulk liquid hazardous waste in these locations is prohibited	40 CFR 264.18(c)
	Wetlands		
Presence of wetlands as defined in Executive Order 11990 §7(c) and 40 CFR 6, Appendix A §4(j)	Agency action which involves: – acquiring, managing, and disposing of lands and facilities – providing federally undertaken, financed, or assisted construction and improvements – conducting federal activities and programs affecting land use	Whenever possible, actions must avoid or minimize adverse impacts on wetlands and act to preserve and enhance their natural and beneficial values. New construction in wetlands areas should be particularly avoided unless there are no practicable alternatives Wetlands protection considerations shall be incorporated into planning, regulating, and decision-making processes	Executive Order 11990 40 CFR 6.302(a) 40 CFR 6, Appendix A 10 CFR 1022

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Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of wetlands as defined in 40 CFR 230.3(t) and 33 CFR 328.3(b)	Action involving discharge of dredge or fill material into wetlands	Action to avoid degradation or destruction of wetlands must be taken to the extent possible. Discharges for which there is a practicable alternative with less adverse impacts or those which would cause or contribute to significant degradation are prohibited If adverse impacts are unavoidable, action must be taken to enhance, restore, or create alternative wetlands	Clean Water Act §404 40 CFR 230 33 CFR 320-330
		Floodplains	
Within 100-year floodplain	Treatment, storage, or disposal facility RCRA-defined listed or characteristic hazardous waste (40 CFR 261) -or- RCRA- permitted facility	Facility must be designed, constructed, operated, and maintained to prevent washout of any hazardous waste by 100-year flood	40 CFR 264.18(b)

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Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Within "lowland and relatively flat areas adjoining inland and coastal waters and other flood-prone areas such as offshore islands, including at a minimum, that area subject to a one percent or greater chance of flooding in any given year." [Executive Order 11988 §6(c) and 40 CFR 6, Appendix A §4(d)]	Action which involves: - acquiring, managing, and disposing of lands and facilities - providing federally undertaken, financed, or assisted construction and improvements - conducting federal activities and programs affecting land use	Action shall be taken to reduce the risk of flood loss, minimize the impact of floods on human safety, health and welfare, and restore and preserve the natural and beneficial values of flood-plains The potential effects of actions in floodplains shall be evaluated and consideration of flood hazards and floodplain management ensured If action is taken in floodplains, alternatives that avoid adverse effects and incompatible development and minimize potential harms shall be considered	Executive Order (EO) 11988 40 CFR 6.302(b) 40 CFR 6 (Appendix A) 10 CFR 1022
Wilderness areas, Wildlife resources, Wildlife refuges, Scenic rivers			
Within area encompassing or affecting waters of the state of Tennessee as defined in TCA[b] 69-3-103(32) and the presence of wildlife or aquatic life	Action involving the discharge of any pollutants into the waters of the state [see TCA 69-3-103(18) and (21) for noninclusive list]	Discharge of "substances" which "will result or will likely result in harm, potential harm or detriment to the health of animals, birds, fish, or aquatic life" is prohibited	Tennessee Water Quality Control Act of 1977 (TCA 69-3-101 *et seq.*) Stream Use Classifications (TDEC[c] Rules - Chap. 1200-4-4)

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Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Within area affecting stream or river *-and-* presence of fish or wildlife resources	Action which results in the control or structural modification of a natural stream or body of water	The effects of water-related projects on fish and wildlife resources must be considered Action must be taken to prevent, mitigate, or compensate for project-related damages or losses to fish and wildlife resources Off-site actions that alter a resource require consultation with the FWS[d], NMFS[f], and/or appropriate state agency Consultation is also strongly recommended for on-site actions	Fish and Wildlife Coordination Act (16 USC 661 *et seq.*) 40 CFR 6.302(g)
Location encompassing aquatic ecosystem with dependent fish, wildlife, other aquatic life, or habitat	Action involving the discharge of dredge or fill material into aquatic ecosystem	Degradation or destruction of aquatic ecosystems must be avoided to the extent possible. Discharges which cause or contribute to significant degradation of the water of such ecosystem are prohibited	Clean Water Act §404 40 CFR 230 33 CFR 320-330
Location encompassing a state-designated natural area		The scientific, scenic, recreational, and educational values of these areas must be preserved and steps taken to prevent impairment thereof	TCA 11-14-101 *et seq*

000398

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Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
		Endangered, Threatened, or Rare Species	
Presence of endangered or threatened species -*or*- critical habitat of such species as designated in 50 CFR 17, 50 CFR 226, or 50 CFR 227	Action which is likely to jeopardize species or destroy or adversely modify critical habitat	Actions that jeopardize species/habitat must be avoided or appropriate mitigation measures taken Off-site actions that affect species/habitat require consultation with DOI, FWS, NMFS, and/or state agencies, as appropriate, to ensure that proposed actions do not jeopardize the continued existence of the species or adversely modify or destroy critical habitat Consultation is also strongly recommended for on-site actions	Endangered Species Act of 1973 (16 USC 1531 *et seq.*) 50 CFR 402 40 CFR 6.302(h) Fish and Wildlife Coordination Act (16 USC 661 *et seq.*)
Presence of endangered or threatened species or critical habitat (see above citation) of same within an aquatic ecosystem as defined in 40 CFR 230.3(c)	Action involving discharge of dredge or fill material into aquatic ecosystem	Dredge or fill material shall not be discharged into an aquatic ecosystem if it would jeopardize such species or would likely result in the destruction or adverse modification of a critical habitat of the species	Clean Water Act §404 40 CFR 230.10(b)

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Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of Tennessee state-listed endangered or threatened animal species as created and amended pursuant to TCA 70-8-105		Protected species may not be taken, possessed, transported, exported, processed, sold, offered for sale, or shipped. Certain exceptions may be allowed such as for educational, scientific, etc., reasons or where necessary to alleviate property damage or protect human health or safety. These exceptions require a permit if the remedial action or its attendant effects are off site	Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 (TCA 70-8-101 *et seq.*)
	Archaeologic and Historic Resources		
Presence of archaeological resources on public land	Action which would impact resource	Steps must be taken to protect archaeological resources and sites	Archaeological Resources Recovery Act of 1979 (16 USC 470aa-ll) 43 CFR 7
Presence of archaeologic or historic resources	Action involving dam construction or other alteration of terrain which might cause irreparable loss or destruction of significant scientific, prehistoric, historic, or archaeologic data	The Secretary of Interior must be advised of the presence of the data A survey of affected areas for resources and data must be conducted and steps taken to recover, protect, and preserve data therefrom or request that DOI do so	Archaeological and Historic Preservation Act (16 USC 469a-c) 40 CFR 6.301

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Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of federally owned, administered, or controlled prehistoric or historic resources -or- the likelihood of undiscovered resources		Cultural resources included on or eligible for inclusion on the National Register of Historic Places (36 CFR 60) or National Historic Landmark Program (36 CFR 65) must be identified Action(s) that will affect such resources must be identified and alternatives to the action(s) examined and considered When alteration or destruction of the resource is unavoidable, steps must be taken to minimize or mitigate the impacts and to preserve records and data of the resource When all or part of a remedial action is off site, the consultation requirements of 16 USC 470f must be completed Consultation is also strongly recommended for on-site actions	National Historic Preservation Act (16 USC 470a-w) Executive Order 11593 40 CFR 6.301 36 CFR 800
Cemetery located on property within Tennessee		Destruction or degradation of property in a graveyard or cemetery is prohibited	Tennessee General Cemetery Act of 1968 (TCA 46-1-101 *et seq.*)

[a]RCRA = Resource Conservation and Recovery Act; definitions appear at 40 CFR 260.10.
[b]TCA = Tennessee Code Annotated.
[c]TDEC = Tennessee Department of Environment and Conservation.
[d]FWS = Fish and Wildlife Service.
[e]NMFS = National Marine Fisheries Service.
[f]DOI = Department of Interior.

Source: E. L. Etnier, E. P. McDonald and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

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6.6.4 Wilderness Areas, Wildlife Refuges, Wildlife Resources, and Scenic Rivers

There are no known designated wilderness areas, wildlife refuges, or scenic rivers on the ORNL site or within range of the reservation, such that RAs would likely impact these resources. However, if any RAs result in the control or structural modification of a natural stream or water body, the provisions found in the Fish and Wildlife Coordination Act (16 USC 661 *et seq.*) and 40 CFR 6.302(g) may be applicable. If any action involves the discharge of dredge or fill material into an aquatic system, the CWA §404, 40 CFR 230, and 33 CFR 320-330 may also be applicable.

The Clinch River, Poplar Creek with its various tributaries and forks, and White Oak Creek have all been classified by TDEC for a variety of uses, including fish and aquatic life and wildlife. It is therefore possible that the provisions of the Tennessee Water Quality Control Act (TCA 69-3-101 *et seq.*) would be legally applicable should any RAs at ORNL cause, or be likely to cause, harm to wildlife or aquatic life in these waters.

Slightly over 5000 acres of ORR have been designated as a DOE National Environmental Research Park (NERP), which also includes research areas located both within and without the NERP itself.[19] Portions of the NERP come to within at least 2–3 km of the K-25 Site, ORNL, and Y-12. Several research areas are within 0.5 km of ORNL, including research area No. 25, carbon monoxide monitoring, and research area No. 37, biomass demonstration plots.[19]

In addition to the NERP and its associated research areas DOE has also designated areas on ORR as DOE-NERP reference areas and DOE-NERP natural areas. The reference areas and natural areas are located in various sites on ORR, with several in close proximity to the reservation facilities. Eight of the reference areas and natural areas have also been registered by Tennessee as State Natural Areas.

Because of the unique purposes and goals in establishing the NERP, the uses and restrictions that apply to these resources should be considered nonregulatory guidance if remedial activities appear likely to impact the designated areas. Guidance regarding the permitted uses and restrictions of the various locations can be obtained from the NERP Project Manager at ORNL. For a general overview, please refer to Vol. 23 of *The Resource Management Plan for the Oak Ridge Reservation*.[19] Such impacts should be avoided. In addition, should areas which are also designated State Natural Areas by the state of Tennessee be affected, the provisions of the Tennessee Natural Areas Preservation Act of 1971 (TCA 11-14-101 *et seq.*) may be applicable.

6.6.5 Rare, Threatened, or Endangered Species

In addition to the several Tennessee state-listed endangered or threatened plants found at ORNL, there are a number of federal- and state-listed endangered or threatened or "in need of management" animal and avian species known to inhabit east Tennessee (50 CFR 17).[20] An in-depth discussion of these species appears in Vol. No. 24 of *The Resource Management Plan of the Oak Ridge Reservation*.[20] The list of rare and endangered species for ORR, provided by the state of Tennessee, also includes two state-listed and federally listed endangered clams.[21]

Should any RAs at ORNL impact any federally listed endangered or threatened species, the provisions found in the Endangered Species Act (16 USC 1531 *et seq.*), 50 CFR 492, 40 CFR 6.302(h), and the Fish and Wildlife Coordination Act (16 USC 661 *et seq.*) may be legally applicable. Additionally, if the RAs involve the discharge of dredge or fill

material, CWA §404 and 40 CFR 230.10(b) may be applicable. If any proposed actions impact state-listed endangered or threatened animal species, the Tennessee Non-Game and Endangered or Threatened Wildlife Species Conservation Act of 1974 (TCA 70-8-101 *et seq.*) may be applicable. The prohibitions of the Tennessee Rare Plant Protection and Conservation Act of 1985 (TCA 11-26-201 *et seq.*) do not apply to a landowner, lessee, or other person entitled to possession of the land on which the species is located (TCA 11-26-209). This also includes managers in the case of publicly owned land and those with written permission of the landowner or manager (TCA 11-26-209). These exclusions would apparently apply to ORNL. However, the purpose of the statute to protect and preserve rare plants should be considered guidance for any RAs on the reservation.

6.6.6 Historic Sites and Archaeological Findings

ORR, as well as the surrounding region, is rich in both archaeological and historic resources.[22] Although there have not been complete and exhaustive archaeological or historical surveys of the reservation, there have been a number of studies over the years, all indicating the presence of abundant resources on and around the reservation. These surveys are summarized in Vol. 3 of the *Resource Management Plan for the U. S. Department of Energy Oak Ridge Reservation*[22] which also includes a list and descriptions of most of the documented sites. Eight archaeological sites were identified at ORNL; of the eight, it was recommended that three (40RE27, 40RE101, and 40RE1-32) be extensively tested and possibly excavated if threatened by construction or remedial activities.[22] None of the surveys done is recent, however, nor have they covered all of the specific sites where RAs may be planned or contemplated. Several laws require that such information be obtained and documented if there is ample reason to suspect the presence of these resources [Archaeological and Historic Preservation Act (16 USC 469a-c); Archaeological Resources Recovery Act of 1979 (16 USC 470aa-ll)].

The National Register of Historic Places lists the Graphite Reactor located at ORNL as an historic site, and the National Historic Preservation Act (16 USC 470a-w) mandates identification of cultural resources eligible for the National Register of Historic Places (36 CFR 60) or the National Historic Landmark Program (36 CFR 65).

If any RA is undertaken which would cause irreparable harm, loss, or destruction to any historic or archaeological site, the provisions of the Archaeological Resources Recovery Act (16 USC 470aa-ll), 43 CFR 7, the Archaeological and Historic Preservation Act (16 USC 469a-c) and 40 CFR 6.301 may be legally applicable. The provisions of this latter statute would also apply to the Graphite Reactor along with EO 11593, 40 CFR 6.301 and 36 CFR 800 *et seq.*

Lastly, there are a number of cemeteries located on ORR which predate the acquisition of the property by the government. Any RAs that affect these cemeteries would be subject to the provisions of the Tennessee Cemetery Protection Act (TCA 46-1-101 *et seq.*), which prohibits their destruction or degradation.

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APPENDIX

PARTIAL 1992 AND 1993 TECHNICAL TASK PLAN SEARCH DATA BASE LISTING

Partial 1992 and 1993 Technical Task Plan search data-base listing

AL004201
AL014204
AL014209
AL014212
AL024204
AL024207
AL027001
AL034201
AL101202
AL113101
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000407

Partial 1992 and 1993 Technical Task Plan search data-base listing (continued)

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OR113201	OR128019	RL311101	RL331002	RL431001	SF234202
OR113202	OR130003	RL311103	RL331003	RL432001	SF234203
OR113203	OR130004	RL311104	RL332001	RL432002	
OR113204	OR138001	RL313101	RL332002	RL432003	SR023101
OR113205	OR138002	RL313201	RL332003	RL432004	SR104201
OR113206	OR138005	RL313202	RL332004	RL438005	SR104202
OR120001	OR141102	RL313203	RL332006	RL438601	SR113201
OR121101	OR221101	RL313205	RL332008	RL439001	SR113202
OR121102	OR221102	RL314202	RL332009	RL439005	SR121101
OR121103	OR221103	RL315001	RL332010	RL439006	SR121102
OR121104	OR221104	RL321101	RL332011	RL439007	SR121103
OR121105	OR914201	RL321102	RL332012		SR121105
OR121106	OR925001	RL321104	RL332013	SF121101	SR121106
OR121108		RL321105	RL332014	SF211104	SR121107
OR121110	PE021103	RL321112	RL334101	SF211203	SR121202
OR121111	PE021104	RL321113	RL401203	SF213201	SR123201
OR121114	PE025001	RL321114	RL401206	SF213203	SR123202
OR121115	PE031001	RL321201	RL411101	SF213204	SR125001
OR121116	PE033502	RL321204	RL413101	SF213205	SR128101
OR121201		RL321205	RL413201	SF221101	SR131000
OR121203	RF025001	RL321211	RL413203	SF221102	SR131001
OR121204	RF026001	RL321221	RL415003	SF221205	SR131002
OR121206	RF101201	RL321701	RL421103	SF221207	SR132001
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OR121211	RF111202	RL322101	RL421201	SF221210	SR132003
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OR123201	RF121204	RL323301	RL421211	SF223203	SR134101
OR123301	RF132001	RL324103	RL421215	SF223401	SR135002
OR123302	RF138101	RL324105	RL421216	SF224102	SRNEW010
OR124101					

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OAK RIDGE NATIONAL LABORATORY
TECHNOLOGY LOGIC DIAGRAM

VOLUME 1

TECHNOLOGY EVALUATION

PART C

Waste Management

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Prepared for the
Office of Technology Development

1993
Edition

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ORNL/M-2751/V1/Pt. C

Oak Ridge National Laboratory Technology Logic Diagram

Volume 1
Technology Evaluation

Part C
Waste Management

Prepared for the Office of Technology Development
U.S. Department of Energy

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Prepared by
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CONTENTS

LIST OF TABLES vii
LIST OF FIGURES ix
ACKNOWLEDGMENTS xi
ACRONYMS AND INITIALISMS xv
FOREWORD xvii

1. INTRODUCTION 3
   1.1 OAK RIDGE NATIONAL LABORATORY 3
   1.2 ORNL MISSION 4
      1.2.1 Laboratory Mission 4
      1.2.2 Waste Management and Remedial Action Division Mission 4
      1.2.3 Waste Management Goal 6
   1.3 ORNL PROBLEM DEFINITION 7
      1.3.1 Radioactive-Waste Management 7
      1.3.2 Hazardous-Waste Management 10
      1.3.3 Mixed-Waste Management 11
      1.3.4 Sanitary-Waste Management 13
   1.4 ORNL ROADMAP 14
      1.4.1 Introduction 14
      1.4.2 Roadmapping Methodology 14
      1.4.3 Summary of Major Committed Milestones 15
   1.5 TOP ORNL WASTES NEEDING TREATMENT TECHNOLOGY DEVELOPMENT 16
   1.6 ISSUES FOR WASTE MANAGEMENT 18
   1.7 REFERENCES 19

2. DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM 23
   2.1 PURPOSE AND SCOPE 23
   2.2 STAFFING FOR THE TLD 24
   2.3 TECHNICAL APPROACH 26
   2.4 TECHNOLOGY RANKINGS 30
      2.4.1 Overall Assessment 30
      2.4.2 Status of Technology 31
      2.4.3 Estimates for Time to Maturity 32
   2.5 REFERENCES 33

3. CHARACTERIZATION 37
   3.1 INTRODUCTION 37
   3.2 TECHNOLOGIES 38
      3.2.1 Characterization Technology Options 38
      3.2.2 Crosscutting Technologies 41
   3.3 SCIENCE AND TECHNOLOGY NEEDS 42
   3.4 IMPLEMENTATION NEEDS 43
   3.5 TECHNOLOGY RANKINGS 44
   3.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 52

4. WASTE PROCESSING, HANDLING, AND DISPOSAL 63
4.1 INTRODUCTION 63
4.2 TECHNOLOGY OPTIONS 64
4.2.1 Introduction 64
4.2.2 Conceptual Framework for Waste Management Planning 64
4.2.3 Description of Functional Areas 68
4.3 SCIENCE AND TECHNOLOGY NEEDS 95
4.3.1 Introduction 95
4.3.2 Summary of Science and Technology Needs 95
4.4 IMPLEMENTATION NEEDS 97
4.5 TECHNOLOGY RANKINGS 98
4.5.1 Introduction 98
4.5.2 Prioritized Rankings of Technologies 98
4.5.3 Ranking Procedure 98
4.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 128
4.7 REFERENCES 134

5. ROBOTICS AND AUTOMATION 137
5.1 INTRODUCTION 137
5.2 TECHNOLOGY OPTIONS 138
5.2.1 Waste Handling and Packaging Plant 138
5.2.2 Inspection and Monitoring of Waste Barrels and Containers 138
5.3 SCIENCE AND TECHNOLOGY NEEDS 142
5.3.1 Waste Handling and Packaging Activities 142
5.3.2 Inspection and Monitoring of Waste Barrels and Containers 142
5.4 IMPLEMENTATION NEEDS 144
5.5 TECHNOLOGY RANKINGS 145
5.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE 148

6. REGULATORY COMPLIANCE 155
6.1 INTRODUCTION 155
6.2 TYPES OF WASTES 157
6.3 SOLID- AND HAZARDOUS-WASTE MANAGEMENT 158
6.3.1 Resource Conservation and Recovery Act 158
6.3.2 Tennessee Regulations 159
6.3.3 Solid Waste Regulations 159
6.3.4 Hazardous-Waste Management Regulations 162
6.4 RADIOACTIVE-WASTE MANAGEMENT 182
6.4.1 General Requirements 182
6.4.2 Regulation of Radioactive Waste 190
6.5 MIXED-WASTE MANAGEMENT 196
6.6 ASBESTOS 200
6.6.1 Clean Air Act 200
6.6.2 Occupational Safety and Health Administration 201
6.6.3 State Regulations 201
6.6.4 DOE Orders 202
6.7 WASTE MINIMIZATION 203
6.8 CLEAN WATER ACT 205
6.9 TOXIC SUBSTANCES CONTROL ACT 207
6.10 THE FEDERAL INSECTICIDE, FUNGICIDE, AND RODENTICIDE ACT . . 208

6.11 TRANSPORTATION OFF SITE 209
6.12 NATIONAL ENVIRONMENTAL POLICY ACT 211
6.13 OSHA REQUIREMENTS 214
6.14 REFERENCES 215

APPENDIX: PARTIAL 1992 AND 1993 TECHNICAL TASK PLAN
SEARCH DATA-BASE LISTING 219

LIST OF TABLES

Table		Page
1.1	Current waste management activities at ORNL	7
1.2	Federal Facility Agreement for the Oak Ridge Reservation Major committed milestones—waste management (ORNL)	15
1.3	Top ORNL wastes needing treatment technology development	17
2.1	How the logic diagram works	27
2.2	Scale for overall assessment rating	31
2.3	Scale for status of technology	31
2.4	Definitions for progress of development and time periods	32
2.5	Correspondence of terms for state of the technology	32
3.1	Rankings of characterization technologies for waste management	45
3.2	Characterization technologies under development by DOE	53
4.1	Categories of waste management needs for technology applications	67
4.2	Waste management options for mixed-solid wastes	69
4.3	Waste management options for solid-liquid wastes	78
4.4	Waste management options for liquid wastes	83
4.5	Waste management options for gaseous wastes	88
4.6	Generic waste stabilization technologies	93
4.7	Rankings of waste management options for mixed-solid wastes	99
4.8	Rankings of waste management options for solid-liquid wastes	109
4.9	Rankings of waste management options for liquid wastes	116
4.10	Rankings of waste management options for gaseous wastes	123
4.11	Waste processing technologies under development by DOE	129
4.12	Waste disposal technologies under development by DOE	133
5.1	Relationship of robotics/automation technologies to waste management activities	139
5.2	Rankings of robotics/automation technologies for waste management	145
5.3	Robotics/automation technologies under development by DOE	149
6.1	RCRA Subtitle C—standards for the treatment, storage, and disposal of hazardous waste	170
6.2	Federal RCRA land disposal regulations	177
6.3	DOE Order 5400.5, "Radiation Protection of the Public and the Environment"	184
6.4	Radiation protection standards for ORNL Waste Management activities	188
6.5	Rules of the TDEC Bureau of Environment Division of Air Pollution Control	190

LIST OF FIGURES

Figure		Page
1.1	Aerial view of the Oak Ridge National Laboratory	5
2.1	The ORNL Technology Logic Diagram Team	25
4.1	Conceptual framework for waste management and technology planning	65
4.2	Combination of technologies in the planning of waste management systems	66

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ACRONYMS AND INITIALISMS

AEA	Atomic Energy Act
AES	Auger electron spectroscopy
ALARA	as low as reasonably achievable*
ARARs	applicable, relevant, and appropriate requirements
BMP	Best Management Practice
CAA	Clean Air Act
CAMU	Corrective Action Management Unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CT	computer tomography
CWA	Clean Water Act
CYRTS	Coal Yard Runoff Treatment System
D&D	decontamination and decommissioning
DOE	Department of Energy
DOT	Department of Transportation
EDE	effective dose equivalent
EDX	Energy dispersive X ray
EM	Environmental Management
EP	Extraction Procedure
EPA	Environmental Protection Agency
ER/WM	environmental restoration/waste management
ER	environmental restoration
ERPP	Environmental Radiological Protection Program
ESPIP	Efficient Separations and Processing Integrated Program
FFA	Federal Facility Agreement
FFCA	Federal Facilities Compliance Agreement
FR	Federal Regulations
FTIR	Fourier transform infrared
FY	fiscal year
HEPA	high-efficiency particulate air
HLI	high-level incidental waste
HOC	halogenated organic compound
HSWA	Hazardous and Solid Waste Amendments
ICP	inductively coupled plasma
ICRP	International Commission on Radiological Protection
LDR	land disposal restriction
LDR-FFCA/ORR	The Federal Facilities Compliance Agreement for Mixed Waste Liability Act Subject to Land Disposal Restrictions for The Oak Ridge Reservation
LLWDDD	Low-Level Waste Disposal Development and Demonstration
LRAD	Long-range alpha detecter
MCLs	maximum contaminant levels
MTRs	minimum technology requirements
NARM	naturally occurring and accelerator-produced radioactive materials
NEPA	National Environmental Policy Act

NESHAPs	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
PCBs	polychlorinated biphenyls
PCE	perchloroethylene
R&D	research and development
RA	remedial action
RCRA	Resource Conservation and Recovery Act
SC	special case
SCWO	Supercritical water oxidation
SLF	Sanitary Landfill Facility
SLF II	Sanitary Landfill Facility II
SLLW	solid low-level waste
SR	Savannah River
SRIDP	Savannah River Integrated Demonstration Project
SWMUs	solid waste management units
SWSA	Solid Waste Storage Area
TCLP	Toxicity Characteristic Leaching Procedure
TDEC	Tennessee Department of Environment and Conservation
TLD	Technology Logic Diagram
TOA	Tennessee/DOE Monitoring and Oversight Agreement
TRU	transuranic
TSCA	Toxic Substances Control Act
TSDF	treatment, storage, disposal facility
TSR	Technology Status Report
TTP	Technical Task Plan
TU	Temporary Unit
UST	underground storage tanks
UV	Ultraviolet
VOC	volatile organic compounds
WHPP	Waste Handling and Packaging Plant
WIPP	Waste Isolation Pilot Plant
WM	waste management
WMRAD	Waste Management and Remedial Action Division
WPH&T	waste packaging, handling, and transportation
XRF	X-ray fluorescence

FOREWORD

The *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) was developed to provide a decision-support tool that relates environmental restoration (ER) and waste management (WM) problems at Oak Ridge National Laboratory (ORNL) to potential technologies that can remediate these problems. The TLD uses information from the *Strategic Roadmap for the Oak Ridge Reservation*, a recently completed K-25 Site TLD, and a previous Hanford TLD.

The TLD consists of three fundamentally separate volumes: Vol. 1 (*Technology Evaluation*), Vol. 2 (*Technology Logic Diagram*), and Vol. 3 (*Technology Evaluation Data Sheets*). Part A of Vols. 1 and 2 focuses on D&D. Part B of Vols. 1 and 2 focuses on RA of contaminated facilities. Part C of Vols. 1 and 2 focuses on WM. Each part of Vol. 1 contains an overview of the TLD, an explanation of the program-specific responsibilities, a review of identified technologies, and the rankings of remedial technologies. Volume 2 (Pts. A, B, and C) contains the logic linkages among environmental management goals, environmental problems, and the various technologies that have the potential to solve these problems. Volume 3 (Pts. A, B, and C) contains the TLD data sheets.

The focus of Vol. 1, Pt. C, is WM, and it has been divided into six chapters. The first chapter is an introduction, which defines problems specific to the WM Program for ORNL. Chapter 2 provides a general overview of the TLD. Chapters 3 through 5 are organized into necessary sublelement categories: characterization; waste processing, handling, and disposal; and robotics and automation. The final chapter contains regulatory compliance information concerning WM.

The technology evaluations contained in these volumes are based on the best information available during compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. L. Fellows, Editor, *Oak Ridge National Laboratory Technology Logic Diagram*, Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

1. INTRODUCTION

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1.1 OAK RIDGE NATIONAL LABORATORY

The Oak Ridge National Laboratory (ORNL) was built in 1943 as part of the World War II Manhattan Project. Its original mission was to produce and chemically separate the first gram quantities of plutonium as part of the national effort to produce the atomic bomb. The peacetime history of the laboratory first began in the late 1940s. Through 1973, ORNL was concerned with the development of nuclear technology for electrical power generation. From 1973 to 1980, ORNL was largely devoted to finding solutions for the energy crisis. The primary missions since 1980 have been to conduct applied research and engineering development in support of U.S. Department of Energy (DOE) programs in fusion, fission, conservation, fossil, and other energy technologies and to perform basic scientific research in selected areas of the physical and life sciences. The laboratory also operates "user facilities" for the benefit of university and industry researchers and supplies radioactive isotopes that are not otherwise commercially available.

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1.2 ORNL MISSION

1.2.1 Laboratory Mission

The mission statement that follows was reproduced from the *ORNL Institutional Plan FY 1993–FY 1998*.[1] ORNL, which is managed by Martin Marietta Energy Systems, Inc., for DOE, is one of the nation's premier research institutions (see Fig. 1.1 for aerial view of ORNL). The primary mission of the laboratory is to perform leading-edge research and development (R&D) in support of the nonweapons roles of DOE. Significant elements of ORNL's mission are to perform basic and applied research that is of importance to the nation; to provide the scientific and technical community with unique national user facilities; to improve the nation's competitiveness through technology development and transfer by partnering universities and industry; and to improve science and math education through contributions to the national initiative.

ORNL will accomplish the mission through its core competencies:

- energy production, conservation, and utilization technologies;
- materials sciences and engineering;
- physical, chemical, and engineering sciences;
- biological and life sciences;
- environmental sciences and technologies;
- computational sciences; and
- manufacturing sciences and technologies.

The principal sponsor of ORNL's work is DOE, but, in a larger sense, the laboratory serves many national—even international—customers. ORNL staff are involved in research on global energy and environmental problems and in the development of technologies that will improve U.S. competitiveness in international markets. The laboratory's more fundamental scientific research, much of which is done in collaboration with researchers from around the world, contributes to the storehouse of human knowledge; this work, therefore, has a very broad customer base. In the conception, construction, and operation of national research facilities, the laboratory's customers are drawn from major segments of the scientific and technical community. Much of the applied research and technology development work at ORNL is expected to provide services for other government agencies and private companies.

Several factors combine to distinguish ORNL from other R&D institutions. The laboratory melds a unique blend of excellent researchers with a large array of world-class facilities to conduct broad interdisciplinary research in areas of national importance. The laboratory's ability to integrate basic research, applied research, technology development, information dissemination, and technology transfer is unsurpassed among research institutions. The style of teaming with industry and academia to bring a multidisciplinary approach to problem solving provides exceptional value to ORNL's customers. Finally, the Laboratory's ability to conceive, construct, and manage large, complex projects provides DOE and the nation with a rare resource.

1.2.2 Waste Management and Remedial Action Division Mission

The ORNL waste management (WM) mission is to reduce, collect, treat, store, and dispose of DOE wastes, in order to protect human health and safety and the

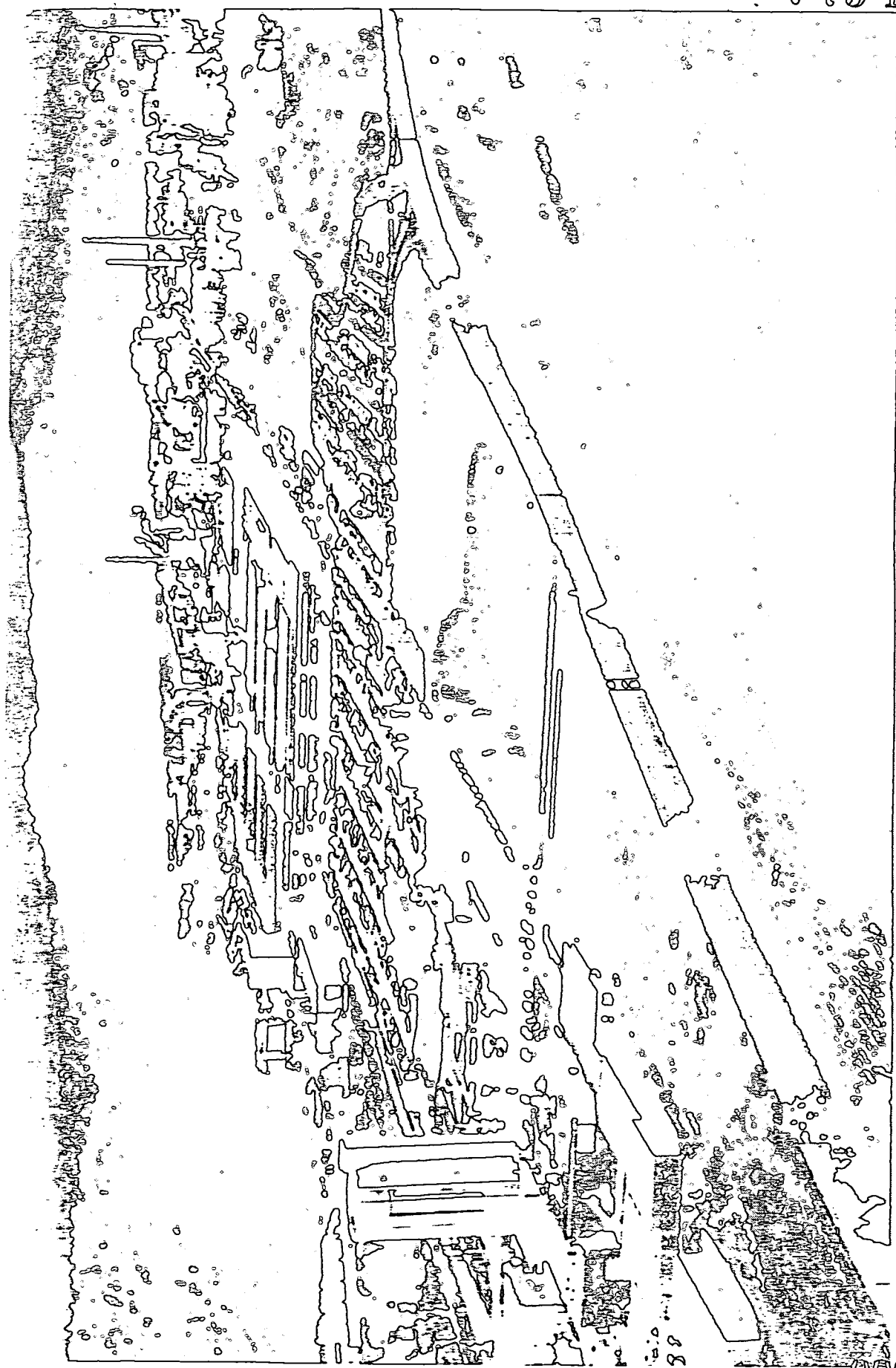

Fig. 1.1 Aerial view of the Oak Ridge National Laboratory.

environment. In carrying out this mission, WM staff in the Waste Management and Remedial Action Division (WMRAD) will (1) guide ORNL in optimizing waste reduction and WM capabilities and (2) conduct WM operations in a compliant, publicly acceptable, technically sound, and cost-effective manner.

1.2.3 Waste Management Goal

Through proactive planning, progressive programs, and sustained excellence in the performance of waste management functions, supported by cost-effective, cradle-to-grave technological systems, WM activities will be state of the art. WM activities will be conducted in compliance with all applicable laws, regulations, and agreements. This will be accomplished by maximal recycling and reuse of materials and facilities, development of disposal solutions for everything that is waste, and reduction of wastes and environmental discharges to the lowest levels possible.

ORNL WM will be viewed as a good neighbor in the community, deserving of local support and both national and international recognition for reducing potential health and environmental impacts and wastes. WM staff will not experience health or safety concerns; will not be the focus of organizational or personal liability; will receive fair compensation and recognition in relation to level of training, responsibilities, and performance; and will be provided with challenging career development opportunities that will allow achievement of unrecognized individual potential in a fair and equitable manner.

1.3 ORNL PROBLEM DEFINITION

Because ORNL is a multipurpose research facility, it handles numerous chemicals and radionuclides in pursuit of its missions. Because of the nature of its operations, the wastes generated are often small in quantity (volume or mass) but numerous. Sections below provide synopses of the current WM activities at ORNL. This summary was extracted from *Oak Ridge National Laboratory Waste Management Plan*.[2]

WM operations are activities that minimize, treat, store, recycle, or dispose of all radioactive, hazardous, mixed, and sanitary/industrial wastes generated as a result of operations at active and inactive facilities. Most routine WM operations at ORNL are the direct responsibility of WMRAD. Table 1.1 shows the quantities of solid waste generated and handled at ORNL during FY 1991 and FY 1992. In addition to newly generated wastes, significant quantities of transuranic (TRU) waste and some solid low-level waste (SLLW) and mixed waste from past operations have been placed in long-term storage.

Table 1.1. Quantities of solid waste generated and handled at ORNL

Waste stream	FY 1991	FY 1992
Radioactive		
• Transuranic waste	8 m^3 (297 ft^3)	23 m^3 (814 ft^3)
• Low-level waste	1,952 m^3 (69,711 ft^3)	2,783 m^3 (99,394 ft^3)
Hazardous	106,343 kg (234,447 lb)	81,902 kg (180,563 lb)
Mixed	22,633 kg (49,898 lb)	19,538 kg (43,074 lb)
Sanitary/industrial	13,300 m^3 (474,984 ft^3)	10,310 m^3 (368,199 ft^3)

1.3.1 Radioactive-Waste Management

ORNL radioactive WM activities involve TRU mixed, and low-level waste. Small quantities of naturally occurring and accelerator-produced radioactive materials (NARM) are generated and managed as low-level waste. ORNL does not generate high-level waste but does store a small quantity as a special-case waste, such as irradiated and spent fuel. Stored TRU waste consists of sludge primarily from previous operations and lesser volumes of hot-cell-derived waste. Only small amounts of solid TRU waste are currently being generated. Radioactive WM operations include solid, liquid, and gaseous waste activities.

1.3.1.1 Transuranic Waste

Under DOE guidance, ORNL has been segregating and retrievably storing the majority of its solid alpha-contaminated waste since 1970, pending the availability of permanent disposal. Some of these wastes, such as gloveboxes and other large, bulky items, have been irretrievably buried as special-case waste. The Waste Isolation Pilot Plant (WIPP), located in New Mexico, is the planned DOE disposal facility for TRU waste. Over the past several years ORNL has been developing procedures to certify TRU waste for disposal at WIPP. ORNL has employed the Waste Examination and Assay Facility for

nondestructive assaying and nondestructive examination of stored contact-handled TRU waste. ORNL stores significant quantities of mixed-waste sludges contaminated with TRU radionuclides from liquid-waste operations. The proposed Waste Handling and Packaging Plant (WHPP) at ORNL is designed to process these sludges as remotely handled TRU waste. A number of issues, however, have been recently identified that may impact the WHPP Project.

Solid TRU wastes and TRU mixed wastes at ORNL are stored in various facilities in the north area of Solid Waste Storage Area (SWSA) 5. Sludges are stored in the Melton Valley storage tanks and other active and inactive tanks in the Liquid Low-Level Waste System at ORNL.

1.3.1.2 Solid Low-Level Waste

Until 1986 all solid low-level waste, including some mixed waste (primarily lead), generated at ORNL was disposed of on site by shallow land burial in unlined trenches and auger holes. SWSA 6, which is the active low-level waste disposal area at ORNL, has been used for low-level waste disposal since 1969. Starting in 1984, the practice of shallow land disposal on the Oak Ridge Reservation (ORR) came under close scrutiny by federal and state regulators and DOE officials. Major changes in the operation of SWSA 6 were initiated in 1986, including (1) the exclusion of all mixed waste from disposal, (2) the increased use of greater confinement-disposal techniques, such as concrete silos and lined auger holes for disposal of contact-handled and remotely handled low-level waste, and (3) the storage of some contact-handled low-level waste at the Oak Ridge K-25 Site. Because of the disposal practices in SWSA 6 prior to 1986, some areas in SWSA 6 are being remediated under the ORR Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Federal Facility Agreement (FFA).

Current plans are to phase out below-grade disposal in SWSA 6 by December 1993 and to begin closure of the site. Beginning in January 1994, the ORNL low-level waste will be disposed only in the above-grade tumulus Interim Waste Management Facility. The Interim Waste Management Facility began operation in FY 1992. In the late 1990s or early 2000s, new low-level waste disposal facilities being developed by the Energy Systems Waste Management Operations will begin operation, and the Interim Waste Management Facility will close.

DOE Order 5820.2A, Chap. III, requires that each operating low-level waste disposal facility meet radiological performance objectives. SWSA 6 and the Interim Waste Management Facility will demonstrate compliance with these performance objectives by preparing a site-specific radiological performance assessment. The current strategy for managing ORNL low-level waste is to develop radionuclide concentration limits for each disposal technique at SWSA 6 and the Interim Waste Management Facility based on the final results of the performance assessment. This strategy is used in lieu of the Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program strategy developed by Martin Marietta Energy Systems, Inc., in 1987. The LLWDDD strategy established classes of waste disposal technologies (i.e., Classes L-I, L-II, L-III, and L-IV), depending on the isotopic composition and concentrations in the waste. The LLWDDD waste classes continue to be used to refer to types of low-level waste storage or disposal facilities but are only a carryover from the former LLWDDD Program.

In general, Class L-I refers to wastes suitable for below-grade trench disposal; Class L-II refers to wastes requiring disposal in engineered facilities designed to isolate the waste from the environment for long time periods; and Classes L-III and L-IV refer to higher-activity wastes not suitable for disposal on ORR. The "classes of waste" system

may be adopted by ORNL in the future if the Energy Systems Waste Management Operations disposal facilities require it.

1.3.1.3 Solid Special-Case Waste

Special-case wastes do not fit into typical management strategies developed for the other major low-level waste waste types, nor do they fit into a TRU waste category; therefore, they require special management and disposal strategies. Five categories of special-case waste and one category of special interest, DOE-owned materials have been identified for management as special-case waste: (1) DOE comparable greater than Class C, (2) performance assessment limiting, (3) uncertified or uncharacterized, (4) noncertifiable, nontransportable TRU, and (5) high-level incidental waste. The special interest category is commercially held, DOE-owned radioactive material. This category, although not a waste category, has been included in the special-case identification and characterization task in order to meet the needs of DOE's management plan development. ORNL has been asked by DOE to identify special-case wastes or potential waste materials that may fall within these six categories and, if possible, to provide a detailed characterization of waste in each category.

Under the former LLWDDD Program, performance assessment limitations for on-site disposal were the principle consideration for the special-case waste, which included Class L-III and Class L-IV waste. The exact segregation, storage, and disposal requirements for various categories of the special-case waste at ORNL have yet to be determined.

1.3.1.4 Liquid Low-Level Waste

ORNL employs two systems for handling and processing liquids that contain radioactive constituents: the Liquid Low-Level Waste System and the Process Waste System. The Liquid Low-Level Waste System handles waste solutions with significant amounts of radioactivity, including waste streams originating from hot sinks and drains in R&D facilities and from other sources such as TRU processing facilities, the High Flux Isotope Reactor, and the Process Waste Treatment Plant. The Liquid Low-Level Waste System, which uses an evaporation system for volume reduction, processed about 2 million L (540,000 gal) of waste and produced 83,279 L (22,000 gal) of concentrate in FY 1992. The evaporator overhead was discharged to the Process Waste System, and the concentrates were placed in storage in the Melton Valley storage tanks.

1.3.1.5 Process Waste

The Process Waste System handles all liquid-aqueous waste that contains trace amounts of radioactivity, heavy metals, and organics or has the potential to be contaminated with these constituents. The process waste solutions generated by various program activities throughout ORNL are collected into central holding tanks and processed through the Process Waste Treatment Plant, which employs softening and ion-exchange units to remove radionuclides. The Process Waste Treatment Plant throughput is about 260 million L per year (70 million gal). In April 1990 the Nonradiological Wastewater Treatment Plant began polishing the Process Waste Treatment Plant effluent and other ORNL process-waste streams before releasing to White Oak Creek. The Nonradiological Wastewater Treatment Plant throughput was about 550 million L (146 million gal) in 1991. The Nonradiological Wastewater Treatment Plant effluent is

released to White Oak Creek through a National Pollutant Discharge Elimination System (NPDES) monitoring station. Operations for both the Liquid Low-Level Waste System and the Process Waste System are monitored, controlled, and recorded at the Waste Operations Control Center.

1.3.1.6 Gaseous Waste

The three general types of radioactive air streams at ORNL are (1) process off-gas streams characterized as low-volume, potentially high-activity gaseous streams from process vessels and from systems or other sensitive areas where the concentration of radioactivity may be routine and highly concentrated; (2) cell ventilation air streams characterized as high-volume, low-activity gas streams from enclosed areas such as containment or confinement areas, limited-access areas, and hot cells; and (3) laboratory hoods and individual vents that provide controlled ventilation for laboratory-type operations or exhaust from vessels that are vented through appropriate pollution control devices at the source location.

Seven cell ventilation systems with stacks are currently used for discharging cell ventilation air and process off-gas containing gaseous radioactive effluents. The basic equipment used in most of the cell ventilation systems that discharge to major stacks includes the filters, fans, and ducts used to transport air. Radiation-monitoring instruments are connected to either the stacks or the ducts entering the stacks. Where conditions dictate, charcoal absorbers or chemical scrubbers are used in the process off-gas streams to remove reactive gases such as halogens and acidic vapors. This is done before discharging to the cell ventilation system. For short, half-life radionuclides, such as radon, holdup is used to allow decay before discharge. Noble gases are diluted with cell ventilation air and discharged to the stacks.

In addition to the major stacks at ORNL, a number of individual vents are used that discharge small quantities of radioactive material. Located throughout the ORNL facilities, these sources are mainly vents from storage tanks and exhausts from hoods and gloveboxes used for individual, small-scale experiments and analytical chemistry work.

Many of the facilities for handling radioactive gas emissions have been in operation for over 20 years. Generally, the accessible equipment has been maintained well. Some systems have undergone significant upgrading through a line-item capital project initiated in 1981. The program strategy is to identify and to implement system upgrades that ensure regulatory compliance and meet DOE "as low as reasonably achievable" (ALARA) objectives. In addition, potential regulatory changes or new regulations are evaluated to determine if additional upgrades or new equipment will be required for future compliance.

1.3.2 Hazardous-Waste Management

The Resource Conservation and Recovery Act (RCRA) is the primary regulatory driver for ORNL hazardous waste management operations. The state of Tennessee has been authorized by the U. S. Environmental Protection Agency (EPA) to develop and implement laws and regulations equivalent to those of RCRA. The state regulations are addressed in the Tennessee Hazardous Waste Management Rules.

The Toxic Substances Control Act (TSCA) is a second driver for ORNL hazardous waste management operations. Under TSCA, the EPA regulates the handling, management, and disposal of polychlorinated biphenyls (PCBs). At ORNL, hazardous

wastes include those regulated by RCRA or TSCA, special sanitary wastes, and other wastes identified by ORNL as unacceptable hazards to personnel or to the environment if improperly managed.

1.3.2.1 Solid- and Liquid-Hazardous Wastes

ORNL's diverse R&D activities produce numerous and various waste streams. All the characteristically hazardous, and many of the listed hazardous wastes defined by the EPA and the Tennessee Department of Environment and Conservation (TDEC), appear on ORNL's RCRA Part A permit application. Because liquid and containerized-gaseous wastes are considered "solid" wastes by the EPA and the TDEC, they are subject to solid waste rules. ORNL manages liquid, gaseous (containerized), and solid-hazardous wastes as solid wastes.

The focus of hazardous WM is segregation, repackaging, and storage in preparation for shipment to commercial facilities that will treat and/or dispose. Waste tracking and documentation is a critical aspect of the ORNL management strategy. Waste treatment is provided for bulk non-nitrate acid at the Acid Neutralization Facility, and explosive wastes are treated at the Chemical Detonation Facility.

Several facilities are currently used for the short-term storage of hazardous waste at ORNL. The majority of waste is stored in 208-L (55-gal) drums in Bldg. 7652, which has a capacity of 57,254 L (15,125 gal). Inventories of waste in the various storage facilities vary monthly, since these areas are used for staging the waste for final disposition. Additional hazardous-waste storage facilities are located in the Hazardous Waste Management Area off the Health Physics Research Reactor access road at ORNL.

Two policy developments in 1991 continue to have a major impact on hazardous- and mixed-waste operations: the so-called "Off-Site Shipment Moratorium" and the "No Rad Added" policies. The Off-Site Shipment Moratorium was implemented by DOE on May 17, 1991, and it halted all off-site shipments of hazardous or mixed waste from ORR sites. This was followed in November 1991 by the companion policy referred to as the Performance Assessment for the Certification of Nonradioactive Waste. This policy stipulated that no waste shall be shipped to a private sector treatment, storage, and disposal facility unless it has been certified as free of DOE-added radioactive contamination (i.e., no rad added). Compliance with these policies has placed an additional administration and certification burden on the various WM organizations. To help alleviate the storage problems created by accumulating wastes on ORR sites, the Energy Systems Waste Management Operations has been evaluating the potential for off-site shipment of radioactive wastes to other DOE sites for disposal.

1.3.2.2 Gaseous-Hazardous Waste

About 12 leaking cylinders are handled per year at ORNL. The current management strategy involves the venting of compressed gases to the atmosphere at a remote site (i.e., away from inhabited areas) off Ramsey Drive and the Melton Valley access road at ORNL.

1.3.3 Mixed-Waste Management

Mixed waste contains both hazardous and radioactive components. Currently, the hazardous components of mixed wastes are defined and regulated under RCRA and the radioactive components under the Atomic Energy Act (AEA). Regulation under both of

these acts has evolved because the handling and disposing of mixed wastes involves both toxic and radioactive hazards and because no regulatory program focused exclusively on mixed wastes. DOE Order 5400.3 states that "whenever any hazardous waste identified or listed in 40 CFR 261 is mixed with any source material, special nuclear material, or by-product material, the hazardous component is subject to regulation under Subtitle C of the RCRA." A parallel strategy has been implemented for radioactively contaminated PCB wastes. These are also classified as mixed wastes.

Examples of mixed waste at ORNL are cleaning fluids and oils removed from systems operated in contaminated environments and from scintillation fluids that contain radioactive tracer elements used for chemical and biological analyses. In addition, small quantities of a wide variety of mixed wastes are generated by ORNL R&D and operational activities. These wastes fall into hazard categories, such as PCBs, corrosives, oxidizers, poisons, and flammables. Because liquid and containerized-gaseous wastes are considered solid wastes by EPA and are subject to respective solid waste regulations, solid-, liquid-, and gaseous-mixed wastes are managed similarly at ORNL.

ORNL generates about a hundred 208-L (55-gal) drums of mixed waste annually. Currently, commercial treatment is available only for some scintillation wastes. On-site treatment of only aqueous-mixed waste is available at this time. Decontamination of surface-contaminated lead is planned. Until additional treatment methods become available, these wastes must be stored on-site. Additional characterization and evaluation is needed to determine whether some of these wastes may be accepted for treatment at the TSCA incinerator at the Oak Ridge K-25 Site.

Mixed-waste storage capacity at ORNL is severely limited at present. Drum storage for solid and liquid-mixed waste is currently provided in Bldgs. 7654, 7507W, and 7823. Bulk storage of mixed-waste oils is provided by two tanks: 7075 and 7830a. Building 7507W has been filled to capacity, and Building 7654 is nearing capacity. Tank 7860a was used until early 1991 for mixed-oil storage but has been closed under RCRA. To relieve this congestion, new mixed-waste storage facilities are planned.

An effort to better characterize 850 mixed-waste drums was initiated in early 1991. The objectives of this work include (1) identification of drums that would meet the Process Waste Treatment Plant waste acceptance criteria to facilitate treatment, (2) improvement of characterization data to help identification and selection of off-site waste treatment facilities, including the K-25 Site TSCA Incinerator, and (3) characterization of those drums that have little or no process data traceable to them in accordance with RCRA. This work is expected in fiscal year (FY) 1995. These drums were received by WMRAD prior to 1984 and did not undergo the level of tracking and documentation currently applied to newly generated waste.

On May 8, 1992, the RCRA land disposal restriction (LDR) rule prohibiting the land disposal of all untreated mixed wastes became fully effective. This development prompted the signing of a Federal Facilities Compliance Agreement (FFCA) to provide a system of schedules and milestones intended to bring ORNL into compliance with RCRA LDR. The primary deliverables for the FFCA are a Waste Treatment Plan, a Waste Treatment Strategy Plan, a Waste Minimization Plan, a Waste Storage Plan, and an Implementation Plan. Successful completion of the FFCA has become one of the highest priority activities for WMRAD for FY 1993 and beyond. Significant levels of resources are being devoted to implementation of the FFCA.

1.3.4 Sanitary-Waste Management

Sanitary wastes at ORNL include both solid and liquid wastes. The state of Tennessee regulates these waste streams at ORNL via the Tennessee Solid Waste Disposal Act and ORNL's NPDES permit.

1.3.4.1 Solid-Sanitary Waste

Solid-sanitary wastes that contain no radioactive or hazardous wastes or free liquids include filter cake from the Coal Yard Runoff Treatment Facility, flyash from the ORNL steam plant, general refuse collected in trash cans and dumpsters, and construction debris. The volume of general refuse is estimated to be about 45.9 m^3/day (60 yd^3); flyash and sludge from coal pile runoff accounts for about 9.2 m^3/day (12 yd^3).

Other than the equipment used for the compaction of general refuse, no treatment or storage facilities currently exist at ORNL for handling solid-sanitary waste. The majority of ORNL sanitary waste is now disposed of in Sanitary Landfill Facility II (SLF II), which is located on Chestnut Ridge south of the Oak Ridge Y-12 Plant and about 9.66 km (6 miles) east of ORNL. About 300–400 m^3 (400–500 yd^3) of soil, rock, and concrete mixtures are deposited at the Y-12 SLF II dirt fill area annually. The SLF II is scheduled to be closed when the new Industrial Landfill V is opened (around July 1993).

ORNL has established recycling programs for white paper, cardboard, and aluminum beverage containers to reduce the amount of solid sanitary waste disposed in the Y-12 SLF II.

1.3.4.2 Liquid-Sanitary Waste

Liquid-sanitary waste includes nonradioactive waste streams that are discharged, either directly or following treatment, to White Oak Creek. ORNL sources include (1) sewage treatment plant effluent from Bethel and Melton Valleys, (2) area runoff of rainwater, and (3) Coal Yard Runoff Treatment Facility effluent.

About 2.0×10^5 gal/day of ORNL sanitary sewage is treated by an aerobic digestion process. The ORNL Sewage Treatment Plant, operated under ORNL's NPDES permit, produces a sludge that is dewatered on sludge-drying beds. Most of the Storm Sewer System is constructed of reinforced concrete piping and contains catch basins that drain areas in Bethel and Melton Valleys to White Oak Creek.

Acidic rainwater runoff from the ORNL Coal Storage Yard is collected in a clay-lined basin. Neutralization of the acid with magnesium hydroxide in the Coal Yard Runoff Treatment Facility causes precipitation of contaminants that have been leached from the coal pile. The precipitated solids can be disposed in a commercial landfill but are likely to be disposed of in the SLF II as a special waste.

1.4 ORNL ROADMAP

1.4.1 Introduction

The *Strategic Roadmap for the Oak Ridge Reservation*[3] is a generalized planning document identifying broad categories of issues that keep ORNL in compliance with the law and other legally binding agreements.[2] The *Strategic Roadmap for the Oak Ridge Reservation* identifies possible generic paths to compliance and the schedule for resolution of the issues. The role of the *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) is then to identify specific site issues (problems), identify specific technologies that can be brought to bear on the issues, and assess the current status and readiness of these technologies and how they can remediate the problems within the constraints of the schedule commitment.

Regulatory requirements and commitments contained in the *Strategic Roadmap for the Oak Ridge Reservation* are also included in the TLD as constraints to the application of immature technological solutions. Some otherwise attractive technological solutions may not be employed, for example, because these technologies may not be deployable on the schedule enumerated in the regulatory agreements. Conversely, negotiators in the process of defining regulatory agreements may keep the TLD assessments in mind when scheduling remediation milestones that allow cheaper, faster, better, or safer technologies to be used.

The roadmap for ORNL includes a list of 46 comprehensive logic diagrams for WM of low-level, radioactive, mixed, hazardous, sanitary and industrial, and transuranic waste. The roadmapping process gives comparisons of the installation as it exists to the way the installation should exist under full compliance. The goal of roadmapping is to identify the issues that will allow the accurate and timely formulation of activities. The following information is excerpted from the March 26, 1992, version of the *Strategic Roadmap for the Oak Ridge Reservation*.[3]

1.4.2 Roadmapping Methodology

The roadmapping methodology is divided into nine steps and covers three phases—assessment, analysis, and issue resolution.

The assessment phase identifies the current status and background of the installation. This phase is accomplished in four steps: (1) identifying installation assumptions that provide for the conduct of Environmental Management (EM) activities; (2) identifying regulatory requirements of federal, state, and local regulations and codes, DOE orders, and other agreements that DOE is responsible to comply with; (3) describing those DOE commitments, which include interagency agreements and FFAs; and (4) preparing a schedule that includes all commitments with all currently budgeted and forecasted activities.

The analysis phase identifies key issues and actions needed for resolution. This phase is accomplished in four steps: (1) identifying issues that prevent the installation from accomplishing EM objectives; (2) analyzing of issues to determine the root causes; (3) converting of issues to resolution needs and identifying activities that satisfy these needs; and (4) preparing the schedule for the desired activities.

The issue resolution phase merges the issue resolution activities with ongoing and planned activities as the ninth and final step. Specific recommendations for modifications, additions, or deletions to current plans are formulated and captured in Activity Data Sheets or are forwarded to DOE Headquarters for resolution.

1.4.3 Summary of Major Committed Milestones

The major committed FFA milestones for ORNL WM are listed in Table 1.2. These milestones are negotiated annually with the regulators based on DOE funding and priority consideration. These milestones reflect activities initiated in the past and the planned support activities.

Table 1.2. Federal Facility Agreement for the Oak Ridge Reservation Major committed milestones—waste management (ORNL)

1. Containment/detection of releases and operational standards for secondary containment tank systems(s)
   - Submit to EPA[a]/TDEC[b] schedule for written design demonstrations for existing tank systems. [Within 60 days of FFA[c] effective date]
   - Submit to EPA/TDEC written design demonstrations showing that existing tank systems with secondary containment meet or can be retrofitted to meet standards in Section C (Appendix F) of FFA (includes plans and schedules for retrofitting).
     [partly done]

2. Schedules for removal of tank system(s) from service
   - Submit to EPA/TDEC a plan and schedule for removal from service of all tank systems not meeting secondary containment and/or leak detection design and performance standards in FFA (Subsection E). (This submission includes a required risk assessment for tank systems that cannot be removed from service without posing unacceptable risk to worker health and safety or an immediate risk to human health or the environment.)
     [completed]

3. Structural integrity assessment(s) for non-secondary containment tank system(s)
   - Submit to EPA/TDEC a schedule for providing all available information on structural integrity of non-secondary containment tank systems.
     [completed]

4. Removal of tank system(s) from service
   - Provide to EPA/TDEC schedule for characterization of waste contents (hazardous/radioactive) in tank system(s) removed from service.
     [mostly done]

5. Reporting
   - Submit first quarterly progress report on implementation of FFA to EPA/TDEC.
     [30 days from end of first quarter following FFA effective date]

6. Periodic requirements
   - Quarterly progress reports on FFA implementation.
   - Quarterly calendar-year compilations of quality assured data from samples collected, analyzed, and reported in preceding calendar quarter (due February, May, August, November).
   - Annual establishment of priorities for implementing FFA in succeeding fiscal year (by March 15).
   - Annual report to Congress (include specific cost estimates and budgetary proposals associated with FFA implementation).
   - Annual update of Five-Year Plans.

[a]EPA = Environmental Protection Agency
[b]TDEC = Tennessee Department of Environment and Conservation
[c]FFA = Federal Facility Agreement

Source: *Strategic Roadmap for the Oak Ridge Reservation*, U.S. DOE Field Office—Oak Ridge and Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, March 26, 1992.

1.5 TOP ORNL WASTES NEEDING TREATMENT TECHNOLOGY DEVELOPMENT

Several knowledgeable WMRAD staff collectively reviewed the current ORNL wastes and the potential wastes likely to be generated as a result of future decontamination and decommissioning (D&D), remedial action (RA), and WM operations to identify those wastes that would be prime candidates requiring treatment technology development. They used the following criteria in their evaluation:[4]

- regulatory requirement for waste treatment criteria that reviews the need for waste treatment [i.e., whether the treatment is driven by regulation or other factor(s)];
- risk reduction potential criteria that examines the risk reduction due to reducing either the toxicity, mobility, or the quantity of the waste; and
- applicability to ORNL wastes criteria, (i.e., whether the treatment is for a current waste or for a potential future waste).

Based on the above criteria, the top ORNL wastes that need technology development are listed in Table 1.3.[4] This analysis does not imply that the remaining ORNL wastes could not benefit from treatment technology development; however, it does imply that there is either available treatment technology for these wastes or that the perceived need for treatment technology development is less urgent.

Table 1.3. Top ORNL wastes needing treatment technology development[a]

Waste description	Ranking
Melton Valley Storate Tank (MVST) and Radiochemical Engineering Development Center (REDC) mixed caustic aqueous waste	1
Process dilute liquid low-level waste	2
REDC mixed acidic waste	3
Melton Valley and REDC RAD only caustic aqueous waste	4
Ignitable and reactive waste	5
REDC RAD (radioactive) only acidic waste	6
MVST waste processing sludge	7
Lab packs	8
Irradiated and spent fuel elements and components	9
Spent ion exchange media	10
REDC liquid organic waste	11
Listed halogenated solvents	12
Listed nonhalogenated solvents	13
Sanitary/industrial wastewater (RAD contaminated only)	14
Sanitary/industrial wastewater (not RAD or hazardous waste contaminated)	15
Radioactive gases	16
Particulate laden gases	17
Toxic organic wastes	18
Corrosive wastes	19
Nonferrous metals (lead)	20
Volatile organic compounds in gases	21
Semi-volatile organic compounds in gases	22

[a]All the streams listed in the table have an "importance of site problem" (see Sect. 2.4 for details) ranking of "5" or "4" with "5" representing highest importance.

1.6 ISSUES FOR WASTE MANAGEMENT

Listed below are some of the issues facing ORNL WM:

1. Uncertainty regarding new regulatory requirements (like the Federal Facility Compliance Act and the PCB FFCA) and revisions of existing requirements (e.g., DOE Order 5820.2A) impacts the ability to plan WM activities to meet acceptable long-term goals. Short-term WM planning is also affected by the changing regulations.

2. The availability and accessibility of disposal capacity for all wastes in FY 1995 is key to the overall WM strategy. The storage needs and plans for the increased utilization of the K-25 Site TSCA Incinerator are based on the assumption that disposal capacity will be identified by 1995. Implementation of the "no rad added" performance objective will severely limit the waste types and volumes that can be shipped off site.

3. The wastes from the environmental restoration (ER) and D&D programs are expected to increase dramatically in the next few years. The uncertainty associated with the ER and D&D programs' waste generation estimates hampers WM's ability to adequately plan for treatment, storage, and disposal needs.

4. Remotely handled TRU storage capacity at ORNL is limited. The effective implementation of a national strategy for TRU wastes is necessary to resolve ORNL remotely handled TRU WM needs. The continuing deferral of approval of the ORNL WHPP (or similar facility) (due in part to the lack of a national strategy for remotely handled TRU) is limiting WM's ability to plan for handling the TRU wastes.

5. The WM capital projects funding requirements are projected to increase dramatically in the out years and will not be supported by the 5% to 10% incremental growth in target funding. There is a need to develop funding profiles for major line item increases [such as the WHPP (or similar facility)] in FY 1996 and beyond.

6. The projected staffing requirements and the mix of expertise are insufficient to provide adequate planning and oversight of WM activities. There is a need for relief from the caps placed on personnel requirements for the WM organization.

1.7 REFERENCES

1. *Oak Ridge National Laboratory Institutional Plan FY 1993–FY 1998*, U.S. DOE and Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, November 1992.

2. *Oak Ridge National Laboratory Waste Management Plan*, ORNL/TM-11433/R2, Office of Waste Management and Remedial Actions, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, December 1992.

3. *Strategic Roadmap for the Oak Ridge Reservation, March 1992*, U.S. DOE Field Office-Oak Ridge and Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, March 26, 1992.

4. D. L. Daugherty, WMRAD, personal communication with S. P. N. Singh, Oak Ridge National Laboratory, June 7, 1993.

2. Description of the Technology Logic Diagram

2. DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM

2.1 PURPOSE AND SCOPE

The purpose of the TLD is to provide a planning document for DOE, DOE operating contractors, and private industry that relates the environmental restoration/waste management (ER/WM) problems at ORNL to the technologies that can be used to remediate these problems. In doing so, the status of each potential remediation technology is evaluated. This is a significant focus of the diagram preparation.

Several important aspects impacting implementation of each technology are folded into the evaluation so that the appropriateness of each technology can be evaluated:

1. Potential efficacy of the technology—how successful will its application be to the site problem?
2. Level of maturity of the technology—when can it be applied to site problems?
3. Level of WM required for the technology—what wastes are generated as a result of the use of the technology?

The TLD addresses the enforceable compliance and cleanup agreements that have designated timetables for ameliorating the specific site problems. For potentially attractive but immature technologies, or those for which improvement paths (which make them faster, better, safer, and cheaper) are visualized, priorities are assigned to technology development activities.

Because of enforceable compliance agreements, DOE is bound by Executive Order 12088, which requires the Secretary of the Department of Energy to submit a plan and request sufficient funding each year to comply with federal pollution control standards. This document will aid in the annual planning and budget submittals.

This document will address all WM problems that have been identified at ORNL. The technology listings in the diagrams were judged to have some reasonable prospect for application at ORNL. In a few cases the prospects are limited, however.

The TLD provides several benefits to the DOE community. The diagram identifies technologies that can be used for EM programs. It serves as a vehicle to identify the deficiencies in technologies that otherwise have potential to (1) foster faster remediation; (2) allow safer project activities; (3) result in better remediation efforts; and (4) allow these projects to be accomplished at a lower cost to DOE and the United States. Improving existing technologies, demonstrating the applicability of promising technologies, developing immature technologies, and supporting fundamental technology investigations are options that DOE can pursue to deploy technologies necessary for successful EM of DOE facilities. The diagram will highlight areas for private industry and university involvement in EM.

2.2 STAFFING FOR THE TLD

The formulation of the ORNL TLD was led by the same team leaders who formulated and published the *Oak Ridge K-25 Site Technology Logic Diagram*, with participation from across the Oak Ridge Reservation (ORR). Although a number of ORNL personnel were involved, about half of the team was selected from other Energy Systems organizations in Oak Ridge, such as the K-25 Site, the Y-12 Plant, Central Engineering, and other DOE contractors. The personnel from these organizations represent input from personnel associated with programs under the DOE Deputy Assistant Secretaries of Waste Management (EM-30), Environmental Restoration (EM-40), and Technology Development (EM-50), as well as professionals not associated with these programs. Figure 2.1 shows the staffing plan for the ORNL TLD Team.

Specialists worked as members of each team formed for the *subelement* categories. Representatives from each team served on a coordinating committee, which functioned as a common communication forum for the TLD. More than 100 specialists were involved in this effort. The teams (1) compiled the site problems in terms that were applicable to each team; (2) identified and evaluated technologies that could be applied to remediate the problems; (3) furnished, through the technology evaluation, information on the opportunities that were evident for development and improvement in each technology; and (4) furnished the requirements for deployment of these developed and improved technologies.

Technology evaluation was a significant component of the TLD effort. Team members identified potential technologies, but it was not necessary for the technology evaluation experts to become familiar with the concepts of the TLD before their evaluations. The data sheets allowed the evaluations to be performed on a systematic basis. The data sheets (Vol. 3, Pts. A, B, and C) provide detailed information and the basis upon which the diagram (Vol. 2, Pts. A, B, and C) was devised.

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REMEDIAL ACTION	DECOMMISSIONING		WASTE MANAGEMENT	CROSS CUTTING ACTIVITIES		
	DECONTAMINATION	DISMANTLEMENT		CHARACTERIZATION	ROBOTICS/ AUTOMATION	REGULATORY COMPLIANCE
J. Watson (Env. Restr.) Deputy Leader J.K. Kaberowski (CH2M) Deputy Leader J. Kahnle (ORNL ER) D. Allen (Radian Corp.) J.Autry (ORNL ER) C.W. Francis (ORNL Env. Sci.) S.B. Garland (ORNL ER) J. Greene (ORNL ER) C. Kendrick (ORNL CTD) B. Spalding (ORNL Env. Sci.) W. Thompson (MMES Engr.)	R.D. Bundy (K-25 Tech.) Deputy Leader J.H. Wilson (ORNL CTD) R.B. Alderter (K-25 Tech.) C.E.Benson (ORNL CTD) D.H. Bunch (K-25 Tech.) J. Devore (MMES Engr.) W.L. Gardner (ORNL Fusion Energy) H.H. Haselton (K-25 Environ. Tech.) E.B. Munday (K-25 Tech.) W.D. Nelson (ORNL Fusion Energy) D.B. Smith (ORNL Appl. Tech.) C.C. Tsai (ORNL Fusion Energy)	L.C. Hennessy (MMES Engr.) Deputy Leader W.Kay (ORNL Appl. Tech.) T. Barnes (Mech. Kinetics Corp.) B. Barton (MMES Engr.) P.E. Denny (Penn. State) J.M. Kennedy (MMES Cont. D&D) J.M. Moore (MMES Engr.) J. Munro (ORNL I&C) S.L. Schrock (ORNL Robotics) B.H. Singletary (MMES Engr.) G.S. Smith (MMES Engr.) J.W. Smith (MMES Engr.) C. Strange (Mech. Kinetics Corp.) L. Tallrico (ORNL App. Tech.) B. Vantley (MMES Engr.)	S.P.N.Singh (ORNL CTD) Deputy Leader G.D. DeCat (K-25 Tech.) K.E. Bass (ORNL CTD) W.D. Bostick (K-25 Tech.) J.M. Chiang (MMES Engr.) D.L. Dougherty (ORNL WM) W.H. Hannas (MMES Engr.) T.E. Kent (ORNL CTD) K.E. Plummer (ORNL Robotics) R.B. Pope (ORNL CTD) A.A. Richmond (ORNL HASRD) A.L. Rivera (ESMSC) J.T. Shor (ORNL CTD)	Wayne Griest (ORNL ACD) Deputy Leader H.M. Hanson (K-25 Tech.) J. Bock (K-25 Quality) M.R. Guerin (ORNL ACD) R.B. Gammage (ORNL HSRD) C. Dudney (ORNL HSRD) R. Hagenauer (Int. Tech.) D.P. Hoffmann (K-25 Tech.) J. Keller (ORNL ACD) S.Y. Lee (ORNL ACD) T. Mueller (ORNL ACD) J. Munro (ORNL I&C) D. White (Bin. Engr. ORNL/UT) J. Zolyniak (K-25 Quality)	S.L. Schrock (ORNL Robotics) D.C Haley (ORNL Robotics) R. Evanoski (ORNL Chem. Tech.) J.H. Hamann (ORNL Robotics) L. Klatt (ORNL Robotics) H.E. Kane (ORNL Engr., Phy., Math) B.H. Singletary (MMES Engr.)	C.G. Jones (MMES Env. Compl.) S.E. Arnold (ORNL HASRD) E.L. Elster (ORNL HASRD) B. Gains (MMES Legal) J.P. Hicks (ORNL HASRD) L.M. Hoadley (ORNL HASRD) M.E. Mitchell (MMES Env. Compl.) S.L. Taylor (ORNL HASRD)

Fig. 2.1. The ORNL Technology Logic Diagram team.

2.3 TECHNICAL APPROACH

This section describes the overall layout and development of the TLD. The logical progression flows from DOE Environmental Management (EM) Goal → EM Problem → ORNL Problem → Problem Area (Target Constituent) → Reference Requirements → Subelement → Alternative (Generic Technology) → Technology → Technology Status → Science/Technology Need → Implementation Need.

Three different levels of information are provided. First, the technologies are evaluated and ranked in Vol. 1, Pts. A, B, and C. Second, more detailed diagrams are provided in Vol. 2, Pts. A, B, and C. Although each large sheet contains the entire logic path, several sheets are necessary to describe each evaluation area. Finally, each single logic path is published as a technology data sheet. These sheets are more detailed sources of information about each technology and are provided in Vol. 3, Pts. A, B, and C.

The information found under each logic element is described below.

EM Goal has three components: clean up legacy of waste, prevent future insult, and develop environmental stewardship. These problems are shared by all elements of the DOE complex to varying extents.

EM Problem contains problem areas agreed upon by EM/DOE such as decommissioning of facilities (D&D); cleanup of soils, ground water, and surface water RA; and WM from inception to final disposition.

ORNL Problem describes the problem areas identified at ORNL. These problem areas have been defined by the site's D&D, ER, and WM staff. Where feasible, the magnitudes of the site problems will be indicated in terms of floor areas, estimated metal tonnages, etc.

Problem Area/Constituent addresses a subelement-specific (see below) list of problems, all of which are traceable directly to ORNL problems.

Reference Requirements refers the reader to chapters of Vol. 1, Pts. A, B, and C. Requirements can only be determined after consideration of detailed site-, waste-, and technology-specific characteristics.

Subelement specifies the different components that must be addressed to solve the problem. All D&D activities have been categorized into the following subelement groups: characterization, decontamination, dismantlement, robotics/automation, materials disposition, and regulatory compliance.[1] The subelements for RA are characterization; treatment and fixation; retrieval; robotics/automation; materials disposition; and regulatory compliance. The subelements for WM are waste retrieval, characterization, processing, stabilization, minimization, packaging handling and transportation, disposal, and regulatory compliance. Table 2.1 lists these various subelements for D&D, RA, and WM.

Alternative defines the general technology approaches that may be applied to the problem.

Table 2.1. Subelement categories in the Technology Logic Diagram

Area of environmental management	Subelements ("Universe" of Activities)					
Decontamination and decommissioning	Characterization	Decontamination	Dismantlement	Robotics/ automation	Materials disposition	Regulatory compliance
Remedial action	Characterization	1. Treatment 2. Fixation	Retrieval	Robotics/ automation	Materials disposition	Regulatory compliance
Waste management	Characterization	1. Processing 2. Stabilization 3. Minimization	1. Transportation 2. Retrieval 3. Disposal	Robotics/ automation	Materials disposition	Regulatory compliance
	Crosscutting			Crosscutting	Crosscutting	Crosscutting

000447

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Technology identifies specific technologies that may be applied to remediate the problem.

Technology Status provides information on the status of the technologies identified in the previous column using the standard categories.

Some accepted technologies are *fully developed* or *commercially available* and if so are noted. These terms are used to denote slightly different meanings. *Fully developed* means that both the basis of the technology and the methods for designing remediation equipment or operations using the method are well known and covered in public literature. *Commercially available* means that the technology is offered by one or more commercial firms, but the data, design methods, or experience needed to assess the technology are not fully available to the public. The only difference in these two categories is that the public's ability to assess the performance and reliability of the technology is restricted for commercial technology. It suggests an unknown degree of risk in the commercially available technologies that cannot be fully evaluated with generally available information (even though the amount of risk may be negligible).

- *In Use*—technology is presently being used to remediate the identified problem.
- *Accepted*—accepted by industry and/or the regulators. The demonstrated technology exists for use at ORNL and is accepted by site personnel.
- *Demonstration*—technology is available but is not demonstrated and/or accepted for the problem at ORNL.
- *Predemonstration*—technology is under laboratory-, bench-, or pilot-scale testing.
- *Evolving Technology*—technology status is at a conceptual or preconceptual stage.

  - *Conceptual*—a scientific or knowledge basis for the technology exists.
  - *Preconceptual*—only a partial scientific or knowledge basis of the technology exists.

These classifications should provide indirect, relevant information on the present view of the short- or long-term availability of technologies.

Several different areas are specifically addressed to further clarify the status designations chosen above.

- *Efficacy*—the effectiveness of the technology in remediating the problem is addressed. Normally, quantitative measures are given for the technology's performance in standard practice, such as estimating the final dpm/cm^2 of surface contamination for a decontamination technology; the time to cut a 24-in. pipe for a dismantlement technology; or the analysis time and lower detection limit for a characterization technology.
- *Waste*—output from the technology. This describes the nature and volume of both the waste and the potentially useful materials.

Science and Technology Needs are perceived needs where support should be applied to develop an "immature" technology. Science and technology needs are related to the fundamental understanding of the scientific phenomena that form the basis for the technology. These needs are typically for laboratory or bench-scale experiments. Technology development needs identify areas where work is necessary. Technology improvement needs suggest improvements that will make a current technology more economical to apply, safer, and more effective or efficient. The demonstration of a technology on a site-specific problem is classified as a technology improvement need.

If scientific needs are specified, it should be understood that the needs of scientific technology development or improvement are necessary to implement newly developed scientific understanding. Likewise, testing a technology development opportunity implies that technology improvements are also likely to be needed.

DOE funding for a project that addresses the technology deficits is indicated by a Technical Task Plan (TTP) number, Activity Data Sheet number, or other reference number. Other work related to the technology area may also be referenced.

Most new technologies that are not in common use will require a large-scale test or demonstration to show that they are capable of achieving expected results on the site-specific problem. These tests demonstrate that a suitable and workable process or facility can be designed, built, and operated successfully. They show that no unknown condition prevents the process or facility from functioning as it was designed and that the equipment can last an acceptable lifetime. Demonstrations are intended to provide final tests of all aspects of a technology. If, however, particular questions remain about the technology, these are specifically mentioned on the diagram.

· **Implementation Needs** or specialized needs were evaluated for both development of a technology and deployment of a mature technology. These needs were evaluated in the areas of (1) resources such as financial or personnel; (2) hardware such as process equipment, development equipment, and computers; (3) software such as models, procedures, computer programs; (4) facilities such as labs, shops, and buildings; and (5) education such as training classes or degreed personnel. An estimate of the cost of the process and any potential cost payback are also given. Only extraordinary needs are highlighted, (i.e., those needs that would require long lead time or unusual procurements, such as line items for facility construction).

The cost of applying the technology and the payback cost potential has been estimated. There are many reasons for payback, such as reducing the waste volume compared to a reference process, the sale of useable products, and the reduction of labor compared to a reference technology.

When standard laboratory facilities are sufficient, facility needs are not identified. Since the facilities on ORR are relatively extensive—including the K-25 Site, ORNL, and the Y-12 Plant—the diagram does not address needs for standard facilities but focuses on unique facility needs.

However, additional conventional facilities may be needed to meet the technology needs for remedial actions at ORNL because the available facilities may not provide adequate capacity for testing the various technologies. To assess the availability of standard facilities for these programs, it will be necessary to know (1) the rate at which technology development in Oak Ridge will proceed and (2) the extent at which other programs will compete for the facilities.

Throughout the technology evaluation a method of conveying information about the priority and status of each technology and its application is used to communicate separate information about the following:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low).
- Importance of site problem to which the technology is applied (1–5 is the scale of lowest importance to highest importance).
- Time required to bring the technology to the state of being acceptable for application at large scale (commercial or mature state) at the site. This is expressed in number of years and depends on the current state of its development.
- The cost for bringing the technology from its present state to acceptable for use commercially or at large scale. The costs are presented as $M or $K, which indicates the number of millions or thousands of dollars without escalation.
- Projected unit processing cost for mature technology ($ per ft^2 for other unit or N no estimate). This includes annual ranking costs for software.

An example of a ranking follows:

H-5-5 ($3.5M;N)

This means that this technology has a high overall usefulness; the technology is estimated to take five years to reach an acceptable state for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

2.4.1 Overall Assessment

Following are the criteria used to determine the overall assessment of a technology and its application.

- *Waste Generation Reduction*—the ability of the technology to minimize additional waste generation (1–no confidence, 5–complete confidence).
- *Compliance with Requirements*—confidence that the technology will comply with applicable, relevant, and appropriate requirements (ARARs) (1–no confidence, 5–complete).
- *Environmental, Safety, and Health (ES&H)*—ability of the technology to meet the requirements of ES&H (1–no confidence, 5–complete).
- *Versatility*—ability of the technology to meet a wide range of requirements and to adapt to changes in requirements (1–no confidence, 5–complete).
- *Complexity*—ability of the technology to be deployed without requirements for extraordinary levels of expertise, training, and oversight (1–very high level of requirements, 5–low level of requirements).
- *Technical Risk*—confidence that the technology will work at the site(s) being evaluated (1–no confidence, 5–complete confidence).
- *Technical Maturity*—readiness of the technology relative to final application at large (commercial) scale (1–very immature-idea for research, 5–ready for commercial application).

000450

- *Development Required*—relative amount of time required to bring the technology to commercial application (1–all research, development, and demonstration steps required, 5–now commercial/no tests required).
- *Development Cost*—relative cost of bringing the technology to commercial application (1–highest cost for development of a technology within a technical area, 5–no costs, not even field testing).
- *Process Cost*—relative cost of process in terms of unit production costs in application (1–prohibitively expensive relative to other methods, 5–very inexpensive compared with other methods).

After scoring the criteria, the scores were averaged and the overall assessment rating was determined by the scale in Table 2.2.

Table 2.2. Scale for overall assessment rating

Assessment code	Code meaning	Score	Meaning
E	Essential	Any score	No other processes or technology available for essential requirement
H	High	3.67 to 5	High potential for application
M	Medium	2.33 to <3.67	Medium potential for application
L	Low	<2.33	Low potential for application

2.4.2 Status of Technology

The development state for technology was assessed using the scale provided in Table 2.3.

Table 2.3. Scale for status of technology

State of technology	Score
Accepted	5
Demonstration needed	4
Predemonstration—evolving	3
Conceptual	2
Preconceptual	1

2.4.3 Estimates for Time to Maturity

Definitions for progress of development and time periods, which were used as guidelines for estimating the total period required to bring technology to the state of large-scale application (state of acceptance), are provided in Table 2.4.

Table 2.4. Definitions for progress of development and time periods

Step in development	Definition of step	Years
	New technology	
Applied research	Work required to define scientific feasibility	1–3
Development	Bench or engineering scale to define scaling of the technology	2–3
Pilot	Integrated test of process or technology at less than full scale	3–4
Prototype demonstration	Integrated demonstration at full scale	3–5
Commercialization or mature application	Application of the technology at large scale	1–2
	Adaptation of existing technology (existing at mature state)	
Synthesis demonstration	Combining existing technologies to meet requirement—demonstrate at pilot scale	2–3
Field test	Testing on the exact site problems and configuration	1–3

These stages of development correspond to the state of the technology and are shown in Table 2.5.

Table 2.5. Correspondence of terms for state of the technology

Status of technology	Score	Development period expressed by time	Development stages
Accepted	5	Available	Mature
Demonstration	4	Short range	Field test
Predemonstration	3	Medium range	Development, pilot, prototype, or synthesis of technology
Evolving—conceptual	2	Long range	Development
Evolving—preconceptual	1	Unknown	Applied research

2.5 REFERENCES

1. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge National Laboratory, October 29, 1992.

3. Characterization

3. CHARACTERIZATION

3.1 INTRODUCTION

WM problem areas require several types of characterization to answer the following questions:

1. What contaminants are present?
2. How concentrated are the contaminants?
3. Where are they?
4. How far have they spread?

Characterization is needed to define regulated and nonregulated contaminants in waste materials. It is required to meet regulatory requirements, to permit risk assessment, and to guide remedial treatments. The technologies involve, for the most part, the analysis of debris and wastes from RA and D&D activities in the field and laboratory. These may include materials as diverse as concrete rubble, liquid and gaseous waste streams, ion exchange resins, steam plant ash, sealed radioactive sources, and gas cylinders. The main contaminant groups of concern are radioactive elements, heavy metals, and organic compounds or mixtures of organic compounds (e.g., PCBs or fuels). Pathogenic organisms are also screened.

This chapter presents the characterization technologies required to support WM activities at ORNL, brief overviews of the science and technology needs to bring the technologies to a useable level, implementation needs to deploy these technologies, and ratings of these technologies for WM.

3.2 TECHNOLOGIES

3.2.1 Characterization Technology Options

Characterization technology options for WM at ORNL are listed with their rankings in Table 3.1 in Sect. 3.5. These technologies are for current waste streams at ORNL and those anticipated from future remediation activities. These are for the most part the same technologies as those for RA and D&D. All technologies are not required for each environmental management (EM) problem, but many of the technologies for a given constituent are alternates. Many of these technologies are broadly applicable to a variety of constituents and WM problem areas, and they are listed in the TLD under a "general" problem category. This reflects the applicability of a technology to more than one group of constituents (e.g., radioactive elements and metals) and to more than one problem area (e.g., contaminated concrete, gravel, asbestos, and fiberglass). Under this general heading, the technologies are grouped as the following alternatives: sampling design, sample collection, sample preparation, detection/measurement—field method, and detection/measurement— laboratory method. Technologies specific to a group of constituents are then listed in the TLD under a specific alternative: radioactive elements (which includes both specific radionuclides and radioactivity), inorganic constituents (cations, anions, and elemental metals such as mercury), organic constituents, physical characteristics, and pathogens. These constituent-specific technologies are subdivided by their deployment in the field or laboratory. Technologies for in situ and ex situ determinations are included in the field and laboratory classifications. Simple and highly common characterization technologies, such as for pH measurements, are omitted for simplicity in this compilation.

3.2.1.1 Sampling Design

The main technologies needed under this alternative are statistical designs or approaches for planning sample collection. For example, the large number of samples called for by a conventional sampling design applied to waste retrieval can be reduced by statistical considerations to a more manageable number without sacrificing information value.

3.2.1.2 Sample Collection

Conventional sample collection methods exist for most of the WM problems at ORNL, but many are inadequate or expensive, and technology improvements are needed. Examples are the collection of specimens from highly radioactive materials, such as concrete pads or liquid wastes in tanks. The constraints of handling radioactive materials or working in radioactive fields severely hamper sampling methods. The DOE ALARA principle is the guiding factor for adaptation and development of such technologies.

Perhaps the most difficult sample collection problem is the collection of truly representative samples from heterogenous wastes. This would include wastes contained in drums and boxes in storage areas. The contents may range from bottles, gloves, wipes, and shoe covers to broken, damaged, or contaminated equipment and apparatuses. Technology needs include not only statistical designs for directing the sample collection, but also the physical means of obtaining the representative sample(s).

3.2.1.3 Sample Preparation

One of the largest technology needs is the adaptation of conventional sample preparation methods to the special requirements of radioactive samples where containment in a radiochemical hood (low activities of alpha, beta, or gamma emitting samples) or glove box (primarily for samples with alpha activities of 10^6 disintegrations per minute and greater) or shielding in a hot cell (generally, samples with beta/gamma radiation fields of 500 mR/hr or greater) may be required. This includes upgrading organic and inorganic preparation methods and also regulatory leaching procedures. Current methodologies have not been able to meet regulatory requirements in some applications. High-pressure ashing is an example of a critically needed technology for preparing waste samples for inorganic and radiochemical analyses.

3.2.1.4 Detection/Measurement-Field Methods

Measurement technologies for field use are needed to define and measure contamination in wastes. They can also screen samples in the field such that only those with significant contamination are returned to the laboratory for more extensive and expensive characterization. Field-method technologies are also discussed under specific contaminant group alternatives. Deployment of these measurement technologies with robotics and automation is an important crosscutting area that promises to streamline and reduce costs of such surveys. It will also reduce personnel exposures to radiation and hazardous organic and inorganic compounds. Please refer to the robotics and automation chapter (Chap. 5) of this volume.

3.2.1.5 Detection/Measurement—Laboratory Methods

Laboratory-based technologies capable of multi-analyte (e.g., inorganic and organic components) determinations are listed under the "general" alternative, while constituent group-specific technologies are presented under the specific alternatives. A technology need general to laboratory measurements is contamination control of the analytical equipment. This need goes hand-in-hand with adaptation of the sample preparation technologies for radioactive samples.

3.2.1.6 Data Analysis/Management

A wide range of information management and data analysis technologies will be needed, perhaps in some cases required, to support the level of tracking and accounting necessary to assure compliance with environmental laws and guidelines for conduct of activities. Configuration management support will be needed to meet the demands of working in a highly regulated environment, especially in dealing with hazardous materials. Decision aids, including simulation models, data bases, full text information retrieval applications, and expert systems will be needed to assist with planning. Statistical analysis, graphical display, and geographical information and data will need to be transferred between the various groups of people working on the various aspects of the ER effort. Quick, reliable access to data or information distributed among many different organizations will be needed. All of these areas of support are best taken care of using computer networks. Network communications support then becomes yet another area of technology that must be included. The demands on project management and

3.2.1.12 Organics—Laboratory Methods

Technologies for determination of regulated organic and DOE-unique compounds (e.g., chelator or chelated radionuclides) are required. Improvements in these technologies to reduce secondary waste generation, increase analytical speed and efficiency, or to address DOE-unique compounds (e.g., chelators) are needed. Supercritical fluid extraction as a virtually waste-free sample preparation method and liquid chromatography-mass spectrometry for nonvolatile organic analyses are examples of technologies whose development and deployment are needed to support site remediation.

3.2.1.13 Physical—Field Methods

Technologies for in-field determination of physical properties may assist in WM tasks.

3.2.1.14 Physical—Laboratory Methods

Characterization of particles and other materials is a small technology need.

3.2.1.15 Pathogens—Laboratory Methods

Handling and disposing of biological wastes will require surveillance for pathogenic organisms as a part of worker protection as well as waste treatment.

3.2.2 Crosscutting Technologies

An important area of technology crosscutting is robotics and automation. This is particularly relevant in two areas of characterization: sample collection in situations too hazardous or remote for direct human participation (as during the sampling of highly radioactive concrete), and also in preparation of highly radioactive samples for analysis (as for nuclear wastes). These crosscutting technologies are discussed in Chap. 5 of this volume.

3.3 SCIENCE AND TECHNOLOGY NEEDS

The basic R&D needs for characterization technologies range from none to considerable. Many characterization technologies are already mature and available on site. Examples of such technologies are gas chromatography-mass spectrometry for identification and quantification of regulated organic compounds and inductively coupled plasma-emission spectroscopy for metals. Some technologies require some development, such as the use of stable isotopes of RCRA toxicity-characteristic metals in isotope dilution inductively coupled plasma-mass spectrometry, or supercritical fluid extraction directly interfaced with gas chromatography.

Other technologies will require basic R&D. The specific needs are explained in the *Technology Evaluation Data Sheets*, which comprise Vol. 3, Pt. A. An important example of such a technology is the sampling of heterogeneous wastes, where both statistical sampling design and the equipment used for obtaining the representative sample(s) from the waste require development.

3.4 IMPLEMENTATION NEEDS

Implementation needs, like science and technology needs, range from none to considerable. Instruments and protocols already exist for the determination of many regulated organics and inorganics using EPA protocols. These technologies have essentially no implementation needs and are ready as is for samples that can be handled in nonzoned laboratories. Other mature technologies are available on site, but some work is needed to deploy them. This work may entail calibration for the specific constituents and/or sample matrices or adaptation for deployment in certain locations, such as fieldable-gas chromatography or radiation sensors. The performance validation needed for method quality assurance is included in the implementation costs. Other technologies are not available on site and will require greater effort to obtain them and implement them at ORNL.

Some facility upgrades at ORNL are required to handle the anticipated sample load. This is particularly true for radioactive samples that require shielding or containment and for which current facilities are inadequate.

3.5 TECHNOLOGY RANKINGS

The rankings assigned to the characterization technologies for WM at ORNL are included in the last column of Table 3.1. The ranking system is essentially the same as that explained in Sect. 2.

Table 3.1. Rankings of characterization technologies for waste management

Alternative	Data sheet code number	Technology	Ranking[a]
Sampling design	CHAR-252-OL	Sequential sampling plans	M-3-.5 ($0.1;$.5Kam[b])
	CHAR-71-OL	Optimization of sampling designs	H-5-0.5 ($0.1M;$N)
	CHAR-228-OL	Sampling program configuration management system	E-5-1 ($.5M;$50Kam)
Sample collection	CHAR-20-OL	Ultrasonic extraction	M-4-1 ($0.2M;$400)
	CHAR-270-OL	Sampling heterogeneous wastes	H-4-3 ($2.8M;N)
	CHAR-210-OL	In situ solid phase microextraction of organics	H-4-1 ($.25M;$200)
	CHAR-62-OL	In situ solvent extraction	M-4-2 ($.4M;N)
	CHAR-81-OL	Sampling and mixing methods	E-4-1 ($.25M;N)
	CHAR-271-OL	Sampling interface for surface contamination by organics	M-4-3 ($.775M;N)
	CHAR-257-OL	Sampling underground storage tanks for volatile organics	H-4-1 ($.26M;$500)
	CHAR-254-OL	Solid sorbent sampling for airborne organics	H-4-1 ($.2M;$50)
	CHAR-55-OL	Membranes for sample collection and concentration	M-4-1 ($.25M;$50)
	CHAR-276-OL	Sediment sampling from restricted access locations	M-4-2 ($.45M;N)
	CHAR-64-OL	Multiangle drilling for depth profiling of containments	M-4-1 ($.2M;N)
Sample preparation	CHAR-205-OL	Radioactive sample preparation	H-4-1 ($.1M;N)
	CHAR-208-OL	Supercritical fluid extraction of organics	M-3-1 ($.33M;$100)
	CHAR-201-OL	Supercritical fluid extraction of inorganics	M-3-2 ($.2M;N)
	CHAR-209-OL	Adaptation of the EPA[c] toxicity characteristic leaching process for use with radioactive samples	E-4-1 ($.45M;N)
	CHAR-19-OL	Microwave digestion	H-4-1 ($.2M;$100)
	CHAR-67-OL	Metallographic sectioning and sample preparation	M-4-0 ($0M;<$500)
	CHAR-203-OL	High-pressure ashing for sample preparation	H-4-1 ($.1M;N)

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Table 3.1 (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Detection/ measurement— field methods	CHAR-25-OL	Fiber-optic chemical sensors	H-4-1 ($1M;$10)
	CHAR-264-OL	Ion mobility mass spectrometry	M-4-2 ($1M;$50)
	CHAR-23-OL	Immunoassay detection	H-4-3 ($1M;$50)
	CHAR-84-OL	Portable Raman spectrometer	M-4-2 ($1M;$10)
	CHAR-27-OL	Optical absorption spectroscopy	H-4-1 ($.6M;$50)
	CHAR-59-OL	Air monitoring	L-4-0 ($.25M;$500)
	CHAR-18-OL	Infrared spectroscopy (wavelength dispersion)	M-4-1 ($.5M;$100)
	CHAR-52-OL	Personnel monitoring	H-4-1 ($.2M;N)
	CHAR-10-OL	Electrochemical methods	M-4-2 ($.5M;$100)
	CHAR-92-OL	Portable luminescence detection	M-4-1 ($.5M;$10)
Detection/ measurement— laboratory methods	CHAR-204-OL	Contamination control—analytical equipment	H-5-2 ($.5M;N)
	CHAR-8-OL	Fourier transform infrared spectroscopy	M-4-1 ($.2M;$50–$500)
	CHAR-48-OL	Isotopic dilution mass spectrometry	M-4-0 ($0M;$100–$1000)
	CHAR-11-OL	Nuclear magnetic resonance	M-4-1 ($.2M;$200–$500)
	CHAR-3-OL	Secondary ion mass spectroscopy	H-4-0 ($0M;$400)
	CHAR-9-OL	Ultraviolet/visible spectroscopy	H-4-0 (<$.1M;$50–$200)
	CHAR-4-OL	Laser ionization mass spectrometry	M-4-1 ($.25M;$300–$500)
Data analysis/ management	DISM-151-OL	Project information access services (needed enabling technologies)	E-5-1 ($.5M;$100Kam)
	CHAR-221-OL also DISM-152-OL	Network architecture with integrated workstations	E-5-1 ($.5M;$60Kam)
	DISM-153-OL	Client/server access to standards and regulatory guidelines (needed enabling technologies)	E-5-.5 ($.25M;$25Kam)

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Table 3.1 (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Data analysis/ management (continued)	DISM-154-OL	Data access services (needed enabling technologies)	E-5-1 ($.5M;$200Kam)
	DISM-181-OL	Geographic information system of DOE sites (needed enabling technologies)	E-5-1 ($1M;$200Kam)
	DISM-155-OL	Automated scanning and conversion of engineering drawings (needed enabling technologies)	E-5-2 ($2M;$300Kam)
	CHAR-233-OL	Hazard analysis expert system	E-5-2 ($.5M;$150Kam)
	CHAR-234-OL	Application of approximate reasoning to data analysis/evaluation	E-5-2 ($.5M;$150Kam)
	DISM-171-OL	Simulated walkthrough facility for robotics task sequence analysis (needed enabling technologies)	E-5-1 ($.3M;$60Kam)
	DISM-191-OL	Computer-based training systems (needed enabling technologies)	E-5-1 ($.3M;$100Kam)
	DISM-172-OL	Computer-aided task analysis and procedure preparation (needed enabling technologies)	E-5-1 ($.5M;$150Kam)
	DISM-157-OL	Client/server/architecture for data base access (needed enabling technologies)	E-5-1 ($.5M;$200Kam)
	DISM-158-OL	Hypertext information systems (needed enabling technologies)	E-5-1 ($.3M;$150Kam)
	CHAR-253-OL	Spatial sample and data analysis plans	H-3-0.5 ($.1M;$.5Kam)
	CHAR-251-OL	Statistical methods for the analysis of large data sets	M-3-3 ($.5M;$.5Kam)
	CHAR-250-OL	Quality control for measurement processes	E-4-.25 ($.05M;$.5Kam)
	CHAR-249-OL	Analysis of censored data	H-4-.25 ($.05M;$.5Kam)
	CHAR-44-OL	Criticality indices	L-2-1 ($.25M;N)
	CHAR-53-OL	Modeling of volatile organics compounds migration in porous materials	M-4-1 ($.25M;N)
	CHAR-241-OL	Task scheduling aids	E-5-1 ($.5M;$80Kam)

Table 3.1 (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Data analysis/ management (continued)	CHAR-260-OL	Integrated microprocessor/sensor monitoring for radioactive waste storage containers	H-5-1 ($.5M;$50/sensor unit installed)
	CHAR-240-OL	Fiber-optic detection and monitoring system (intelligent materials)	M-4-3 ($3M;$1000/ container fabricated)
	DISM-156-OL	3-D CAD data base of buildings and structures (needed enabling technologies)	E-5-2 ($2M;$300Kam)
	CHAR-242-OL	Stored material neural net identification system	E-5-2 ($1M;$100/ container analyzed)
	DISM-173-OL	Generalized object-oriented simulation software (needed enabling technologies)	E-3-2 ($.5M;$200Kam)
	DISM-174-OL	Automated engineering system life-cycle planning (needed enabling technologies)	E-5-1 ($.3M;$60Kam)
	DISM-175-OL	Automated system reliability and safety analysis (needed enabling technologies)	E 5 2 ($.5M;$150Kam)
Radioactive elements— field methods	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 ($.1M;$100)
	CHAR-102-OL	Passive monitors for weak beta radionuclides	M-4-2 ($.6M;$20)
	CHAR-103-OL	Thermoluminescence dosimeter array for spatial characterization of alpha contamination	M-4-3 M;$.6M;$20)
	CHAR-65-OL	Long-range alpha detector	M-4-1 ($.4M;$100)
	CHAR-216-OL	Bubble dosimeters for neutron flux	M-4-1 ($.2M;$15)
	CHAR-96-OL	Alpha track etch detectors for surface alpha contamination	H-4-1 ($.4M;$10)
	CHAR-261-OL	Waste drum gamma activity monitor	M 4 0 ($0M;$200)
	CHAR-269-OL	Advanced radiation monitors	M-4-2 ($.4M;$50)
	CHAR-263-OL	Portable gamma ray scintillometers	H 4 0 ($0M;$100)

2251

Table 3.1 (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Radioactive elements—laboratory methods	CHAR-107-OL and CHAR-266-OL	Neutron activation	H-4-1 ($.2M;$300)
	CHAR-106-OL	Sodium iodide-germanium gamma spectroscopy	H-4-0 ($0M;N)
	CHAR-104-OL	Passive neutron detection	M-4-0 ($0M;N)
	CHAR-202-OL	Radioanalytical procedures	H-4-2 ($1M;N)
Radioactive elements—laboratory methods (continued)	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 ($.1M;$100)
	CHAR-97-OL	Photon electron rejecting alpha liquid scintillation	H-4-0 ($0M;N)
	CHAR-268-OL	Gamma-ray spectrometry	H-5-0 ($.1M;$100)
	CHAR-267-OL	Liquid scintillation counting	H-5-0 ($.1M;$100)
Inorganics—field methods	CHAR-76-OL	Atomic emission spectroscopy	M-5-1 ($.2M;N)
	CHAR-6-OL and CHAR-219-OL	Portable X-ray fluorescence	H-5-1 ($.2M;$25)
Inorganics—laboratory methods	CHAR-78-OL	Inductively coupled plasma—mass spectroscopy	H-4-2 ($1M;$200)
	CHAR-77-OL	Inductively coupled plasma spectroscopy	H-4-0 ($.1M;$200)
	CHAR-76-OL	Atomic emission spectroscopy	H-4-0 ($.1M;$200)
	CHAR-50-OL	Ion chromatography	H-4-0 ($.1M;$100)
	CHAR-37-OL	Electron diffraction	M-4-0 ($0M;$100)
	CHAR-36-OL	Wavelength dispersive X-ray spectroscopy	M-4-0 ($0M;$100)
	CHAR-35-OL	Energy dispersive X-ray spectroscopy	M-4-0 ($0M;$100)
	CHAR-34-OL	Transmission electron microscopy	M-4-0 ($0M;$100)
	CHAR-33-OL	Scanning electron microscopy	M-4-0 ($0M;$100)
	CHAR-17-OL	Particle-induced X-ray emission	M-4-0 ($0M;$100)
	CHAR-24-OL	Cold-vapor (mercury) analysis	H-4-0 ($0M;$100)

Table 3.1 (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Inorganics—laboratory methods (continued)	CHAR-266-OL	Neutron activation analysis	H-4-1 ($.2M;$200)
	CHAR-31-OL	Powder X-ray diffraction	M-4-0 ($0M;$>100)
	CHAR-1-OL	Electron spectroscopy for chemical analysis	M-4-0 ($0M;$200-$600)
	CHAR-2-OL	Auger electron spectroscopy	M-4-0 ($0M;$300-$800)
	CHAR-56-OL	Glow discharge ionization mass spectrometry	H-4-1 ($.5M;N)
Organics—field methods	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-4-1 ($.2M;$<50)
	CHAR-100-OL	Portable gas chromatography/electron capture detection for analyzing PCBs[d]	M-4-0 ($.25M;$50)
	CHAR-5-OL	Portable volatile organic compound detectors	M-4-0 ($.25M;$10)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-5-2 ($.2M;$50)
	CHAR-262-OL	Gas chromatography in the field	H-4-0 ($.25M;$50)
Organics—laboratory methods	CHAR-206-OL	Analytical methods for chelators and decontamination agents	H-4-1 ($.25M; $500-$1000)
	CHAR-207-OL	Capillary zone electrophoresis	M 4-1 ($.25M;$300)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-4-1 ($.25M;$300)
	CHAR-66-OL	Gas chromatography—Fourier transform infrared spectroscopy	H-4-2 ($.5M;$400)
	CHAR-89-OL	Liquid chromatography—mass spectrometry	H-4-1 ($.3M;$500)
	CHAR-88-OL	Gas chromatography—mass spectrometry	E-5-0 ($0M;$2-$800)
	CHAR-94-OL	Gas chromatography	E-5-0 ($0M;$300)
	CHAR-211-OL	Solid phase microextraction analytical method	H-4-1 ($.3M;$500)
Physical—field methods	CHAR-246-OL	Instrument response models for remote sensing	E 5 2 ($.6M;$200/km)

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Table 3.1 (continued)

Alternative	Data sheet code number	Technology	Ranking[a]
Physical—field methods (cont.)	CHAR-248-OL	Fiber-optic systems for measuring multiple physical variables	E-5-3 ($1M;$.25/measurement made)
Physical—laboratory methods	CHAR-26-OL	Particle size analysis	M-4-0 ($0M;$1000)
	CHAR-32-OL	Optical microscopy	M-4-0 ($0M;$100–$800)
	CHAR-41-OL	Computer tomography	M-4-0 (N;N)
Pathogens—laboratory methods	CHAR-215-OL	Pathogen surveillance	E-4-1 ($.25M;N)

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^3 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b]Kam = thousands of dollars annual maintenance

[c]EPA = Environmental Protection Agency

[d]PCBs = polychlorinated biphenyls

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3.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the characterization technologies listed in Table 3.1. Table 3.2 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches, with the complete set of characterization technologies listed in the TLD, Vol. 1, Pts. A, B, and C. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding characterization technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 92 matches, these were entered in the TTP column. Characterization technologies for which no matches were found are omitted from the table. When many matches were found, specific TTPs may or may not be cited, but it is noted that many exist. The relevance column indicates the degree of overlap between the technologies listed in Vol. 1, Pts. A, B, and C and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 3.2. Characterization technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Auger electron spectroscopy (AES)	CHAR-2-OL	OR121115	M	Uses Energy dispersive X ray (EDX) for U analysis
Laser ionization mass spectrometry	CHAR-4-OL	CH101101		Laser-ablated inductively coupled plasma (ICP)
Portable volatile organic compound detectors	CHAR-5-OL	CH101104	H	Portable VOC analyzer
Portable X-ray fluorescence	CHAR-6-OL	RL321114	H	Field portable XRF
		RL321113	H	Develop field portable XRF
Fourier transform infrared spectroscopy	CHAR-8-OL	AL221108	M	Uses FTIR for chromium
		AL239002	L	Uses in package tests
		CH111203	M	Integration demo: sensors, monitoring
		CH131001	H	FTIR analysis of waste
Ultraviolet/visible spectroscopy	CHAR-9-OL	OR121101	H	In situ fiber-optic probe development
		OR101101	H	In situ fiber-optic deriv. UV spectroscopy
		CH101101	H	Mobile ICP atomic emission spectroscopy
		AL213204	M	Robotics to include AES
		AL221108	M	Uses AES for chromium
		CH114101	M	Center for Advanced Technical Development and Toxicology Information Program: sensors, monitors
Electrochemical methods	CHAR-10-OL	RL321112	H	Stripping voltammetry
Nuclear magnetic resonance	CHAR-11-OL	RL132002	M	Using technique on polymers
Laser photoacoustic spectroscopy	CHAR-15-OL	AL113101	M	Technology studies
		AL121122	M	Use on Fernald soil samples
		CH101104	M	Portable VOC analyzer
		CH131001	M	Photoacoustic Spect
Infrared spectroscopy (wavelength dispersion)	CHAR-18-OL	CH101104	L	FTIR (but not atmospheric)
Microwave digestion	CHAR-19-OL	AL132006	H	Microwave detoxification of mixed waste
		OR123101	H	Lead lab for Environmental Protection Agency (EPA) SW-846 mixed waste adaptation
		AL123101	H	EPA SW-846 for mixed waste
Ultrasonic extraction	CHAR-20-OL	RF121204	L	Ultrasonic cleaning at Rocky Flats Plant

Table 3.2 (continued)

Technology	Code	1993 TIP[a]	Relevance[b]	Focus of TIP
Fiber-optic chemical sensors	CHAR-25-OL	OR101101	H	Fiber-optic derivative UV spectrometry
		ID111701	M	Innovative technology development
		SF211203	H	Fiber-Optic Raman system development
		SR132003	H	Infrared (IR) fiber-optic spectrophotometer
		Many more		Widely pursued technology
Optical absorption spectroscopy	CHAR-27-OL	OR101101	M	Fiber-optic version
		SF211203	H	Fiber-optic differential abs spectrometer
Scanning electron microscopy	CHAR-33-OL	OR121115	M	One example of widely used technology
		Many More		
Transmission electron microscopy	CHAR-34-OL	OR121115	M	Example. Mature tech. needs careful sample preparation
Energy dispersive X-ray spectroscopy	CHAR-35-OL	AL221108	M	Using on Cr mobility study
Electron diffraction	CHAR-37-OL	AL121120	H	Site geochemistry characterization use
		AI121122	H	Site geochemistry characterization use
		AL221108	H	Cr mobility studies
		OR121115	H	Uranium solubility in soil study
Inorganic cementitous matrix composites	CHAR-39-OL	CH331001	L	Cement matrix grout development and application
Computer tomography	CHAR-41-OL	AL221123	M	Electromag. tomography (esp water) of underground sites
		SF223203	H	Developing CT for waste drum inspection
Subsurface complexation	CHAR-45-OL	AL931102	L	Geochemistry: Monticello, Utah
		ID111701	L	Chelation: lanthanides, actinides
		RL331002	L	Chemical barriers in-ground
Ion chromatography	CHAR-50-OL	Many		Accepted and widely used
Migration of volatile organic compounds in porous materials	CHAR-53-OL	None except soil	NA	Much work directed at soil
Membrane technology for sample collection and concentration	CHAR-55-OL	OR111204	M	High-efficiency particulate air filter
		AL131007	M	VOC in air sampling
		AL221107	L	Borehole membrane liner
		SR121106	L	Membrane use
Glow discharge ionization mass spectroscopy	CHAR-56-OL	AL131007	M	Membrane sampling ion-trap mass spectrometry

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Magnetic resonance imaging	CHAR-58-OL	RL132002	M	Using technique on polymers
Air monitoring	CHAR-59-OL	Many		Widely used. Tailor to application need
Tomographic seismic monitoring	CHAR-60-OL	AI201101	H	Seismic tomography development, use Savannah River Integrated Demonstration (SRID)
				Underground imaging (resistance)
		AI221123	M	Seismic wave measurement of clay at
		CH221101	M	Savannah River (SR)
		SF121101	H	High-resolution seismic imaging
		SF121102	M	Underground imaging (resistance)
		AL921102	M	Seismic survey and analysis
Modeling of heterogeneous sampling materials	CHAR-61-OL	SR132003	L	Chemometric models tank waste spectrophotometry
In situ, solvent extraction	CHAR-62-OL	SR121107	L	Vacuum extraction of VOC from soil at SRID
		Many more	L	
Long-range alpha detector	CHAR-65-OL	AL131002	H	Long-range alpha detecter (LRAD) developed, used at Fernald
Atomic emission spectroscopy	CHAR-76-OL	Many		Widely used technique
Inductively coupled plasma spectroscopy	CHAR-77-OL	CH101101	H	Mobile ICP-AES development
		Many		Widely used technology
Inductively coupled plasma—mass spectroscopy	CHAR-78-OL	OR111105	M	Direct sampling ion-trap mass spectrometers
		AL113101	M	Covered in field screening project
Sampling and mixing methods	CHAR-81-OL	AL131003	H	Use on Fernald soil
		NV031001	H	Use on Nevada Test Site soil
Portable Raman spectrometer	CHAR-84-OL	OR121101	H	Fiber-optic Raman sensor development
		OR101101	H	Employ sensor on aromatic hydrocarbons
		RL401206	M	Use Raman sensing in hot cell
		SF211203	H	Development Raman sensor for RL401206
Infrared absorption (laser-based source)	CHAR-85-OL	RL401206	M	Near IR absorption
		SF211203	H	Near IR Raman with diode laser
Laser ablation for sample collection	CHAR-86-OL	CH101101	H	Laser ablation ICP development
Gas chromatography—mass spectrometry	CHAR-88-OL	Many	N.A.	Widely used

Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Liquid chromatography—mass spectrometry	CHAR-89-OL	AL113101	M	Considered in field screening
		ID101301	H	Used on halogenated organic compounds (HOCs)
		SR132002	H	Used on cesium extraction project
Direct sampling ion trap mass spectrometry	CHAR-90-OL	OR101102	H	Development
		OR101103	H	Development and application
		OR101105	H	Use with army toxic materials
		OR121103	H	Use at Savannah River Integrated Demonstration Project (SRIDP)
		Others		
Portable luminescence detection	CHAR-92-OL	OR121201	H	Luminescence spot test for polychlorinated biphenyls
Laser ablation organic mass spectrometry	CHAR-93-OL	CH101101	H	Laser ablation ICP
Gas chromatography	CHAR-94-OL	Many		Widely used
Photon electron rejecting alpha liquid scintillation	CHAR-97-OL	ORNL-DOSAR Facility	H	Evaluate uranium resuspension at Weldon Springs cleanup
Portable gas chromatograph/electron capture detection for analyzing PCBs	CHAR-100-OL	RL321101	M	HOC monitoring off-gas treatment project VOC nonarid
Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	CHAR-101-OL	OR121101	H	In situ fiber-optic probe development
Sodium iodide-germanium gamma spectroscopy	CHAR-106-OL	AI131004	M	Gamma detector used in project
		AL031001	M	Gamma detector used in project
Neutron activation	CHAR-107-OL	AL911201	M	Neutron activated fission for detection of uranium
		AL921101	M	Prompt fission neutron logging
		AL031001	M	Neutron activated fission
Fluorescence diagnosis of contaminated surfaces	CHAR-110-OL	OR121101	M	In situ fiber-optic probe development
Laser ablation; inductively coupled plasma; atomic emission spectroscopy	CHAR-111-OL	CH101101	H	Laser ablation ICP
		CH501301	H	Field test, Fernald
On-line supercritical fluid extraction—multidetector gas chromatography	CHAR-115-OL	AL123101	M	Use for SW-846 methods
		ID4231010	M	Use for SW-846 methods
Ground-penetrating radar	CHAR-124-OL	AL921102	H	Used on mixed waste landfill
		NV001102	M	Airborne tests
		RL313203	H	Tested on landfill

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Electrical and electromagnetic detection of ground and geologic features	CHAR-125-OL	SF121102	H	Underground imaging (resistance)
Seismic methods (refraction, profiling, reflection)	CHAR-126-OL	AI201101	H	Seismic tomography development, use SRID
		CH221101	M	Seismic wave measurement of clay at SR
		SF121101	H	High-resolution seismic imaging
		AL921102	M	Seismic survey and analysis
Magnetics	CHAR-128-OL	AL911201	H	Tensor magnetic gradiometer
		AL921102	M	Landfill characterization
		ID132003	H	Use for site characterization
Supercritical fluid extraction of inorganics	CHAR-201-OL	ID111701	H	Lanthanides and actinides with lariat crown ethers
Radioanalytical procedures	CHAR-202-OL	CH013102	L	Environmental Management (EM) analytical laboratories performance evaluation
Contamination control—analytical equipment	CHAR-204-OL	AL213203	L	Characterization automation
Radioactive sample preparation	CHAR-205-OL	OR123101	M	Adapted SW-486 methods for rad. mixed waste analysis
Analytical methods for chelators and decontamination agents	CHAR-206-OL	AL132002	M	Polymers for Pu and Am concentration for wastewater
Capillary zone electrophoresis	CHAR-207-OL	SF213203	M	Robotic crosscutting advanced technology
Supercritical fluid extraction of organics	CHAR-208-OL	ID111701	L	Lantanides and actinides with lariate crown ethers
Adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples	CHAR-209-OL	RF101205	L	Incineration alternatives
Fissile material locator/profiler	CHAR-212-OL	NV021701	H	Associated particle imaging
		AL931001	L	Multispectral neutron logging
XRF for in situ monitoring of toxic heavy metals	CHAR-219-OL	RL321114	H	Field portable XRF
		RL321113	H	Field portable XRF development
Sampling program configuration management system	CHAR-228-OL	Many	H	Used at many other sites
Configuration management system	CHAR-229-OL	Many	H	Used at many other sites
Fiber-optic systems for measuring multiple physical variables	CHAR-248-OL	SF213203	H	Microsensor systems development

Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Quality control for measurement processes	CHAR-250-OL	CH013101	H	Analytical manage. - quality assessment program (Environmental Measurements Laboratory)
Sequential sampling plans	CHAR-252-OL	Many	H	Accepted and widely used
Spatial sample and data analysis plans	CHAR-253-OL	Many	H	Accepted and widely used
Solid sorbent sampling for airborne organics	CHAR-254-OL	AL113101	M	Field screening study
Soil/sediment sampling for volatile organics analysis	CHAR-256-OL	Many	H	Widely found
In situ ground-water flow meter	CHAR-258-OL	OR121104	H	Colloidal borescope
Ground-water discharge location	CHAR-259-OL	Many	H	Accepted and widely used
Waste drum gamma activity monitor	CHAR-261-OL	SF223203 SR113201	H H	Waste facilities operation & sorting technology SR robotics, waste facilities operations
Gas chromatography in the field	CHAR-262-OL	ALTTPMSA	M	Mobile sample analysis laboratory
Portable gamma-ray scintillometers	CHAR-263-OL	AL112101 SF223203	L M	Field-screening studies Used in waste facilities operations
Surface-enhanced Raman scattering	CHAR-265-OL	OR121101 SF211203	H M	Spectoelectrochemical sensors Adv. fiber-optic spectroscopy for inorganic contaminants
Neutron activation analysis	CHAR-266-OL	AL131004 AL931001	M H	Multi-spectral neutron logging Multi-spectral neutron logging
Liquid scintillation counting	CHAR-267-OL	AL931102 ORNL-DOSAR Facility	L H	Chemical barriers demonstration Uranium resuspension evaluation
Gamma-ray spectrometry	CHAR-268-OL	RL132002	M	Polymer concentration of U and Pu (gamma technique)
Advanced radiation monitors	CHAR-269-OL	AL121218 ID111701 ID121210	M M M	Real-time emission monitor Fiber-optic thermoluminescence dosimeter monitor development BWID contamination control
Sampling of heterogeneous wastes	CHAR-270-OL	AL123101	M	Adapted SW-846 methods for mixed waste analysis

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Table 3.2 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Sampling interface system for surface contamination by organics	CHAR-271-OL	CH101101	H	Laser-ablated ICP mass spectrometer
Electromagnetic offset log survey	CHAR-272-OL	AL221123	M	EM tomography underground
SEAMIST inverted membrane	CHAR-273-OL	AL221107	H	Landfill characterization system
Ground-water monitoring	CHAR-274-OL	Many	H	Accepted and widely used
Sediment sampling from restricted access locations	CHAR-276-OL	OR113203	H	Robotics advanced technologies

[a] TTP = Technical Task Plan

[b] The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need; and
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

4. WASTE PROCESSING, HANDLING, AND DISPOSAL

4.1 INTRODUCTION

The WM section of the TLD focuses on addressing the technologies for processing the waste streams likely to be generated as a result of the D&D, RA, and current WM operations at ORNL. The objectives of the WM diagrams are to enumerate and evaluate the WM options and to rank these options following the standardized methods. The WM diagrams were developed to address the following EM problem areas as they relate to ORNL D&D, RA, and WM activities:

- waste stabilization,
- waste retrieval,
- waste processing,
- waste minimization,
- waste packaging, handling, and transportation (WPH&T), and
- waste disposal.

The WM diagrams used followed the following plan to address the EM problem areas:

- For waste stabilization and waste processing, the approach was to identify and enumerate the plausible alternate processing routes for treating the solid, liquid, and gaseous wastes likely to be generated by the D&D, RA, and related WM operations at ORNL. It was assumed that RA and D&D operations would precede WM, providing the waste streams for WM to treat for release to the environment in compliance with all applicable environmental regulations and DOE orders.
- At ORNL, waste retrieval is more closely associated with RA activities. Although waste retrieval is nominally under WM, a decision was made to present the waste retrieval diagram as part of the RA TLD, given in companion Vols. 1 and 2 Pt. B to provide a more logical discussion of the ORNL TLD.
- Because waste minimization is more an operating philosophy than a technology, the waste minimization diagram was developed to reflect the philosophical approach. Waste minimization can and should be applied at every step in the process, preferably at the start of the operation(s).
- For WPH&T, the approach was to examine the pertinent issues involved with packaging, handling, and transporting wastes both on and off site.
- For waste disposal, the approach was to examine plausible disposal options for the final disposal of the residues from WM operations. These residues are defined as the wastes (predominantly solids) that result from following cost-effective, environmentally compliant treatment of the wastes, while recognizing waste minimization objectives. These residues are likely to be hazardous, mixed, TRU, and/or low-level waste that should be sequestered from the environment for a long period of time (in some cases, hundreds or even thousands of years). Because the subject of repositories or land disposal facilities, where these residues can be buried, is still being debated nationally, the current (circa 1992) thinking on potential repositories for these wastes was used to develop the waste disposal diagram. The projected residues from ORNL and their burial sites are given in the waste disposal diagram.

4.2.1 Introduction

The purpose of the TLD to provide DOE and its operating contractors with a technical framework that relates the ER/WM problems at ORNL to the potential technological solutions for WM. The WM sections are intended to serve as resource information for the technology component of short- and long-range strategic planning. WM emphasizes the identification of technology options and provides a preliminary technology implementation assessment of relevance to the projected WM needs and opportunities for ORNL. Technology implementation assessment considers the status of technology within the context of technology life cycle from the conceptual to the operational phase.

The primary objective of this section is to scope the problem and the technical solutions for WM. A conceptual framework based on a systems approach is presented. This framework also supports the development of the information presented in Vol. 3, Pt. C.

4.2.2 Conceptual Framework for Waste Management Planning

A systems approach is used as a conceptual framework to support the development of the WM diagrams for ORNL. This conceptual framework is illustrated in Fig. 4.1. The development considers two categories of waste generation activities—primary and secondary. The primary waste generation activities (Fig. 4.1) include: (1) D&D activities, (2) RA activities, and (3) mission-support activities (excluding waste operations activities). Mission-support activities include research, development, production, fabrication, maintenance, analytical, and facility upgrades.

Waste operations activities are considered a secondary waste generator. Waste operations include treatment, storage, disposal, and recycling. Relevant waste inventories are those wastes accumulated because there is no identified existing capability (i.e., technology and capacity) for their treatment or disposal. Inventory accumulation includes untreated waste (e.g., incinerable waste destined for the K-25 Site TSCA Incinerator) and waste treatment residuals. For the purposes of the diagram, waste inventories generated from mission and support activities are considered part of waste operations activities.

Four combinations of end-product streams and their destinations for WM are shown in Fig. 4.1. These combinations are as follows:

End-Product Stream—Quality Controlled Recyclable Material
End-Product Stream Destination—Recycled Material Application

End-Product Stream—Permitted Gaseous Emission
End-Product Stream Destination—Ambient Air

End-Product Stream—Permitted Liquid Discharge
End-Product Stream Destination—Water Stream

End-Product Stream—Certified Land Disposable Waste Form
End-Product Stream Destination—Land Disposal Unit

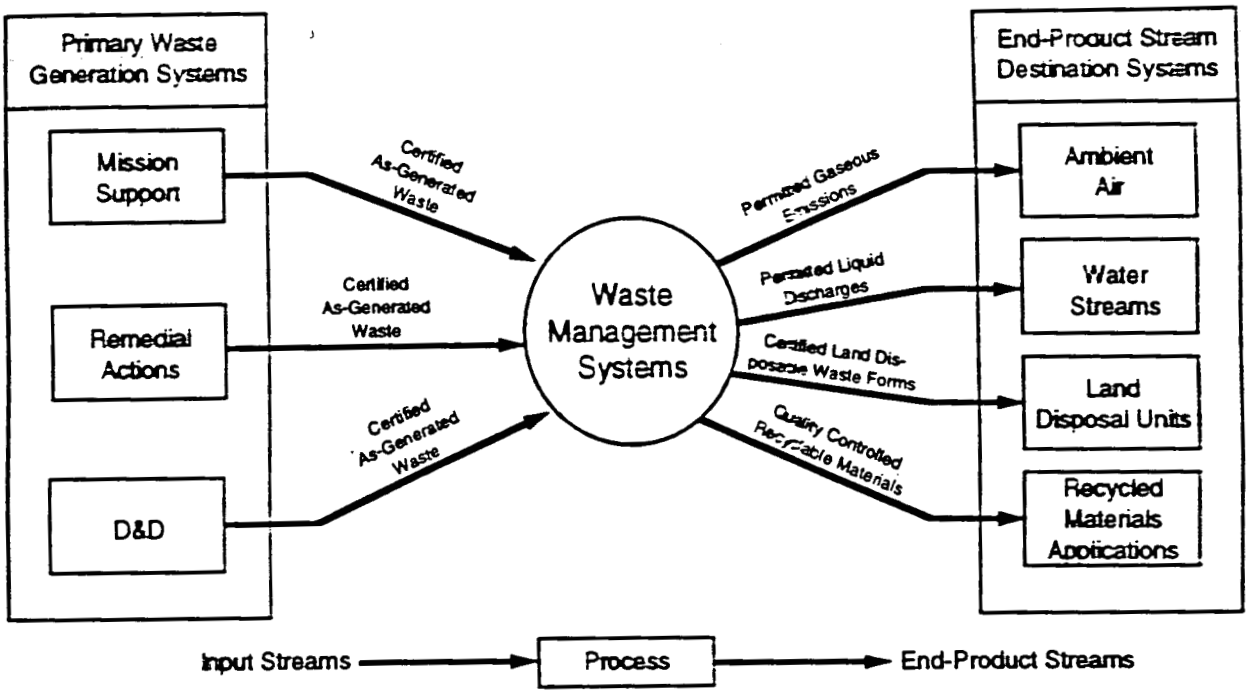

Fig. 4.1. Conceptual framework for waste management and technology planning.

WM systems are designed, evaluated, and prioritized by combining technologies into treatment processes so that the waste characteristics of the as-generated waste are transformed into one or more of the end-product streams. An illustrative example for a combination of technologies for the management of a solid waste stream is shown in Fig. 4.2. As an element of WM planning, technology planning is typically preceded by a needs assessment that includes (1) projected waste generation and inventory accumulation (waste quantities and characteristics), (2) projected WM requirements, opportunities, and strategies, (3) projected WM capability needs, (4) existing and planned WM capabilities, and (5) additional projected WM capability needs. Categories of WM needs for technology applications are shown in Table 4.1.

For the purposes of the TLD, WM capability is equivalent to the combination of a technology base and a capacity. The technology base is determined mainly by the characteristics of the waste as it is generated and the characteristics of the end-product streams. The characteristics of the end-product streams are specified by the end-product stream destination acceptance criteria.

WM systems are similar to production systems and are engineered around the optimum combination of product-based technologies and process-based technologies. Product-based technology identification is aimed at engineering to control the desirable characteristics of the end-product streams and the intermediate materials. It is also aimed at engineering a process consisting of one or more technologies to produce and control the quality of the end-product streams. End-product stream quality control can be obtained by monitoring critical characteristics of the product or the process.

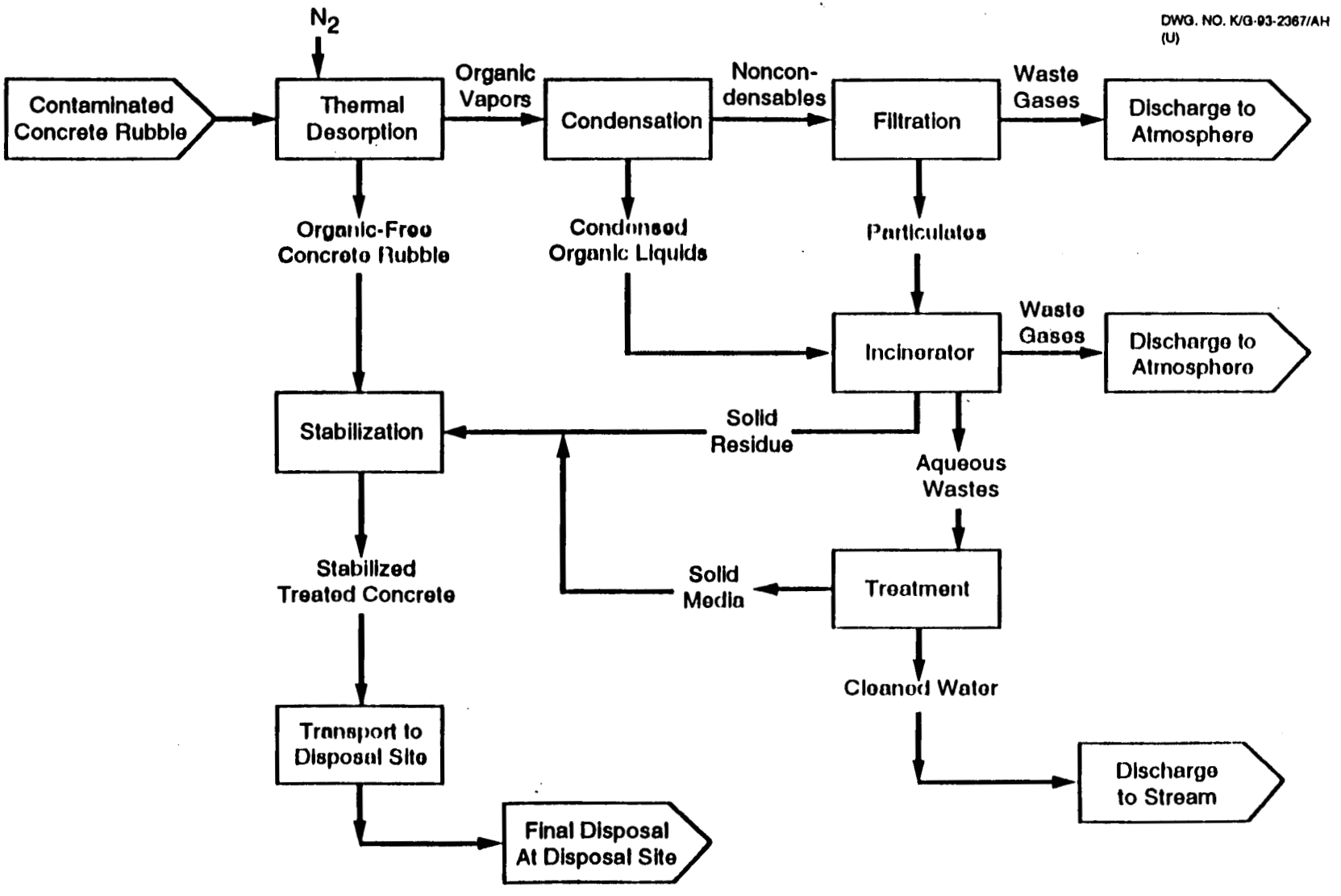

Fig. 4.2. Combination of technologies in the planning of waste management systems.

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Table 4.1. Categories of waste management needs for technology applications

Waste Management Capability Needs Category	Waste Management Capability Needs	Sample Technologies
A	Reduction of waste volume or size	Compaction Supercompaction Shredding
B	Separation of phases or waste components	Filtration Evaporation Centrifugation
C	Reduction of the hazardousness or toxicity of the waste or waste components by chemical transformation (i.e., changing the chemical forms via detoxification, deactivation, destruction, oxidation, or reduction)	Incineration Neutralization Dechlorination Ozonation Biooxidation
D	Reduction of the release of hazardous components during disposal	Stabilization Technologies
E	Reduction of the release of hazardous components and health, safety, and environmental impacts during waste handling, storage, and transfer	Packaging Transportation

Regulatory requirements for WM tend to specify the characteristics of the end-product stream (i.e., concentration limits) or the technology to process the waste (e.g., incineration). Product-based technology options assume that the characteristics of the end-product stream are variables to be established. In most cases, however, the characteristics of the end-product streams are specified by regulatory drivers (i.e., water discharge limits, gaseous emission limits, and disposable waste form limits).

Opportunities for product-based technology options can be found in engineered waste forms. The incentive behind engineering final waste forms is obtaining performance credits for disposal (i.e., higher allowable concentration limits for the disposal of engineered waste forms). Additional criteria for engineering waste forms include the lack of on-site/off-site disposal capacity, economics, and intruder scenarios.

Evaluation of technology options for selection and implementation at ORNL consider the following: (1) the desired characteristics of the end-product streams, (2) the technical and operational adequacy of the technical alternatives, (3) the economics, and (4) the regulatory compliance criteria and schedules. Other criteria for evaluation include locations (on-site vs off-site), risks, public acceptance, type of facilities (fixed vs mobile facilities), and facility ownership (DOE vs private). A qualitative evaluation or ranking of technology options is presented in Sect. 4.5.

For the purposes of the TLD, identified technologies are evaluated on the basis of anticipated technical performance or the ability of the combination of technology options to produce an end-product stream with the desirable characteristics. Those technologies that satisfy the performance expectations are considered technology options.

4.2.3 Description of Functional Areas

Six areas of WM for potential application of technology are considered in WM. These areas are: (1) waste minimization, (2) waste retrieval, (3) waste processing, (4) waste stabilization, (5) waste packaging, handling, and transportation, and (6) waste disposal. Waste characterization is an area of critical importance for WM. This area has been addressed in Chap. 3.

4.2.3.1 Waste Minimization

Waste minimization is the first element of a comprehensive pollution prevention strategy. Waste minimization can be characterized with the four R's (i.e., reduce, reuse, recycle, and replace). Reduction focuses at reducing the total amount of media or contaminant. Recycle and reuse refer to using materials so that they do not become wastes. Replace refers to substituting materials that perform the same service. Waste segregation (i.e., radioactive from nonradioactive, hazardous from nonhazardous, radioactive from hazardous) is another area of opportunity for waste minimization. Although waste minimization is considered in all waste operations, it is an issue of main concern to primary waste generators (i.e., mission support, D&D, and RA).

4.2.3.2 Waste Retrieval

Waste retrieval is relevant in remediating underground storage tanks that contain a toxic residual waste inventory and in removing waste packages from low-level waste burial grounds of storage areas. At ORNL for example, waste retrieval may be relevant in removing radioactive sludges from underground tanks. Retrieval of waste materials from process equipment before dismantlement is another area of concern. As mentioned previously, the waste retrieval discussion is given in Vols. 1 and 2, Pt. B under RA.

There is concern for waste retrieval during the handling of waste inventories that have been in storage for long periods of time. This specifically means the transfer of waste materials from the storage container to processing or stabilization treatment. Retrieval can be significant to WM if waste retrievability becomes a waste disposal criteria.

4.2.3.3 Waste Processing

Waste processing includes all waste treatment before atmospheric release, water discharge, and land disposal. Waste processing can be implemented for removal, separation, destruction, detoxification, or volume reduction. Technological options can be grouped as physical, chemical, thermal, or biological. A list of processing options for solids, liquids, and gaseous waste streams projected for ORNL are shown in Tables 4.2 through 4.5. Where applicable, the Mixed Waste Treatment Project treatability codes (MTCs) have been given for the ORNL wastes. The MTCs were developed based on information given in the *Strategic Plan for the Treatment of Appendix B Wastes*.[2] Parenthetically, the MTCs are being developed by DOE/HQ as a uniform means of

Table 4.2. Waste management options for mixed-solid wastes

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6300	1100/ 1200	5420	2200	NA[b]
Mixed and hazardous waste (RAD[c] and RCRA[d]/TSCA[e] contaminants)																		
Waste stabilization (encapsulation)	X	X	X	X	X	X	X	X		X	X	X						
Sonification					X	X												
Acid digestion							X		X		X							
Catalytic destruction			X			X					X							
Electrochemical metal removal					X	X												
Electropolishing/ osmosis/ migration	X		X															
Gamma radiolysis	X	X	X			X	X	X										
Gas-phase ClF_3 treatment					X	X												
Leaching and stripping	X	X		X	X	X	X	X		X	X	X	X					
Mond process (nickel only)						X												

Table 4.2 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Plastic materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Mixed and hazardous waste (continued)																		
NAO/ process (aluminum only)						X												
Supercritical fluid extraction	X	X	X	X	X		X	X		X	X	X						
Calcination/ roasting		X	X															
Chem char process		X		X			X			X	X	X						
Incineration		X	X			X	X	X	X	X	X	X	X					
Microwave treatment	X		X	X				X		X		X						
Molten glass combustor		X		X			X	X	X	X	X	X	X					
Molten salt oxidation		X					X		X	X	X	X						
Plasma arc furnace	X	X	X	X	X		X	X	X	X	X	X	X					
Pyrolysis		X									X							

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Table 4.2 (continued)

Treatment/ management options	Solid waste																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Mixed and hazardous waste (continued)																		
Smelting					X	X												
Thermal desorption	X	X		X	X	X					X	X						
Anaerobic digestion							X											
Biosorption							X			X								
Supercompaction												X						
HF dissolution										X								
Supercritical water oxidation											X							
Transmutation												X						
Wet air oxidation											X	X						
Waste containing RAD and TRU[c] contaminants																		
Waste stabilization (encapsulation)	X	X	X	X	X	X	X	X		X	X	X						
Sonification					X	X												

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Table 4.2 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Waste containing RAD and TRU contaminants (continued)																		
Acid digestion							X		X		X	X						
Catalytic destruction																		
Electrochemical metal removal					X	X												
Electropolishing/ osmosis/migratio n	X		X															
Gamma radiolysis																		
Gas-phase ClF_3 treatment						X	X											
Leaching and stripping	X	X		X		X	X	X		X	X	X						
Mond process (nickel only)						X												
NAC process (aluminum only)						X												
Solvent extraction			X															

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Table 4.2 (continued)

Treatment/ management options	Solid waste																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Waste containing RAD and TRU contaminants (continued)																		
Supercritical fluid extraction																		
Calcination/ roasting			X															
Chem char process											X							
Incineration		X	X			X	X	X	X	X	X	X				X		
Microwave treatment	X		X	X				X		X		X						
Molten glass combustor		X		X			X	X	X	X	X	X				X		
Molten salt oxidation							X		X	X	X					X		
Plasma arc furnace	X	X	X	X	X		X	X	X	X	X	X				X		
Pyrolysis																		
Smelting					X	X												

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Table 4.2 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Waste containing RAD and TRU contaminants (continued)																		
Thermal desorption	X																	
Anaerobic digestion							X											
Biosorption							X			X								
Package to WIPP[h] WAC[i] (TRU wastes only)	X	X	X	X	X	X	X	X		X	X	X						
Supercompaction								X		X		X						
HF dissolution										X								
Supercritical water oxidation											X							
Transmutation												X					X	
Wet air oxidation											X			X				
Dry storage														X				
Pool storage														X				

Table 4.2 (continued)

Treatment/ management options	Solid waste																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Waste containing RAD and TRU contaminants (continued)																		
Cask to Savannah River Site for storage														X				
Reprocessing														X				
Safe storage for eventual disposal																		
Uncontaminated wastes (no RAD, TRU, or RCRA/TSCA contaminants)																		
Landfill disposal	X	X		X	X		X		X			X						
Landfill disposal (except waste containing As, Ag, Ba, Cd, Cr, Hg, Pb, Se)						X												
Recycle/reuse	X	X	X	X	X	X	X	X				X			X			
Sell as scrap					X	X		X										
Incineration							X		X			X						
Microwave treatment				X														

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Table 4.2 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Plastic materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Uncontaminated wastes (continued)																		
Molten glass combustor				X					X									
Molten salt oxidation									X									
Plasma arc furnace				X					X									
Sell for salvage value												X						X
Solar evaporation																		X
Shallow land burial																		X
Leaching and stripping												X						

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Table 4.2 (continued)

Treatment/ management options	Solid waste																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
MTC[a]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[b]
Uncontaminated wastes (continued)																		
Transmutation																	X	
Thermal desorption												X						
Solvent extraction																		

[a] MTC = Mixed Waste Treatment Project treatability code
[b] NA = not applicable
[c] RAD = radioactive
[d] RCRA = Resource Conservation and Recovery Act
[e] TSCA = Toxic Substances Control Act
[f] NAC = nitrate-ammonia-ceramic process
[g] TRU = transuranic
[h] WIPP = Waste Isolation Pilot Plant
[i] WAC = waste acceptance criteria

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Table 4.3. Waste management options for solid-liquid wastes

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[a] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
MTC[b]	3120	6390	1100/ 1200	5420	2200	8000	NA[c]	NA
Mixed and hazardous waste (RAD[d] and RCRA/TSCA[e] contaminants)								
Waste stabilization (encapsulation)	X							
Adsorption				X	X			
Filtration					X			
HGMS[f]				X				
Inorganic microporous filters			X	X	X			
Reverse osmosis			X	X				
Acid digestion					X			
Catalytic destruction		X				X		
Chemical oxidation/reduction		X				X		
Chemical precipitation			X	X				
Enviro-CP process				X				
Gamma radiolysis				X	X	X		
Ion exchange			X	X				
Leaching and stripping	X	X			X			
Neutralization			X					
Solvent extraction	X	X		X				
Supercritical fluid extraction	X	X						

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Table 4.3 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[a] hazardous wastes	Coal yard run off sludge	Infectious medical wastes
MTC[b]	3120	6390	1100/ 1200	5420	2200	8000	NA[c]	NA
Mixed and hazardous waste (continued)								
Supercritical water oxidation		X			X	X		
Wet air oxidation	X					X		
Distillation					X			
Evaporation			X	X				
Incineration	X	X		X	X	X		
Microwave treatment	X							
Molten glass combustor	X	X		X	X	X		
Molten salt oxidation		X		X	X	X		
Plasma arc furnace	X	X		X	X	X		
Thermal desorption	X							
Aerobic/anaerobic digestion					X	X		
Biodegradation	X							
Biosorption				X	X			
Waste containing RAD and TRU[d] contaminants								
Waste stabilization (encapsulation)	X							
Acid digestion								X
Gamma radiolysis								X
Ion exchange			X					
Leaching and stripping	X							

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Table 4.3 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[a] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
MTC[b]	3120	6390	1100/ 1200	5420	2200	8000	NA[c]	NA
Waste containing RAD and TRU contaminants (continued)								
Neutralization			X					
Solvent extraction	X							
Evaporation	X							
Incineration	X							X
Microwave treatment	X							
Molten glass combustor	X							X
Molten salt oxidation								X
Plasma arc furnace	X							X
Biosorption	X							
Package to WIPP[h] WAC[i] (TRU waste only)	X							
Autoclaving								X
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)								
Adsorption					X			
Encapsulation	X							
Inorganic microporous filters			X					
Reverse osmosis			X					
Recycle/reuse (if possible)	X	X	X		X		X	
Sell as scrap (if permitted)		X						

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Table 4.3 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[a] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
MTC[b]	3120	6390	1100/ 1200	5420	2200	8000	NA[c]	NA
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants) (continued)								
Shallow land burial							X	
Acid digestion					X			X
Catalytic destruction		X						
Chemical oxidation/ reduction		X						
Chemical precipitation			X					
Gamma radiolysis					X			X
Ion exchange			X					
Leaching and stripping		X			X			
Neutralization			X					
Solvent extraction		X						
Supercritical fluid extraction		X						
Supercritical water oxidation		X			X			
Autoclaving								X
Distillation					X			
Evaporation			X					
Incineration	X	X			X			X
Microwave treatment	X							

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Table 4.3 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[a] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
MTC[b]	3120	6390	1100/ 1200	5420	2200	8000	NA[c]	NA
Uncontaminated waste (continued)								
Molten glass combustor		X			X			X
Molten salt oxidation		X			X			X
Plasma arc furnace		X			X			X
Thermal desorption	X							
Aerobic/anaerobic digestion					X			
Biodegradation	X	X						

[a] RCRA = Resource Conservation and Recovery Act
[b] MTC = Mixed Waste Treatment Project treatability code
[c] NA = not applicable
[d] RAD = radioactive
[e] TSCA = Toxic Substances Control Act
[f] HGMS = high-gradient magnetic separation
[g] TRU = transuranic
[h] WIPP = Waste Isolation Pilot Plant
[i] WAC = waste acceptance criteria

Table 4.4. Waste management options for liquid wastes

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
MTC[b]	2210	2220	1000	1200	1100	2900	1900
Mixed and hazardous waste (RAD[c] and RCRA[d]/TSCA[e] contaminants)							
Adsorption	X	X				X	
Air stripping		X		X	X		
Filtration				X	X	X	
HGMS[f]							
Inorganic microporous filters				X	X	X	
Reverse osmosis				X	X		
Bradtec process				X	X		
Bucky ball chemistry						X	
Chemical dechlorination	X						
Catalytic destruction	X	X					
Chemical oxidation/ reduction				X	X	X	
Chemical precipitation				X	X	X	
Electrochemical metal removal				X	X		
Electrolysis				X	X		
Gamma radiolysis	X						
Ion exchange				X	X		
Leaching and stripping	X						
Neutralization				X	X		
NAC[g] process				X	X		
Ozonation photolysis	X	X		X	X		

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Table 4.4 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
MTC[b]	2210	2220	1000	1200	1100	2900	1900
Mixed and hazardous waste (continued)							
Solvent extraction	X	X		X	X	X	
Supercritical fluid extraction						X	
Supercritical water oxidation	X	X					
Wet air oxidation	X	X					
Advanced electric thermolysis						X	
Chem char process		X				X	
Distillation	X	X				X	
Evaporation				X	X		
Incineration	X	X				X	
Low-temperature separation		X					
Microwave treatment				X	X		
Molten glass combustor		X				X	
Molten salt oxidation	X	X				X	
Plasma arc furnace	X					X	
Aerobic/anaerobic digestion		X				X	
Biodenitrification				X	X		
Biosorption			X				
Microbial dechlorination	X						

Table 4.4 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
MTC[b]	2210	2220	1000	1200	1100	2900	1900
Waste containing RAD and TRU[h] contaminants							
Adsorption			X			X	X
Air stripping			X	X	X		
Filtration			X	X	X	X	X
HGMS			X				
Inorganic microporous filters			X	X	X	X	X
Reverse osmosis			X	X	X		X
Bradtec process				X	X		
Bucky ball chemistry						X	
Chemical dechlorination							
Catalytic destruction			X				
Chemical oxidation/ reduction			X	X	X	X	
Chemical precipitation			X	X	X	X	
Electrochemical metal removal			X	X	X		
Electrolysis				X	X		
Gamma radiolysis			X				X
Ion exchange				X	X		
Leaching and stripping							
Neutralization				X	X		
NAC process			X	X	X		
Ozonation photolysis			X	X	X		

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Table 4.4 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhologenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
MTC[b]	2210	2220	1000	1200	1100	2900	1900
Waste containing RAD and TRU contaminants (continued)							
Solvent extraction				X	X	X	X
Supercritical fluid extraction						X	
Supercritical water oxidation							X
Wet air oxidation							X
Advanced electric thermolysis						X	
Chem char process						X	
Distillation			X			X	
Evaporation			X	X	X		X
Incineration						X	
Low-temperature separation							
Microwave treatment				X	X		
Molten glass combustor						X	
Molten salt oxidation						X	
Plasma arc furnace						X	
Aerobic/anaerobic digestion						X	X
Biodenitrification				X	X		
Biosorption			X				

Table 4.4 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
MTC[b]	2210	2220	1000	1200	1100	2900	1900
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)							
Recycle/reuse		X					
Adsorption		X					
Air stripping		X					
Catalytic destruction		X					
Ozonation photolysis		X					
Solvent extraction		X					
Supercritical water oxidation		X					
Wet air oxidation		X					
Chem char process		X					
Distillation		X					
Incineration		X					
Low-temperature separation		X					
Molten glass combustor		X					
Molten salt oxidation		X					
Aerobic/anaerobic digestion		X					X

[a] REDC = Radiochemical Engineering Development Center
[b] MTC = Mixed Waste Treatment Project treatability code
[c] RAD = radioactive
[d] RCRA = Resource Conservation and Recovery Act
[e] TSCA = Toxic Substances Control Act
[f] HGMS = high-bradient magnetic separation
[g] NAC = nitrate-ammonia-ceramic process
[h] TRU = transuranic

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Table 4.5. Waste management options for gaseous wastes

Treatment/ management options	Gaseous wastes										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[a] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
MTC[b]	NA[c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Mixed and hazardous waste (RAD and RCRA[d]/TSCA[e] contaminants)											
Adsorption	X	X	X	X						X	
Cyclone separation			X								
Filtration			X	X							
HGMS[f]			X	X							
Inorganic membrane separation	X	X	X	X						X	
Recharacterization and disposal											X
Scrubbers	X	X	X	X							
Catalytic destruction	X	X									
$DeNO_x$ processes									X		
FGD[g] processes								X			
Leaching and stripping	X	X	X							X	X
Ozonation photolysis	X	X									
Electron beam destruction	X	X									
Flameless thermal oxidation	X	X									

Table 4.5 (continued)

Treatment/ management options	Gaseous wastes										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[a] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
MTC[b]	NA[c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Mixed and hazardous waste (continued)											
Incineration	X	X						X	X		
Low-temperature separation	X	X		X							
Molten salt oxidation	X	X	X					X	X		
Waste containing RAD and TRU[h] contaminants											
Adsorption					X						
Filtration					X						
Inorganic membrane separation					X						
Recharacterization and disposal											X
Scrubbers					X						
Bucky ball chemistry					X						
Leaching and stripping					X						X
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)											
Recycle/reuse											X
Adsorption			X	X						X	

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Table 4.5 (continued)

Treatment/ management options	Gaseous wastes										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[a] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
MTC[b]	NA[c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Uncontaminated waste (continued)											
Cyclone separation			X	X							
Filtration			X	X							
HGMS			X	X							
Inorganic membrane separation			X	X						X	
Scrubbers			X								
Recharacterization and disposal											
$DeNO_x$ processes									X		
FGD processes								X			
Leaching and stripping			X							X	X

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Table 4.5 (continued)

Treatment/ management options	Gaseous wastes										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[a] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
MTC[b]	NA[c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Uncontaminated waste (continued)											
Incineration								X	X		
Low-temperature separation				X							
Molten salt oxidation			X					X	X		

[a] RAD = Radioactive
[b] MTC = Mixed Waste Treatment Project treatability code
[c] NA = not applicable
[d] RCRA = Resource Conservation and Recovery Act
[e] TSCA = Toxic Substances and Control Act
[f] HGMS = high-gradient magnetic separation
[g] FGD = flue gas desulfurization
[h] TRU = transuranic

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categorizing the mixed wastes at the various DOE sites. The MTCs development effort was started in 1990 and is being conducted by Don Musgrave of Lawrence Livermore Laboratory, Wayne Ross of Battelle Pacific Northwest Laboratories, and Tim Kirtpatrick of EG&G-Idaho.[3]

4.2.3.4 Waste Stabilization

Stabilization is used to designate a technology employing material additives (binders) to reduce the mobility of contaminants, including toxic organics such as PCBs, metals, and radionuclides. This makes the waste acceptable for land disposal. Stabilization treatment is tailored to improve waste handling and physical characteristics, to decrease surface area across which pollutants can transfer or leach, to limit solubility of hazardous constituents, or to detoxify hazardous constituents. Solidification is another term used in stabilization treatment and implies that these treatment results are obtained primarily by the production of a monolith block of treated waste with high-structural integrity. The physical characteristics of the waste may or may not be improved or changed after stabilization. Surface encapsulation (or simply encapsulation) is another stabilization technique to isolate the waste by placing a barrier (jacket), such as a membrane of impermeable material, between the waste and the environment. Micro-encapsulation is used for encapsulation of individual waste particles. Macroencapsulation is used for encapsulation of an agglomeration of waste particles or microencapsulated materials.

Solidification/stabilization technology can be characterized by the binder, by the binding or waste containment mechanism, or by the stabilization treatment operation type. Binders are developed from commonly known and proprietary materials. The binder can be inorganic (i.e, hydraulic cements, pozzolan, gypsum, silicates, or glass), organic (i.e., asphalt, polyester, epoxy) or a combination of both (i.e., diatomaceous earth with cement and polystyrene). A binder formulation is designed by taking into consideration the characteristics of the untreated waste and the performance objectives for the stabilization product (treated waste). Proprietary formulations of binder materials are developed to increase the functionality of the binder during stabilization treatment. For example, binder materials can be formulated to provide chemical destruction or detoxification of organics and chemical fixation of metals. A list of stabilization technology options is shown in Table 4.6.

Table 4.6. Generic waste stabilization technologies

- Cementitious solidification/stabilization
- Polymer-impregnated concrete
- Thermoplastic encapsulation
- Thermosetting-plastics encapsulation
- High-temperature crystalline materials encapsulation
- High-temperature noncrystalline materials encapsulation

Contaminant mechanisms include chemical bonding, precipitation, and physical trapment. Example processes for physical trapment include pozzolan reactions, pozzolan-portland cement reactions, thermoplastic encapsulation, and macroencapsulation.

Pozzolan reactions use a fine, noncrystalline silica in fly ash and the calcium in lime to produce low-strength cementation. Physical trapping of the contaminant in the cured pozzolan-concrete matrix is the primary containment mechanism. Pozzolan-portland cement reactions combine portland cement, fly ash, or other pozzolan to produce a relatively high-strength waste and concrete matrix. Soluble silicates may be added to aid processing and to assist in containment of metals through the formation of silicate gels. Thermoplastic encapsulation blends waste particulates with melted asphalt or similar materials. Physical entrapment is the primary containment mechanism. Macroencapsulation isolates a large volume of waste by jacketing with any acceptable material. A container, such as a 55-gal drum is a good example of macroencapsulation.

Stabilization treatment-operation types include in-drum processing, in-plant processing, mobile-plant processing, and in situ processing.

Regulatory factors are expected to play a major role in the development and use of stabilization treatment technologies. It is expected that regulatory requirements will emphasize contaminant confinement by means of chemical immobilization and less reliance on physical confinement. With the exception of contaminant leaching measured by waste extract from the Toxicity Characteristic Leaching Procedure (TCLP) as required by the RCRA, there are no set regulatory performance criteria that stabilization treatment products must meet. Therefore, stabilization technology effectiveness is limited to the results of the TCLP test. There is a need to understand and predict the long-term durability and performance characteristics of waste forms developed by stabilization treatment. Currently, the stabilization treatment design for a given waste is more trial and error. There is need for a scientifically based design approach to waste stabilization. This knowledge is also needed to support the regulatory guidance in the application of this technology for waste treatment. Whether or not stabilization technology becomes an important technology for the treatment of mixed waste will depend upon regulatory requirements and the ability of the technology to meet these requirements.

Currently, stabilization treatment of hazardous waste can be implemented in accordance with the standards specified in Subpart D of 40 CFR 268. These treatment standards are concentration based and are expressed as a constituent concentration in waste (40 CFR 268.43, Table CCW) or constituent concentration in waste extract (40 CFR 268.41, Table CCWE). Stabilization treatment is used to meet the standards of Table CCWE.

4.2.3.5 Waste Packaging, Handling, and Transportation

The WPH&T component emphasizes the operator safety and environmental protection during the transfer of waste from the generator to treatment, storage, disposal, and recycle. Packaging includes the waste container(s), any absorbent materials used for the control or release of contaminant during the handling of waste, and any shielding to reduce radiation exposure to personnel. Transportation includes the identification of the transfer option (i.e., truck, ship, or plane) as well as the optimum route.

4.2.3.6 Waste Disposal

Land disposal is the final destination for solid waste. Shallow-land burial (i.e., landfill) is the baseline technology for disposal of solid waste. Sanitary/industrial, low-level radioactive, and hazardous waste are currently disposed by landfill technology. However, the designs for low-level radioactive and hazardous waste have additional requirements for leachate collection and treatment. Other alternatives for shallow-land burial include earth-covered tumuli, above-grade concrete structures, deep trenches, augured shafts, below-grade concrete structures, abandoned mines, and rock cavities. These alternative technologies provide greater confinement of waste contaminants than shallow-land burial.

4.3 SCIENCE AND TECHNOLOGY NEEDS

4.3.1 Introduction

Because of the wide scope of activities covered under WM, the science and technology needs for the WM processes and operations are summarized below according to the EM problem categories. The majority of science and technology needs are in waste processing and waste stabilization because these two categories have the bulk of the innovative WM technologies being developed that efficiently treat the wastes expected from D&D, RA, and current waste operations at ORNL. WPH&T and waste minimization have some science and technology needs. Waste retrieval science and technology needs for ORNL are discussed more fully in Vol. 1, Pt. B. Waste disposal has no identified science and technology needs, however, it has policy requirements that are discussed under WM implementation needs Sect. 4.4. When these policy requirements are addressed, some future science and technology needs may result.

4.3.2 Summary of Science and Technology Needs

4.3.2.1 Waste processing and stabilization

The WM processes have the potential to be effective because of their innovative nature and level of development. The science and technology requirements for these WM processes are as follows:

- For processes that list status as conceptual or evolving technology, such as Bucky ball chemistry, transmutation, and gamma radiolysis, the science and technology needs consist of developing the fundamentals of the technology.
- For processes that list status as predemonstration, such as the NAC process, electropolishing/migration/osmosis, E-beam destruction, and inorganic microporous filters, the science and technology needs consist of developing the technical data base on the process to advance its development from the laboratory scale to the pilot-plant scale. This could consist of developing the chemical engineering aspects of the process, such as reaction kinetics, materials of construction, and process economics.
- For processes that list status as demonstration, such as ion exchange, high-gradient magnetic separation, the Mond process, and supercritical water oxidation, the science and technology needs consist of demonstrating that the technology can be efficiently used to treat the ORNL waste stream. This could consist of conducting an industrial-scale (e.g., tons per hour of waste processed) demonstration of the process, while treating the ORNL stream.
- For processes that list status as accepted, such as precipitation, activated carbon or molecular sieve adsorption, and rotary kiln incineration, the science and technology needs may be minimal because these are proven technologies that can be purchased from commercial vendors. The science and technology needs consist of designing and engineering the process to meet ORNL waste treatment requirements.

Other science and technology needs for specific waste processes are as follows:

- Incineration needs consist of understanding the thermochemistry of the incineration operations and the partitioning of the radionuclides and the toxic metals to the three

000510

media—air, water, and residue—during incineration. The science and technology needs should also include developing conditions and/or fluxes that will optimize the partitioning of the radionuclides and toxic metals to the incinerator residue stream.

- Reverse osmosis needs consist of developing membranes that are more effective for removing the radionuclides and hazardous metals from aqueous-waste streams.
- Biotreatment-process needs consist of developing the microorganisms and conditions for effectively degrading hazardous organics and the removal of metals.
- Stabilization process needs consist of developing models that will simulate the long-term, environmentally acceptable release of radionuclides and hazardous metals into the environment. All waste forms will eventually degrade and release the encapsulated species into the environment. It is important to understand the chemistry and the material science aspects of the waste forms.

4.3.2.2 Waste Packaging, Handling, and Transportation

The WPH&T science and technology needs consist of the following:

- new packaging designs required to satisfy expected new industrial packages packaging requirements;
- methods for preparing and processing surface-contaminated objects for satisfying the new surface-contaminated objects and industrial packages packaging requirements;
- developing an operationally efficient, multi-use, Type A package, or packages, for radioactive materials; and
- developing new package designs for the following packages: Type B; Type A fissile; Type B fissile; packages for on-site radioactive and mixed-waste shipments; and performance-oriented packaging for transportation of PCBs, asbestos, and non-radioactive hazardous wastes.

4.3.2.3 Waste Minimization

Waste minimization needs consist of developing and testing the Waste Minimization Evaluation System computer simulation model.

4.3.2.4 Waste Retrieval

The science and technology needs for waste retrieval at ORNL are given under RA in companion Vols. 1 and 2, Pt. B.

4.3.2.5 Waste Disposal

The waste disposal needs basically consist of developing or adapting current technology to prepare the wastes so that they meet the disposal sites' waste acceptance criteria. These criteria are presently in a state of flux because of national waste disposal policy concerns. However, when these concerns are resolved, there may be significant waste disposal science and technology needs.

4.4 IMPLEMENTATION NEEDS

An examination of WM technologies and processes indicates that one of the overwhelming needs is adequate funding to accomplish WM objectives. This includes establishment of waste generation projections, defensible disposal criteria, and technical objectives for waste treatment. Based on the guidelines for developing the implementation needs (Sect. 2.3), some other implementation needs in WM are as follows:

- For waste disposal, needs consist of developing a policy for the disposal of final residues from RA, D&D, and waste treatment operations, stakeholder education and participation, and improved risk communication to the public and stakeholder. An accepted national policy that defines the characteristics of solid residues (for example, national waste repositories) is required. Given the present level of environmental activism, this is a long-term effort that will require national debate for developing a consensus on the waste characteristics that will result in optimizing waste disposal while reducing long-term environmental risk and impact to an acceptable level. This acceptable level cannot be zero because of the nature of the residues. The final residues will either contain hazardous species, long half-life radionuclides, or both. All of these have some environmental risk and impact. The risks can be reduced to varying degrees by appropriate WM operations and strategies. However, the potential environmental risk cannot be reduced to zero. Therefore, a major implementation need in this area is the development of acceptable disposal options and characteristics for the final waste forms and tested materials.
- Waste minimization needs consist of developing and validating the Waste Minimization Evaluation System computer simulation model. Depending upon the emphasis placed on its development (and the related funding level), this could be accomplished within one year of initiation or stretched out over several years.
- For WPH&T most of the implementation needs can only be defined after the Waste Generator/Packaging/Transportation Interface has reached initial conclusions. In addition funding would be required for development (for example, the new packaging designs being required by increasingly stringent transportation regulations).
- Certain waste processing options identified for ORNL operations, such as the NAC process inorganic membranes and filters, and the plasma arc furnace could have high paybacks. These options could become prime candidates for research, development, and demonstration funding. The implementation need for these types of processes would be to perform the obligatory process and cost engineering assessments. These assessments would help to accurately define their payback potential, which would help determine their research, development, and demonstration funding and status.

4.5.1 Introduction

This section reviews the qualitative ranking of the usefulness of applicable WM technologies in managing the waste streams generated because of D&D, RA, and WM operations. The rankings indicate the relative merit of the candidate processes for treating the wastes and provide guidance for potential funding for development to deployment. These rankings were performed based on the best available information on the wastes likely to be generated by D&D, RA, and WM operations, and the desired treatment objectives for the wastes. The details of the ranking procedure are given in Sect. 2.4.

4.5.2 Rankings of Technologies

Rankings were limited to the waste processing technologies. The other WM subelements (waste retrieval, waste minimization, waste stabilization, WPH&T, and waste disposal) were not ranked because of the following reasons:

- As indicated earlier, waste retrieval is discussed more fully in companion Vols. 1 and 2, Pt. B.
- Waste minimization is an operating philosophy that should be recognized and practiced at every stage of the WM operations. It consists of a set of guidelines that need to be followed whenever a unit operation is conducted. These guidelines are given on the waste minimization diagram in Vol. 2, Pt. C, of this document. The guidelines exist as a set, and there are no options that can be ranked.
- The generically specified waste descriptions are not sufficiently detailed to allow ranking of the stabilization technologies. These waste stabilization methods could be ranked at a later date when the specifics of the waste residues to be stabilized, the type and the concentrations of the contaminants in the residues that require immobilization, and the waste acceptance criteria of the disposal site are determined. Resolving the final waste-form issues to meet the disposal site waste acceptance criteria will be paramount.
- Each waste type has identified acceptable packaging, handling, and transportation criteria. All packaging, handling, and transportation options will be utilized.
- The waste disposal technologies (sites) have or will have specific waste acceptance criteria. All available listed options are likely to be used.

4.5.3 Ranking Procedure

The WM technologies were ranked by a team of knowledgeable and experienced Energy Systems professionals. The team members first individually ranked the WM technologies for treating the particular waste stream. Then, these individual rankings were discussed in group sessions to develop the consensus rankings reported in this section. The results of this exercise are given in Tables 4.7 through 4.10.

Table 4.7. Rankings[a] of waste management options for mixed wastes—solid wastes

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Mixed and/or hazardous waste (RAD[d] and RCRA[e]/TSCA[f] contaminants)																		
Waste stabilization (encapsulation)	H-2-1 ($0.5M; $300/ft³)	H-2-1 ($0.5M; $400/ft³)	H-2-1 ($0.5M; $300/ft³)	M-2-1 ($0.5M; $400/ft³)	M-1-1 ($0.5M; $.6/lb)	H-4-1 ($0.5M; $.6/lb)	L-3-1 ($0.5M; $300/ft³)	H-3-1 ($0.5M; $300/ft³)		H-3-1 ($0.5M; $300/ft³)	M-1-1 ($0.5M; $300/ft³)	L-3-3 ($2M; $300/ft³)						
Sonification					M-1-2 ($1M;N)	M-4-2 ($1M;N)												
Acid digestion							M-3-2 ($1M;N)		L-1-2 ($1M;N)		L-1-3 ($2M;N)							
Catalytic destruction			L-2-3 ($3M;N)								M-1-5 ($4M;N)							
Electrochemical metal removal					H-1-3 ($2M;N)	H-4-3 ($2M;N)												
Electropolishing/osmosis/ migration	M-2-4 ($2M;N)	M-2-4 ($2M;N)																
Gamma radiolysis	M-2-5 ($2M;N)	M-2-5 ($2M;N)	M-2-5 ($2M;N)			M-4-5 ($2M;N)	M-3-5 ($2M;N)	M-3-5 ($2M;N)										
Gas-phase ClF3 treatment					L-1-3 ($2M;N)	L-4-3 ($2M;N)												
Leaching and stripping	M-2-3 ($1M;N)	M-2-3 ($1M;N)		M-2-3 ($1M;N)	M-1-3 ($1M;N)	M-4-3 ($1M;N)	M-3-3 ($1M;N)	M-3-3 ($2M;N)		M-3-3 ($1M;N)	M-1-3 ($1M;N)	M-3-2 ($2M;N)	M-4-1 ($1M;N)					

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Table 4.7 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Mixed and/or hazardous waste (continued)																		
Mond process (nickel only)						H-4-1 (@1M;N)												
NAC# process (aluminum only)						M-4-3 (@4M;N)												
Solvent extraction		M-2-2 (@1M;N)	M-2-2 (@2M;N)									M-3-3 (@2M;N)	M-4-2 (@1M;N)					
Supercritical fluid extraction	M-2-5 (@3M;N)	M-2-5 (@3M;N)	M-2-5 (@3M;N)	M-2-5 (@3M;N)	M-1-5 (@3M;N)		M-3-5 (@3M;N)	M-3-5 (@3M;N)		L-3-5 (@3M;N)	L-1-5 (@3M;N)	M-3-5 (@3M;N)						
Calcination/ roasting		M-2-1 (@1M; @1/lb)	M-2-1 (@1M; @2M/lb)															
Chem char process		M-2-7 (@1M;N)		M-2-7 (@1M;N)			M-3-7 (@1M;N)			L-3-7 (@1M;N)	M-1-5 (@1M;N)	L-3-7 (@1M;N)						
Incineration		H-2-1 (@1M; @n/lb)	M-2-2 (@1M; @n/lb)			L-4-1 (@1M; @n/lb)	H-3-1 (@1M; @n/lb)	L-3-1 (@1M; @n/lb)	H-1-1 (@0.5M; @n/lb)	M-3-2 (@1M; @n/lb)	M-1-2 (@1M; @n/lb)	L-3-2 (@1M; @n/lb)						
Microwave treatment	M-2-3 (@3M;N)		M-2-3 (@3M;N)	H-2-5 (@3M;N)				M-3-5 (@3M;N)		M-3-5 (@3M;N)	M-1-5 (@3M;N)	M-3-5 (@3M;N)	M-4-3 (@3M;N)					
Molten glass combustor		M-2-2 (@2M;N)		M-2-2 (@2M;N)			M-3-2 (@2M;N)	M-3-2 (@2M;N)	L-1-2 (@2M;N)		M-1-1 (@1M;N)							

000515

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Table 4.7 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Mixed and/or hazardous waste (continued)																		
Molten salt oxidation		L-2-3 (@2M;N)					M-3-3 (@2M;N)		L-1-2 (@2M;N)		L-1-1 (@2M;N)	M-3-2 (@2M;N)						
Plasma arc furnace	M-2-3 (@2M;N)	M-2-3 (@3M;N)	M-2-5 (@3M;N)	M-2-5 (@3M;N)	M-1-5 (@3M;N)	M-4-5 (@3M;N)	M-3-5 (@3M;N)	H-3-5 (@3M;N)	L-1-5 (@3M;N)	M-3-1 (@1M;N)	M-1-5 (@3M;N)							
Pyrolysis		M-2-1 (@1M; @1/lb)									M-1-1 (@1M; @1/lb)							
Smelting					H-1-1 (@3M; @2/lb)	H-4-1 (@3M; @2/lb)												
Thermal desorption	H-2-2 (@1M; @1/lb)	H-2-2 (@1M; @1/lb)		M-2-2 (@1M; @1/lb)	H-1-2 (@1M; @1/lb)	H-4-2 (@1M; @1/lb)					L-1-1 (@1M; @1/lb)	M-3-2 (@1M; @1/lb)						
Anaerobic digestion							L-3-1 (@0.5M;N)											
Biosorption							L-3-5 (@2M;N)			M-3-1 (@1M;N)								
Supercompaction								H-3-1 (@0.5M;N)				M-3-1 (@0.5M;N)						
HF dissolution										M-3-2 (@1M;N)								

000516

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Table 4.7 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Plastic materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Mixed and/or hazardous waste (continued)																		
Supercritical water oxidation											L-1-3 (@2M;N)							
Transmutation												L-3-10 (@10M;N)						
Wet air oxidation											M-1-2 (@2M;N)	L-3-2 (@2M;N)						
Waste containing RAD and/or TRU[h] contaminants only																		
Waste stabilization (encapsulation)	H-3-1 (@0.5M; @300/ft³)	H-3-1 (@0.5M; @400/ft³)	H-3-1 (@0.5M; @400/ft³)	H-2-1 (@0.5M; @400/ft³)	M-3-1 (@0.5M; @0.6/lb)	H-3-1 (@0.5M; @0.6/lb)	L-3-1 (@0.5M; @300/ft³)	H-3-1 (@0.5M; @300/ft³)		H-3-1 (@0.5M; @300/ft³)	M-4-1 (@0.5M; @300/ft³)	L-3-3 (@2M; @300/ft³)						
Sonification					M-3-2 (@1M;N)	M-3-2 (@1M;N)												
Acid digestion							M-3-2 (@1M;N)		L-3-2 (@1M;N)		L-4-3 (@2M;N)	L-3-5 (@3M;N)						
Electrochemical metal removal					H-3-3 (@2M;N)	H-3-3 (@2M;N)												
Electropolishing/osmosis/ migration	M-3-4 (@2M;N)		M-3-4 (@2M;N)															

000517

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Table 4.7 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Waste containing RAD and/or TRU contaminants only (continued)																		
Gas-phase ClF_3 treatment					L-3-3 (@2M;N)	L-3-3 (@2M;N)												
Leaching and stripping	M-3-3 (@1M;N)	M-3-3 (@1M;N)		M-2-3 (@1M;N)		M-3-3 (@1M;N)	M-3-3 (@1M;N)	M-3-3 (@2M;N)		M-3-3 (@1M;N)	M-4-3 (@1M;N)	M-3-2 (@2M;N)						
Mond process (nickel only)						H-3-3 (@1M;N)												
NAC process (aluminum only)						M-3-3 (@4M;N)												
Solvent extraction			M-3-2 (@2M;N)															
Calcination/ roasting			M-3-1 (@1M;N)															
Chem char process																		
Incineration		H-3-1 (@1M; @n/R)	M-3-2 (@1M; @n/R)			L-3-1 (@1M; @n/R)	H-3-1 (@1M; @n/R)	L-3-1 (@1M; @n/R)	H-3-1 (@0.5M; @n/R)	M-3-1 (@1M; @n/R)	M-4-1 (@1M; @n/R)	M-3-2 (@1M; @n/R)				H-2-1 (@1M; @n/R)		
Microwave treatment	M-3-3 (@4M;N)		M-3-3 (@4M;N)	H-2-5 (@4M;N)				M-3-5 (@4M;N)		L-3-4 (@4M;N)		L-3-5 (@4M;N)						

000518
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Table 4.7 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Plastic materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Waste containing RAD and/or TRU contaminants only (continued)																		
Molten glass combustor		M-3-2 (@2M;N)		M-2-2 (@2M;N)			M-3-2 (@2M;N)	M-3-2 (@2M;N)	L-3-2 (@2M;N)	M-3-2 (@2M;N)	M-4-2 (@2M;N)	M-3-2 (@2M;N)				M-2-2 (@2M;N)		
Molten salt oxidation							M-3-3 (@2M;N)		L-3-2 (@2M;N)	M-3-2 (@3M;N)	M-4-2 (@2M;N)					M-2-2 (@2M;N)		
Plasma arc furnace	M-3-3 (@2M;N)	M-3-3 (@3M;N)	M-3-5 (@3M;N)	M-2-5 (@3M;N)	M-3-5 (@3M;N)		M-3-5 (@3M;N)	M-3-5 (@3M;N)	L-3-5 (@3M;N)							M-2-5 (@3M;N)		
Pyrolysis											M-4-1 (@1M; @1/lb)							
Smelting					II-3-1 (@3M; @2/lb)	II-3-1 (@3M; @2/lb)												
Thermal desorption	II-3-2 (@1M; @1/lb)																	
Anaerobic digestion							L-3-1 (@0.5M;N)											
Biosorption							L-3-5 (@2M;N)			M-3-1 (@1M;N)								

000519

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Table 4.7 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Plastic materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Package to WIPP[f] WAO[j] (TRU waste only)	E-3-5 (@5M;N)	E-3-5 (@5M;N)	E-3-5 (@5M;N)	E-2-5 (@5M;N)	E-3-5 (@5M;N)	E-3-5 (@5M;N)	E-3-5 (@5M;N)	E-3-5 (@5M;N)		E-3-5 (@5M;N)	E-4-5 (@5M;N)	E-3-5 (@5M;N)						
Supercompaction								II-3-1 (@0.5M;N)		M-3-1 (@0.5M;N)		M-3-1 (@0.5M;N)						
HF dissolution										M-3-2 (@1M;N)								
Supercritical water oxidation											L-4-3 (@2M;N)							
Transmutation												L-3-10 (@10M;N)					L-3-10 (@10M;N)	
Dry storage														M-4-2 (@2M;N)				
Pool storage														M-4-2 (@2M;N)				
Cask to Savannah River Site for storage														M-4-3 (@3M;N)				
Reprocessing														L-4-3 (@3M;N)				

000520

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Table 4.7 (continued)

Treatment/ management options	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
	Solid wastes																	
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Waste containing RAD and/or TRU contaminants only (continued)																		
Safe storage for eventual disposal																		
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)																		
Landfill disposal	H-1-1 ($0.5M; $30/yd³)	H-1-1 ($0.5M; $30/yd³)	E-1-1 ($0.5M; $30/yd³)	H-1-1 ($0.5M; $30/yd³)	M-1-1 ($0.5M; $30/yd³)		L-2-1 ($0.5M; $30/yd³)		M-3-1 ($0.5M; $30/yd³)			H-3-1 ($1M; $30/yd³)						
Landfill disposal (exc. As, Ag, Ba, Cd, Cr, Hg, Pb, Se)						M-1-1 ($0.5M; $30/yd³)												
Recycle/reuse	H-1-1 ($0.5M;N)	H-1-1 ($0.5M;N)		H-1-1 ($.5M;N)	H-1-1 ($0.5M;N)	H-1-1 ($0.5M; N)	H-2-1 ($0.5M;N)	H-2-1 ($0.5M;N)				H-3-1 ($0.5M;N)			H-2-1 ($0.5M; N)			
Sell as scrap					H-1-1 ($0.5M;N)	H-1-1 ($0.5M; N)	H-2-1 ($0.5M;N)	H-2-1 ($0.5M;N)										
Incineration							H-2-1 ($0.5M; $6/lb)		E-3-1 ($0.5M; $6/lb)			M-3-2 ($1M; $6/lb)						
Microwave treatment				M-1-3 ($4M;N)														

Table 4.7 (continued)

Treatment/ management options	Solid wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Plastic materials	Steam plant ash
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
Uncontaminated waste (continued)																		
Molten glass combustor				M-1-2 ($2M;N)														
Molten salt oxidation									L-3-2 ($2M;N)									
Plasma arc furnace				M-1-3 ($3M;N)					L-3-5 ($3M;N)									
Sell for salvage value												H-3-1 ($0.5M;N)						H-2-1 ($0.5M; N)
Solar evaporation																		H-2-1 ($0.2M; N)

000522

7251

Table 4.7 (continued)

Treatment/ management options	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
	Solid wastes																	
Treatability code[b]	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	6390	1100/ 1200	5420	2200	NA[c]
	Uncontaminated waste (continued)																	
Shallow land burial																		H-2-1 ($0.2M; N)
Leaching and stripping												M-3-2 ($2M;N)						
Thermal desorption												M-3-2 ($1M;$1/lb)						

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft³ or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b] Treatability code from Mixed Waste Treatment Project
[c] NA = not applicable
[d] RAD = radioactive
[e] RCRA = Resource Conservation and Recovery Act
[f] TSCA = Toxic Substances Control Act
[g] NAC = nitrate-ammonia-ceramic
[h] TRU = transuranic
[i] WIPP = Waste Isolation Pilot Plant
[j] WAC = waste acceptance criteria

000523

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Table 4.8. Rankings[a] of waste management options for solid-liquid wastes

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[b] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code[c]	3120	6390	1100/ 1200	5420	2200	8000	NA[d]	NA
Mixed and/or hazardous waste (RAD[e] and RCRA/TSCA[f])								
Waste stabilization (encapsulation)	M-2-1 ($0.5M: $500/m³)[g]							
Adsorption				M-3-2 ($1M:N)	L-4-2 ($1M:N)			
Filtration				M-3-2 ($2M:N)				
HGMS[h]				L-3-4 ($2M:N)				
Inorganic microporous filters			L-4-8 ($4M:N)	L-3-8 ($4M:N)				
Reverse osmosis			M-4-2 ($1M:N)	M-3-2 ($1M:N)				
Acid digestion					M-4-2 ($1M:N)			
Catalytic destruction		H-5-2 ($1M:N)				M-3-2 ($1M:N)		
Chemical oxidation/ reduction		M-5-2 ($2M:N)				M-3-2 ($2M:N)		
Chemical precipitation			M-4-1 ($0.5M:N)	H-3-2 ($1M:N)				
Enviro CP process				M-3-5 ($2M:N)				
Gamma radiolysis					L-4-5 ($2M:N)	L-3-5 ($2M:N)		
Ion exchange			M-4-2 ($1M:N)	H-3-2 ($1.5M:N)				

Table 4.8 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[b] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code[c]	3120	6390	1100/ 1200	5420	2200	8000	NA[d]	NA
Mixed and/or hazardous waste (continued)								
Leaching and stripping	M-2-3 ($2M:N)	M-5-3 ($1M:N)			M-4-1 ($1M:N)			
Neutralization			H-4-1 ($0.5M:N)					
Solvent extraction	M-2-3 ($2M:N)	M-5-3 ($2M:N)		M-3-2 ($1M:N)				
Supercritical fluid extraction	M-2-5 ($3M:N)	M-5-5 ($3M:N)						
Supercritical water oxidation		H-5-3 ($3M:N)			M-4-3 ($3M:N)	M-3-3 ($3M:N)		
Wet air oxidation	M-2-2 ($2M:N)					M-3-2 ($2M:N)		
Distillation					H-4-2 ($2M:N)			
Evaporation			H-4-1 ($0.5M:N)	H-3-1 ($0.5M:N)				
Incineration	M-2-1 ($1M: $6/lb)	H-5-1 ($0.5M: $6/lb)		L-3-1 ($0.5M: $6/lb)	E-4-1 ($0.5M: $6/lb)	H-3-1 ($0.5M: $6/lb)		
Microwave treatment	M-2-3 ($3M:N)							
Molten glass combustor	M-2-2 ($2M:N)	M-5-2 ($2M:N)			M-4-2 ($3M:N)	M-3-2 ($2M:N)		
Molten salt oxidation		H-5-3 ($2M:N)		L-3-2 ($2M:N)	H-4-2 ($2M:N)	M-3-3 ($2M:N)		
Plasma arc furnace	M-2-5 ($3M:N)	M-5-5 ($3M:N)		L-3-5 ($3M:N)	M-4-3 ($3M:N)	M-3-3 ($3M:N)		

000525

Table 4.8 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[b] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code[c]	3120	6390	1100/ 1200	5420	2200	8000	NA[d]	NA
Mixed and/or hazardous waste (continued)								
Thermal desorption	M-2-2 ($1M: $1/lb)							
Aerobic/ anaerobic digestion					M-4-3 ($2M:N)	M-3-3 ($3M:N)		
Biodegradation	M-2-3 ($2M:N)	L-5-2 ($2M:N)						
Biosorption				L-3-5 ($2M:N)				
Waste containing RAD and/or TRU[f] contaminants only								
Waste stabilization (encapsulation)	M-4-1 ($0.5M: $500/ft³)							
Acid digestion								M-3-1 ($0.5M:N)
Gamma radiolysis								M-3-2 ($2M:N)
Ion exchange			M-4-2 ($1.5M:N)					
Leaching and stripping	M-4-3 ($2M:N)							
Neutralization			H-4-1 ($0.5M:N)					
Solvent extraction	M-4-3 ($2M:N)							
Evaporation	H-4-1 ($1M:N)							

000526

Table 4.8 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[b] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code[c]	3120	6390	1100/ 1200	5420	2200	8000	NA[d]	NA
Waste containing RAD and/or TRU[e] contaminants only (continued)								
Incineration	M-4-1 ($1M: $6/lb)							H-3-1 ($0.5M: $6/lb)
Microwave treatment	M-4-3 ($3M:N)							
Molten glass combustor	M-4-2 ($2M:N)							M-3-2 ($2M:N)
Molten salt oxidation								M-3-3 ($2M:N)
Plasma arc furnace	M-4-5 ($3M:N)							M-3-3 ($3M:N)
Biosorption	L-4-5 ($2M:N)							
Package to WIPP[g] WAC[i] (TRU waste only)	E-4-5 ($5M:N)							
Autoclaving								E-3-1 ($0.5M:N)
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)								
Encapsulation		M-2-1 ($0.5M: $500/ft^3)						
Inorganic microporous filter			L-3-8 ($4M:N)					
Reverse osmosis			M-3-2 ($1M:N)					
Recycle/ reuse	L-3-3 ($2M:N)	L-2-2 ($1M:N)	L-3-2 ($1M:N)				M-1-1 ($0.5M:N)	

000527

Table 4.8 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[b] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code[c]	3120	6390	1100/ 1200	5420	2200	8000	NA[d]	NA
Uncontaminated waste (continued)								
Sell as scrap (if permitted)		L-2-1 ($0.2M:N)						
Shallow land burial							H-1-1 ($0.2M:N)	
Acid digestion								M-3-1 ($0.5M:N)
Chemical oxidation/ reduction	M-3-2 ($2M:N)							
Chemical precipitation		M-2-1 ($1M:N)						
Gamma radiolysis								M-3-2 ($2M:N)
Ion exchange			M-3-2 ($1.5M:N)					
Leaching and stripping		M-2-3 ($1M:N)						
Neutralization			H-3-1 ($0.5M:N)					
Solvent extraction		M-2-3 ($2M:N)						
Supercritical fluid extraction		M-2-5 ($3M:N)						
Supercritical water oxidation		H-2-3 ($3M:N)						
Autoclaving								E-3-1 ($0.5M:N)

Table 4.8 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[b] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code[c]	3120	6390	1100/ 1200	5420	2200	8000	NA[d]	NA
Uncontaminated waste (continued)								
Evaporation			H-3-1 ($0.5M:N)					
Incineration	M-3-3 ($3M:N)	H-2-1 ($0.5M: $6/lb)						E-3-1 ($0.5M: $6/lb)
Microwave treatment	M-3-1 ($0.5M: $6/lb))							
Molten glass combustor		M-2-2 ($2M:N)						M-3-2 ($2M:N)
Molten salt oxidation		H-2-3 ($2M:N)						M-3-3 ($2M:N)
Plasma arc furnace		M-2-5 ($3M:N)						M-3-5 ($3M:N)
Thermal desorption	M-3-2 ($1M: $1/lb)							
Aerobic/ anaerobic digestion								

Table 4.8 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA[b] hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code[c]	3120	6390	1100/ 1200	5420	2200	8000	NA[d]	NA
Uncontaminated waste (continued)								
Biodegradation	M-3-3 ($2M:N)	L-2-2 ($2M:N)						

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M:N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b] RCRA = Resource Conservation and Recovery Act
[c] Treatability code for Mixed Waste Treatment Project
[d] NA = not applicable
[e] RAD = Radioactive
[f] TSCA = Toxic Substances Control Act
[g] For Melton Valley Storage Tanks (MVST), this ranking is M-4-1 ($0.5M;$500/ft^3)
[h] HGMS = high-gradient magnetic separation
[i] TRU = transuranic
[j] The ranking shown is the ranking for the MVST sludges. This criteria is ranked "3" for the Process Waste Treatment Plant (PWTP) and the Nonradiological Wastewater Treatment Plant (NRWTP) sludges.
[k] WIPP = Waste Isolation Pilot Plant
[l] WAC = waste acceptance criteria

Table 4.9. Rankings[a] of waste management options for liquid wastes

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[b] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code[c]	2210	2220	1000	1200	1100	2900	1900
Mixed and/or hazardous waste [radioactive (RAD) and RCRA[d]/TSCA[e] contaminants]							
Adsorption	L-4-2 ($1M:N)	L-4-2 ($1M:N)				M-4-3 ($2M:N)	
Air stripping		M-4-1 ($0.5M:N)					
Filtration				L-5-1 ($1M:N)	L-4-1 ($1M:N)		
HGMS[f]							
Inorganic microporous filters				L-5-8 ($4M:N)	L-4-8 ($4M:N)		
Reverse osmosis				L-5-2 ($1M:N)	L-4-2 ($1M:N)		
Bradtec process				M-5-3 ($4M:N)	M-4-2 ($4M:N)		
Bucky ball chemistry						L-4-10 ($10M:N)	
Chemical dechlorination	L-4-5 ($2M:N)						
Catalytic destruction	M-4-2 ($1M:N)	H-4-2 ($1M:N)					
Chemical oxidation/ reduction				M-5-2 ($2M:N)	M-4-2 ($2M:N)	L-4-2 ($2M:N)	
Chemical precipitation				M-5-2 ($2M:N)	M-4-2 ($2M:N)	M-4-2 ($2M:N)	
Electrochemical metal removal							
Electrolysis				M-5-4 ($3M:N)	M-4-4 ($3M:N)		

Table 4.9 (continued)

Treatment/ management options	Liquid waste						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[b] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code[c]	2210	2220	1000	1200	1100	2900	1900
Mixed and/or hazardous waste (continued)							
Gamma radiolysis	L-4-5 ($2M:N)						
Ion exchange				M-5-2 ($2M: $0.20/gal)	M-4-2 ($2M: $0.20/gal)		
Leaching and stripping	M-4-2 ($2M:N)						
Neutralization				H-5-1 ($0.5M:N)	H-4-1 ($0.5M:N)		
Nitrate-ammonia-ceramic process				M-5-3 ($4M:N)	M-5-3 ($4M:N)		
Ozonation photolysis	M-4-2 ($1M:N)	M-4-2 ($2M:N)		M-5-3 ($3M:N)	M-4-3 ($3M:N)		
Solvent extraction	L-4-2 ($1M:N)	M-4-2 ($1M:N)		M-5-3 ($2M:N)	M-4-3 ($2M:N)	M-4-3 ($2M:N)	
Supercritical fluid extraction						M-4-5 ($3M:N)	
Supercritical water oxidation	M-4-3 ($3M:N)	M-4-3 ($3M:N)					
Wet air oxidation	L-4-2 ($2M:N)	M-4-2 ($2M:N)				M-4-3 ($3M:N)	
Advanced electric thermolysis						L-4-5 ($4M:N)	
Chem char process		M-4-5 ($4M:N)				M-4-5 ($4M:N)	
Distillation	H-4-1 ($1M:N)	H-4-1 ($1M:N)				H-4-2 ($1M:N)	
Evaporation				H-5-1 ($1M:N)	H-4-1 ($1M:N)		

000532

Table 4.9 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code	2210	2220	1000	1200	1100	2900	1900
Mixed and/or hazardous waste (continued)							
Incineration	E-4-1 ($0.5M: $6/lb)	E-4-1 ($0.5M: $6/lb)				M-4-1 $1M: $6/lb)	
Low-temperature separation		M-4-2 ($1M:N)					
Microwave treatment				M-5-3 ($4M:N)	M-4-3 ($4M:N)		
Molten glass combustor		H-4-2 ($2M:N)				M-4-2 ($2M:N)	
Molten salt oxidation	L-4-2 ($2M:N)	H-4-3 ($2M:N)				M-4-3 ($2M:N)	
Plasma arc furnace	L-4-3 ($3M:N)					M-4-5 ($3M:N)	
Aerobic/ anaerobic digestion		M-4-1 ($1M:N)				L-4-2 ($2M:N)	
Biodenitrification				M-5-2 ($1M:N)	M-4-2 ($1M:N)		
Microbial dechlorination	L-4-8 ($4M:N)						
Waste containing RAD and/or transuranic (TRU) contaminants only							
Adsorption			M-5-3 ($2M:N)			M-4-3 ($2M:N)	M-4-2 ($2M:N)
Air stripping							
Filtration			H-5-1 ($1M:N)	L-5-1 ($1M:N)	L-5-1 ($1M:N)	L-4-1 ($1M:N)	H-4-1 ($1M:N)
HGMS			L-5-4 ($2M:N)				

000533

Table 4.9 (continued)

Treatment/ management options	Liquid waste						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and HFIX[b] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code[c]	2210	2220	1000	1200	1100	2900	1900
Waste containing RAD and/or TRU contaminants only (continued)							
Inorganic microporous filters			L-5-8 ($4M:N)	L-5-8 ($4M:N)	L-5-8 ($4M:N)	L-4-8 ($4M:N)	M-4-8 ($4M:N)
Reverse osmosis			M-5-2 ($1M:N)	M-5-2 ($1M:N)	L-5-2 ($1M:N)		H-4-2 ($1M:N)
Bradtec process				M-5-3 ($4M:N)	M-5-3 ($4M:N)		
Bucky ball chemistry						L-4-10 ($5M:N)	
Chemical dechlorination							
Catalytic destruction							
Chemical oxidation/ reduction			M-5-2 ($2M:N)	M-5-2 ($2M:N)	M-5-2 ($2M:N)	L-4-2 ($2M:N)	
Chemical precipitation			H-5-2 ($2M:N)	M-5-2 ($2M:N)	M-5-2 ($2M:N)	M-4-2 ($2M:N)	
Electrochemical metal removal			M-5-3 ($2M:N)	M-5-3 ($2M:N)	M-5-3 ($2M:N)		
Electrolysis			M-5-4 ($3M:N)	M-5-4 ($3M:N)	M-5-4 ($3M:N)		
Gamma radiolysis							M-4-3 ($2M:N)
Ion exchange			H-5-4 ($2M: $0.2/gal)	M-5-2 ($2M: $0.2/gal)	M-5-2 ($2M: $0.2/gal)		
Leaching and stripping							

000534

Table 4.9 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code	2210	2220	1000	1200	1100	2900	1900
Waste containing RAD and/or TRU contaminants only (continued)							
Neutralization				H-5-1 ($0.5M:N)	H-5-1 ($0.5M:N)		
Nitrate-ammonia-ceramic processes				M-5-3 ($4M:N)	M-5-3 ($4M:N)		
Ozonation photolysis			M-5-3 ($3M:N)	M-5-3 ($3M:N)	M-5-3 ($3M:N)		
Solvent extraction			M-5-3 ($2M:N)	M-5-3 ($2M:N)	M-5-3 ($2M:N)	M-4-3 ($2M:N)	M-4-3 ($2M:N)
Supercritical fluid extraction						M-4-5 ($3M:N)	
Supercritical water oxidation							M-4-3 ($3M:N)
Wet air oxidation							M-4-3 ($3M:N)
Advanced electric thermolysis						L-4-5 ($4M:N)	
Chem char process						M-4-5 ($4M:N)	
Distillation						H-4-2 ($1M:N)	
Evaporation			H-5-1 ($0.5M:N)	H-5-1 ($1M:N)	H-5-1 ($1M:N)		H-4-1 ($1M:N)
Incineration						M-4-1 ($1M: $6/lb)	
Low-temperature separation							
Microwave treatment				M-5-3 ($4M:N)	M-5-3 ($4M:N)		

000535

Table 4.9 (continued)

Treatment/ management options	Liquid waste						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[b] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code[c]	2210	2220	1000	1200	1100	2900	1900
Waste containing RAD and/or TRU contaminants only (continued)							
Molten glass combustor						M-4-2 ($2M:N)	
Molten salt oxidation						M-4-3 ($2M:N)	
Plasma arc furnace						M-4-5 ($3M:N)	
Aerobic/ anaerobic digestion						L-4-2 ($2M:N)	E-4-1 ($0.5M: $0.5)
Biodenitrification				M-5-2 ($1M:N)	M-5-2 ($1M:N)		
Biosorption			L-5-5 ($2M:N)				
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)							
Recycle/reuse		H-4-1 ($0.5M:N)					
Adsorption		L-4-2 ($1M:N)					
Air stripping		M-4-1 ($0.5M:N)					
Catalytic destruction		H-4-2 ($0.5M:N)					
Ozonation photolysis		M-4-2 ($2M:N)					
Solvent extraction		M-4-2 ($1M:N)					
Supercritical water oxidation		M-4-3 ($3M:N)					

000536

Table 4.9 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC[a] caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code	2210	2220	1000	1200	1100	2900	1900
Uncontaminated waste (continued)							
Wet air oxidation		M-4-2 ($2M:N)					
Chem char process		M-4-5 ($4M:N)					
Distillation		H-4-1 ($1M:N)					
Incineration		E-4-1 ($0.5M: $6/lb)					
Low-temperature separation		M-4-2 ($1M:N)					
Molten glass combustor		H-4-2 ($2M:N)					
Molten salt oxidation		H-4-3 ($2M:N)					
Aerobic/anaerobic digestion		M-4-1 ($1M:N)					

[a] The technologies are ranked according to the following criteria:

- Overall assessment of the technology's usefulness (E—essential, H—high, M—medium, and L—low).
- Ranking of site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring to commercial or mature state from its current state (expressed in number of years).
- Cost to bring technology to large-scale commercial use (presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^3 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M:N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b] REDC = Radiochemical Engineering Development Center

[c] Treatability Code for Mixed Waste Treatment Project

[d] RCRA = Resource Conservation and Recovery Act

[e] TSCA = Toxic Substances Control Act

[f] HGMS = high-gradient magnetic separation

000537

Table 4.10. Rankings[a] of waste management options for gaseous wastes

Treatment/ management options	Gaseous wastes										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[b] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code[c]	NA[d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Mixed and/or hazardous waste [radioactive (RAD) and RCRA[d]/TSCA[e] contaminants]											
Adsorption	M 4-2 ($1M;N)	M 4-2 ($1M;N)	M-2-2 ($1M;N)	H-2-2 ($1M;N)						H 2-1 ($1M;N)	
Cyclone separation			H-2-1 ($1M;N)								
Filtration			E-2-1 ($1M;N)	E-2-1 ($1M;N)							
High-gradient magnetic separation			L-2-4 ($2M;N)	L-2-4 ($2M;N)							
Inorganic membrane separation	M-4-5 ($.4M;N)	M-4-5 ($.4M;N)	M-2-5 ($4M;N)	M-2-5 ($4M;N)						M-2-5 ($4M;N)	
Recharacterization and disposal											H 1-1 ($.2M;N)
Scrubbers	H-4-1 ($.5M;N)	H-4-1 ($.5M;N)	H-2-1 ($1M;N)	H-2-1 ($1M;N)							
Catalytic destruction	H 4 1 ($1M;N)	H 4 1 ($1M;N)									
DeNO$_x$ processes									E-2-1 ($1M; $700/ton)		

000538

2251

Table 4.10 (continued)

Treatment/ management options	Gaseous waste										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[b] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code[c]	NA[d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Mixed and/or hazardous waste (continued)											
Flue gas desulfurization processes								E-2-1 ($1M; $600/ton)			
Leaching and stripping	M-4-2 ($1M;N)	M-4-2 ($1M;N)	M-2-2 ($1M;N)							M 2-1 ($.2M,N)	M 1 2 ($.3M,N)
Ozonation photolysis	M 4-2 ($1M;N)	M-4 2 ($1M;N)									
Electron beam destruction	L-4-2 ($1M;N)	L-4-2 ($1M;N)									
Flameless thermal oxidation	M-4-2 ($1M;N)	M-4-2 ($1M;N)									
Incineration	E-4-1 ($.5M; $6/lb)	E-4-1 ($.5M; $6/lb)						H-2-1 ($.5M; $6/lb)	H-2-1 ($.5M; $6/lb)		
Low-temperature separation	M-4-1 ($.5M;N)	M-4-1 ($.5M;N)		M-2-2 ($2M;N)							
Molten salt oxidation											

000539

7251

Table 4.10 (continued)

Treatment/ management options	Gaseous waste										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[b] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code[c]	NA[d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Waste containing RAD and/or transuranic (TRU) contaminants only											
Adsorption	M-4-2 (@1M;N)		M-4-2 (@1M;N)		M-4-2 (@1M;N)	M-4-2 (@1M;N)					
Filtration	H-4-2 (@2M;N)		E-4-1 (@1M;N)		H-4-2 (@2M;N)		H-4-2 (@2M;N)				
Inorganic membrane separation	M-4-5 (@4M;N)		M-4-5 (@4M;N)		M-4-5 (@4M;N)		M-4-5 (@4M;N)				
Recharacterization and disposal											
Scrubbers	M-4-1 (@1M;N)		H-4-1 (@1M;N)		M-4-1 (@1M;N)	M-4-1 (@1M;N)					
Bucky ball chemistry	L-4-10 (@10M;N)				L-4-10 (@10M;N)						
Leaching and stripping	M-4-2 (@2M;N)		M-4-2 (@1M;N)		M-4-2 (@2M;N)	M-4-2 (@2M;N)	M-4-2 (@2M;N)				
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)											
Recycle/reuse											H-1-1 (@hM;N)
Adsorption			M-2-2 (@1M;N)	H-2-2 (@1M;N)						M-2-1 (@1M;N)	

Table 4.10 (continued)

Treatment/ management options	Gaseous waste										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[b] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code[c]	NA[d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Uncontaminated waste (continued)											
Cyclone separation			H-2-1 ($.5M;N)								
Filtration			E-2-1 ($1M;N)	E-2-1 ($1M;N)							
High-gradient magnetic separation			L-2-4 ($2M;N)	L-2-4 ($2M;N)							
Inorganic membrane separation			M-3-5 ($4M;N)	M-2-5 ($4M;N)						M-2-5 ($4M;N)	
Scrubbers		H-4-1 ($1M;N)	H-3-1 ($1M;N)								H-1-1 ($.2M;N)
Recharacterization and disposal											
DeNO$_x$ processes									E-2-1 ($1M; $700/ton)		
Flue gas desulfurization processes								E-2-1 ($1M; $900/ton)			
Leaching and stripping				M-2-2 ($1M;N)						M-2-2 ($.2M;N)	M-1-2 ($.3M;N)

Table 4.10 (continued)

Treatment/ management options	Gaseous waste										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD[b] in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code[c]	NA[d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Uncontaminated waste (continued)											
Incineration								H-2-1 ($.5M; $6/lb)	H-2-1 ($.5M; $6/lb)		
Low-temperature separation				M-2-2 ($2M;N)							
Molten salt oxidation			M-3-2 ($2M;N)					M-2-2 ($2M;N)	M-2-2 ($2M;N)		

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^2 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

[b] RAD = radioactive
[c] Treatability code for Mixed Waste Treatment Project
[d] NA = not applicable
[e] RCRA = Resource Conservation and Recovery Act
[f] TSCA = Toxic Substances Control Act

000542

2251

4.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the waste processing and waste disposal options listed in Tables 4.2–4.5. Tables 4.11 and 4.12 give the results of a search of available information on programs funded in FY 1992 and FY 1993 and identify possible matches with these waste processing and disposal technologies. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding remedial action technology code by TTP number. When no FY 1993 match was found and the searchers (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Waste processing and disposal options for which no matches were found are omitted from the table. The relevance column indicates the degree of overlap between the listed options and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 4.11 Waste processing technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Gamma radiolysis	WPRO-100-OL	ID101301	H	Gamma Radiolysis of PCB & HOCs
Nitrate to ammonia and ceramic process	WPRO-105-OL	OR111203	H	NAC process for Hanford UST
Thermal desorption	WPRO-106-OL	RF121204	M	Surface volatile organic compound (VOC) removal
Plasma arc furnace	WPRO-107-OL	RL321211	H	Plasma arc furnace
Incineration	WPRO-108-OL	RF101205	L	Incineration alternatives
Catalytic destruction	WPRO-109-OL	AL223310 (FY92)	H	Catalytic destruction (pulsed) german
Smelting	WPRO-111-OL	RL321211	L	Smelting
Molten salt oxidation	WPRO-113-OL	ID121207 (FY92)	L	Molten salt oxidation
Microwave treatment	WPRO-115-OL	RF101201	L	Microwave fusing
Molten glass combustor	WPRO-116-OL	ID121207 (FY92) RL321211	H L	Molten glass combustor Glass melter TSR
Biodegradation	WPRO-117-OL	OR123302	H	Biodegradation of waste streams
Supercritical fluid extraction	WPRO-118-OL	ID111701 ID423101 RF121204	M H H	Supercritical fluid extraction Supercritical fluid extract VOC Supercritical CO2 extraction
Sonification	WPRO-121-OL	ID111701	M	Sonification investigation
Reprocessing	WPRO-122-OL	AL232004 ID421201	M H	Titanate ion exchangers Molten metal/salt processing
Package to meet Waste Isolation Pilot Plant waste acceptance criteria	WPRO-128-OL	ID132006	M	Similar issues at Idaho National Engineering Laboratory (INEL)
Landfill disposal	WPRO-131-OL	Many		Widely used in past
Air stripping	WPRO-200-OL	SR121107 (FY92) SF211104 (FY92)	M H	Air sparging of VOC Gasoline removal from soil
Filtration	WPRO-201-OL	NV011104	M	Filtration of liquid and gas

Table 4.11 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Adsorption	WPRO-202-OL	RL321204	H	Adsorption, chemisorption
		RL321701	H	Chemisorption of cesium, strontium, chromium, silver and noble metals
Adsorption (using activated carbon or molecular sieves)	WPRO-203-OL	SR121107	M	Charcoal or molecular sieves
		ID121114	M	VOC recovery using adsorption
High-gradient magnetic separation	WPRO-204-OL	AL121203 (FY92)	M	Magnetic separation
Electrolysis	WPRO-205-OL	ID121211 (FY92)	M	Electrolysis
Membranes	WPRO-206-OL	RL421102 (FY92)	M	Membrane removal
		RL421101 (FY92)	H	Membrane removal of trichloroethylene & PCE
		RL421104	L	Membrane removal of VOC offgas
Inorganic microporous filters	WPRO-207-OL	OR014102	H	Inorganic Microporous high-efficiency particulate air (HEPA) Filters.
		OR121210	H	Test of Lawrence Livermore National Laboratory (LLNL) S.S. HEPA Filters
Chemical dechlorination	WPRO-209-OL	OR101202	H	Chemical dechlorination
Chemical precipitation	WPRO-210-OL	RL321204	H	Chemical separation: ground water
		AL121120	M	Uranium complexing in soil
		RL331002	L	Chemically enhanced barriers
		RL332008	M	ESPIP
Solvent extraction—general	WPRO-211-OL	OR121105	L	Solvent extraction—general
Solvent extraction/centrifugal contractor technology	WPRO-212-OL	OR121105	H	Solvent extraction—leaching
Leaching/stripping	WPRO-213-OL	AL121121	H	Extraction/leaching of metals from soil
Ozonation-photolysis	WPRO-214-OL	ID111701	M	Ultrasonic enhanced ultra violet (UV) Photolysis on TiO2
Wet air oxidation	WPRO-215-OL	AL221106	M	HOC destruction by steam reforming
Supercritical water oxidation	WPRO-216-OL	ID121217	H	SCWO demo on mixed and haz wastes
		OR121206	H	Behavior of aqueous electrolytes in SCWO

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Table 4.11 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Ion exchange (radionuclides removal)	WPRO-217-OL	AL232004 RL321204	H H	Titanate ion exchangers transuranics (TRUs), Cs, Sr, Tc, noble metals removal from high-level waste by ion exchange
Ion exchange (mercury removal)	WPRO-218-OL	AL232004 RL321204	H H	Titanate ion exchangers TRUs, Cs, Sr, Tc, noble metals removal from high-level waste by ion exchange
Transmutation	WPRO-219-OL	AL121207 (FY92)	H	Accelerator transmutation of wastes
Distillation	WPRO-222-OL	RF121204	M	Distillation
Evaporation	WPRO-223-OL	RF121204	M	Distillation
Aerobic digestion	WPRO-224-OL	OR123302	H	Biodegradation—aerobic
Anaerobic digestion	WPRO-225-OL	OR101108	H	Biodegradation—anaerobic
Biosorption	WPRO-226-OL	OR123301 ID121103	H M	Biosorption of U, Sr, Pb (Germany) Evaluation for U removal from soil
Microbial dechlorination	WPRO-227-OL	OR123302	H	Biodechlorination of VOCs
Bradtec process	WPRO-228-OL	RL332013	H	Use on Hanford tank wastes
Biodenitrification	WPRO-229-OL	IN USE ID121204	H H	ORNL developed for Y-12 use Use on INEL tank wastes
Inorganic membrane separations	WPRO-300-OL	OR014102 OR121210	H M	Inorganic micropore HEPA filters Test of LLNL S.S. HEPA filters
Scrubbers	WPRO-301-OL	AL121215	H	Packed-bed silent discharge
Cyclone separators	WPRO-302-OL	NV011104 (FY92) AL121203 (FY92) PE021101 (FY92)	H H M	Physical methods of soil separation Magnetic separation Jig and cyclone separation
Electron-beam (E-beam) destruction	WPRO-304-OL	AL132005	H	E-beam destruction organics
Flameless thermal oxidizer	WPRO-305-OL	RF101205 RF111202	M M	Oxidation on hot-ceramic matrix Fluidized-bed treatment of mixed-waste off gas

Table 4.11 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Cementitious solidification/stabilization	WSTA-100-OL	CH321101	H	Cemente solidification stabilization
		RF101202 (FY92)	H	Cemente solidification stabilization
Polymer-impregnated concrete	WSTA-101-OL			
Thermoplastic encapsulation	WSTA-102-OL	CH321201	H	Thermoplastic encapsulation
		RF111203	H	Polymer solidification development
Thermoplastic encapsulation (sulfur polymer cement)	WSTA-103-OL	CH321201	M	Thermoplastic encapsulation
		ID132012	M	Study of waste-form criteria
High-temperature crystalline materials (ceramic)	WSTA-105-OL	ID132006	M	BWID waste-form integration and limits
High-temperature noncrystalline materials (vitrification)	WSTA-106-OL	ID121207 (FY92)	L	Vitrification (noncrystalline)
		CH221203 (FY92)	M	Vitrification development

[a]TTP = Technical Task Plan

[b]The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need; and
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

000547

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Table 4.12. Waste disposal technologies under development by DOE

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Nevada test site	WDIS-102-OL	RF111203	M	Similar effort for Rocky Flats
Waste Isolation Pilot Plant (WIPP)	WDIS-105-OL	AL027001	L	TRANSAX-93 in support of WIPP
Low-specific activity materials	WPHT-102-OL	AL239002	M	Packaging analysis
		OR138001	M	Transportation logistics
		OR130004	L	Shipping regulatory compliance
Surface-contaminated objects	WPHT-103-OL	AL239002	M	Packaging analysis
		OR138001	M	Transportation logistics
		OR130004	L	Shipping regulatory compliance
Type-A radioactive material transportation packages	WPHT-104-OL	AL239002	M	Packaging analysis
		OR138001	M	Transportation logistics
		OR130004	L	Shipping regulatory compliance
Type-B radioactive material packages	WPHT-105-OL	AL239002	M	Packaging analysis
		OR138001	M	Transportation logistics
		OR130004	L	Shipping regulatory compliance
Type-A or type-B fissile radioactive material packages	WPHT-106-OL	AL239002	M	Packaging analysis
		OR138001	M	Transportation logistics
		OR130004	L	Shipping regulatory compliance
On-site packaging, handling, and transportation	WPHT-110-OL	OR138001	M	Transportation logistics
		OR130004	L	Shipping regulatory compliance
Packaging, handling, and transportation for mixed wastes	WPHT-111-OL	OR130004	L	Shipping regulatory compliance
		OR138001	M	Transportation logistics
Waste shipment tracking	WPHT-112-OL	OR130003	H	TRANSCOM operation
		OR130004	L	Shipping regulatory compliance

[a]TTP = Technical Task Plan

[b]The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need; and
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

000548

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4.7 REFERENCES

1. Office of Waste Management and Remedial Actions, *Oak Ridge National Laboratory Waste Management Plan*, ORNL/TM-11433/R2, December 1992

2. U. S. Department of Energy, *Strategic Plan for the Treatment of Appendix B Wastes*, DOE/OR-1083, Rev. 0, February 12, 1993.

3. Ross, W. A., Battelle Pacific Northwest Laboratories, personal communications to S. P. N. Singh, Oak Ridge National Laboratory, May 21, 1993 & June 15, 1993.

5. ROBOTICS AND AUTOMATION

5.1 INTRODUCTION

Many of the WM activities at ORNL will require only minimal use of robotics/automation. The handling of process waste, solid-sanitary waste, and liquid-sanitary waste are examples of those WM activities that are not particularly hazardous and for which the use of robotics or remote handling can not be justified. There are, however, several WM activities that, in the future, could require remote operations or could benefit from capabilities of robotically deployed equipment. These activities include the inspection and monitoring of waste materials stored in barrels or containers in above ground and accessible storage areas; the sorting, handling, and packaging of solid remotely handled TRU; and the processing of liquid remotely handled TRU materials in the proposed WHPP or a similar facility. The specific problems and technology needs of these applications of robotics are described in the following sections.

The robotics/automation technologies that will be required for the WM activities at ORNL are listed in Table 5.1. As shown in the table, the technologies are grouped into nine functional areas, each representing a different element or component of a robotic or automation system.

In Table 5.1, these technologies are related to the specific WM activities that will require the application of robotics or remote handling with an X. These activities are described in the following paragraphs.

5.2.1 Waste Handling and Packaging Plant

WHPP is a facility proposed for construction on ORR. A detailed conceptual design of the facility was completed several years ago and limited testing of several facility features was performed. Although the facility is presently awaiting a decision on the final disposition of TRU wastes, it is anticipated that it will be released for detailed design and construction before the end of the decade.

As presently conceived, WHPP would receive liquid- and solid-TRU waste in a large-volume hot cell. The liquid waste would be processed and solidified in a form suitable for insertion into a WIPP storage canister. The containers with solid-TRU waste would be recovered from burial sites and/or storage areas and transferred into the large-volume hot cell through a double-lid transfer system designed to minimize contamination of the container. The solid waste would be sorted and segregated, volume reduced, and repackaged into WIPP-approved storage packages. Radiological surveys of the external surfaces of the containers would also be performed prior to removal from the hot cell.

As noted above, the materials to be handled in the WHPP include remotely handled liquid waste, presently stored in the Melton Valley Storage Tanks and remotely handled solid waste stored in various types of concrete containers. Some of these concrete containers are easily retrievable and presumably in good condition (post-1980). Others (pre-1980) are not easily retrievable, and the condition of the containers is generally unknown.

All operations in the hot cell would be performed remotely using bridge-mounted servomanipulators for sorting the solid waste and for performing maintenance on the other hot-cell equipment. Automation of the sorting operations would be utilized to the maximum extent possible.

The operation of this facility will require extensive use of robotics/automation and remotely handled technologies. Technology and implementation needs are described in Sects. 5.3 and 5.4.

5.2.2 Inspection and Monitoring of Waste Barrels and Containers

Until suitable waste processing facilities are available, significant quantities of waste materials will be stored in barrels/containers in above ground storage areas. Present regulatory requirements mandate the periodic inspection of these storage vessels for leakage or vessel deterioration. For the past several years, the robotics community has been developing high-efficiency methods to perform this type of inspection. Some of the robotic technologies required for this inspection/surveillance include a field-hardened deployment vehicle, vision systems, proximity probes, and machine-readable symbologies (i.e. high-density bar codes).

In addition, there is an inventory of containers (barrels) presently in storage, and its contents are unknown. Under current regulations, the barrels cannot be opened for sampling. Nonintrusive methods of remotely sampling these barrels is required so that their ultimate disposal method can be determined.

Table 5.1. Relationship of robotics/automation technologies to waste management activities

Data sheet code number	Waste handling and packaging	Surveillance and inspection
Mechanical—mobility		
ROBA-1-OL		X
ROBA-8-OL	X	
ROBA-10-OL		X
ROBA-11-OL		X
ROBA-12-OL		X
ROBA-13-OL	X	X
Mechanical—manipulation		
ROBA-16-OL	X	
ROBA-17-OL	X	
ROBA-19-OL	X	
Mechanical—mechanisms		
ROBA-20-OL	X	X
ROBA-21-OL	X	
ROBA-22-OL	X	X
Mechanical—end-of-arm tooling		
ROBA-23-OL	X	X
ROBA-24-OL	X	
ROBA-25-OL	X	X
ROBA-26-OL	X	X
Controls—algorithms		
ROBA-27-OL	X	X
ROBA-28-OL		X
ROBA-29-OL		X
ROBA-30-OL	X	X

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Table 5.1 (continued)

Data sheet code number	Waste handling and packaging	Surveillance and inspection
Controls—algorithms (continued)		
ROBA-31-OL	X	X
ROBA-32-OL	X	X
ROBA-33-OL	X	X
ROBA-34-OL	X	X
ROBA-35-OL	X	X
ROBA-36-OL	X	X
ROBA-37-OL	X	X
Controls—human/machine interface		
ROBA-38-OL	X	X
ROBA-39-OL	X	X
ROBA-40-OL	X	X
ROBA-41-OL	X	X
ROBA-42-OL	X	X
Sensors—perception		
ROBA-43-OL	X	X
ROBA-44-OL	X	X
ROBA-45-OL	X	X
ROBA-46-OL	X	X
ROBA-47-OL		X
Sensors—control		
ROBA-48-OL	X	X
ROBA-50-OL	X	X
ROBA-51-OL	X	X
ROBA-52-OL	X	X
Other technologies		
ROBA-53-OL	X	X
ROBA-54-OL	X	
ROBA-55-OL[a]	X	X

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Table 5.1 (continued)

Data sheet code number	Waste handling and packaging	Surveillance and inspection
Other technologies		
ROBA-56-OL[a]	X	X
ROBA-57-OL[a]	X	X
ROBA-58-OL[a]		X
ROBA-59-OL[a]	X	X

[a]Technologies designed for characterization applications.
An X indicates that a technology is applicable to the specific waste management activity.

5.3 SCIENCE AND TECHNOLOGY NEEDS

Science and technology needs for WM activities are described in the following paragraphs with short explanations of why additional R&D is required. These needs are correlated to the specific tasks perceived for WM.

5.3.1 Waste Handling and Packaging Activities

Generally, the robotics and remote handling technologies required for waste handling and packaging plants (as described in Sect. 5.2 for the WHPP or a similar facility) are well developed and have been field tested in fuel reprocessing applications. The primary technologies requiring additional R&D are provided in the following sections.

5.3.1.1 Dexterous Manipulators-Single/Dual Arm Configuration and Modular Arm Construction (ROBA-16-OL)

Generally, two types of tasks will be required of the servomanipulators in a large cell waste packaging plant. The manipulators will be required to reach into the casks and retrieve the waste materials prior to sorting, a task that favors an elbows-up configuration. The manipulators will also perform periodic maintenance on other cell equipment, which can include tasks that favor an elbows-down configuration. No existing servomanipulator suitable for hot-cell applications can be configured in both types of stances. Additional R&D is required to develop a system, including the control stations (master arms), that can be used in either elbows-up or elbows-down configurations.

5.3.1.2 Tool Caddies (ROBA-21-OL), End-Effector Changeout Mechanisms (ROBA-24-OL), and General Gripper/Tool Interface (ROBA-25-OL)

Since the servomanipulators may be required to perform maintenance tasks in the hot cell on a variety of equipment items, the availability of a general purpose tool caddie, with a full compliment of hand and power tools, would increase the efficiency of the remote operations. In addition, rapid change-out mechanisms and standard gripper/tool interfaces, with built-in power and instrumentation leads, would also increase the efficiency of operations. These types of specialized systems or capabilities are not currently available, and a modest amount of R&D is required for their development.

5.3.2 Inspection and Monitoring of Waste Barrels and Containers

Waste storage containers or barrels are presently inspected by direct human observation and the validity of the data, particularly on the progressive deterioration of the containers, is qualitative and subjective and depends on the judgement and skill of the inspector. Automated inspection of the containers, using sensors deployed by robotic devices, provides more quantitative information and can be performed more efficiently than the present labor-intensive methods. Robotic inspection also has the advantage that it displaces humans from a potentially hazardous environment.

Remotely operated vehicles can also be used to deploy sensors that could be used for the nonintrusive characterization of barrels whose contents are unknown. It is anticipated that this characterization will not only require specialized sensors, developed

by others, but will also require the application of artificial intelligence, using what little information is known about the contents of the barrels.

5.3.2.1 Advanced Vision Systems (ROBA-43-OL)

The development of vision and image processing techniques will be required to quantitatively characterize the external surfaces of the waste containers/barrels. An initial survey will be required to develop a baseline for comparison with later surveys. Additional R&D is required to enhance the capabilities of presently available systems to minimize the effects of different lighting and shading (sunny vs. cloudy days) and slightly varying observational positioning of the vision system.

5.3.2.2 Data Handling and Data Base Management (ROBA-39-OL)

Since the number of storage barrels is quite large, the amount of data generated by robotic inspection may also be overwhelming unless efficient methods to store and retrieve the data are developed. Data handling, data storage, and data base management are areas requiring additional R&D to improve the efficiency and quality of inspection by robotic devices.

5.4 IMPLEMENTATION NEEDS

Facilities and personnel are presently available to provide most of the implementation needs for robotic/automation applications for WM activities. These facilities can be modified at minimal cost to provide cold test beds for technology development and verification and for personnel training. Other than adequate funding for technology development, no other implementation needs can be identified.

5.5 TECHNOLOGY RANKINGS

The rankings of the robotics/automation technologies required for WM activities is given in Table 5.2. It should be noted that the criteria used for ranking are biased toward those technologies that are commercially available. Hence, a one-for-one comparison between the rankings and the science and technology needs identified in Sect. 5.3 is not possible (i.e. commercially available devices generally require little additional R&D). It should also be noted that several of the criteria suggested for ranking were not considered applicable to robotics/automation. These include (1) compliance with requirements or regulations, (2) environmental, safety, and health requirements, and (3) unit processing costs. Others of the criteria have limited applicability to robotics/automation.

A number of the technologies were considered essential. However, many of these technologies also had a high ranking, which meant they were commercially available. The essential technologies were usually associated with highly ranked site problems also.

The development costs identified in Table 5.2 should be considered rough order-of-magnitude estimates. They have more validity in the comparison of relative costs between the various robotics/automation technologies (i.e., they are internally consistent), than they do in their absolute magnitude.

Table 5.2. Rankings of robotics/automation technologies for waste management

Data sheet code number	Technology	Ranking[a]
	Mechanical—mobility	
ROBA-1-OL	Wheeled/tracked vehicles	E-5-2 ($3M:N)
ROBA-8-OL	Mounted robotic platform	M-2-1 ($5M:N)
ROBA-10-OL	Power sources for mobile platforms	E-5-1 ($0.5M:N)
ROBA-11-OL	Failure recovery systems for mobile platforms	E-5-1 ($0.5M:N)
ROBA-12-OL	Transportation methods for mobile platforms	M-3-1 ($0.5M:N)
ROBA-13-OL	Data/signal transmission	E-5-1 ($1M:N)
	Mechanical—manipulation	
ROBA-16-OL	Dexterous manipulators	E-5-1 ($1M:N)
ROBA-19-OL	Compact, high-capacity manipulators	H-5-1 ($1M:N)
	Mechanical—mechanisms	
ROBA-20-OL	Precise programmable motions	H-5-1 ($0.5M:N)
ROBA-21-OL	Tool caddies	H-4-1 ($0.5M:N)
ROBA-22-OL	Stabilization/support mechanisms or booms	M-3-1 ($0.5M:N)
	Mechanical—end-of-arm tooling	
ROBA-23-OL	End effectors/alternatives	E-5-2 ($1M:N)
ROBA-24-OL	End-effector changeout mechanisms	M-3-1 ($0.5M:N)

Table 5.2 (continued)

Data sheet code number	Technology	Ranking[a]
Mechanical—end-of-arm tooling (continued)		
ROBA-25-OL	General gripper/tool interface	H-4-1 ($0.5M;N)
ROBA-26-OL	Force-limiting/compliant mechanisms	M-3-1 ($0.5M;N)
Controls—algorithms		
ROBA-27-OL	Control modes	E-5-N ($N;N)
ROBA-28-OL	Vehicle/mobility driving	E-5-1 ($0.5M;N)
ROBA-29-OL	Vehicle/mobility navigation	H-4-1 ($0.5M;N)
ROBA-30-OL	Manipulation (joint control)	H-4-1 ($0.5M;N)
ROBA-31-OL	Manipulation (Cartesian control)	H-4-1 ($1M;N)
ROBA-32-OL	Manipulation (special purpose control)	H-4-2 ($1.5M;N)
ROBA-33-OL	Manipulation (redundancy control)	M-3-2 ($2M;N)
ROBA-34-OL	Combined mobility/manipulation	M-2-2 ($1M;N)
ROBA-35-OL	Safety (collision avoidance)	H-4-1 ($1M;N)
ROBA-36-OL	Safety (load/rate limiting)	H-3-1 ($0.5M;N)
ROBA-37-OL	Emergency shutdown	E-4-1 ($0.5M;N)
Controls—human/machine interface		
ROBA-38-OL	Console (fixed/mobile suitcase)	E-5-1 ($0.5M;N)
ROBA-39-OL	Console (data handling methods)	H-5-1 ($1M;N)
ROBA-40-OL	Operator interface (command input)	H-3-1 ($0.5M;N)
ROBA-41-OL	Operator interface (operator assistance)	H-3-2 ($1.5M;N)
ROBA-42-OL	Operator interface (status/alert system)	E-5-1 ($0.5M;N)
Sensors—perception		
ROBA-43-OL	Visual/aural systems	E-5-1 ($1M;N)
ROBA-44-OL	Range finders	M-3-2 ($1.5M;N)
ROBA-45-OL	Proximity probes	M-2-2 ($1M;N)
ROBA-46-OL	Force/torque sensors	M-2-1 ($0.5M;N)

Table 5.2 (continued)

Data sheet code number	Technology	Ranking[a]
	Sensors—control	
ROBA-48-OL	Position/velocity sensors	E-5-1 ($0.5M;N)
ROBA-50-OL	Force/torque	H-3-1 ($0.5M;N)
ROBA-51-OL	Proximity probes as control sensors	H-3-1 ($1M;N)
ROBA-52-OL	Tooling sensors	H-3-1 ($0.5M;N)
	Other technologies	
ROBA-53-OL	Field hardening	E-5-1 ($0.5M;N)
ROBA-54-OL	Radiation hardening	M-3-2 ($2M;N)
ROBA-55-OL	Integrated automated analytical laboratory	E-5-2 ($3M;N)
ROBA-56-OL	Information management for sample handling	E-5-1 ($1M;N)
ROBA-57-OL	Sample collection	E-5-1 ($1.5M;N)
ROBA-58-OL	Characterization sensor integration	M-3-2 ($1M;N)
ROBA-59-OL	Sample preparation	E-5-1 ($1M;N)

[a]The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as $M or $K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology ($ per ft^3 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

5.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the robotics/automation technologies listed in Table 5.1. Table 5.3 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with the complete set of robotics/automation technologies listed in Vol. 1, Pts. A, B, and C, of the TLD. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding robotics/automation technology code by TTP number. When no FY 1993 matches were found and the searchers (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Robotics/automation technologies for which no matches were found are omitted from the table. When many matches were found only one or two were cited. The relevance column indicates the degree of overlap between the technologies listed in Vol. 1, Pts. A, B, and C and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 5.3. Robotics/automation technologies under development by DOE

Technology	Code	93 TIP[a]	Relevance[b]	Focus of TIP
Wheeled/tracked vehicles	ROBA-1-OL	OR113202	M	Robotics for buried waste
		OR113203	H	Crosscutting & advanced technology
		OR113206	H	Demonstr. of telerobotic dismantlement
		SR123201	H	Robotics for decontamination & decommissioning (D&D)
Pipe/duct crawler (internal)	ROBA-5-OL	AL213204	L	Miniature robotics
		SF213203	L	Remote microsensor technology
Pipe/duct crawler (external)	ROBA-6-OL	AL223201	H	Robotic external pipe decontamination
		OR113206	H	Robotic asbestos removal
		SR123201	H	Robotic asbestos bagging
Specialized robotic deployment platforms	ROBA-7-OL	AL213204	H	Crosscutting & advanced technology
		SF213203	H	Crosscutting & advanced technology
		SF223203	H	Robotics technology development
		OR113203	H	Crosscutting & advanced technology
Transportation methods for mobile platforms	ROBA-12-OL	AL213205	M	Remote drum handling equipment
Data/signal transmission	ROBA-13-OL	AL213204	H	High-bandwidth long cable, harsh env.
		AL322002	H	Data acquisition modules
		SF213205	H	Data & video telemetry
Long-reach manipulator (light duty)	ROBA-14-OL	RL313202	H	Long-arm, light-duty manipiator for underground tanks
Long-reach manipulator (heavy duty)	ROBA-15-OL	OR113206	H	Demonstration arm-collision avoidance
		AL213204	H	Development high payload long arm
Dextrous manipulators	ROBA-16-OL	OR113202	H	Robotics for buried waste
		AL213201	H	Robotics for buried waste
		AL213202	H	Robotics for buried waste
Precise programmable motions	ROBA-20-OL	AL213204	M	Programmed robotic motion
		SR113201	M	Programmed teleoperated control
		RL332004	M	Short-reach dexterous manipulator
End effectors/alternatives	ROBA-23-OL	AL213201	H	End-effector development
		AL213207	H	End-effector developmnent
		RL332004	H	End-effector development
End-effector changeout mechanisms	ROBA-24-OL	SR123201	M	Robotics for D&D

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Table 5.3 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Vehicle/mobility navigation	ROBA-29-OL	OR113203	L	Crosscutting & advanced technology
		OR113205	L	Crosscutting & advanced technology
		RL313203	L	Robotics for buried waste
Manipulation (joint control)	ROBA-30-OL	AL213201	M	Joint failure reconfiguration
Manipulation (special purpose control)	ROBA-32-OL	AL221205	L	In-tank hardware removal
Manipulation (redundancy control)	ROBA-33-OL	AL213104	M	Kinematic redundancy of controls in crosscutting
Safety (collision avoidance)	ROBA-35-OL	AL213201 (Many)	M	Robotics for storage tanks (No new methods developed)
Console (data handling methods)	ROBA-39-OL	AL232002	L	Computer interface/end effector
Operator interface (command input)	ROBA-40-OL	RL313203	L	Robotics for buried waste
		OR113202	L	Robotics for buried waste
Operator interface (operator assistance)	ROBA-41-OL	OR113203	L	Crosscutting & advanced technology
		AL213204	L	Crosscutting & advanced technology
Operator interface (status/alert system)	ROBA-42-OL	OR113203	L	Crosscutting & advanced technology
		AL213204	L	Crosscutting & advanced technology
Range finders	ROBA-44-OL	OR113201 (Many)	L	Robotics storage tanks
Proximity probes	ROBA-45-OL	OR113203	L	Crosscutting & advanced technology
		AL213204	L	Crosscutting & advanced technology
Force/torque sensors	ROBA-46-OL	OR113203	H	Crosscutting & advanced technology
		RL313205	H	Crosscutting & advanced technology
Force/torque	ROBA-50-OL	OR113203	H	Crosscutting & advanced technology
		AL213204	H	Crosscutting & advanced technology
Tooling sensors	ROBA-52-OL	SR123201	M	Robotics for D&D
Field hardening	ROBA-53-OL	AL213204 (Many)	L	Crosscutting & advanced technology
Radiation hardening	ROBA-54-OL	AL213204 (Many)	M	Crosscutting & advanced technology

000564

2251

Table 5.3 (continued)

Technology	Code	1993 TTP[a]	Relevance[b]	Focus of TTP
Integrated automated analytical laboratory	ROBA-55-OL	AL213203	H	Robotic contaminant analysis automation
Information management for sample handling	ROBA-56-OL	AL213203	H	Robotic contaminant analysis automation
Sample collection	ROBA-57-OL	AL213203	H	Robotic contaminant analysis automation
Characterization sensor integration	ROBA-58-OL	AL213204	H	Crosscutting & advanced technology
Sample preparation	ROBA-59-OL	AL213203	H	Robotic contaminant analysis automation

[a]TTP = Technical Task Plan

[b]The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need; and
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

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6. Regulatory Compliance

6. REGULATORY COMPLIANCE

6.1 INTRODUCTION

A great challenge facing DOE today is the deactivation, decommissioning, decontamination, dismantling, and recycling of government-owned facilities that supported the early nuclear energy research and defense programs. Many of these facilities have no current use and have been retired. Some of these DOE facilities have residual radioactive or chemical contamination levels that require cleanup and WM.[1] As a part of DOE's ER and WM Program, RA, D&D, and WM issues are being addressed. The D&D Program is concerned with the safe caretaking of surplus nuclear facilities until their decontamination, entombment, dismantling and removal, or conversion to another non-nuclear reuse.[1] RA addresses all CERCLA regulatory concerns brought about as a result of previous WM activities and any environmental contamination discovered as D&D commences. The D&D and RA regulatory concerns are described in Vol. 1, Pts. A and B, respectively. The focus of this regulatory chapter will be on the WM activities resulting not only from D&D and RA actions but also from daily compliance activities at the ORNL.

DOE's hazardous-waste cleanup activities are regulated by the following: RCRA, CERCLA, state and local requirements, and internal DOE orders, standards, and guidance documents.[2] As a result of ORR being listed on the National Priorities List (NPL) under CERCLA, effective December 21, 1989 [54 *Federal Regulations (FR)* 48184], DOE, EPA and TDEC, signed an FFA, effective January 1, 1992, for the ER of ORR. An effort is underway to incorporate into the FFA all inactive facilities that are known or suspected to contain significant quantities of residual hazardous materials.[1] These facilities would be added to project lists under the FFA and would subsequently undergo remediation pursuant to CERCLA or RCRA and subject to the regulatory drivers detailed in Vol. 1, Pt. B, Chap. 6. WM must handle added RA wastes from ER activities, impacting transportation, storage, and ORR disposal activities, including WM activities at ORNL. Facilities containing hazardous wastes that remain listed as D&D activities would be closed under the D&D program, subject to the regulatory drivers detailed in Vol. 1, Pt. A, Chap. 7.

DOE has entered into a number of other agreements with state and federal parties, which either define committed milestones for ER and WM activities or arrange for appraisals and audits.[1] Two major agreements containing committed milestones impacting ORNL activities are the *Tennessee/DOE Monitoring and Oversight Agreement (TOA)*, and *The Federal Facilities Compliance Agreement for Mixed Waste Subject to Land Disposal Restrictions for The Oak Ridge Reservation (LDR-FFCA/ORR)*.[1]

TOA details the obligations and agreements between DOE and TDEC with respect to the DOE provision for technical and financial support of state environmental activities. These activities include the following: participation in the FFA covering ER ORR; oversight, monitoring, access, and emergency response initiatives. Such activities are designed to ensure compliance with applicable federal, state, and local laws and regulations concerning ORR and its environs.[1]

The LDR-FFCA/ORR was signed in June 1992, effective immediately, to bring mixed-waste generation and storage facilities on the reservation into compliance with applicable environmental laws.[1] PCB-FFCA for ORR is under development; one aspect of the agreement is to provide for continued storage of PCB-contaminated materials at ORNL.

A second group of milestones, not considered commitments, are derived primarily from DOE's annual Five Year Plan, Current Year Work Plans, and Activity Data Sheets.[1] At this time, these milestones serve as the regulatory drivers for ER, WM, and D&D activities.[1]

This chapter will define regulatory issues relating to WM, including federal and state regulations, DOE orders, Interagency Agreements, and Federal Facility Compliance Agreements (FFCAs) as they apply to WM practices at ORNL.

6.2 TYPES OF WASTES

One of the challenges to WM at ORNL is the variety and complexity of waste types that must be handled. Adding to the complexity is regulatory language that sometimes makes certain waste types appear to be "not what they seem." Waste types at ORNL include the following: solid, hazardous, mixed, radioactive, medical, asbestos, and PCBs. Through the use of legal labels, liquids and gases can be solid wastes. Stated very simply, wastes that contain constituents that are harmful to human health and the environment are considered "hazardous." Radioactive wastes are made up of the following types: TRU, high-level, low-level, naturally occurring, and accelerator-produced radioactive material. Mixed waste contains both hazardous and radioactive components. Asbestos, usually contained in structural building parts, is a concern at ORNL, especially where the demolition of buildings and structures is anticipated. PCBs are generally associated with electrical, hydraulic, and heat transfer equipment and containers. The last category of wastes that will be discussed in this document is pesticides. Regulatory guidance provides assistance in labeling, storage, and disposal, and container design of pesticide products.

6.3.1 Resource Conservation and Recovery Act

RCRA was passed in 1976 as an amendment to the Solid Waste Disposal Act (SWDA) (1965). The primary goals of RCRA are to protect human health and the environment from the potential hazards of waste disposal, to conserve energy and natural resources, to reduce the amount of waste generated (including hazardous waste), and to ensure that waste is managed in an environmentally sound manner. The most extensive changes to RCRA were the Hazardous and Solid Waste Amendments (HSWA) of 1984. These amendments included new requirements for land disposal restrictions (LDR), underground storage tanks (UST), surface impoundments, corrective action, and permitting deadlines. RCRA, as amended by HSWA, is divided into the following ten subtitles:

Subtitle A—General Provisions. Contains congressional findings related to solid waste, defines the objectives of RCRA, and describes integration between RCRA and other statutes.

Subtitle B—Office of Solid Waste; Authorities of the Administrator. Establishes the Office of Solid Waste and defines the responsibilities of the Administrator.

Subtitle C—Hazardous Waste Management. Establishes a management system that regulates hazardous waste from the time it is generated until its ultimate disposal.

Subtitle D—State or Regional Solid Waste Plans. Establishes a Federal program to promote the environmentally sound disposal of solid waste.

Subtitle E—Duties of the Secretary of Commerce in Resource and Recovery. Requires the Secretary of Commerce to encourage greater commercialization of proven resource recovery technologies.

Subtitle F—Federal Responsibilities. Stipulates that Federal facilities shall be subject to all applicable RCRA requirements.

Subtitle G—Miscellaneous Provisions. Establishes standards and procedures for employee protection, citizen suits, imminent hazard protection, public participation, judicial review, etc... related to RCRA.

Subtitle H—Research, Development, Demonstration, and Information. Encourages special studies, new programs, and innovative technologies, and provides for coordination, collection, and dissemination of information related to solid waste.

Subtitle I—Regulation of Underground Storage Tanks. Regulates petroleum products and hazardous substances (as defined by CERCLA) stored in USTs.

Subtitle J—Medical Wastes. Establishes a two-year demonstration program for tracking medical waste in participating States.

000570

6.3.2 Tennessee Regulations

Section 3006(b) of RCRA allows states to apply to EPA for authorization to administer and enforce a hazardous waste program pursuant to Subtitle C. Therefore, authorized state programs are carried out in lieu of the federal program. However, because HSWA made many changes to the RCRA program, the federal government enforces HSWA requirements in states that are authorized only for the base RCRA program until these states receive HSWA authorization. On July 3, 1986, EPA published a notice announcing that in order to obtain and maintain authorization to administer and enforce a RCRA Subtitle C Hazardous Waste program, states must apply for authorization to regulate the hazardous waste components of radioactive mixed waste. EPA stated in this notice that the radioactive-waste component of radioactive-mixed waste is subject to the Atomic Energy Act (AEA) of 1954, as amended (68 Stat. 923), and that the hazardous-waste component is subject to RCRA. The DOE Byproducts Rule, which discusses how RCRA applies to radioactive waste that contain components of hazardous wastes within the meaning of RCRA, was published on May 1, 1987 (52 *FR* 15937). As a result, in states that are authorized for both base RCRA and mixed waste, facilities are subject only to state regulations. Pursuant to Sect. 3006 of RCRA, 42 U.S.C. § 6930(a), the State of Tennessee was granted final authorization on February 2, 1985 by EPA to operate an equivalent state hazardous-waste program. Federally authorized state RCRA programs relate only to RCRA standards before HSWA. On August 11, 1987, Tennessee received authorization to regulate the hazardous-waste component of radioactive-mixed waste. Therefore, Tennessee is authorized for the RCRA Base Program and for mixed wastes. Also, because HSWA and mixed waste are completely separate programs, a state's mixed waste authorization status is totally independent and unaffected by its HSWA authorization status. However, it should be noted that EPA may revise a state's program, withdraw its approval, or transfer a state's responsibilities back to the federal government when necessary. However, Tennessee's substantive RCRA regulations are identical for the most part to the federal RCRA regulations. New regulations imposed in 1984 by HSWA are to be considered applicable under federal law in all states until each authorized state promulgates its own HSWA-related standards. Although the Tennessee Solid Waste Disposal Control Board has promulgated many of the HSWA regulations, EPA has not yet authorized all parts of the program.[3,1] For example, Tennessee is not authorized for corrective action nor LDRs.[6]

6.3.3 Solid-Waste Regulations

Section 1004(27) of RCRA defines "solid waste" as any garbage, refuse, sludge, from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges, which are point sources subject to permits under Sect. 402 of the Federal Water Pollution Control Act, as amended (86 Stat. 880), or source, special nuclear, or byproduct material as defined by the AEA.

Additionally, EPA in 40 *Code of Federal Regulations* (CFR) § 261.2 has defined solid waste as any discarded material that is not excluded by 40 CFR § 261.4(a) or that is not excluded by variance granted pursuant to 40 CFR § 260.30 and § 260.31. Discarded material is defined in 40 CFR § 261.2(a)(2) as any material that is abandoned, recycled,

or inherently waste-like. Since the terms "abandoned," "recycled," and "inherently waste-like" are capable of broad interpretation, the way they are interpreted will determine whether or not a waste is "solid" and therefore subject to RCRA requirements. Materials are solid waste if they are abandoned by being disposed of burned or incinerated or accumulated, stored or treated before or in lieu of being disposed of, burned or incinerated. In 40 CFR § 261.2(d), EPA has designated four categories of waste that are "inherently waste-like" and which will be classified as "solid wastes" if they are recycled in any manner. Also, materials are solid wastes if recycled or accumulated, stored, or treated before recycling in any of the following ways: in a manner constituting disposal, by burning for energy recovery, by reclamation, or by speculative accumulation. A mixture of a solid waste and a hazardous waste triggers RCRA's "mixture rule," which is discussed under the hazardous waste section of this document.

ORNL sanitary waste includes solid wastes generated from steam plant operations, coal yard runoff, general refuse, and construction debris.[2] Sanitary nonradioactive, nonhazardous solid wastes that contain no free liquids include filter cake from the Coal Yard Runoff Treatment System (CYRTS), fly ash from the ORNL steam plant, general refuse collected in trash cans and dumpsters, and construction debris.[2] Additionally, ORNL sanitary waste includes liquid wastes which are generated from sanitary sewage waste treatment, area runoff of rainwater, and point sources such as coal yard runoff. The State of Tennessee regulates these waste streams at ORNL through the Tennessee Solid Waste Disposal Act (TCA § 68-31-101 *et seq.*), the Tennessee Water Quality Control Act (TCA § 69-3-101 *et seq.*) and ORNL's NPDES Permit (State of Tennessee NPDES Permit No. TN0002950). Because some of these liquid wastes are radioactively contaminated, these discharges are controlled by Tennessee's Regulations for Protection Against Radiation, TDEC Rules Chaps. 1200-2-4 and 1200-2-5 as well as specific limitations described in the ORNL NPDES Permit. Under the NPDES Permit, discharges must be reduced to ALARA levels and must comply with the limitations in Schedule RHS 8-1, Table II, Column 2, of TDEC Rules Chap. 1200-2-5. Other requirements are described in the permit. Pertinent DOE orders are DOE Order 5820.2A and DOE Order 5400.3.

Under RCRA Sect. 1008, EPA has been authorized to develop and publish guidelines for the management of solid waste, including minimum criteria for defining solid WM practices. These criteria, listed in 40 CFR 257, are to be used to determine which facilities and practices pose a reasonable probability of harm to human health or the environment. Practices failing to satisfy these criteria constitute "open dumping," which RCRA Sect. 4005 prohibits. These criteria also provide guidelines for the use and disposal of sludge under Sect. 405(d) of the Clean Water Act (CWA). Activities that are exempted from these criteria are listed at 40 CFR § 257.1(c). 40 CFR § 257.3-1, which prohibits the restriction of flow within floodplains, the reduction of temporary water storage capacity, and practices causing washout of solid waste that pose health and environmental hazards. 40 CFR § 257.3-2 prohibits practices resulting in the destruction or adverse modification of critical habitats of endangered or threatened species of plants, fish, or wildlife. 40 CFR § 257.3-3 prohibits the discharge of pollutants to surface waters in violation of the NPDES under the CWA as well as the non-point source pollution. According to 40 CFR § 257.3-4, a solid WM facility may not contaminate underground drinking water sources beyond concentrations exceeding Safe Drinking Water Act maximum contaminant levels (MCLs). 257.3-5 prohibits application of solid-waste to within 3 feet of the land surface used for food-chain crops. On-site population of disease vectors must be minimized (40 CFR § 257.3-6). Open burning of solid waste is prohibited

and explosive gases generated by the facility may not exceed certain levels (40 CFR § 257.3-8).

The State of Tennessee regulates the operation of sanitary waste landfills pursuant to the Tennessee Solid Waste Disposal Act, as amended, under TDEC Rule 1200-1-7. The State requires permits for solid-waste processing and disposal facilities (TDEC Rules Chap. 1200-1-7-.02). The state regulations are similar to the federal requirements and have adopted by reference all of EPA's rules, which had become final by October 1992. The two state-permitted facilities that have received sanitary-solid waste from ORNL are Sanitary Landfill (SLF) II at the Y-12 Site, permitted on December 20, 1982, and the ORNL Contractor Landfill, permitted on January 23, 1986 and currently closed.[2] The permit for SLF II requires that no liquids, industrial-special waste, or waste requiring special handling shall be accepted at the facility unless prior written approval is obtained for each individual waste.[2] As required by the Tennessee Hazardous Waste Act, no hazardous waste shall be accepted at SLF II.[2] In addition to these general requirements, the SLF II permit established minimum daily and weekly cover requirements.[2] Also, the permit states that only waste specified in the site operations manual as acceptable for disposal shall be deposited unless prior written approval for each individual waste is obtained.[2] Radioactive waste is specifically excluded from disposal.[2] The permit allows disposal of special waste including asbestos, fly ash, and coal yard runoff sludge.[2] SLF II must close by March 15, 1994, and a new SLF, currently under construction, is expected to be operational by that time. Ground-water monitoring is conducted at SLF II pursuant to ground-water sampling parameters established by TDEC Division of Solid Waste Management in TDEC Rule 1200-1-7-.04(7)(a).[2]

Whenever ORNL contemplates any new works or changes in existing works that causes sewage, industrial wastes or other waste to be discharged into or adjacent to any waters of the State, a registered engineer must plan, design, and inspect the construction of any such works. A registered engineer is also required to assist in the start-up of and the outlining of correct operating procedures for any new or altered waste water treatment or water quality control facilities. Further detailed guidance for specific activities, including developing plans, obtaining site approval, and submitting reports, is provided in TDEC Rules 1200-4-2-.02 through 1200-4-2-.06. The submission of letters, reports, plans, and specifications constitute an application for a permit for the construction, installation, or modification of any treatment works or part thereof, or any extension or addition thereto, the operation that will likely to cause an increase in the discharge of wastes into the waters of the state or would otherwise alter the physical, chemical, biological or bacteriological properties of any waters of the state in any manner not already legally authorized. This applies to the construction of any new outlets as well. The official letter issued by the Commissioner's representative approving a project, together with the plans and specifications giving the official "Approved for Construction" stamp of the Commissioner constitutes a valid permit to construct, install or modify in conformance with all conditions shown in the plans and drawings (TDEC Rule 1200-4-2-.07). TDEC Rule Chap. 1200-4-2 should be referred to for further detail and limitations. This permit is separate and distinct from the permit required to operate a sewage system or a sewage treatment system, and to discharge waste from any new or existing outlet, following treatment (TDEC Rule Chap. 1200-4-2.-.07).

Sanitary liquid waste includes waste streams discharged, either directly or indirectly or following treatment, to White Oak Creek.[2] ORNL sanitary liquid waste streams include the following: sanitary sewage wastes from Bethel and Melton Valleys, area runoff of rainwater and point sources.[2] Current regulatory requirements include the CWA, the SDWA, and Tennessee rules governing the Waters of Tennessee (Tennessee water Quality

Control Act, T.C.A. § 69-3-101 *et seq.*). The NPDES permit for ORNL sets the parameters for sanitary liquid waste collection, treatment, and discharge.[2] The sanitary sewage wastes are radioactive due to leakage into sewer piping and resulting contamination of aeration/sludge drying basins. The state rules and DOE orders regulating these wastes have already been specified in Sect. 6.3.2.

Whenever any new works or change in existing works are being considered where sewage, industrial wastes, or other waste will be discharged into or adjacent to any waste of the state, a registered engineer must plan, design, and inspect the construction or any such works. A registered engineer must also assist in the startup of and outline correct operating procedures for any new or altered wastewater treatment or water quality-controlled facilities (TDEC Rule 1200-42-.01).

6.3.4 Hazardous-Waste Management Regulations

Under RCRA, hazardous wastes are defined as a subset of solid wastes. Therefore, unless a waste is first a solid waste, it cannot be a hazardous waste. See Sect. 6.3.3 for the solid waste definition. Hazardous waste is defined at 40 CFR § 261.3, and a solid waste as defined in 40 CFR § 261.2 is a hazardous waste if it meets any of the following criteria:

1. Does the waste exhibit any one of the four *characteristics* of a hazardous waste identified in 40 CFR 261, Subpart C?
2. Has the waste been *listed* as a hazardous waste in 40 CFR 261, Subpart D?
3. Is the waste a *mixture* containing a listed hazardous waste and a nonhazardous solid waste?
4. Is the waste *derived from* the treatment of a listed hazardous waste?
5. Is the waste not *excluded* from regulation as a hazardous waste?
6. Is the waste a hazardous waste *contained-in* an environmental medium, such as ground water or soil?

6.3.4.1 Characteristics of Hazardous Waste

In 40 CFR 261, EPA has identified four characteristics of hazardous wastes that are ignitability, corrosivity, reactivity, and toxicity. First, a solid waste is considered ignitable under 40 CFR § 261.21 if the waste is a liquid, except an aqueous solution containing less than 24% alcohol that has a flash point of less than 60°C (140°F); it is a non-liquid capable, under normal circumstances, of spontaneous and sustained combustion; or it is an ignitable compressed gas or an oxidizer per Department of Transportation (DOT) regulation. Second, a solid waste is considered corrosive under 40 CFR § 261.22 if it is an aqueous material with a pH less than or equal to 2.0 or greater than or equal to 12.5, or if it is a liquid that corrodes steel at a rate greater than 1/4 inch per year at 55°C (130°F). Third, a solid waste is considered reactive under 40 CFR § 261.23 if it has the following properties: it is normally unstable and reacts violently without detonating; it reacts violently, forms an explosive mixture, or generates toxic gases, vapors, or fumes when mixed with water; it contains cyanide or sulfide and generates toxic gases, vapors, or fumes at a pH of between 2.0 and 12.5; it is capable of detonation if heated under confinement, subjected to strong initiating force, or at standard temperature and pressure; or it is listed as a DOT Class A or B explosive. Fourth, a solid waste exhibits the toxicity characteristic under 40 CFR § 261.24 if after conducting the Toxicity Characteristic Leaching Procedure (TCLP) test described at 40 CFR 261, Appendix II, the

extract from the waste contains any of the 39 hazardous constituents listed in Table I of 40 CFR § 261.24 at a concentration level equal to or greater than is specified in the same table. EPA adopted a new rule (51 *FR* 21648) on March 29, 1990 that replaced the Extraction Procedure (EP) with the TCLP and expanded the list of toxic constituents from 14 to 39. As a result of this rule, the amount of wastes DOE facilities must handle as hazardous or radioactive mixed wastes has been significantly increased. Since revision of the EP toxicity standard was a HSWA requirement pursuant to Sect. 3001(g) of RCRA, mixed waste exhibiting the toxicity characteristic is considered HSWA regulated. After September 25, 1990, a state's authorization status does not affect the definition of toxicity characteristic-contaminated mixed waste because it is always considered a hazardous waste.

6.3.4.2 Listed

Any solid waste that is listed in 40 CFR 261, Subpart D, is considered hazardous. Under 40 CFR 261 there are four separate lists of hazardous waste that consists of

1. "F" wastes found at 40 CFR § 261.31, which are wastes from nonspecific sources and include many solvent wastes generated at DOE facilities that may be mixed radioactive wastes.
2. "K" wastes found at 40 CFR § 261.32, which are wastes from specific sources. This listing identifies waste streams from specified industrial processes.
3. "P" wastes found at 40 CFR § 261.33(e), which are discarded and off-specification commercial chemical products and residues from these products identified as acutely hazardous.
4. "U" wastes found at 40 CFR § 261.33(f)(6), which are discarded and off-specification commercial chemical products and residues from these products identified as toxic.

The "P" and "U" lists are limited in scope, covering only those products generically identified using the name of a single listed constituent and including only unused portions of these products. Other materials containing "P" or "U" listed constituents are not considered hazardous unless they are listed elsewhere in the regulations or exhibit a hazardous characteristic.

6.3.4.3 Hazardous Constituents Regulated Under RCRA and Hazardous-Waste Constituents

RCRA also identifies a large number of hazardous constituents. Although the presence of hazardous constituents alone in a waste stream does not automatically define that waste stream as hazardous under RCRA, these constituents potentially pose a threat to human health and the environment and form the basis for listing a solid waste as hazardous. The following are the four constituent lists: 40 CFR 261, Appendix VII—Hazardous Waste Constituents; 40 CFR 261, Appendix VIII—Hazardous Constituents; 40 CFR 264, Appendix IX—Ground-water Monitoring List; and 40 CFR § 265.92(b)(1)-(3)—Interim Status Monitoring Parameters.

First, a hazardous-waste constituent is defined as a constituent that caused the Administrator to list the hazardous waste in 40 CFR 261, Subpart D, or a constituent listed in Table I of 40 CFR § 261.24 (40 CFR § 260.10). Appendix VII constituents were used by EPA as a basis for the listing of specified "F" and "K" wastes, while Table I of 40 CFR § 261.24 represents those constituents that define a waste as hazardous by the

toxicity characteristic. Also, hazardous-waste constituents are used as groundwater assessment monitoring parameters under the interim status monitoring program cited at 40 CFR 265, Subpart F. Ground-water assessment monitoring parameters are relevant at DOE facilities that are not yet subject to the permitted facility standards of 40 CFR 264.

Appendix VIII, cited at 40 CFR 261, lists over 350 constituents identified as hazardous under RCRA. This list contains chemicals that have toxic, carcinogenic, mutagenic, or teratogenic effects on humans or other life forms.

Appendix IX, ground-water monitoring list, was created by EPA as a shortened and modified version of Appendix VIII for use in the 40 CFR 264, Subpart F, ground-water monitoring program. This list contains over 200 constituents that must be monitored for in groundwater (40 CFR 264)

In order to establish background ground-water quality at interim status facilities, 40 CFR § 265.92(b) contains 31 parameters that must be monitored. These constituents are used to determine the suitability of ground water as a source of drinking water, the general quality of ground water, and the presence of ground-water contamination.

6.3.4.4 Wastes Excluded From Subtitle C Regulation

40 CFR § 261.4(b) lists a number of common waste streams that are excluded from regulation under RCRA's hazardous-waste program. Used oil that is generated by small quantity generators, or used oil that exhibits a hazardous characteristic, but is recycled in some way other than being burned for energy recovery, is exempt. Used oil burned for energy recovery is exempt from Subtitle C, but is regulated under 40 CFR 266.

6.3.4.5 Delisting Petitions

In 40 CFR 261, Subpart D, over 90 industrial waste streams are listed as hazardous. Currently, listed wastes remain hazardous unless they are "delisted" according to procedures set forth in 40 CFR §§ 260.20 and 260.22. 40 CFR §§ 260.20 and 260.22. These also contain procedures for petitioning EPA to exclude a listed waste from a particular facility because that waste does not pose a threat to human health and the environment. These procedures may also be used for delisting the hazardous component of a mixed waste. If the owner or operator of a facility is able to delist the hazardous component of a mixed waste, the waste is no longer subject to the requirements under RCRA. Instead, the delisted material becomes a radioactive waste regulated solely by DOE. A facility seeking a delisting must demonstrate that its particular waste does not contain the hazardous constituents that required EPA to list the waste or any other constituents that could cause the waste to be hazardous (40 CFR § 260.22). If the facility owner or operator is able to delist the contents of a hazardous WM unit that will be closed, the wastes that are removed during closure do not have to be disposed as hazardous wastes and are not subject to the LDRs program.

6.3.4.6 Waste Mixtures

On May 19, 1980, EPA promulgated the definitions of "mixture" and the "derived-from" hazardous wastes (45 *FR* 33066).

Mixture Rule. For WM activities dealing with hazardous waste, the mixture rule must be considered. Under the mixture rule, a mixture of a listed hazardous waste and a solid waste is a hazardous waste, unless the mixture qualifies for an exemption. The

exemptions apply if the listed hazardous waste in the mixture was listed solely because it exhibits a hazardous characteristic and the mixture does not exhibit that characteristic; the mixture consists of wastewater and certain specified hazardous wastes in dilute concentrations, the discharge of which is subject to regulation under the CWA; or the mixture consists of a discarded commercial chemical product resulting from *de minimis* losses during manufacturing operations. It should be noted that these exemptions apply only when the hazardous waste becomes mixed with other wastes as part of normal WM activities and not when the wastes are intentionally mixed to achieve dilution. If the wastes are intentionally mixed, this mixing could constitute treatment and trigger the requirement of a RCRA permit. Additionally, if one of the above exemptions does not apply to a waste and the hazardous component of the mixture is a listed waste, then a delisting petition may be applied for under 40 CFR §§ 260.20 and 260.22. In contrast, if the mixture contains a characteristic hazardous waste (a waste that is listed in 40 CFR 261, Subpart D, solely because it exhibits one or more of the characteristics listed in Subpart C) and the resultant mixture no longer exhibits the characteristic(s) for which it was originally listed, the mixture is not a hazardous waste. Therefore, a mixture of a characteristic hazardous waste and a solid waste will be deemed hazardous only if the entire mixture continues to exhibit a hazardous characteristic. However, on December 6, 1991, the U.S. Court of Appeals in Washington, DC ruled in *Shell Oil Co. v. U.S. Environmental Protection Agency*, that EPA did not properly seek public comment prior to promulgation of the mixture and derived-from rules, in violation of the Administrative Procedure Act. As a result of the *Shell* decision, these rulemakings were remanded to EPA. EPA responded to the remand on March 3, 1992 by reinstating the rules on an interim basis with a "sunset" date of April 28, 1993, when these rules will expire if EPA fails to adopt a replacement for them [57 *FR* 7628, March 3, 1992, codified at 40 CFR § 261.3(e)]. However, these rules continue in full effect because EPA removed the April 28, 1993 expiration date from its reinstatement of the mixture and derived-from rules in order to assure continuity of the existing national hazardous-waste program, while EPA determines the most appropriate approach for modification of the rules.[4] EPA anticipates promulgating revised regulations for mixtures and treatment residues. Congress has charged EPA with promulgating rules to address the derived-from and mixture issues by October 1994[4].

Derived-From Rule. Another important rule for WM activities dealing with hazardous waste is the derived-from rule. According to this rule, a waste generated from the treatment, storage, or disposal of a hazardous waste, such as ash, leachate, or emission control dust, is also a hazardous waste, unless exempted. If the waste is derived from a listed hazardous waste, the waste is considered a hazardous waste until delisting procedures under 40 CFR §§ 260.20 and 260.22 are followed. If the waste is derived from a characteristic hazardous waste, it is not hazardous if it does not exhibit that characteristic. This rule is currently operating on an interim basis and will require EPA action by October 1994.

Contained-in Policy. Another important rule to WM activities is the "contained-in rule." Pursuant to the contained-in rule, environmental media containing a listed waste, such as contaminated soils and ground water, must be managed (regulated under RCRA Subtitle C) as if they were hazardous wastes, for as long as they continue to contain the listed hazardous waste. The contaminated media are said to contain the listed hazardous waste. EPA has now codified contained-in rule that has previously served as an interpretive gloss on the existing mixture and derived-from rules (57 *FR* 37225, August 18, 1992). As a result, the contained-in concept will apply to both media and nonmedia debris (57 *FR* 37225, August 18, 1992). Additionally, EPA has codified the corollary part

of the contained-in rule, which provides debris that no longer "contains" listed hazardous-waste would no longer be subject to Subtitle C regulation as long as it does not exhibit any hazardous waste characteristic (57 FR 37226, August 18, 1992).

Mixed Waste. Section 1004 of the SWDA was amended by the FFCA of 1992 by adding a definition for mixed waste as follows: "waste that contains both hazardous waste and source, special nuclear, or by-product material subject to the AEA of 1954 (42 U.S.C. 2001 *et seq.*)." Mixed wastes are those containing an RCRA hazardous waste, as defined in 40 CFR 261, and a radioactive waste subject to the AEA. See Sect. 6.5 for discussion of ORNL mixed WM regulatory issues.

6.3.4.7 Generator Requirements under RCRA Subtitle C

A generator is defined as any person, by site, whose act or process produces hazardous waste identified or listed in 40 CFR 261 or whose act first causes a hazardous waste to become subject to regulation (40 CFR § 260.10). The requirements for generators of hazardous waste are cited at 40 CFR 262. The scope of the requirements for generators includes any owner or operator who initiates a shipment of hazardous waste from a treatment, storage, disposal facility (TSDF) [40 CFR § 262.10(f)]. However, a generator who treats, stores, or disposes of hazardous waste on site must only comply with the generator standards at 40 CFR § 262.11, § 262.12, § 262.34, § 262.40, and § 262.43. A generator must first determine whether any of its solid waste is a hazardous waste (40 CFR § 262.11). Then, a generator must obtain an EPA Identification Number before any hazardous waste can be transported, treated, stored, or disposed of [40 CFR § 262.12(a)]. Additionally, a generator must not offer his hazardous waste to transporters or hazardous-waste treatment, storage, and disposal facility (TSDFs) that have not received an EPA Identification Number [40 CFR § 262.12(c)]. The Tennessee generator requirements parallel the federal generator requirements, except Tennessee's more stringent generator notification and annual reporting requirements of TDEC Rule 1200-1-11-.03(2) and (5)(b). As a result, an ORNL WM generator of hazardous waste must comply with the notification requirements cited at TDEC Rule 1200-1-11-.03(2). Also, a generator must not offer his hazardous waste to transporters whom do not have a valid permit from TDEC to transport hazardous waste in Tennessee (TDEC Rule 1200-1-11-.03(1)(c)3). A WM generator who is transporting the hazardous waste off site for treatment, storage, or disposal must also prepare the Uniform Hazardous Waste Manifest that accompanies the hazardous waste at all times (40 CFR § 262.20). The generator must specify the name and EPA Identification Numbers of each authorized transporter and the TSDF that will receive the waste, describe the waste as required by DOT regulations, certify that it is properly packaged and labeled, and sign the manifest certifications by hand. A final copy of the signed manifest must be returned to the generator by the TSDF and the generator must keep the final signed manifest for at least three years (40 CFR § 262.40). If the generator has not received the manifest back from the designated facility within the time requirements cited at TDEC Rule 1200-1-11-.03(5)(c), then the generator must contact the transporter and/or the TSDF to determine the status of the manifest and the hazardous waste. In addition, if the generator has not received the manifest after 45 days from shipping the waste, the generator must file an exception report pursuant to the requirements listed in TDEC Rule 1200-1-11-.03(5)(c) and submit the report to the Commissioner within five days after the 45-day period expires.

The generator, before transporting the hazardous waste off site, must package, label, mark, and placard the waste according to the applicable DOT regulations. However, in

addition to the DOT regulations. EPA requires that any container of 110 gal or less must be specifically marked with the generator's name, address, manifest document number and the words cited at 40 CFR § 262.32(b).

A generator is allowed to accumulate hazardous waste on site without a RCRA storage permit in two instances. First, the generator can accumulate up to 55 gal of hazardous waste at or near the point of generation in satellite accumulation areas provided the requirements in 40 CFR § 262.34(c)(1) are met. Second, a generator may store hazardous waste on site prior to shipment for a period of up to 90 days in tanks or containers provided the requirements in 40 CFR § 262.34 are met.

Since Tennessee's annual reporting requirements are more stringent than the federal reporting requirements, ORNL WM generators must comply with the provisions of TDEC Rule 1200-1-11-.03(5)(b). The generator must submit an annual report to the TDEC by March 1 for the preceding calendar year. The report must include the information listed at TDEC Rule 1200-1-11-.03(5)(b)1(i) through (vi).

6.3.4.8 Transporter Requirements under RCRA Subtitle C

A transporter is any person engaged in the off-site transportation of hazardous waste by air, rail, highway, or water (40 CFR § 260.10). The federal requirements for transporters of hazardous waste are found at 40 CFR 263, while the Tennessee permit requirements and standards for transporters of hazardous waste are cited at TDEC Rule 1200-1-11-.04. None of the requirements for transporters of hazardous waste apply to the on-site transportation of hazardous waste by generators or by owners or operators of permitted hazardous WM facilities. As a result, if WM moves a hazardous waste that is required to be manifested off the site where it was generated, or the site where it is being treated, stored, and disposed of, then WM will be subject to the transporter requirements. A transporter of hazardous waste must first obtain an EPA Identification Number before transporting hazardous wastes [40 CFR § 263.11(a)]. Additionally, each person who transports a hazardous waste that originates or terminates in Tennessee must have a valid transporter permit obtained from the TDEC in accordance with the requirements listed in TDEC Rule 1200-1-11-.04(b) through (c). As noted earlier, generators may use only permitted transporters [TDEC Rule 1200-1-11-.03(1)(c)3]. Also, transporters can only accept hazardous waste that is accompanied by a manifest signed by the generator (40 CFR § 263.20). In addition, the transporter must comply with the applicable manifest requirements cited at 40 CFR § 263.20, which includes signing and dating the manifest to acknowledge acceptance of the hazardous waste and returning one copy to the generator before leaving the generator's property. When the transporter delivers the waste to another transporter or to the designated facility, the transporter must date the manifest and obtain the signature of the next transporter or the designated facility operator, retain one copy of the manifest, and give the remaining copies to the accepting transporter or designated facility [40 CFR § 263.20(d)]. It should be noted that a transporter may hold a hazardous waste for up to ten days at a transfer facility without being required to obtain a RCRA storage permit (40 CFR § 263.12). Lastly, if an accidental spill or other discharge of a hazardous waste occurs during transportation, the transporter must take appropriate action to protect human health and the environment [40 CFR §263.30 and TDEC Rule 1200-1-11-.04(4)].

6.3.4.9 TSDF Requirements under RCRA Subtitle C

RCRA Sect. 3004 regulates owners and operators of hazardous-waste TSDFs and Section 3005 lists the permit requirements for the treatment, storage, and disposal of hazardous waste. Section 3004 directed EPA to establish regulations governing all aspects of TSDFs, including location, design, operation, reporting, monitoring, and closure. The implementing regulations established general requirements that owners and operators of TSDFs must meet, including obtaining identification numbers, conducting waste analyses, preparing contingency plans and emergency procedures, complying with manifests, recordkeeping and reporting, and establishing ground-water monitoring systems. Also, the implementing regulations established specific technical requirements for categories of facilities including the following: containers, tanks, surface impoundments, waste piles, land treatment facilities, landfills, incinerators, and miscellaneous units. Pursuant to 40 CFR § 260.10, a treatment facility is a facility that uses "any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste nonhazardous, or less hazardous; safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume." A storage facility is a facility that "holds hazardous waste for a temporary period, at the end of which the hazardous waste is treated, disposed of, or stored elsewhere." A disposal facility is a "facility or part of a facility at which hazardous waste is intentionally placed into or on any land or water, and at which waste will remain after closure." Under 40 CFR § 264.1, some TSDFs are excluded from regulation. TSDFs that operate under a state hazardous-waste program authorized pursuant to RCRA Sect. 3006 are excluded from regulation under federal law, but are subject to regulation under the state program (40 CFR § 264.1). Tennessee does have an authorized TSDF hazardous waste program since this program is a part of the RCRA base authorization program.[6] Therefore, Tennessee law regulates ORNL TSDFs.[6]

TDEC Rule 1200-1-11-.06 contains the standards for owners and operators of hazardous waste TSDFs and TDEC Rule 1200-1-11-.05 contains the interim status standards for owners and operators of existing hazardous waste TSDFs. A facility owner or operator who has complied with TDEC Rule 1200-1-11-.07(3) must comply with the interim status requirements until final administrative disposition of the permit application is made. TDEC Rule 1200-1-11-.06 establishes standards that define the acceptable management of hazardous wastes in Tennessee and provides a basis upon that permit applications for facilities will be evaluated. TDEC Rule 1200-1-11-.07 establishes the procedures, documentation, and other requirements that must be met in order for a TSDF to be permitted. Pursuant to TDEC Rule 1200-1-11-.06(2)(d), before an owner or operator can treat, store, or dispose of any hazardous wastes, a detailed chemical and physical analysis of a representative sample of the wastes must be obtained. Additionally, the owner or operator must develop and follow a written waste analysis plan and control unauthorized entry to the TSDF. The owner or operator of a TSDF must conduct inspections of the facility for malfunctions and deterioration, operator errors, and discharges which may cause a release of hazardous waste constituents to the environment or endanger human health. Also, TDEC Rule 1200-1-11-.06 contains manifest system, recordkeeping, and reporting requirements, as well as an annual report requirement that must be complied with. Tennessee has incorporated by reference the federal specific technical requirements for most of the categories of facilities, including containers, tank systems, surface impoundments, waste piles, land treatment

facilities, incinerators, and miscellaneous units. The federal requirements for owners and operators of each of these facilities are cited at 40 CFR 264, some of which are discussed below. The interim status standards for owners and operators of each of these facilities are cited at 40 CFR 265.

First, incinerators, defined at 40 CFR § 260.10, are used to destroy hazardous wastes with controlled flame combustion. The RCRA requirements for incinerators are cited at 40 CFR § 264.340 *et seq.* However, EPA announced on May 18, 1993 that no new hazardous waste incinerators will be allowed for 18 months under a temporary capacity freeze. Containers are defined as any portable device used for storing or handling hazardous waste, including drums, pails and boxes. In contrast, tank systems are stationary devices constructed primarily of nonearthen materials that provide structural support, and any ancillary equipment. RCRA requirements for containers are cited at 40 CFR § 264.170–264.178. In addition, ORNL must adhere to the requirements of 40 CFR 262, Subpart C, 49 CFR 172, Subpart D and E, 49 CFR 173, Subpart I, and WIPP-DOE-029. RCRA requirements for tanks are cited at 40 CFR § 264.190–264.199.

Surface impoundments are defined as any natural or man-made excavation or diked area designed to hold hazardous wastes containing free liquids, such as pits, ponds, or lagoons where as a waste pile is any noncontainerized accumulation of solid, nonflowing hazardous waste. Landfills are disposal facilities where hazardous waste is placed in or on the land. RCRA requirements for surface impoundments are cited at 40 CFR §§ 264.220–264.231. RCRA requirements for waste piles are contained in 40 CFR § 264.250–264.259. Last, RCRA requirements for landfills are located in 40 CFR § 264.300–264.317. (See Table 6.1).

Permitting Requirements under RCRA. Pursuant to RCRA, all facilities that treat, store, or dispose of hazardous or mixed waste are required to obtain a RCRA permit (40 CFR 270). Although, RCRA requires TSDFs to operate under the conditions of a permit, Congress, recognizing the time period necessary for EPA to issue all of the required permits, established interim status under Sect. 3005(e) of RCRA. Section 3005(e) allows owners or operators of facilities in existence on November 19, 1980 (or brought under Subtitle C due to an amendment), who meet certain conditions, to continue operating under interim status until a final permit application is approved or denied. As a result, eligible facilities were granted interim status as long as they submitted a Part A application by November 19, 1980 and are subject to the RCRA interim status standards cited at 40 CFR 265 until a Part B application is filed and a final decision on a permit has been made. Part B, the second part of the permit application, provides detailed facility information for all hazardous WM units at the facility. Therefore, existing facilities with interim status must submit the Part B application either when requested by EPA or a state agency or on the date mandated by RCRA, whichever date is earlier. Since 1984, DOE has been submitting to TDEC and EPA Part A hazardous WM permit applications according to Sect. 3005(e) of RCRA, 42 U.S.C. § 6925(e), and 40 CFR § 270.70 for various units at DOE-ORR. Through these efforts, DOE-ORR has been achieving interim status with respect to specific units. A list of the Part A applications submitted for the various units at ORNL is found in the FFCA/LDR, Appendix 4. DOE has been submitting Part B hazardous WM permit applications to TDEC and EPA since December 11, 1984 for various units at DOE-ORR, also listed in Appendix 4 of the FFCA/LDR. Last, Appendix 4 of the FFCA/LDR contains a list of sites for which permits have been issued.

Table 6.1.[7] RCRA[a] Subtitle C—standards for the treatment, storage, and disposal of hazardous waste

Federal	Tennessee	Category
40 CFR Part 264	*1200-1-11-.06*[b]	
Subpart I	Section 9	Containers
Subpart J	Section 10	Tanks
Subpart K	Section 11	Surface impoundments
Subpart L	Section 12	Waste piles
Subpart M	Section 13	Land treatment
Subpart N	Section 14	Landfills
Subpart O	Section 15	Incinerators
Subpart X	Section 19	Miscellaneous treatment units
40 CFR Part 265	*1200-1-11-.05*	
Subparts I-O	Sections 9-15	As listed above
Subpart P	Section 16	Thermal treatment
Subpart Q	Section 17	Chemical, physical, and biological treatment

[a]RCRA = Resource Conservation and Recovery Act.
[b]Rule 1200 of the Tennessee Department of Environment and Conservation Hazardous Waste Management Regulations.

6.3.4.10 Corrective Action Requirements

The HSWA of 1984 established a broad new mandate for the EPA and the states to take corrective action at hazardous waste TSDFs regulated under Subtitle C of RCRA (58 *FR* 8658, February 16, 1993). Pursuant to RCRA Sect. 3004(u), permits issued to TSDFs must address corrective action for all releases of hazardous waste or constituents from any solid waste management units (SWMUs) at the facility. Additionally, under RCRA Sect. 3008(h), EPA may issue administrative orders that compel corrective action at interim-status facilities. The implementing regulations under 40 CFR 264, Subpart F, require that an owner or operator of a SWMU establish a corrective action program and, at a minimum, discharge the duties listed at 40 CFR § 264.100(a) through (h). Also, all SWMUs must comply with the requirements listed in 40 CFR § 264.101 [40 CFR § 264.90(a)(2)]. For example, the owner or operator of a TSDF must institute corrective action as necessary to protect human health and the environment for all releases of hazardous waste or constituents from any SWMU at the facility and is not relieved from implementing corrective actions beyond the facility boundary, when necessary, to protect human health and the environment (40 CFR § 264.101).

In addition, on July 27, 1990, EPA issued a proposed rulemaking to establish under Subpart S of 40 CFR 264 a comprehensive regulatory framework for implementing corrective actions at RCRA facilities. EPA received numerous comments on the proposed Subpart S, which raised issues that must be resolved prior to a final rulemaking. EPA has delayed promulgating the Subpart S final rule until December 1993 (57 *FR* 52080, November 3, 1992). The proposed Subpart S regulations contained several key

remediation WM provisions (58 *FR* 8658, February 16, 1993). These provisions were to reduce or eliminate certain WM requirements of RCRA Subtitle C regulations that, when applied to remediation wastes, impede the use of innovative technologies and potentially more protective remedies.[5] As a result, EPA expedited the promulgation of these key provisions of Subpart S. The final Corrective Action Management Unit (CAMU)/Temporary Unit (TU) rule was published in the Federal Register on February 16, 1993 at 58 *FR* 8658. The effective date of the final CAMU/TU rule is April 19, 1993. A CAMU is defined as an area within a facility that is designated by the Regional Administrator under 40 CFR 264, Subpart S for the purpose of implementing corrective action requirements under 40 CFR § 264.101 and RCRA Section 3008(h) (58 *FR* 8683, February 16, 1993). Additionally, a CAMU shall only be used for the management of remediation wastes in order to implement corrective actions at the facility. Under this final rule, any waste generated as part of a facility's corrective action and managed within a CAMU is not subject to RCRA LDRs (58 *FR* 8662, February 16, 1992). Also, because CAMUs and TUs are limited to managing remediation wastes, they cannot be used to manage wastes generated from ongoing production processes or other industrial activities (as generated wastes) or to manage off-site wastes brought on site (unless the off-site wastes resulted from cleaning up a release originating on-site) (58 *FR* 8664, February 16, 1993). As applied to DOE sites, these CAMU/TU provisions imply that remediation wastes generated within the boundaries of contiguous property controlled by DOE at a site, or as part of cleaning up a release that has migrated off site, can be managed as CAMUs at that site without being subject to LDRs.[5]

EPA has determined that CAMU/TU regulations are less stringent than existing federal corrective action requirements.[5] Therefore, CAMU/TU regulations will not apply in states authorized for the existing HSWA corrective action program until the states adopt comparable provisions under their own state law.[5] States that are not yet authorized for corrective action are not required to include the rule's provisions in their programs when they seek authorization.[5] However, if any unauthorized state has adopted corrective action standards more stringent than the final CAMU/TU rule, the state standards apply.[5] As a result, the rule takes effect immediately in states that are unauthorized for the RCRA base program and states that are authorized for the RCRA base program but are not yet authorized for the HSWA corrective action program.[5] Tennessee is not authorized for the HSWA corrective action program.[6] Therefore, the CAMU/TU rule will take effect immediately in Tennessee.[6] However, Tennessee does have corrective action regulations that ORNL must comply with. Additionally, Tennessee is currently in the process of drafting CAMU/TU regulations.[6] If an ORNL site taking corrective action has a RCRA permit, CAMUs can be designated by an EPA-initiated permit modification, or by a request made by the site's WM personnel according to procedures for an owner/operator-initiated Class 3 permit modification.[5] For interim status facilities, CAMUs can be designated only through a RCRA Sect. 3008(h) Order (58 *FR* 8672-73, February 16, 1993). If a site is already subject to a Sect. 3008(h) Order, the order would have to be amended to reflect the added CAMU.[5] However, there is no regulatory mechanism for sites to initiate a Sect. 3008(h) Order or an order modification.[5] As part of the final Subpart S rule, EPA will consider possible options that allow accelerated cleanups to proceed outside the context of an enforcement order at interim status facilities (58 *FR* 8673, February 16, 1993). As a result, WM at DOE interim status sites must await action from EPA under Sect. 3008(h) before using CAMUs.[5]

As previously noted, placing remediation wastes into a CAMU does not constitute land disposal of hazardous waste [40 CFR § 264.552(a)(1)]. In addition, consolidation or placing remediation wastes into the CAMU does not create a hazardous WM unit subject

to minimum technology requirements (MTRs) [40 CFR § 264.552(a)(2)]. Therefore, remediation wastes generated at a DOE site, but outside a CAMU, can be consolidated into the CAMU, and remediation wastes can be moved between two or more CAMUs at the site without triggering LDRs.[5] Also, if remediation wastes are excavated from a CAMU, treated in a separate unit inside or outside the CAMU at the site, and redeposited into the CAMU, LDRs are not triggered because 40 CFR § 264.552(a)(1) indicates that placing treated wastes into the CAMU is not land disposal.[5] Additionally, MTRs do not apply to the excavated area receiving the redeposited material (40 CFR § 264.552(a)(2).

When designation of a CAMU is being considered for ORNL, WM personnel are required to provide enough information so that the Regional Administrator can determine that the CAMU will meet the following seven criteria pursuant to 40 CFR § 264.552(c):

1. The CAMU will help implement a reliable, effective, protective, and cost-effective remedy [40 CFR § 264.552(c)(1)].
2. CAMU-associated WM activities will not create unacceptable risks to humans or to the environment as a result of exposure to hazardous wastes or constituents [40 CFR § 264.552(c)(2)].
3. The CAMU will include uncontaminated facility areas (to manage remediation waste) only if doing so is more protective than managing such wastes at contaminated facility areas [40 CFR § 264.552(c)(3)].
4. Areas within the CAMU, where wastes remain after CAMU closure, will be managed and contained to minimize future releases to the extent practicable [40 CFR § 264.552(c)(4)].
5. The CAMU will expedite the timing of remedial activity implementation when appropriate and practicable [40 CFR § 264.552(c)(5)].
6. The CAMU will allow the appropriate use of treatment technologies (including innovative technologies) to enhance RA by reducing the toxicity, mobility, or volume of wastes that remain after CAMU closure [40 CFR § 264.552(c)(6)].
7. To the extent practicable, the CAMU will minimize the facility's land area upon which wastes will remain after CAMU closure [40 CFR § 264.552(c)(7)].

In addition, a permit or an order designating a CAMU must contain the requirements listed at 40 CFR § 264.552.

Furthermore, the final CAMU/TU rule authorizes the EPA Regional Administrator to designate as TUs certain tanks and container storage areas within a facility's boundaries but not necessarily within a CAMU's boundaries.[5] At ORNL, the designation may be initiated by WM personnel as a Class 2 permit modification, by EPA (or by the state of Tennessee when authorized) as an agency-initiated permit modification, or as a RCRA Sect. 3008(h) Order or order modification [40 CFR § 264.553(f)]. Under the new rule, a TU must be used only for treating and storing remediation wastes generated at the site and its operating time must be limited to one year or less [40 CFR § 264.553(b) and (d)]. Last LDR and MTR applicability is not a concern for TUs since tanks and container storage areas are nonland based units.[5]

6.3.4.11 RCRA Land Disposal Restrictions

The HSWA enacted in 1984 required the EPA to evaluate all listed and characteristic hazardous wastes according to a strict schedule and to develop requirements by which disposal of these wastes would be protective of human health and the environment. The HSWA were designed to minimize the country's reliance on land disposal of untreated

hazardous wastes, and to require advance treatment and recycling of wastes. The implementing regulations for accomplishing this statutory requirement are established within the LDRs. The LDRs are codified at 40 CFR 268. Additionally, Tennessee has a LDR program that is similar to the federal LDR program and is found at TDEC 1200-1-11-.10. These LDR regulations impose significant requirements on WM activities at ORNL. For hazardous wastes restricted by statute from land disposal, EPA is required to set levels or methods of treatment that substantially reduce the waste's toxicity or the likelihood that the waste's hazardous constituents will migrate. Upon the specified LDR effective dates, restricted wastes that do not meet concentration-based treatment standards are prohibited from land disposal unless they qualify for certain variances or exemptions.

The HSWA established a series of statutory deadlines for EPA to implement rules defining conditions under which land disposal could occur. All of these deadlines established by statute have passed. The statutory deadlines applied to particular groupings of wastes that were listed or identified as hazardous as of November 8, 1984. Pursuant to HSWA, hazardous wastes listed or identified after 1984 must be addressed within six months of the date of identification or listing. However, EPA has not met this requirement for establishing standards for all newly listed or identified wastes.

Land disposal is defined as the placement in or on the land and includes, but is not limited to, placement in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, underground mine or cave, or placement in a concrete vault or bunker intended for disposal purposes [40 CFR § 268.2(c)]. Pursuant to the LDR requirements and after specified effective dates, the disposal of RCRA hazardous wastes in or on the land is prohibited unless the waste has been treated to meet applicable treatment standards or it has been demonstrated to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous. Treatment standards are based on the performance of the best demonstrated available technology and are either constituent concentration levels (in the waste or a waste extract) that reflect the performance of best demonstrated available technology, or as specific treatment technologies.

Congress mandated a series of five LDR rulemakings under HSWA. Additionally, at specified deadlines, further land disposal of particular categories of hazardous wastes was to be prohibited if EPA had not set treatment standards, provided an extension to the LDR effective date, or granted a no-migration petition. The following are the five mandated LDR rulemakings:

1. **Solvent-Dioxin Rule.** This rule was effective on November 8, 1986 and established the framework for implementing the LDR program. The rule also included specific treatment standards and effective dates for the first category of wastes subject to the restrictions, F001-F005 spent solvent wastes, and F020-F023 and F026-F028 dioxin-containing wastes.
2. **California List Rule.** This rule was effective on July 8, 1987.
3. **First Third Rule.** This rule was effective on August 8, 1988 and covered 183 hazardous wastes. Also, it prohibited the land disposal of 62 wastes and set restrictions on 121 others.
4. **Second Third Rule.** This rule was effective on June 8, 1989. The treatment standards for 67 additional wastes and for the F-coded wastes not addressed in the First-Third Rule are established in this rule. This rule sets treatment standards for

many Second-Third wastes, some First-Third wastes subject to soft hammer provisions, and certain Third-Third wastes.

5. **Third-Third Rule.** This rule was effective on May 8, 1990 and sets treatment standards and imposes restrictions on 344 listed wastes, five newly listed wastes, and the characteristic hazardous wastes (except for the newly identified TC wastes). Additionally, the rule established treatment standards specific to certain radioactive mixed waste.

A sixth major LDR final rule was published by EPA in the *Federal Register* on August 18, 1992, which covers certain newly listed wastes and hazardous debris (57 *FR* 37194). Pursuant to this rule, hazardous debris, subject to RCRA Subtitle C standards, must be treated prior to land disposal by using specific technologies from one or more of the following families of debris treatment technologies: extraction, destruction, or immobilization (57 *FR* 37196, August 18, 1992). However, hazardous debris may continue to be handled in accordance with the contained-in policy and land disposed if it no longer contains a hazardous waste (57 *FR* 37196, August 18, 1992). Also, residuals generated from the treatment of debris contaminated with listed wastes would still be hazardous wastes pursuant to the derived-from rule and would be subject to the hazardous WM system (57 *FR* 37196, August 18, 1992).

In addition, EPA has promulgated revised treatment standards for certain ignitable and corrosive wastes that are not managed in one of the following ways: (1) in centralized wastewater treatment systems subject to the CWA or in Class I underground injection wells subject to the Safe Drinking Water Act Underground Injection Control program; or, (2) by a zero discharger with a wastewater treatment system equivalent to that utilized by CWA dischargers prior to land disposal (58 *FR* 29866, May 24, 1993). This interim final rule was effective on May 10, 1993 and added 40 CFR § 268.37 "Waste specific prohibitions—Ignitable and corrosive characteristic wastes whose treatment standards were vacated" to 40 CFR 268, Subpart C, "Prohibitions on Land Disposal." The treatment standards that were promulgated in the interim rule retained the requirement of deactivation to remove the hazardous characteristic and established numerical treatment standards for the underlying hazardous constituents that may be present in the wastes (58 *FR* 29866, May 24, 1993). EPA is granting a three-month national capacity variance that extends the effective date until August 9, 1993, for persons affected by the interim final rule, and an additional extension for those who manage ignitable or corrosive wastes and dispose of them in Class V UIC wells, which facilities are not performing CWA-equivalent treatment before injection, that extends the effective date until February 10, 1994 (58 *FR* 29866, May 24, 1993).

Under the LDR regulations, storage of prohibited wastes by generators or TSDFs is prohibited except where storage is solely for the purpose of accumulating sufficient quantities of waste to facilitate proper treatment, recovery or disposal. However, TSDFs may store restricted hazardous wastes for the purpose of accumulating such quantities of hazardous waste necessary to facilitate proper recovery, treatment, or disposal as long as the requirements listed in 40 CFR § 268.50 are complied with. Tanks and containers that are used for storing restricted wastes must be clearly marked with a description identifying the contents, and with the date on which accumulation of waste in the tank or container began (40 CFR § 268.50). However, wastes that are placed in storage prior to the LDR effective date applicable to that waste are not subject to the LDR prohibitions on storage.

The LDR regulations provide compliance alternatives that delay the effective date of prohibitions or allow a variance from the prohibitions. Under certain conditions, EPA may

grant a variance from the treatment standard, an extension to the LDR effective date based on capacity determinations, or an exemption from the prohibition for a specific waste at a specific site. The following are the six types of variances, extensions and exemptions EPA has established:

1. **National Capacity Variance.** A national capacity variance is provided when EPA determines that sufficient treatment capacity for specific RCRA hazardous waste codes is not available on a nationwide basis. During the period of a national capacity variance, the waste may be land disposed without treatment. The variance extends the LDR effective date of the waste until the earliest date treatment capacity becomes available, but the variance cannot be longer than two years. When the LDR effective date for a waste is extended, the new effective date is listed in Appendix VII of 40 CFR 268.
2. **Case-by-Case Extension.** A case-by-case extension may be granted if WM can demonstrate that a binding contractual commitment exists to provide alternative treatment for the waste, but through no fault of WM, this new capacity cannot be brought on line by the effective date of the LDR standards (40 CFR § 268.5). EPA may grant a case-by-case extension of up to one year, renewable only once, for a total of two years (40 CFR § 268.5). In November 1991, DOE submitted an application to EPA requesting a case-by-case extension for certain mixed wastes subject to the Third–Third LDR rule. On May 26, 1992, EPA published in the *Federal Register* a notice of proposed decision to grant a one-year extension for mixed wastes addressed in the DOE case-by-case petition (57 *FR* 22024). Additionally, EPA published a notice approving a generic case-by-case capacity variance for many types of hazardous debris (57 *FR* 20766, May 15, 1992 and 57 *FR* 47772, October 20, 1992). EPA indicated that the case-by-case capacity variance would end on May 8, 1993. However, under 40 CFR § 268.5, EPA renewed the extension of the case-by-case variance to May 8, 1994, for all persons managing certain hazardous debris (58 *FR* 28506, May 14, 1993).
3. **Treatability Variance.** Generators whose wastes cannot be treated to the established treatment standards may petition EPA for a treatability variance. In order for a treatability variance to be granted, WM must successfully demonstrate that the waste differs significantly from the wastes evaluated by EPA in developing the treatment standards (40 CFR § 268.44). Also, WM must demonstrate that the waste cannot be treated to the level or by the method specified as the treatment standard, or that the existing level or method is inappropriate for the waste.
4. **Equivalent Method Variance.** If EPA has specified a method of treatment as the treatment standard for a waste, WM may submit an application to the EPA Administrator demonstrating that an alternative treatment method can achieve performance equivalent to that of the method specified as the treatment standard [40 CFR § 268.42(b)]. If approved, wastes treated by this alternative treatment method comply with the treatment standard and thus can be land disposed.
5. **No-Migration Petition.** EPA will consider allowing land disposal of restricted wastes if it can be demonstrated to a reasonable degree of certainty that such disposal will not allow migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous (40 CFR § 268.6). A successful no-migration petition will allow land disposal of specific restricted wastes at a specific site.
6. **Treatment in Surface Impoundment Exemption.** Owners and operators of surface impoundments seeking an exemption for treatment of restricted wastes must certify

to the EPA Regional Administrator that the impoundment meets MTRs and must submit a copy of the facility's revised waste analysis plan that outlines methods for representative sampling and proper testing, frequency of removal, and methods for removal of restrictive residuals (40 CFR § 268.4).

Restricted wastes are those categories of hazardous wastes that are prohibited from land disposal, regardless of whether or not subcategories of such wastes are subject to a case-by-case extension, no-migration exemption, or national capacity variance, any of which would make the waste eligible for land disposal. Therefore, if WM has a restricted waste, it is not necessarily prohibited from land disposal. However, prohibited wastes are restrictive wastes that are currently ineligible for land disposal. Restricted wastes, whether treated and disposed on site or sent off site to a TSDF, are subject to the testing and recordkeeping requirements, which include notification and certification requirements. Also, generators and treatment facilities must comply with the waste analysis and recordkeeping requirements cited at 40 CFR § 268.7. Records must be maintained of notices, certifications, demonstrations, and waste analysis.

In some instances, hazardous wastes prohibited from land disposal must be stored for short periods of time to facilitate recycling, recovery, treatment, or transport off site to meet LDR requirements. Treatment may also be performed while the waste is being stored. Prior to the effective date of Subpart DD, this type of management unit was classified as an indoor waste pile (57 *FR* 37211, August 18, 1992). Pursuant to Subpart DD, containment buildings are not land disposal units and prohibited wastes can be stored in containment buildings without first meeting a treatment standard (57 *FR* 37211, August 18, 1992). A containment building is defined as a hazardous waste management unit that is used to store or treat hazardous waste under the provisions of 40 CFR 264, Subpart DD and 40 CFR 265, Subpart DD. Permitted and unpermitted containment buildings must meet the same level of performance (57 *FR* 37211, August 18, 1992). As a result, containment buildings operated under Subpart DD interim status standards must be designed, operated, and maintained to meet the same design and operating requirements as permitted containment buildings (see Table 6.2).

6.3.4.12 Underground Storage Tanks under Subtitle I

In an attempt to address the problems with underground storage tanks (USTs), Congress enacted the HSWA of 1984 which in part added Subtitle I, "Regulation of Underground Storage Tanks" to RCRA. RCRA Subtitle I established a federal program for the regulation of USTs and required EPA to adopt regulations for new and existing USTs. Subtitle I addresses both the problem of existing tanks, which may have caused environmental problems, and new tanks, which should be designed and operated to eliminate the problems of the past. On September 23, 1988, EPA adopted final regulations governing USTs (53 *FR* 37082, September 23, 1988, codified at 40 CFR Part 280). The RCRA UST program is a delegated program that allows states to adopt laws and regulations that meet the minimum federal standards. As a result, EPA has delegated authority to certain states that have adequate UST programs. In these cases, states rather than EPA are the primary permitting and enforcement authorities for USTs. Additionally, on September 23, 1988, EPA finalized regulations permitting states to run UST programs in lieu of the federal program (53 *FR* 37212, September 23, 1988, codified at 40 CFR Part 281).

An UST is defined as any one or combination of tanks, including underground pipes connected thereto, that is used to contain an accumulation of regulated substances, and

Table 6.2. Federal RCRA[a] land disposal regulations

Waste category	Citation	40 CFR Part
Spent-solvent and dioxin-containing wastes	51 *FR* 40572 (Nov. 7, 1986)	268.30 268.31
"California List" wastes	52 *FR* 25760 (July 8, 1987)	268.32
First Third wastes[b]	54 *FR* 31138 (Aug. 17, 1988)	268.33
Second Third wastes[b]	54 *FR* 26594 (June 23, 1989)	268.34
Newly Listed wastes	57 *FR* 37194 (Aug. 18, 1992)	268.36
Ignitable and Corrosive Characteristic wastes whose treatment standards were vacated	58 *FR* 29860 (May 24, 1993) Interim Final Rule	268.37
Final Third wastes[b]	55 *FR* 22520 (June 1, 1990)	268.35

[a]RCRA = Resource Conservation and Recovery Act.
[b]All listed hazardous wastes identified under 40 CFR 261.
Source: E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *ARARs for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R1, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, 1992.

the volume of which, including the volume of underground pipes connected thereto, is 10% or more beneath the surface of the ground (40 CFR § 280.12). However, the following systems are specifically excluded from the definition of UST under RCRA Subtitle I:

1. farm or residential tanks of 1100 gal or less capacity that are used noncommercially for storage of motor fuel;
2. heating oil storage tanks that are used on the premises where the tank is stored;
3. septic tanks;
4. pipeline facilities (including gathering lines) that are regulated under:
   a. The Natural Gas Pipeline Safety Act of 1968, or
   b. The Hazardous Liquid Pipeline Safety Act of 1979, or
   c. state laws comparable to the provisions of law referred to in subparagraphs a or b above;
5. surface impoundments, pits, ponds, or lagoons;
6. stormwater or wastewater collection systems;
7. flow-through process tanks;
8. liquid traps or associated gathering lines directly related to oil or gas production and gathering operations;
9. storage tanks that are situated in an underground area if the tank is situated upon or above the surface of the floor in that area; or
10. pipes connected to any of the tanks which are described in subparagraphs 1 through 9 above.

In addition to the systems excluded from the definition of UST, several systems are specifically excluded from regulation under RCRA Subtitle I. These systems include the following:

1. UST systems holding hazardous wastes listed or identified under Subtitle C of RCRA, or a mixture of such hazardous wastes and other regulated substances;
2. Wastewater treatment tank systems that are part of a wastewater treatment facility regulated under Sect. 402 or Sect. 307(b) of the CWA;
3. Equipment or machinery that contains regulated substances for operational purposes;
4. UST systems with capacities of 110 gal or less;
5. UST systems that contain a *de minimis* concentration of regulated substances; and
6. emergency spill or overflow containment UST systems that are expeditiously emptied after use.

Also, EPA has deferred several other UST systems from some of its regulations. These deferred UST systems include the following:

1. wastewater treatment tank systems;
2. UST systems containing radioactive material that are regulated under the AEA of 1954;
3. UST systems that are part of an emergency generator system at nuclear power generation facilities regulated by the Nuclear Regulatory Commission (NRC) under 10 CFR Part 50, Appendix A;
4. airport hydrant fuel distribution systems; and
5. UST systems with field-constructed tanks.

As stated in the definition of UST, the RCRA UST program applies to tanks that contain "regulated substances." A regulated substance means any substance defined in Sect. 101(14) of CERCLA but not including any substance regulated as a hazardous waste under RCRA Subtitle C and petroleum, including crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure (40 CFR § 280.12). Regulated substances include, but are not limited to, petroleum and petroleum-based substances comprised of a complex blend of hydrocarbons derived from crude oil through processes of separation, conversion, upgrading, and finishing, such as motor fuels, jet fuels, distillate fuel oils, residual fuel oils, lubricants, petroleum solvents, and used oils (40 CFR § 280.12). Therefore, Subtitle I does not apply to any UST system holding a listed hazardous waste or waste that exhibits a hazardous characteristic under Subtitle C of RCRA, or a mixture of such hazardous waste and other regulated substances. Rather, hazardous wastes are regulated under RCRA Subtitle C. Although RCRA hazardous wastes are excluded, petroleum or CERCLA hazardous substances in UST storage that meet the definition of RCRA solid wastes are not excluded from Subtitle I.

However, for WM activities involving the low-level radioactive waste tank system, Sect. IX of the FFA applies and the requirements listed in the FFA must be met. Appendix F lists the four categories of tank systems associated with ORNL, which are the following: new or replacement tank systems with secondary containment, existing tank systems with secondary containment, existing tank systems without secondary containment, and existing tank systems without secondary containment that are removed from service. The requirements listed in Subsections B through D apply to existing tank systems that have secondary containment and to new or replacement tank systems installed after the

effective date of the FFA which was January 1, 1992. The requirements listed in Subsections E and F apply to existing tank system(s) that do not have secondary containment, while the requirements of Subsection G apply to all tank systems that are permanently removed from service. Also, Appendix F of the FFA illustrates the requirements of Sect. IX by listing the standards for integrity assessment for tank system(s), standards for design/installation of new or replacement tank systems, standards for containment/release detection, and requirements of leaking tank system(s).

For WM activities involving new UST systems, any owner who brings an UST system into use after May 8, 1986 must notify the designated regulatory agency of the existence of such a tank system within 30 days of bringing the UST into use [40 CFR § 280.22(a)]. Additionally, owners and operators of new UST systems must certify in the notification form that they have complied with the requirements for installation of tanks and piping, cathodic protection, financial responsibility, and release detection [40 CFR §280.22(e)(1) through (4)]. Also, the installer of the UST systems must certify in the notification form that the methods used to install the tank system comply with the industry codes of practice developed by a nationally recognized association or independent testing laboratory in accordance with the manufacturer's instructions [40 CFR § 280.20(e)]. Furthermore, owners and operators of new UST systems must meet the performance standards for tanks [40 CFR § 280.20(a)], piping [40 CFR § 280.20(b)], spill and overfill prevention equipment [40 CFR § 280.20(c)], and installation [40 CFR § 280.20(d)].

For WM activities involving existing UST systems, those UST systems that were in the ground on or after May 8, 1986, owners are required to notify the designated regulatory agency of the existence of the tank system, unless the owner knew that the tank system was subsequently removed from the ground. However, no notification is required if the UST systems were taken out of operation on or before January 1, 1974. Additionally, all existing UST systems are required pursuant to 40 CFR § 280.21(a) to meet one of the following requirements by no later than December 22, 1998: new UST system performance standards under 40 CFR § 280.20, tank upgrading requirements in 40 CFR § 280.21(b) through (d), or closure and corrective action requirements in 40 CFR 280, Subpart G and F, respectively. Also, existing UST systems must comply with the new UST system requirements for spill and overfill prevention cited at 40 CFR § 280.20(c). Existing metal piping systems must also be upgraded to meet the performance standards for new piping systems pursuant to 40 CFR § 280.21(c).

The general operating requirements for UST systems are found at 40 CFR 280, Subpart C. Some of the general operating requirements include the following: spill and overfill control requirements found at 40 CFR § 280.30, operation and maintenance of corrosion protection systems requirements found at 40 CFR § 280.31, substance compatibility requirements found at 40 CFR 280.32, UST system repairs requirements found at 40 CFR § 280.33, reporting and recordkeeping requirements found at 40 CFR § 280.34.

In addition, owners and operators of new and existing UST systems must provide a method or combination of methods of release detection that can detect a release from any portion of the tank and connected underground piping that routinely contains regulated substances (40 CFR § 280.40). Some of the requirements for release detection govern the installation, operation and performance of release detection equipment and methods for tanks (40 CFR § 280.40 *et seq.*). However, the date by which owners and operators of UST systems must comply with release detection requirements depends on when the tank and piping systems were installed because these requirements are being phased in (40 CFR § 280.40).

Also, 40 CFR 280, Subpart D, contains specific requirements for petroleum USTs. For example, USTs containing petroleum products must be monitored at least every 30 days for releases (40 CFR § 280.41). However, the 30-day monitoring requirement does not apply to those UST systems that meet the performance standards for new and upgraded tank systems and employ monthly inventory control or monthly manual tank gauging in conjunction with tank tightness testing. Also, UST systems that do not meet the performance standards for new or upgraded USTs may use monthly inventory controls or manual tank gauging in conjunction with annual tank tightness testing until December 22, 1998 when the tank must be upgraded or permanently closed [40 CFR § 280.419(a)(2)]. Owners and operators of tanks with capacities of 550 gal or less may use weekly tank gauging in lieu of other release detection methods [40 CFR § 280.41(a)(3)]. Furthermore, underground piping systems must also be monitored for releases pursuant to the requirements listed in 40 CFR § 280.41(b). For example, underground piping that conveys regulated substances under pressure must be equipped with an automatic line-leak detector and have annual line-tightness testing or monthly monitoring [40 CFR § 280.41(b)(1)].

40 CFR 280, Subpart D, also contains specific requirements for hazardous-substance UST systems that must be complied with. First, owners and operators of existing hazardous-substance UST systems must employ release detection that at least meets the requirements for petroleum UST systems until December 22, 1998 [40 CFR § 280.42(a)]. After December 22, 1998, all existing hazardous-substance UST systems must comply with the release detection requirements for new hazardous-substance UST systems [40 CFR § 280.42(a)]. Secondly, 40 CFR § 280.42(b) requires that new hazardous substance UST systems to have secondary containment systems and be checked for evidence of a release at least every 30 days. Also, underground piping that conveys hazardous substances must also be equipped with secondary containment and, if under pressure, must also be equipped with an automatic line-leak detector system [40 CFR § 280.42(b)].

Owners and operators of UST systems must report any suspected release to the implementing agency within 24 hours or another reasonable time period specified by the implementing agency (40 CFR § 280.50). 40 CFR 280, Subpart E, contains the requirements for the reporting of suspected releases that must be complied with if any WM activities result in suspected releases.

If any WM activities involve the temporary closure of a UST for an extended period, the requirements governing the operation and maintenance of corrosion protection and release detection systems—as well as requirements for release reporting, investigation, confirmation, and corrective action if a release is suspected or confirmed during the period of temporary closure—must still be complied with. The requirements for temporary closure are cited at 40 CFR § 280.70. Additionally, 40 CFR § 280.71 contains the requirements for permanent closure and changes-in-service of UST systems. First, if any WM activities involve either permanent closure or a change-in-service of a UST system, then the implementing agency must be notified at least 30 days before beginning either activity of the intent to undertake the activity, unless the action is in response to corrective action associated with any release from the UST system [40 CFR § 280.71(a)]. For permanent closure, the tanks must be emptied, cleaned, and either removed from the ground or filled with inert solid material (40 CFR § 280.71).

As stated previously, EPA has primary responsibility for implementation and enforcement of RCRA Subtitle I. However, under the UST program, EPA may delegate this authority to the states. As a result, on December 8, 1989, Tennessee adopted the Underground Storage Tank Program cited at TDEC Rules 1200-1-15-.01 *et seq.* Under

the Tennessee regulations, a UST is defined as any one or combination of tanks, including underground pipes connected thereto, that is used to contain an accumulation of petroleum, and the volume of which, including the volume of underground pipes connected thereto, is 10% or more beneath the surface of the ground. In contrast to the federal definition of an UST, the Tennessee definition of a UST refers specifically to tanks used to contain an accumulation of petroleum where as the federal definition of a UST refers to tanks used to contain an accumulation of regulated substances. The Tennessee requirements for petroleum USTs are cited at TDEC Rules 1200-1-15-.01 *et seq.* Additionally, it should be noted that ORNL complies, as a Best Management Practice (BMP), with TDEC Rule 1200-1-15-.04 with regard to UST systems that store fuel solely for use by emergency power generators even though TDEC Rule 1200-1-15-.01(1)(c) exempts the application to TDEC Rule 1200-1-15-.04 to these UST systems.

6.4 RADIOACTIVE-WASTE MANAGEMENT

6.4.1 General Requirements

The radioactive WM activities at ORNL deal primarily with TRU and low-level wastes. ORNL generates small amounts of NARM, which are managed as low-level waste. Although ORNL does not generate high-level waste, it does store a small amount of special case (SC) waste. Radioactive waste at ORNL exist in solid, liquid, and gaseous states.[2]

The AEA of 1946 first brought nuclear energy under federal regulation. The AEA, as amended, delegates authority to regulate nuclear energy to EPA, DOE, and the NRC. After the NRC has determined that a state's radiation control program is acceptable and state enabling legislation has been enacted, NRC's authority can be transferred to individual states by means of an agreement between the NRC and the state's governor. In 1965 Tennessee became an Agreement State, giving it licensing and other authority. Tennessee enforces NARM standards pursuant to TDEC Rules Chap. 1200-2-5, under the authority of TCA Chapter 23. DOE is not only exempt from NRC licensing but was delegated authority under the AEA to manage nuclear materials at sites that DOE oversees. However, in some instances, DOE facilities and operations are subject to regulatory requirements of the NRC and the EPA, including those found at 10 CFRs 60 and 72 and 40 CFRs 61, 191, and 192 [DOE Order 5400.5(II.c2)]. DOE orders outline the DOE regulations for management and, where needed, cleanup of radioactive materials.[1] Generally, DOE orders are not promulgated regulations; however, the orders are binding between DOE and Martin Marietta Energy Systems, Inc., based on contractual agreement. Because many of the requirements of DOE orders are based on NRC regulations, the requirements are frequently identical or similar. These orders are summarized in the following paragraphs. Because it addresses WM issues for various types of radioactive wastes, DOE Order 5820.2A, *Radioactive Waste Management*, is a primary driver of WM activities at ORNL. For this reason, this order will be discussed in greater detail than other orders. It will be specifically described under individual types of radioactive wastes, such as high level, TRU, and low level.[7]

6.4.1.1 DOE Orders

On March 25, 1993, DOE proposed for codification at 10 CFR 834 (58 *FR* 16268) radiation protection requirements for the public and environment for DOE and DOE contractor operations, as currently included in DOE Order 5400.5 (*Radiation Protection of the Public and the Environment*, February 8, 1990). The four basic areas encompassed in the proposal are as follows: (1) a dose limitation system for the protection of the public, (2) requirements for the management of radioactive materials in liquid-waste discharges, soil columns and selected solid waste, as well as establishment of site ground water protection programs, (3) requirements for decontamination, survey, management, storage, disposal, and release of buildings, land, equipment, personal property containing residual radioactive material, and (4) requirement of an Environmental Radiological Protection Program (ERPP) for each DOE activity, including effluent monitoring and environmental surveillance programs (58 *FR* 16268, March 25, 1993). The final rule is anticipated by March 1994[4].

DOE Order 5400.5 establishes standards and requirements for operations of DOE and DOE contractors for the protection of members of the public and the environment

against undue risk from radiation. These standards are adopted and implemented consistent with the recommendations of the International Commission on Radiological Protection (ICRP). Because DOE must comply with other federal, state, and local rules and regulations, some of which have not adopted the ICRP system, the DOE order includes both traditional dose terms and units as well as ICRP terms and concepts. The primary DOE dose standard to be applied to DOE, and thus, ORNL operations, including WM, D&D activities, RA monitoring, and cleanup of residual radioactive material, is 100 mrem/year [5400.5(I.3)]. To the extent required by 40 CFR 191, the radiation exposure limits for members of the public due to direct radiation or radioactive material released from DOE management and storage activities at a disposal facility for spent nuclear material, high-level waste or TRU radioactive wastes that are not regulated by the NRC are as follows: (1) an effective dose equivalent (EDE) of 25 mrem/year to the whole body, or (2) 75 mrem/year to any organ [5400.5(II.1c)]. An important principle throughout the order is that all releases of radioactive material shall be ALARA. Chapter IV of the order lists guidelines for cleanup of radioactive-real and personal property, management of the resulting wastes and residues, and release of property. Table 6.3 summarizes the contents of DOE Order 5400.5.[7]

DOE Order 5820.2A (*Radioactive Waste Management*, Sept. 26, 1988) establishes policies, guidelines, and minimum requirements by which the DOE manages its radioactive waste and contaminated facilities. The order is composed of six chapters that deal with radioactive waste categories individually—high-level waste, TRU, low-level waste, and NARM—as well as decommissioning requirements, and requirement and format for a WM plan for each DOE facility.[1] The order does not apply to the management by DOE of the following: (1) commercially generated spent nuclear fuel; (2) commercially generated high-level radioactive waste; nor (3) the geologic disposal of high-level waste produced by DOE activities and operations. The current version of ORNL's WM plan, as called for in the order, is the *Oak Ridge National Laboratory Waste Management Plan*, published in December 1992.[2]

DOE Order 5480.11 (*Radiation Protection for Occupational Workers*) establishes standards and DOE program requirements to protect workers from ionizing radiation. These standards, which also apply to DOE contractor operations, are pertinent to WM activities to the extent that workers are associated with radioactive wastes or that other persons, such as the general public, enter a controlled area. DOE's policy, reiterated in this order, is to maintain radiation exposures to levels ALARA. DOE's intent is to implement standards consistent with presidential-approved guidance to federal agencies, promulgated by EPA, and recommended by authoritative organizations, including the National Council on Radiation Protection and Measurements and the ICRP. This order specifies standards to protect occupational workers and on site members of the public (see Table 6.4). DOE has proposed regulations to be codified at 10 CFR 835, called "Radiation Protection for Occupation Workers," to promulgate radiation protection standards, limits, and program requirements for protecting workers and other persons from ionizing radiation at DOE facilities. The proposed rule includes subparts that describe "Posting and Labeling," "Design Control," "Radiation Safety Training," "Release of Material and Equipment from Radiological Areas," and "Accidents and Emergencies." Two major elements of the proposed regulations include requirements for a written Radiation Protection Program, as well as increased emphasis on ALARA exposure limits for worker protection (56 *FR* 64334, December 9, 1991). A final rule is expected in July 1993.[4] When promulgated, these standards will then be legal requirements for WM activities at ORNL.

Table 6.3. DOE Order 5400.5, "Radiation Protection of the Public and the Environment"

Action	Requirement	Chapter
Planning and performance of all DOE activities	DOE will carry out all DOE activities to ensure that radiation doses to individuals will be as low as reasonably achievable (ALARA).	I.4
Routine DOE activities including remedial action	DOE must comply with all legally applicable requirements of 40 CFR 61 (NESHAPS[a] for DOE Facilities) and 40 CFR 191 (spent nuclear fuel, high-level, and transuranic wastes).	I
	Exposures to members of the public from all radiation sources shall not cause an effective dose equivalent to be greater than 100 mrem (1 mSv) per year.	II.1a
	Exposures to members of the public from all radiation sources released into the atmosphere shall not cause an effective dose equivalent to be greater than 10 mrem (0.1 mSv) per year.	II.1b
Management and storage of spent nuclear fuel, high-level or transuranic waste at a disposal facility that is not regulated by the NRC[b]	Members of the public shall not receive an effective dose equivalent greater than 25 mrem (0.25 mSv) to the whole body or 75 mrem (0.75 mSv) to a single organ per year.	II.1c
	Radioactive materials released into public drinking water supplies shall not cause an effective dose equivalent to be greater than 4 mrem (0.4 mSv) to an individual per year. Gross alpha activity shall not exceed 1.5×10^{-8} µCi/ml.	II.1d
	Liquid effluents shall not cause private or public drinking water systems downstream of the facility to exceed the maximum contaminant level MCL(s) of 40 CFR 141.	II.1d(3)
Discharge of liquid waste containing radionuclides to surface water	Implementation of best available technology (BAT) treatment required if discharge is at an annual average concentration greater than the derived concentration guide (DCG) level.	II.3a(1)

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Table 6.3 (continued)

Action	Requirement	Chapter
Discharge of liquid waste containing radionuclides to surface water (continued)	Discharge of liquid waste containing radionuclides to surface water at an annual average concentration less than the DCG level does not require the implementation of BAT treatment.	II.3a(2)
	The absorbed dose to native aquatic animal organisms shall not exceed 1 rad/day from exposure to liquid wastes discharged to natural waterways.	II.3a(5)
	Liquid wastes containing concentrations of radioactive materials greater than 5 times the DCG(s) may be discharged to a federal sanitary sewerage system that provides liquid waste treatment prior to discharge to surface water according to II.3a(1). ALARA process considerations are required.	II.3d(3)
	If a waste stream contains multiple radionuclides, then the DCG shall be the sum of the fractional DCG values.	II.3a(3)
Management of low-level radioactive solid waste containing no RCRA[c] constituents	Design, operational, and monitoring requirements are found in DOE Order 5820.2A (Radioactive Waste Management).	II.4
Demonstration of compliance with the dose limits	DOE shall make appropriate documentation containing information about compliance with dose limits for members of the public in the immediate vicinity and within 80 km of the site.	II.6
Conduct of radiological environmental protection programs	DCGs for water ingestion, air inhalation, and immersion in a gaseous cloud are provided as reference values. These DCGs are based on a committed effective dose equivalent of 100 mrem for the radionuclide taken into the body by ingestion or inhalation during one year.	III.2
	The DCG values apply to only one mode of exposure (i.e., either ingestion or inhalation).	III.2a

Table 6.3 (continued)

Action	Requirement	Chapter
Conduct of radiological environmental protection program (continued)	For known mixtures of radionuclides the sum of the ratios of the observed concentration of each radionuclides to its corresponding DCG must not exceed 1.0.	III.2c
Management of resulting wastes or residues from cleanup of residual radioactive material	DOE facilities shall develop plans and protocols for the implementation of this guidance.	IV.1 & 2
	Monitoring, cleanup, and control of residual radioactive material are subject to the ALARA policy.	IV.2e
	The basic dose limits for exposure to residual radioactive material is 100 mrem (1 mSv) annually.	IV.3a
	Under unusual circumstances, the dose limit for exposure to residual radioactive material is increased from 100 mrem (1 mSv) to 500 mrem (5 mSv) annually.	IV.3b
Management of residual radioactivity above the guidelines specified in IV.1-4	Interim storage control and stabilization features shall be planned to have a minimum life of 25 years and, if reasonably achievable, an effective life of 50 years.	IV.6b(1)
	Control features must be designed so that radionuclide concentration in the groundwater shall not exceed applicable federal and state standards.	IV.6b(3)
	If residual radioactive material is in inaccessible locations and would be unreasonably costly to remove and when residual radioactive material exceeds guideline values, an interim management plan may be arranged to maintain the property.	IV.6c(1)
	Administrative controls shall include (but are not limited to): · periodic monitoring as appropriate, · appropriate shielding, · physical barriers to prevent access, and · appropriate radiological safety measures.	IV.6c(2)

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Table 6.3 (continued)

Action	Requirement	Chapter
Management of residual radioactivity above the guidelines specified in IV.1-4 (continued)	Control and stabilization for uranium, thorium, and their decay products must be designed to last at a minimum of 200 years and if reasonably achievable have an effective life of 1000 years.	IV.6d(1)(a)
	In accordance with legally applicable federal and state standards, DOE facilities shall protect groundwater.	IV.6d(1)(d)
	Use of and access to residual radioactive material shall be controlled through appropriate administrative and physical controls.	IV.6d(1)(e)
	Long-term management of other radionuclides shall be controlled by applicable requirements in Chapters II, III, and IV of DOE 5820.2A.	IV.6d(2)

[a]NESHAPS = National Emission Standards for Hazardous Air Polluting Substances.
[b]NRC = Nuclear Regulatory Commission.
[c]RCRA = Resource Conservation and Recovery Act.
Source: E. L. Etnier, E. P. McDonald, L. M. Haulberg, *ARARs for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R1, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, 1992.

Table 6.4. Radiation protection standards for ORNL Waste Management activities

Regulation	Applicability	Exposure conditions	Standard
40 CFR 61	National Emission Standards for Hazardous Air Pollutants for DOE facilities	Public exposure, airborne emissions	10 mrem/year
40 CFR 141	Drinking water maximum contaminant levels	Community water systems, gross beta	4 mrem/year
40 CFR 191	Spent nuclear fuel, high-level and transuranic wastes	Public exposure, all sources	25 mrem/year (total body) 75 mrem/year (thyroid)
DOE Order 5400.5[a]	Radiation Protection of the Public and the Environment	Public exposure, all sources	100 mrem/year
		Temporary exemption, maximum limit	500 mrem/year
		Aquatic organism exposure, absorbed dose	1 rad/d
DOE Order 5820.2A	Radioactive Waste Management	Public exposure, all sources.	25 mrem/year
		Public exposure, atmospheric releases	10 mrem/year
DOE Order 5480.11[b]	Radiation Protection for Occupational Workers	Worker exposure limits, continuous exposure	5 rem/year, cancer effects 50 rem/year, noncancer effects, any organ or tissue; other than loss of eye, 15 rem/year
		Public exposures, controlled areas, effective dose equivalent	100 mrem/year

[a]DOE plans to propose this order as 10 CFR 834 in March 1993 (58 *FR* 16268, March 25, 1993). The final rule is expected by March 1994.

[b]Proposed as 10 CFR 835 (56 *FR* 64334, Dec. 9, 1991); final rule expected July 1993.

Source: E. L. Etnier, E. P. McDonald, L. M. Haulberg, *ARARs for Remedial Action at the Oak Ridge Reservation, A compendium of Major Environmental Laws*, ES/ER/TM-1/R1, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, 1992.

6.4.1.2 Clean Air Act and Tennessee Air Quality Laws

Most gaseous wastes from ORNL are discharged through stacks.[2] Radioactivity may be present in gaseous wastes in any or all of three forms as a solid (particulates), as an absorbable gas, or as a nonabsorbable species (i.e., noble gas).[2] Before discharge, gaseous wastes that might contain radioactivity are treated to reduce the radioactivity to acceptable levels. Not only are stack effluents monitored, but atmospheric concentrations of materials are monitored continuously at 27 stations around ORNL, ORR, and the surrounding area.[2] The Clean Air Act (CAA) as amended, 42 U.S.C. 7401 *et seq.* establishes the requirements for control of airborne emissions from ORNL facilities.

Section 118 of the CAA emphatically clarifies that DOE, as a Department of the Federal Government, is to comply with the CAA in the same manner as any nongovernment entity. The State of Tennessee, as mandated by Sect. 110 of the CAA, has provided its own plan for the implementation, maintenance, and enforcement of air quality standards under the Tennessee Air Quality Act (TCA § 68-25-101 *et seq.*) and the Tennessee Air Pollution Control Regulations (TDEC Rules Chap. 1200-3-1 through 1200-3-21). The stated purpose of the rules is to "define ambient air quality standards to be achieved and maintained and to provide for an orderly and equitable regulation of air quality by limiting emissions of air contaminants." [TDEC Rule 1200-3-1-.01(2)]. An emission standard is a limit on the amount of air contaminant emitted from a source and is intended to bring the ambient air within acceptable "air quality limits." [TDEC Rule 1200-3-1-.01(6)]. With a few exceptions as noted at 40 CFR § 52.22, the Tennessee plans for the attainment and maintenance of the national standards are approved by EPA and satisfy all the requirements of Part D, Title I, of the CAA. The plan, called the Tennessee Air Pollution Control Implementation Plan, was officially submitted on January 27, 1972. The ambient standards (TDEC Rules Chap. 1200-3-3) are translated into source-specific emission limitations (TDEC Rules Chap. 1200-3-4 through 1200-3-21) that must be adhered to for daily compliance activities, as well as RAs or D&D activities.[1] Table 6.5 lists sections of the Tennessee air emission standards that should be analyzed on a site-specific basis for each WM, RA, or D&D activity or technology.

EPA promulgated the "National Emission Standards for Emissions of Radionuclides other than Radon from DOE Facilities" on December 15, 1989. Executive Order 12088 was signed on October 13, 1978 to ensure compliance of federal facilities with applicable pollution control standards. These standards are found at 40 CFR 61, Subpart H. DOE is considered an owner or operator of a facility under the CAA, and ORR, of which ORNL is a part, is an existing "stationary source," as defined in 40 CFR 61. 40 CFR § 61.92 under Subpart H, requires that emissions of radionuclides from DOE facilities not exceed those amounts that would cause any member of the public to receive in any year an EDE of 10 mrem/year. In order to determine the compliance with emission standards, 40 CFR § 61.93 details monitoring and test procedures of radionuclide emissions from point sources. As of May 1992, certain air emission monitoring systems at ORR did not comply with all the criteria specified in the National Emission Standards for Hazardous Air Pollutants (NESHAPs) regulations. The FFCA for Radionuclide NESHAPs, with EPA Region IV and DOE-Oak Ridge Operations as the parties, went into effect on May 26, 1992. Whenever an executive agency, in this case DOE, is notified that it is in violation of an applicable pollution control standard, that agency must provide a plan for achieving and maintaining compliance, including an implementation schedule. The above-mentioned agreement constitutes this plan. A schedule of compliance for ORR, including ORNL sources, has been developed based on consultation between EPA and DOE, in order to bring DOE-ORR into compliance as quickly and efficiently as is practical. The schedule is set forth in Appendix A of the signed agreement. In addition, DOE has agreed to submit monthly reports to EPA, describing its progress toward meeting the requirements of the agreement.

Table 6.5. Rules of the TDEC[a] Bureau of Environment Division of Air Pollution Control

Chapter	Subject
1200-3-1	General provisions
1200-3-2	Definitions
1200-3-4	Open burning
1200-3-5	Visible emissions
1200-3-6	Nonprocess emission standards
1200-3-7	Process emission standards
1200-3-8	Fugitive dust
1200-3-11	Hazardous air contaminants
1200-3-14	Control of sulfur dioxide emissions
1200-3-16	New source performance standards
1200-3-18	Volatile organic compounds
1200-3-21	General alternate emission standards
1200-3-22	Lead emission standards
1200-3-23	Visibility protection
1200-3-24	Stack height regulations

[a]TDEC = Tennessee Department of Environment and Conservation.

Source: E. L. Etnier, E. P. McDonald, L. M. Haulberg, *ARARs for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R1, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, 1992.

6.4.2 Regulation of Radioactive Waste

6.4.2.1 Transuranic Waste

40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Waste," establishes environmental protection standards for the management, storage, and disposal of spent nuclear fuel, high-level waste, and TRU wastes at all facilities operated by DOE. Management and storage must be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent, to any member of the general public, not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrems to any other critical organ (40 CFR § 191.03). If a DOE facility finds that such levels are exceeded continually, the facility can apply to EPA to issue alternative standards (§ 191.04). EPA may issue alternative standards if the agency decides that such alternative standards will prevent any member of the public from receiving a continuous exposure of more than 100 mrems per year dose equivalent and an infrequent exposure of more than 500 mrems dose equivalent yearly from all sources, excluding natural background and medical procedures. EPA proposed, on February 10, 1993, certain standards to establish limits for the release of radioactive materials to the environment (58 *FR* 7924; final rule expected, February 1994).[4] These standards would apply to the disposal of spent nuclear fuel and high-level waste and TRU radioactive waste and would require that disposal systems be designed so that undisturbed performance of the disposal system would not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment to exceed 15 mrem. These standards are to be codified at

40 CFR § 191.15 and Subpart C. At the same time, EPA proposed adding a provision to the EPA Underground Inspection Control Program regulations to clarify that compliance with 40 CFR 191, Subparts B and C, constitutes compliance with the federal SDWA statutory requirements and the Underground Inspection Control Program requirements, not to endanger underground sources of drinking water. This clarification will appear at 40 CFR § 144.31(a). Last, EPA has given advance notice of proposed rulemaking for compliance criteria with the standards codified at 40 CFR 191. The purpose of these criteria will be to provide EPA with tools to assess compliance of the WIPP facility with the 40 CFR 191 disposal standards (58 *FR* 8029, February 11, 1993).

EPA intends to develop public health and environmental radiation protection criteria for cleanup of residual radioactive materials at decommissioned DOE sites, Department of Defense sites, and NRC-licensed sites, as well as others. At present, no schedule for action for these criteria has been announced.[4]

DOE Order 5820.2A, Chap. II, addresses the management of TRU waste from its generation to burial. The stated policy is to manage these wastes in a manner protective of the public and workers, protective of the environment, and in compliance with regulations and radiation protection standards. The volume and toxicity of TRU waste is to be reduced in cost-effective and practical ways. Further, it is DOE policy that TRU waste be certified in compliance with the WIPP-Waste Acceptance Criteria, placed in interim storage if required, and sent to the WIPP. This plant, an R&D facility of DOE, is to be used for demonstrating the safe disposal of radioactive wastes from defense activities. A five-year test phase will be conducted to determine whether TRU waste can be permanently and safely stored at WIPP. Once this test has been met and the decision is made to use WIPP for permanent storage, WIPP will operate as a waste repository for 20 years. If and when WIPP begins accepting TRU waste, all certified TRU waste, including mixed, is to be deposited at this site. DOE has submitted to EPA for review of the WIPP Test Phase Plan and the WIPP Waste Retrieval Plan. The submittal was in accordance with the WIPP Land Withdrawal act. The WIPP Test Phase Plan: (1) describes the Test Phase activities to be conducted at WIPP; (2) specifies the quantities and types of TRU waste required for such activities; (3) describes how the activities will provide information directly relevant to a certification of compliance with the final disposal regulations or compliance with the SWDA; and (4) provides justification for the activities. The WIPP Waste Retrieval Plan describes the plan for the removal of the waste put in place during the WIPP Test Phase, if such removal is required under the Act. EPA will review these plans and determine, through a rulemaking, whether to approve, in whole or in part or disapprove the Test Phase Plan and whether to approve or disapprove the Waste Retrieval Plan (58 Fed Reg. 15845, March 24, 1993). Other TRU waste that does not need the degree of isolation of a geologic repository or that cannot be certified for acceptance at WIPP must be disposed of by alternate means. These means must comply with EPA and state requirements and with National Environmental Policy Act (NEPA).

A mandate of DOE Order 5820.2A is that waste be classified. ORNL must evaluate as soon as possible, all material known or suspected of being contaminated with transuranium radionuclides. In order to avoid the commingling of different waste streams, the appropriate persons must determine if the waste falls into one of the following categories: recoverable material, TRU waste, low-level waste, mixed waste, or non-radioactive waste. Mixed TRU waste meeting the WIPP-waste acceptance criteria must be sent to WIPP. Generators must include in the Data Package, information on the kinds and quantities of hazardous components in each waste package, in accordance with RCRA regulations.

At the time of generation or treatment, technical and administrative controls must be used to reduce the gross volume generated and the amount of radioactivity requiring disposal. Generators of TRU waste are to use technical and administrative controls to reduce TRU-waste volume or the amount of radioactivity requiring disposal, wherever cost-effective or feasible. Treatment facilities must be permitted under the appropriate regulatory authorities (i.e, RCRA and state rules). TRU waste must be assayed or evaluated prior to storage to estimate the hazardous-waste components, and treated, where feasible, to destroy the hazardous-waste component. The generator must declassify classified TRU waste by treating to remove the classified characteristics before certification.

After certification according to the WIPP-WAC, the waste is to be placed in interim storage to be sent to WIPP when operational. In order to assure safe storage consistent with RCRA, TRU waste must be either clearly identified or separated from HLW and LLW. It is to be monitored periodically and stored in such a manner that radiation exposures are ALARA.

All TRU waste certification sites must prepare a certification plan describing how the WAC are met. Each certification plan is to define its quality assurance activities. The certification plans are submitted for review by the WIPP-WAC Certification Committee, which submits it to the New Mexico Environmental Evaluation Group for review and comment before approval of such plans is granted. The *ORNL TRU Waste Management Strategy Plan*, issued in March 1990, outlines the actions necessary to store ORNL TRU waste in a compliant, safe manner, to certify the waste to meet WIPP-WAC, and to ship to the WIPP. ORNL also issued the updated *ORNL Contact-Handled-TRU Waste Certification Program Plan* for approval by the WIPP-WAC Certification Committee. Generating sites implement the approved certification plan utilizing written operating procedures. Periodic auditing of certification activities will occur. Failure to resolve and bring closure to audit findings or sending non-complying waste to WIPP will be judged by the WIPP-WAC Certification Committee to be serious violations, resulting in suspension of certification authority.

Newly generated TRU waste must be placed in non-combustible packaging meeting DOT regulations. All Type A TRU waste containers must be equipped with pressure-relief devices, and all packagings must be marked, labeled, and sealed in accordance with WIPP-WAC, EPA, and DOT regulations before shipping. In addition, ORNL must adhere to the requirements of 40 CFR 262, Subpart C, 49 CFR 172, Subpart D and E, 49 CFR 173, Subpart I, and WIPP-DOE-029.

Section 3(f) of the DOE Order 5820.2A specifies requirements for shipping of TRU waste. Among these are adherence to 49 CFR 172, Subpart C, WIPP DOE-157, and as necessary, the manifest required by 40 CFR 261 and 262. Type B packaging is required for all TRU waste as well as a DOE-controlled carrier system, if shipped by truck. "Exclusive use" vehicles, as defined in 49 CFR 173, must be utilized in all shipments.

Provisions have been made for interim storage facilities in Sect. 3(g) to provide for certain uncertified waste and for certified waste by off-site as well as on-site generators. Design, construction, and operation of new interim storage facilities must meet RCRA requirements. Precise details should be drawn from the Order itself.

The DOE report, "Comprehensive Implementation Plan for the DOE Defense Buried Transuranic-Contaminated Waste Program," (DOE-J10-025, September 1987), addresses alternatives to the long-term management of buried TRU-contaminated waste at inactive DOE waste sites, including those at ORNL. Closure is to occur at each site, in accordance with all federal and state regulations, including RCRA and CERCLA. After each waste site

is characterized, a closure strategy is to be developed. Each site must also have a closure plan; a list of requirements for the plan is found at Sect. 3(i) of the Order.

6.4.2.2 High-Level Radioactive Waste

40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," discussed under the heading of TRU Waste, describes environmental protection standards for the management, storage, and disposal of high-level waste at all facilities for the disposal of such fuel or waste operated by DOE. Just as with TRU waste, liquid and solidified high-level waste must be characterized consistent with radiation protection requirements to determine its hazardous components, per 40 CFR 261 and 40 CFR 264.

DOE Order 5820.2A, Chap. III, establishes internal policies for the management of high-level waste and other materials requiring similar handling due to their highly radioactive nature. All high-level radioactive wastes are considered radioactive-mixed wastes and subject to the AEA and RCRA, unless demonstrated to the contrary. The policies of Chap. I, "High-Level Waste" are several fold: the safe storage, treatment, and disposal of all high-level waste generated by DOE operations; storage operations must comply with EPA and state regulations; and geologic disposal must comply with both NRC regulations and EPA standards. New facilities for storage and treatment must meet the requirements of 40 CFR 264 and DOE Order 6430.1. Because ORNL has no high-level waste, this document will not discuss requirements for this waste category in further detail.

6.4.2.3 Low-Level Radioactive Waste

EPA plans to establish generally applicable standards for the management and disposal of low-level waste under the authority of the AEA, as amended, to be codified at 40 CFR 193 (57 *FR* 52061, November 11, 1992). In the same category, EPA may develop criteria for declaring certain wastes as being below regulatory concern. the Agency intends to regulate the disposal of certain NARM wastes under 40 CFR 764 (57 *FR* 52061, November 11, 1992). The proposed rule is expected in September 1993 and the final rule is scheduled for September 1994.[4]

The FFA for the ORR, effective January 1, 1992, covers the active Liquid Low-Level Waste System at ORNL. This system is an assemblage of tanks, associated transfer pipelines, and ancillary equipment, such as pumps and evaporators, designed for collecting, neutralizing, concentrating, and storing wastes prior to disposal. The bulk of the Liquid Low-Level Waste tanks and transfer lines are buried underground for purposes of radiation shielding. Both past and current waste treatment and storage practices, including waste neutralization and evaporation, have produced Liquid Low-Level Waste concentrates and sludges containing concentrations of hazardous chemicals high enough to be subject to new regulatory controls, including RCRA LDRs for mixed-radioactive and hazardous-chemical wastes. The FFA contains provisions applicable to DOE's Liquid Low-Level Waste tank system(s) listed in Appendix F of the FFA. Four categories of tank systems are associated with ORNL. They are as follows: (1) new or replacement tank system(s) with secondary containment; (2) existing tank system(s) with secondary containment; (3) existing tank system(s) without secondary containment; and (4) existing tank system(s) without secondary containment that are removed from service. In this FFA, DOE assented to remediate all Liquid Low-Level Waste tank system(s) for each of the four categories of tanks that are permanently removed from service. Detailed

requirements are delineated in the FFA. For example, a professional licensed engineer in the State of Tennessee must assess and certify that each new or replacement tank system(s) has sufficient structural integrity and is acceptable for the storage or treatment of hazardous and/or radioactive substances. DOE must submit the engineer's written assessment to EPA and TDEC for review and approval at least ninety days before installation of a new or replacement tank system(s). The FFA must be referred to for specific requirements, including but not limited to design/installation assessments, detection standards, monitoring, maintenance, and disposition of leaking tank system(s) for the entire active life of the tank system(s) and until removed from service.[8]

DOE Order 5820.2A specifies that the management of low-level waste must ensure that external exposure to the waste and concentrations of radioactive material that may be released into surface water and soil does not exceed 25 mrem/year to any member of the public. Releases to the atmosphere shall not exceed 10 mrem/year. Chapter III, 3, establishes performance objectives for proper management of DOE-low-level waste that was not disposed of prior to September 26, 1988. Included are requirements for ensuring that inadvertent intruders to the facility after the loss of active institutional control (100 years) not be exposed to EDEs exceeding 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure. Ground-water resources must be protected in accordance with federal, state, and local requirements.

6.4.2.4 Special-Case Waste

Special case is a DOE term used to describe radioactive wastes that do not fit the criteria of the high-level waste, low-level waste or TRU waste. These waste may have some characteristics of one or more other major waste types. However, they may also have additional characteristics that prevent them from being managed as typical high-level waste, low-level waste, or TRU waste. Because of these characteristics, such wastes are potential problems to generators, handlers, and disposal facility operators and may require special management and disposal schemes. Five categories of special-case waste and one category of special interest DOE-owned materials have been identified for management as special-case waste: (1) performance-assessment limiting, (2) greater than Class C, (3) uncertified or uncharacterized (UC), (4) high-level incidental waste (HLI), and (5) noncertifiable, nontransportable TRU waste. The special interest category is commercially held, DOE-owned radioactive material. This category, although not a waste category, has been included in the special-case identification and characterization task in order to meet the needs of DOE's management plan development. ORNL has been asked to identify special-case wastes or potential waste materials that may fall within these six categories and, if possible, to provide detailed characterizations of each category of waste.[9]

6.4.2.5 Spent Nuclear Fuel

40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" is the federal regulatory authority for managing spent nuclear fuel. Spent nuclear fuel is defined in 40 CFR § 191.02 as "fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing." 40 CFR § 191.03(b) requires that the management and storage of all spent nuclear fuel at facilities operated by DOE and not regulated by the NRC or agreement states must be carried out in a such a manner that members of the public are not

exposed to a combined annual does equivalent from discharges and direct radiation to exceed 25 mrems to the whole body and 75 mrems to any critical organ. On February 10, 1993, EPA proposed certain new standards for disposal of these waste types at 40 CFR § 191.15 and Subpart C. See Sect. 6.4.2.1, TRU Waste, for a more complete discussion of the proposed rule making.

-7751

Section 1004 of SWDA was amended by the FFCA of 1992 by adding the following definition for mixed waste: "waste that contains both hazardous waste and source, special nuclear, or by-product material subject to the Atomic Energy Act of 1954 (42 U.S.C. 2001 *et seq.*)." Mixed wastes are those containing an RCRA hazardous waste, as defined in 40 CFR 261, and a radioactive waste subject to the AEA. On July 3, 1986, EPA published a notice announcing that in order to obtain and maintain authorization to administer and enforce an RCRA Subtitle C Hazardous Waste Program, states must apply for authorization to regulate the hazardous-waste components of radioactive-mixed waste. EPA stated in this notice that the radioactive-waste component of radioactive mixed-waste is subject to the AEA, and that the hazardous-waste component is subject to RCRA. When the application of both standards is conflicting or inconsistent, RCRA yields to the AEA (52 *FR* 15940). The DOE Byproducts Rule, which discusses how RCRA applies to radioactive wastes that contain components of hazardous wastes within the meaning of RCRA, was published on May 1, 1987 (52 *FR* 15937). Tennessee received authorization on August 11, 1987, to regulate the hazardous-waste component of radioactive mixed waste. Tennessee received final authorization to regulate radioactive mixed waste on July 3, 1986 (53 *FR* 37045, Sept. 23, 1988). However, Tennessee has not implemented any regulations or guidance related to the handling of mixed waste.[10] HSWA regulates mixed waste exhibiting the toxicity characteristic and prohibits the disposal of hazardous wastes that have not been pretreated to standards established by EPA. The prohibitions are called the LDRs of RCRA and are discussed fully in Sect. 6.3.4.11.

In June 1992, EPA and DOE signed the LDR-FFCA/ORR to bring mixed-waste generation and storage facilities on the reservation into compliance with Subtitle C of RCRA, regarding matters specifically named in the FFCA. The mixed wastes covered under the LDR-FFCA/ORR include flammable and corrosive liquids, Liquid low-level waste concentrates/TRU waste sludges, solvents, paint waste, waste oils and organics, and solid-mixed wastes. The FFCA directly affects WM at ORNL; effective immediately, DOE-ORR was to submit plans to include treatment and storage options for LDR mixed wastes to meet the requirements of RCRA. The FFCA applies to LDR requirements pertaining to past, ongoing, and future generation, storage, treatment and/or disposal of the radioactive-mixed wastes and dioxin-containing hazardous wastes at ORNL identified in the appendices of the FFCA. Under this FFCA, DOE has submitted a plan for a waste minimization program at DOE-ORR. It was required that the program provide for the segregation of hazardous waste from radioactive-mixed wastes, the substitution of nonhazardous solvents for hazardous solvents where technically practicable, and the minimization of the generation of hazardous waste throughout DOE-ORR. It was agreed that DOE would implement the waste minimization program in accordance with the plan and report its progress annually to EPA. The agreement also provided that DOE would submit to EPA for review and approval a plan for treatment of the LDR- prohibited wastes with identified existing treatment. A second plan was agreed to and submitted, for the treatment of the identified LDR-prohibited waste that has no existing treatment. This plan included the treatment strategy for such wastes to meet LDR treatment standards and a schedule, not to exceed two years, for the evaluation of prioritization of treatment method options, treatability studies if required, and technology development. DOE submits quarterly progress reports for implementation of this plan. DOE still must obtain all necessary permits and approvals under applicable local, state and federal laws and

000608

regulations. All actions taken pursuant to the agreement must be undertaken in accordance with all applicable laws.[11]

The FFCA of 1992 (Public Law 102-386, October 6, 1992) amends Section 6001 of SWDA (42 U.S.C. 6961 *et seq.*) to clarify the application of certain regulations and sanctions for federal facilities. Specifically, Sect. 102 of the FFCA of 1992 waives immunity of the United States for all substantive and procedural requirements with respect to the control, abatement, or management of solid and hazardous waste. This waiver encompasses any immunity otherwise applicable to the United States, including injunctive relief, administrative orders, and civil or administrative penalties or fines, and subjects the federal government to the full range of available enforcement tools for penalizing isolated, intermittent, or continuing violations. The FFCA recognizes that unique problems exist for the storage of certain hazardous and radioactive-mixed wastes and has delayed the effective date for three years from enactment in certain instances. In particular, if the storage of mixed waste is not the subject of a permit, agreement, administrative order, or judicial order, and if the waste is managed in accordance with other applicable requirements, then this waiver will not apply for three years [FFCA of 1992, Sect. 102(c)(2)]. At the end of the three year period, the waiver shall apply to all departments and agencies of the United States for violations of Sect. 3004(j), with the possible exception of DOE. Even though the waiver is not delayed for DOE facilities that are subject to an existing agreement, permit, administrative or judicial order addressing compliance with the LDR storage prohibition for mixed wastes, the waiver will not apply to DOE as long as DOE meets certain conditions specified in the act [FFCA of 1992, Sect. 102(c)(3)]. Specifically, the waiver shall not apply to DOE for mixed-waste violations of Sect. 3004(j) of SWDA so long as DOE has submitted, has in effect, and is in compliance with, a plan pursuant to Sect. 3021(b) of SWDA, and is in compliance with an order issued pursuant to SWDA § 3021(b) requiring compliance with such plan. The new Sect. 3021, added to SWDA by the FFCA, requires that DOE, within 180 days of October 6, 1992, submit national inventory reports of all mixed-wastes and national inventory reports of mixed waste treatment capacities and technologies. In addition, DOE is required under the same time frame to submit, for each DOE facility where DOE generates or stores mixed waste, a plan for developing treatment capacities and technologies to treat all mixed wastes, regardless of when the wastes were generated. The specified treatment standards to be achieved are those promulgated pursuant to Sect. 3004(m) of SWDA for waste subject to land disposal prohibition. However, if a DOE facility is already subject to a permit establishing a schedule for treatment of such waste, or any existing agreement or order, to which the state in which the facility is located is a party, then the requirement for such a plan is not required. To meet this deadline, DOE published its draft strategy for development of a national compliance plan for DOE mixed waste on December 3, 1992 (57 *FR* 57170).[4] Based on comments received, DOE has revised its approach and intends to begin discussions on the plans as soon as possible. DOE's plan, called the National Compliance Plan, will integrate DOE's current mixed WM activities into a comprehensive long-range plan, not only to promote compliance with applicable laws and regulations, but to ensure development of adequate waste-treatment capacity. To fulfill the requirements of Sect. 105(a) of the FFCA, DOE, on April 6, 1993, published a schedule for submitting plans for treating mixed waste for each facility at which DOE generates or stores mixed waste (58 *FR* 17875)[4]. The schedule provides time and opportunity for necessary discussions among states and DOE sites and reflects the fact that sites will have varying needs regarding the amount of time necessary to identify treatment alternatives and prepare a plan for their LDR mixed waste. The schedule allows for discussions of technical and policy issues associated with site-specific plans and the

national plan and considers the need to closely coordinate the site treatment plans with DOE's ongoing efforts to prepare the ER and WM Programmatic Environmental Impact Statement. The goal of the schedule is to have all plans in place and orders issued by October 6, 1995 (58 *FR* 17878).

DOE identifies ORNL as one of 50 sites at which DOE generates or stores mixed wastes. DOE executed an LDR agreement with EPA for the ORR on June 12, 1992, but because this Agreement does not include the State of Tennessee, ORR facilities are required to submit site treatment plans under the FFCA of 1992 (58 *FR* 17880). However, the State of Tennessee could waive the plan requirement and develop a plan and order with the specific site, pursuant to Sect. 3021(b)(5) of RCRA. Either way, DOE intends that all sites follow the process outlined in the publication of its schedule (58 *FR* 17878, April 6, 1993). The primary concern of DOE is that conflicts not arise between commitments made and approved for site treatment plans under the FFCA and DOE's existing agreements with EPA. DOE is concerned that a smooth transition of authority occur from EPA to the states when plans are approved and the states issue orders. Where interagency agreements are in effect under CERCLA for restoration activities at ER sites, the provided information required in such agreements is similar to that required a plan under the FFCA. If a separate site treatment plan is prepared, DOE is concerned that there be consistency in terms of time frames, as well as a reflection in the site treatment plan of the decisions established through the restoration process (58 *FR* 17880). DOE will use the information in the April 6, 1993, report as a starting point in developing the treatment plans (58 *FR* 17876). On April 28, 1993, DOE announced the availability of the Interim Mixed Waste Inventory Report on Waste Streams, Treatment Capacities, and Technologies (58 *FR* 25822) with comments to be accepted and considered in the development of the final report.[4]

DOE Order 5400.3 established DOE's hazardous and radioactive-mixed waste policies and requirements. The order clarifies DOE's interpretation of the definition of "by-product material" (10 CFR 962) as it relates to RCRA regulation of mixed wastes, and establishes the lines of authority at DOE Headquarters for RCRA implementation. CERCLA requirements are addressed in DOE Order 5480.4. This order provides DOE policy resolving RCRA/CERCLA overlap issues and integrating NEPA with RCRA/CERCLA processes.[9] DOE Order 5820.2A, in Chap. VI, "Waste Management Plan Outline," calls for a section in each site's WM plan to address radioactive and mixed WM. The section describes the site WM systems, waste characteristics, the problems, and future plans for radioactive and mixed WM activities. ORNL has responded to this requirement by inclusion of Chap. 5 in the *ORNL Waste Management Plan* of December 1992.[2]

When D&D activities take place with regard to certain ORNL buildings, large quantities of radioactive lead shielding may be generated that will require action by WM. Although treatment standards exist for lead-contaminated debris, certain radioactive wastes are excluded from the definition of debris [see 40 CFR § 268.2(g)] and are subject to waste-specific treatment standards (57 *FR* 37238, August 18, 1992). 40 CFR § 268.42, Table 3, lists technology-based standards for specific radioactive hazardous-mixed waste, including the Radioactive Lead Solids Subcategory, which includes lead shielding. This treatment subcategory has been given a RCRA waste code designation of D008. The designated technology-based standard applicable to this subcategory, shown in Table 1 of 40 CFR § 268.42, is "macroencapsulation with surface coating materials such as polymeric organics (e.g. resins and plastics) or with a jacket of inert inorganic materials to substantially reduce surface exposure to potential leaching media." [40 CFR § 268.42(a)(2), Table 1].

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One of the types of mixed wastes generated at ORNL is mixed-waste oils that have been removed from systems operating in radiation areas.[2] These waste oils include vacuum-pump oil, axle oil, refrigeration oil, and oil/water mixtures.[2] Used oils directed for disposal are not listed as hazardous wastes by EPA (57 FR 21524, May 20, 1992), but the hazardous waste characteristics still apply to the used oil.

ORNL discharges mixed-gaseous wastes into the 3039 Off-Gas System for treatment.[2] The 3039 system is one of seven major cell ventilation systems with stacks that currently discharge cell ventilation air and process off-gas containing gaseous radioactive effluents. The 3039 stack handles off-gas from most of the Bethel Valley facilities. Large underground ducts and aboveground steel ducts connect the ventilation systems in major areas to this stack. The gas streams from most areas pass through high-efficiency particulate air (HEPA) filters. A discussion of the treatment requirements for these emissions is included in Sect. 6.4.1.2, which deals with radioactive air streams.

A Moratorium on Shipment of Potentially Radioactive Hazardous and went into effect on May 17, 1991. The moratorium applies only to those TSCA wastes and RCRA hazardous wastes that are potentially contaminated with radioactivity and that are to be shipped to off-site commercial treatment, storage and disposal companies. A companion policy, referred to as the Performance Objective for Certification of Non-Radioactive Hazardous Waste or "No Rad Added" policy, followed on November 15, 1991. This policy requires a determination that RCRA-hazardous or TSCA-regulated waste is not radioactive before the waste can be transported off site to non-DOE-owned TSDFs not licensed for management of radioactive materials. The performance objective will remain in effect until DOE, in coordination with other agencies, derives risk-based numeric limits for release of wastes containing such a low level of radioactivity that impact to public health and the environment would be insignificant. The policy requires certification that off site waste shipments to commercial TSDFs contain no radioactive waste. For shipment of mixed waste, compliance with DOE Order 5820.2A is necessary. Permit and license status of receiving facilities for mixed wastes must be verified, documented, and clearly traceable to the waste shipment. All DOE contractors must put into place formal documented procedures and criteria to address the management of mixed wastes sent off-site, including adherence to Department of Transportation regulations. The DOE contractor must make a commitment to approve, and the local DOE office must commit to accept, these procedures as a condition for lifting the moratorium. A Readiness Review Team has been established to review and approve such procedures.

6.6 ASBESTOS

6.6.1 Clean Air Act

The CAA of 1970 is the major federal law regulating the air emissions of processes and facilities.[1] The objectives of CAA are to protect and enhance the quality of the nation's air resources and to protect public health and welfare, while fostering a beneficial productive capacity.[1] As a result, under Sect. 112 of the CAA, NESHAPS were established to control pollutants that may be reasonably anticipated to result in an increase in mortality, or an increase in serious irreversible, or incapacitating reversible, illness. Due to the seriousness of the health implications NESHAPs are intended to control, the standards apply to both existing and new sources. Congress has designated asbestos as a hazardous-air pollutant, and as a hazardous-air pollutant, it is regulated under the CAA. In order to further implement Sect. 112 of CAA, EPA issued revisions to the asbestos NESHAP at 40 CFR 61. These revisions were made to improve enforcement and promote compliance with the current standard without altering existing controls. Some of the changes require the following: additional notification requirements by owners or operators of a demolition or renovation activity, warning signs during loading and unloading of vehicles used to transport asbestos-containing waste material, and owners or operators of an active waste disposal site must keep waste shipment records and provide written reports to EPA upon receipt of significant amounts of improperly enclosed or uncovered waste within a day. The regulations are not limited to existing friable material, but include future additional friable material that may be produced by nonfriable forms. Additionally, it should be noted that EPA has not listed asbestos-containing material as hazardous waste under RCRA. However, asbestos wastes are treated as solid wastes for purposes of RCRA regulation. Also, asbestos is listed as a hazardous substance covered by CERCLA at 40 CFR § 302.4. Several WM activities involving asbestos are regulated by the CAA.

First, 40 CFR § 61.150 provides the standard for WM activities dealing with waste disposal for asbestos manufacturing, fabricating, demolition, renovation, and spraying operations. Some of the waste disposal requirements include discharging no visible emissions to the outside air during collection, processing, packaging, or transporting of any asbestos-containing waste material unless an allowed emission-control and waste-treatment method is used and process asbestos-containing waste material into nonfriable forms.

Secondly, 40 CFR § 61.152 contains the requirements for air cleaning. These air-cleaning requirements are applicable to WM activities involving air cleaning as a procedure for asbestos emission control in 40 CFR § 61.145(c)(3)(i)(B)(1), 40 CFR § 61.145(c)(4)(ii), and 40 CFR § 61.145(c)(11)(i), as well as WM activities involving waste disposal for demolition and renovation operations in 40 CFR § 150(a)(1)(ii) and 40 CFR § 61.150(a)(2)(ii).

Also, WM activities involving asbestos activities must comply with the reporting requirements cited at 40 CFR § 61.153 by providing the EPA Administrator with the applicable information.

In addition, owners and operators of active waste disposal sites that receive asbestos-containing waste material from demolition and renovation operations and operations that convert asbestos-containing waste material into nonasbestos (asbestos-free) material must meet the requirements in 40 CFR § 61.154. Some of the requirements include warning signs, fencing, waste shipment records and no visible emissions to the outside air, unless the requirements of 40 CFR § 61.154(c) or (d) are met.

Last, any WM activities that involve or may in the future involve the conversion of regulated asbestos-containing material and asbestos-containing waste material into nonasbestos (asbestos-free) material must comply with the requirements cited at 40 CFR § 61.155.

6.6.2 Occupational Safety and Health Administration

The Occupational Safety and Health Administration (OSHA) was enacted in order to provide employees with a safe working environment. The applicable OSHA requirements for WM activities dealing with asbestos must be complied with. First, 29 CFR § 1926.58 applies to all construction work as defined in 29 CFR § 1910.12(b) and includes, but is not limited to the following activities: demolition or salvage of structures where asbestos is present; removal or encapsulation of materials containing asbestos; construction, alteration, repair, maintenance, or renovation of structures, substrates, or portions thereof, that contain asbestos; and transportation, disposal, storage, or containment of asbestos or products containing asbestos on the site or location at which construction activities are performed. Additionally, 29 CFR § 1926.58 provides requirements for asbestos removal, demolition and renovation operations, disposal of wastes contaminated with asbestos, and warning and labeling requirements. In contrast, 40 CFR § 1910.1001 applies to all occupational exposures to asbestos, in all industries covered by OSHA, except construction work as defined in 29 CFR § 1910.12(b). Some of the requirements deal with the following: monitoring, wet methods, exhaust ventilation, removal and storage, warning signs and labels, waste disposal, and record keeping.

However, OSHA has extended a partial administrative stay of the above listed revised final standards for occupational exposure to asbestos, tremolite, anthophyllite and actinolite for general industry cited at 29 CFR § 1910.1001 and construction cited at 29 CFR § 1926.58, insofar as the regulations apply to occupational exposure to non-asbestiform tremolite, anthophyllite and actinolite (57 *FR* 7877, March 5, 1992). The administrative stay was extended to allow OSHA to complete supplemental rulemaking limited to the issue of whether non-asbestiform tremolite, anthophyllite and actinolite should continue to be regulated in the same standard as asbestos (57 *FR* 7877, March 5, 1992). Therefore, during the period that the revised standards of 29 CFR § 1910.1001 and 29 CFR § 1926.58 have been partially stayed, 29 CFR § 1910.1101 applies "in lieu of the revised standards governing occupational exposure to asbestos, tremolite, anthophyllite and actinolite" (29 CFR § 1910.1101).

6.6.3 State Regulations

The Tennessee Air Pollution Control Regulations define hazardous-air contaminants as any air contaminants that may cause or contribute to an increase in serious irreversible or incapacitating reversible illness and has been so designated by the Tennessee Air Pollution Control Board, referred to as the board. Asbestos has been designated a hazardous-air contaminant by the board and as a designated hazardous air contaminant, asbestos is regulated under the Tennessee Air Pollution Control Regulations. As a result, several asbestos activities or operations pertinent to WM activities are regulated by the Tennessee Air Pollution Control Regulations.

First, WM activities involving waste disposal of asbestos resulting from manufacturing, fabricating, demolition, renovation, and spraying operations must meet the requirements of TDEC Rule 1200-3-11-.02(2)(j). Some of the waste disposal requirements of asbestos-containing waste materials resulting from manufacturing, fabricating, demolition, renovation, and spraying include the following: no visible emissions to the

outside air during the collection or processing (including incineration, packaging, transporting, or deposition) of any asbestos-containing waste material or treatment of asbestos-containing waste with water or process asbestos-containing waste material into nonfriable forms and all asbestos-containing waste materials shall be deposited at waste disposal sites that are operated according to the provisions of TDEC Rule 1200-3-11-.02(2)(j)(5). However, an owner or operator may elect not to meet the no-visible emission requirements of TDEC Rule 1200-3-11-.02(2)(j) stated above nor of TDEC Rule 1200-3-11-.02(2)(d) pertaining to demolition or renovation activities if the owner or operator elects to use the air cleaning methods specified in TDEC Rule 1200-3-11-.02(3)(b) to clean emissions containing particulate asbestos material before such emission escapes or are vented to the outside air.

Also, the Tennessee Air Pollution Control Regulations provide the requirements for asbestos waste disposal sites. In order to be an acceptable site for disposal of asbestos-containing waste materials from manufacturing, fabricating, demolition, renovation, and spraying operations, an active waste disposal site must meet the requirements of TDEC Rule 1200-3-11-.02(5). ORNL nonradioactive asbestos waste is directed to SLF II located on Chestnut Ridge, south of the Y-12 Site.[2] However, radioactive asbestos is disposed of in Greater Confinement Disposal silos in SWSA 6 at ORNL. In addition, the Asbestos Tracking System provides data on ORNL's removal and disposal of asbestos from building demolition or renovation.[2] The Asbestos Tracking System provides such information as volume, weight, waste origin (demolition or renovation), waste type (friable or transite), date of removal, radioactive contamination, and final disposition.[2] The system is used to generate quarterly summary reports on asbestos activities and to compile yearly disposal totals for other hazardous waste reports.[2] The WM Operations Group is responsible for the management of this data base.[2]

6.6.4 DOE Orders

In addition to federal and state regulatory requirements, DOE and DOE contractors are subject to the requirements of DOE orders. DOE Order 6430.1A provides in Sect. 0205-1 that demolition plans shall define methods for handling and disposing of hazardous-waste materials, including asbestos. Additionally, DOE Order 6430.1A provides in Sect. 0110-5.4 that maintenance, repair, and demolition of DOE facilities with asbestos-containing material shall comply with the OSHA and EPA regulations found in CFR Title 40.

6.7 WASTE MINIMIZATION

A key objective of DOE is the minimization of wastes—an avoidance of the generation of wastes—as well as a reduction in volume and concentration. DOE intends to achieve a 50–80% reduction in manufacturing waste generation by means of substituting materials, altering processes, using new production hardware, and recycling.[12] The focus is on source reduction rather than recycling. A successful waste minimization program will reduce treatment, storage, and disposal costs and lower health risks.[12] Waste minimization has been incorporated as a legal requirement in Sect. 3002(b) and 3005(h) of RCRA. Section 3002(b) requires generators of hazardous waste to certify on their hazardous-wastes manifests that they have a waste minimization program in place to reduce the volume or quantity and toxicity of such waste to an economically practicable degree. Section 3005(h) requires—as a condition for obtaining a permit for the treatment, storage, or disposal of hazardous waste that was generated on the premises—the permittee (owner or operator) to certify at least annually that the generator of the hazardous waste has a waste minimization program in place. EPA has provided interim final guidance to assist generators, owners, and operators in complying with these requirements. This guidance is published in the May 28, 1993, Federal Register (58 *FR* 31114). Additionally, EPA has published a proposed policy statement on source reduction and recycling (54 *FR* 3845, January 26, 1989), committing the EPA to a preventive strategy to reduce or eliminate the generation of harmful pollutants. EPA at the same time proposed to incorporate this strategy in its overall mission of protecting human health and the environment by making source reduction a priority for all aspects of EPA decision making and planning. EPA expanded its policy statement further on February 26, 1991 (56 *FR* 7849) by publishing its "Pollution Prevention Strategy." On January 15, 1993 (58 *FR* 4802), EPA proposed the creation of a program to publicly recognize environmental leadership and to promote pollution prevention in manufacturing.

RCRA requirements have potential application for waste minimization efforts at ORNL. In particular, 40 CFR 261 allows for exclusions for certain wastes and provides special considerations for small-quantity generators and for hazardous wastes that are used, reused, recycled, or reclaimed. 40 CFR 266, Subpart G, regulates persons managing spent lead-acid batteries being reclaimed.

EPA announced on September 10, 1992, that used oil that is recycled will not be listed as a hazardous waste (57 *FR* 41566). At the same time they published management standards for recycled used oil (57 *FR* 41566). Then on May 3, 1993, EPA issued clarifying amendments and several corrections to its previously issued final rule (58 *FR* 26420). The management standards apply to generators, transporters, processors, re-refiners, burners, and marketers of used oil; they are to be codified at 40 CFR 279. The definition of hazardous waste in 40 CFR § 261.3 was amended in the September 10 notice to include most used oils that contain greater than 1000 ppm halogens. Until used oil is disposed of or sent for disposal, it must be managed according to the 40 CFR 279 standards. When the used oil handler decides to dispose of the oil, the handler must determine whether the used oil exhibits a hazardous-waste characteristic, and if so, must dispose of the waste in accordance with 40 CFR 260—266, 268, 270 and 124. Nonhazardous used oil disposal must be carried out in adherence to 40 CFR 257 and 40 CFR 258. The deadline by which Tennessee, as an authorized state, must modify its program to reflect the new rules is July 1994, if a statutory change is not needed. Subpart E of 40 CFR 266, regulations governing the burning of used oil for energy

recovery, was removed from P. 266 and is now incorporated into the P. 279 standards. Because these regulations were already in effect in Tennessee, they remain in effect.[13]

On December 10, 1992, EPA published proposed rules implementing Sect. 608 of CAA, to establish recycling and safe disposal requirements for ozone-depleting refrigerants recovered during servicing and disposal of air conditioning or refrigeration equipment (57 *FR* 58644). Technicians servicing and disposing of such equipment must observe certain service practices that reduce refrigerant emissions. Ozone-depleting compounds contained "in bulk" in appliances, machines, or other goods must be removed prior to disposal. The final Sect. 608 recycling regulations were published on May 14, 1993 (58 *FR* 28660). EPA will phase in these new regulations over a period of 18 months (58 *FR* 28667, May 14, 1993). Depending on the types and quantities of refrigeration systems in buildings to undergo D&D, this issue could be significant for ORNL D&D activities. The rules will apply to routine operations as well.

EPA has identified several products for possible rule changes to encourage and make their recycling easier. Rule revisions involving solvent-contaminated rags, used anti-freeze, and solder materials are potentially relevant to ORNL's recycling activities. The agency might address these on a "fast-track" basis rather than waiting for a comprehensive review of hazardous waste recycling requirements. Solvent-contaminated rags are sometimes classified as solid and hazardous wastes and are subject to full RCRA Subtitle C requirements. EPA may consider exempting such rags from the mixture rule. EPA will consider whether to use streamlined standards to facilitate recycling of used antifreeze. A third issue that EPA will perhaps consider on an accelerated basis is whether to make an exemption from the solid waste definition for all or some solder dross and related materials, if such material is reclaimed.[14]

The State of Tennessee has its own hazardous waste reduction law, the Tennessee Hazardous Waste Reduction Act of 1990 (TCA § 68-46-301 *et. seq.*). The act requires that a waste-reduction plan be completed by January 1, 1992 for large-quantity generators. Small-quantity generators have until January 1, 1994 to complete their plans. The act enumerates the items that must be included in each plan. All generators must make annual progress reports, as well as submit summary information on waste-reduction activities to TDEC as an element of the annual generator report. Civil penalties apply for failure to file reports, records, or documents pursuant to the act.

DOE Order 5820.2A, Sect. 3.c.(2) requires the establishment of an auditable waste reduction program for all low-level waste generators. It further states that any new facilities or changes to existing facilities will incorporate waste minimization into design considerations.

DOE Order 5400.1, Sect. 4.b. requires the preparation of a waste-reduction program plan to be reviewed annually and updated every three years. The Tennessee Hazardous Waste Reduction Act requires a rigorous plan and more detailed annual reporting than DOE Order 5400.1. A major revision to the ORNL Waste Reduction Plan was issued in November 1992 to comply with the state act.

6.8 CLEAN WATER ACT

Because ORNL discharges waste waters to White Oak Creek, a surface water body, the facility must comply with requirements of CWA and Tennessee's Water Quality Control Act. Principal elements of CWA include a cooperative federal/state implementation process; the prohibition of discharges except in compliance with CWA; a permit program limiting and regulating permitted discharges; a system for determining the limits to be set for discharges; a system for the prevention of spills and notification procedures and responses if a spill occurs; and strong enforcement tools. While the federal CWA sets mandatory requirements, the State of Tennessee may establish more stringent requirements if it chooses. Tennessee has been authorized by EPA to implement the NPDES permitting program. Sections 401 and 402 of CWA set out the State's implementation roles. EPA has established limits on the amounts of certain pollutants that can be discharged by industrial facilities such as ORNL. Technology-based limits are called effluent limitations and are included in the required permits issued under the NPDES (Sect. 402 of CWA). Discharges may be further limited to maintaining a certain level of water quality for a water body so that the uses of that water body are protected. A third type of limitation, toxicity requirements, may be necessary to protect the aquatic environment and human health. Each permit specifies the particular standards and conditions under which a permit will be granted. The conditions may include treatment requirements before discharge, as well as monitoring and reporting requirements. Technical criteria and standards for the NPDES are codified at 40 CFR 125. Other important regulations for ORNL include 40 CFR 124, which describes the NPDES permit program; the Water Quality Standards found at 40 CFR 131; and 40 CFR 401, which prescribes effluent guidelines for new and existing point sources.

CWA, as amended in 1987, requires that certain storm-water discharges be regulated as NPDES discharges (40 CFR 122). Final regulations on this issue were published on November 16, 1990 (55 *FR* 47990). A facility that discharges storm water associated with its industrial activity must obtain coverage under a storm water general permit. TDEC Rules Chap. 1200-4-10 require compliance with the full storm-water permitting process.

Section 404 of the CWA strongly regulates the disposal of dredged or fill material into navigable waters. The implementing regulations are found at 40 CFR 230 and 33 CFR 320–330. The U.S. Army Corps of Engineers is authorized to designate disposal areas and has permitting authority for discharges of dredge-and-fill material into such waters. Under this same section, states may set up their own permit programs for dredge-and-fill activities in non-navigable waters. The Corps of Engineers and EPA, in November 1989, signed a memorandum of understanding in which it was agreed that the Corps of Engineers, through its permit review authority, would strive toward minimizing the impact on wetlands. In effect, the Corps of Engineers must choose the least harmful alternative that is practical in its permit decisions. These requirements would be applicable to any WM activities at ORNL impacting wetland areas.

Tennessee has its own legislation to protect the waters of the State, called the Water Quality Control Act (TCA § 69-3-101 *et seq.*) and implementing regulations (TDEC Rules Chap. 1200-4-1 *et seq.*), closely corresponding to the federal regulations. This act enables the state to qualify for full participation in the NPDES established under the federal CWA.

CWA and its implementing regulations do not apply to some radioactive materials, such as source, byproduct, or special nuclear materials, which are regulated by AEA. However, the nonradioactive hazardous component of a waste stream that contains byproduct material is regulated under RCRA (10 CFR 962). Additionally, ORNL cannot

discharge high-level waste nor any radiological warfare agent into waters [Sect. 301(f) of the CWA]. Other discharges containing radioactive materials are regulated by CWA under Tennessee's EPA-authorized permitting program.

It should be noted that the standards regulating TSDFs, codified at 40 CFR 264, do not apply to NPDES-permitted wastewater treatment units (40 CFR § 260.10).

6.9 TOXIC SUBSTANCES CONTROL ACT

TSCA was enacted on October 11, 1976 to regulate those chemicals that present an unreasonable risk of harm to human health or the environment. Section 6 of TSCA specifically requires EPA to regulate PCBs. As a result, PCBs are regulated under TSCA rather than under RCRA Subtitle C, unless the waste also meets the definition of a hazardous waste. The implementing regulations for PCBs are codified at 40 CFR 761, and most of the provisions apply to PCBs only if PCBs are present in concentrations above a specified level [40 CFR § 761.1(b)]. For example, Subpart D, "Storage and Disposal," applies generally to materials at concentrations of 50 ppm and above. Some of the PCB regulations pertinent to WM include the following: marking and labeling requirements, storage and disposal requirements, spill cleanup policy, and record-keeping requirements.

The exterior of PCB transformers must be marked, as well as doors, fences, hallways, or means of access, other than grates and manhole covers to PCB transformer locations (40 CFR § 761.40). In addition, the label must be either a white or yellow background and sufficiently durable to equal or exceed the life of the PCB article, equipment, or container (40 CFR § 761.45).

When PCBs and PCB items are removed from service and disposed of, the applicable disposal requirements of 40 CFR 761, Subpart D, must be complied with. For example, 40 CFR § 761.65 contains the requirements pertinent to the storage for disposal of PCBs at concentrations of 50 ppm or greater and PCB items with PCB concentrations of 50 ppm or greater. The current TSCA regulations require chemical waste landfill disposal or incineration for any PCB or PCB item containing 50 ppm or greater. The same disposal requirements apply to materials contaminated with PCBs from an original source containing 50 ppm PCBs or greater [40 CFR § 761.60(a)]. Some of the storage facility standards include the following: adequate roof and walls to exclude rainfall; adequate floor with six-inch curb or containment; no drains, valves, joints and openings; floors and curbing that is continuous and imperious; and access control. All PCB equipment placed in storage must be marked with the date it was placed there and removed from storage within one year. In addition, Subpart D contains the requirements for incineration (40 CFR § 761.70). The K-25 TSCA Incinerator is used to process PCB contaminated materials. Currently, the TSCA Incinerator is operationally restricted to burning liquids, even though the incinerator is permitted to burn solids. This incinerator meets the TSCA requirements of 99.9999 destruction efficiency to ensure no toxic emissions are released.

Also, 40 CFR 761, Subparts J and K contain the record-keeping and reporting requirements that apply to WM activities dealing with PCBs, PCB items, and PCB storage and disposal facilities. A PCB-FFA for ORR is being developed to provide for the continued storage of PCB-contaminated materials.

DOE has been involved in the EPA Workgroup, developing the Notice of Proposed Rulemaking on the disposal of PCBs.[15] Based upon the latest draft available to DOE, the Notice of Proposed Rulemaking will probably address PCB remediation wastes and propose that the remediation of sites contaminated with PCBs follow the requirements of RCRA and CERCLA.[15]

6.10 THE FEDERAL INSECTICIDE, FUNGICIDE, AND RODENTICIDE ACT

The current law regulating chemical pesticides is the Federal Insecticide, Fungicide, and Rodenticide Act of 1947, as amended (7 U.S.C. Sect. 135, *et seq.*). The Federal Insecticide, Fungicide, and Rodenticide Act gives EPA the authority to regulate the management of pesticides, including labeling, storage and transportation of pesticides, as well as pesticide container designs, and standards for the removal of pesticides from containers prior to disposal. In 40 CFR 165, Subpart C, promulgated in 1974, EPA "recommended" certain procedures for the storage and disposal of pesticides, pesticide containers, and pesticide-related wastes. However, the 1988 amendments to the Federal Insecticide, Fungicide, and Rodenticide Act gave EPA clearer and broader authority to regulate these activities, and EPA plans to exercise this authority through new regulations being published in three parts. Phase I was published on May 5, 1993 (58 *FR* 26856) with final rule scheduled for May 1994; the Phase II Notice of Proposed Rulemaking is expected in July 1993; and the Phase III Notice of Proposed Rulemaking is due in 1994.[4] The only revision proposed in Phase I that is potentially applicable to ORNL WM operations removes EPA's responsibility for accepting suspended and canceled pesticides for safe disposal and places this burden now with owners and registrants who hold such pesticides. Phase II is expected to involve the addition of data requirements to 40 CFR 158 regarding storage and disposal, as well as an amendment to 40 CFR 165 adding requirements for container design and residue removal. Phase III would involve storage and transportation of pesticides and management of excess pesticides. Other pertinent regulations implementing Federal Insecticide, Fungicide, and Rodenticide Act include 40 CFR 156, which regulates labeling for pesticides and 40 CFR 157, which prescribes packaging requirements.

6.11 TRANSPORTATION OFF SITE

The Hazardous Materials Transportation Act of 1975, as amended, is the major transportation related statute affecting ORNL. The objective of the HMTA is "to improve the regulatory and enforcement authority of the Secretary of Transportation to protect the nation adequately against risks to life and property which are inherent in the transportation of hazardous materials in commerce." Any transportation of hazardous or radioactive materials off site from ORNL operations or from a D&D site at ORNL would be regulated under the Hazardous Materials Transportation Act.

The pertinent provisions of the Hazardous Materials Transportation Act to WM activities include the implementing regulations cited at 49 CFR 171-179 discussed below

- 49 CFR 171—Lists the requirements of the Department of Transportation applicable to the transportation of hazardous materials and the packaging used in the transportation of those materials.
- 49 CFR 172—Lists and classifies the materials that the Department of Transportation has designated as hazardous materials for the purpose of transportation and prescribes the communications regulations applicable when shipping those materials.
- 49 CFR 173—Defines hazardous materials for the purpose of transportation; establishes requirements in packaging materials for shipment; lists inspection, testing, and retesting responsibilities concerning containers built, repaired, or conditioned for use in the transportation of hazardous materials; classifies materials having more than one hazard; and prescribes criteria for instructing those responsible for preparing hazardous materials for shipment.
- 49 CFR 174—Lists additional requirements for transportation of hazardous materials by rail cars.
- 49 CFR 175—Lists additional requirements for transportation of hazardous materials by aircraft.
- 49 CFR 176—Lists additional requirements for transportation of hazardous materials by vessel.
- 49 CFR 177—Lists the requirements to minimize danger to life and property in the transportation of hazardous materials by public highway, including loading and unloading requirements for radioactive materials.
- 49 CFR 178—Prescribes the manufacturing and testing specifications for packaging and containers used for the transportation of hazardous materials.
- 49 CFR 179—Lists the specifications for tanks which are mounted on or form parts of tank cars used for the transportation of hazardous materials.

10 CFR 71 specifies the standards for the packaging and shipment of NRC-licensed material. Even though DOE is exempt from most NRC regulations, DOE has specified in DOE Order 5480.3 that DOE activities are to be in compliance with the requirements of 10 CFR 71. In addition, under 49 CFR § 173.7(d) DOE may use its own packagings for transportation of Class 7 (radioactive) materials as long as DOE evaluates, approves, and certifies that its packaging standards are equivalent to those in 10 CFR 71. "Packages shipped in accordance with this paragraph shall be marked and otherwise prepared for shipment in a manner equivalent to that required by this subchapter for packagings approved by the NRC" (49 CFR § 173.7). DOE Order 1540.2, "Hazardous Material Packaging for Transportation Administrative Procedures" establishes administrative

procedures for the certification and use of radioactive and other hazardous materials packaging by DOE.

6.12 NATIONAL ENVIRONMENTAL POLICY ACT

NEPA established national environmental policies and goals for the protection of the environment. NEPA primarily seeks to establish and carry out the following two objectives: consider every significant aspect of the environmental impact of a proposed action and inform public officials and citizens of environmental concerns before decisions are made and actions are taken. NEPA imposes environmental responsibilities on all agencies of the federal government by directing federal agencies to consider the impact of their actions on the environment during their decision making processes. Section 101 of NEPA imposes on the federal government the policy to use all practicable means to administer federal programs in the most environmentally sound fashion. This policy is implemented by Sect. 102 which sets out the procedural requirements to ensure environmental concerns are addressed in the decision making process. To implement this policy at ORNL, an environmental review and documentation program is maintained that is applicable to all ORNL facilities, programs, and operations as well as subcontractor activities or other work performed for or at ORNL under contractual arrangements. The following are the three levels of NEPA analysis depending on the significance of impacts anticipated:

- A categorical exclusion document is prepared to record a DOE decision that the action is automatically excluded and therefore does not require the preparation of an Environmental Assessment or an Environmental Impact Statement. NEPA are fully described in 10 CFR 1021 Appendices A and B. The that may apply to WM activities at ORNL include, but are not limited to, the following:

  - B1.3 Routine maintenance/custodial services for buildings, structures, infrastructures, equipment
  - B1.4 Installation/modification of air conditioning systems for buildings, structures, infrastructures, equipment
  - B1.7 Acquisition/installation/operation/removal of communication systems, data processing equipment
  - B1.11 Fencing, no adverse effect on wildlife movement/surface water flow
  - B1.16 Removal of asbestos from buildings
  - B1.17 Removal of PCB-containing items from buildings, other aboveground locations
  - B1.22 Relocation/demolition/disposal of buildings
  - B2.2 Installation of/improvements to building/equipment instrumentation
  - B2.5 Safety and environmental improvements of a facility, replacement/upgrade of facility components
  - B6.1 CERCLA removals/similar actions under RCRA or other authorities, meeting CERCLA cost/time limits or exemptions
  - B6.2 Siting/construction/operation of pilot scale waste collection/treatment/stabilization/containment facilities
  - B6.3 Improvements to environmental control systems
  - B6.4 Siting/construction/operation/decommissioning of facility for storing packaged hazardous waste for 90 days or less
  - B6.5 Siting/construction/operation/decommissioning of facility for characterizing/sorting packaged waste, overpacking waste (not high-level, spent nuclear fuel)

- B6.6 Modification of facility for storing, packaging, repacking waste (not high-level, spent nuclear fuel)
- B6.7 Granting/denying petitions for allocation of commercial disposal capacity
- B6.8 Modifications for waste minimization/reuse of materials

The regulations specifically provide that B6 categorical exclusions apply to WM and ER activities.

- When an exclusion is not possible, a written environmental assessment is conducted. This document is prepared to assess whether a proposed action is a "major Federal action significantly affecting the quality of the human environment." It serves as the basis for a determination of whether an environmental impact statement is required. If an environmental impact statement is not considered necessary, a document called a Finding of No Significant Impact is prepared by DOE to record the DOE decision.

3. An environmental impact statement results when it is expected that an action may have a significant impact on the environment. The environmental impact statement is the primary driving force behind NEPA, to ensure that federal agencies act and conform to the policies and goals of NEPA. The purpose of the environmental impact statement requirement is to verify that federal agencies evaluate the environmental impact of their decisions so that the use and alteration of the environment is planned and controlled instead of arbitrary. Specifically, Sect. 102(2)(C) requires that "all agencies of the federal government shall... include in every recommendation or report on proposals for legislation and other major federal action significantly affecting the quality of the human environment, a detailed statement by the responsible official on (i) the environmental impact of the proposed action, (ii) any adverse environmental effects... (iii) alternatives to the proposed action, (iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and (v) any irreversible and irretrievable commitments of resources..."

DOE's NEPA documentation has been limited somewhat by categorical exclusions which exempts DOE from or limits the level of NEPA documentation required. These categorical exclusions are set out in 10 CFR 1021, Subpart D, and are subject to certain terms and conditions.

The procedural requirements of NEPA are implemented by the Council on Environmental Quality, which was established by NEPA to promulgate regulations and advise the President on environmental matters. However, an EPA Cabinet Bill, including a provision to abolish the Council on Environmental Quality, has cleared the Senate Governmental Affairs Committee. Pursuant to this bill, some Council on Environmental Quality powers would shift to the White House and others to EPA. Instead of the council, President Clinton is creating a new Office on Environmental Quality to coordinate and initiate policies.[16]

Also, according to DOE Order 5440.1E, DOE's policy is to comply fully with the letter and spirit of NEPA. The order provides that in order to ensure environmental factors are considered in the decision making process and to promote environmentally responsible decisions, DOE will incorporate NEPA requirements early in the planning process for proposed actions. Additionally, owners or operators of DOE facilities should consider

coordinating data collection efforts required for closure and postclosure care plans under RCRA to facilitate compliance with NEPA.

Last, the Central Waste Management Division provides support to the DOE-ORR WM Environmental Impact Statement.[2] This environmental impact statement will assess the potential environmental impacts from WM activities at ORNL as well as at the Y-12 Site and the K-25 Site.[2] In addition, the acceptability of continued disposal of low-level waste on ORR will be assessed in this environmental impact statement.[2]

6.13 OSHA REQUIREMENTS

Title I, Sect. 126(b) of the Superfund Amendments and Rehabilitation Act mandated that OSHA promulgate standards for regulation of employee health and safety during hazardous waste operations at RCRA or CERCLA sites and during emergency response to hazardous-substance releases. The final regulations for *Hazardous Waste Operations and Emergency Response* (29 CFR 1910) appeared in 54 *FR* 9294 (Final Rule, March 6, 1989; effective date, March 6, 1990). These regulations are designed to protect workers involved with hazardous wastes during storage, treatment, and disposal operations or during cleanup of abandoned waste sites.

Employers must comply with pertinent OSHA standards found in 29 CFR 1910 (*General Industry*) as well. On July 7, 1992, a U.S. Circuit Court of Appeals vacated and remanded the final rule for Air Contaminant Permissible Exposure Limits for general industry for 212 substances that had been revised on Jan. 19, 1989 (54 *FR* 2332). The current PELs are those listed in the "transitional column" in Tables Z-1, Z-2, and Z-3 of the final rule.

6.14 REFERENCES

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8. U.S. Environmental Protection Agency Region IV, Tennessee Department of Environment and Conservation, and U.S. Department of Energy Federal Facility Agreement for the Oak Ridge Reservation, effective date January 1, 1992.

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11. Federal Facilities Compliance Agreement for Storage of Radioactive Mixed Waste Subject to Land Disposal Restriction for the Oak Ridge Reservation, effective June 12, 1992.

12. Environmental Restoration and Waste Management (EM) Program, An Introduction, DOE/EM-0013P, U.S. DOE Assistant Secretary for Environmental Restoration and Waste Management, Revised December 1992.

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13. Personal communication with W. Gregory, TDEC, Division of Hazardous Waste, by J. Hitch, June 17, 1993, 615-532-0847.

14. "EPA May Fast-Track Recycling of Certain Hazardous Wastes," *Hazardous Waste News*, May 25, 1993, pp. 166.

15. U.S. Department of Energy. RCRA/CERCLA Update, *Changes to TSCA PCB Regulations Proposed by EPA*, Office of Environmental Guidance, April 1993.

16. *Environmental Manager*, "Changes at the White House," April 1993.

APPENDIX:

PARTIAL 1992 AND 1993 TECHNICAL TASK PLAN SEARCH DATA-BASE LISTING

Partial 1992 and 1993 Technical Task Plan search data-base listing

AL004201	AL213206	AL231009	CH026001	ID101101	ID425001
AL014204	AL213207	AL232001	CH028001	ID101301	ID431001
AL014209	AL213401	AL232002	CH036001	ID104201	
AL014212	AL214103	AL232004	CH038601	ID105001	NEWDALEY
AL024204	AL221103	AL232005	CH039001	ID111701	NEWPENCE
AL024207	AL221104	AL232006	CH039002	ID114103	NV001102
AL027001	AL221106	AL2332P1	CH101101	ID121102	NV004201
AL034201	AL221107	AL234103	CH101103	ID121103	NV011101
AL101202	AL221108	AL234104	CH101104	ID121110	NV021701
AL113101	AL221110	AL234301	CH111203	ID121114	NV025001
AL121101	AL221111	AL238023	CH114101	ID121203	NV026011
AL121120	AL221112	AL238024	CH123401	ID121204	NV031001
AL121121	AL221114	AL239001	CH124201	ID121208	
AL121122	AL221116	AL239002	CH125001	ID121210	OR013101
AL121125	AL221120	AL239003	CH131001	ID121217	OR014103
AL121202	AL221121	AL239004	CH213101	ID121301	OR014104
AL121215	AL221123	AL239005	CH221101	ID121701	OR021201
AL121218	AL221205	AL239007	CH221102	ID125001	OR021301
AL121219	AL221206	AL239008	CH224201	ID131001	OR023101
AL123101	AL221302	AL239009	CH225001	ID132001	OR023301
AL123102	AL223201	AL435001	CH225002	ID132002	OR024103
AL123103	AL223301	AL911201	CH228006	ID132003	OR024201
AL124103	AL223302	AL921101	CH239001	ID132005	OR101100
AL131001	AL223305	AL921102	CH239002	ID132006	OR101101
AL131002	AL224103	AL923101	CH239003	ID132007	OR101102
AL131003	AL224104	AL924201	CH321101	ID132008	OR101103
AL131004	AL224202	AL924202	CH321201	ID132009	OR101104
AL131005	AL225001	AL924203	CH321205	ID132010	OR101106
AL131006	AL228021	AL925001	CH323401	ID132011	OR101108
AL131007	AL228024	AL931001	CH324201	ID132012	OR101201
AL132005	AL231001	AL931102	CH331001	ID134101	OR101202
AL132006	AL231002	AL932002	CH331002	ID332001	OR101204
AL201101	AL231003	ALTTPMSA	CH332001	ID332002	OR111101
AL213201	AL231004		CH525001	ID332004	OR111102
AL213202	AL231005	CH013101		ID413200	OR111103
AL213203	AL231006	CH013102	ID018101	ID421102	OR111105
AL213204	AL231007	CH023101	ID025001	ID421201	OR111107
AL213205	AL231008	CH023102	ID034301	ID423101	OR111202

000630

Partial 1992 and 1993 Technical Task Plan search data-base listing (continued)

OR111203
OR113101
OR113201
OR113202
OR113203
OR113204
OR113205
OR113206
OR120001
OR121101
OR121102
OR121103
OR121104
OR121105
OR121106
OR121108
OR121110
OR121111
OR121114
OR121115
OR121116
OR121201
OR121203
OR121204
OR121206
OR121210
OR121211
OR123101
OR123201
OR123301
OR123302
OR124101
OR124103
OR124201
OR128019
OR130003
OR130004
OR138001
OR138002
OR138005
OR141102
OR221101
OR221102
OR221103
OR221104
OR914201
OR925001

PE021103
PE021104
PE025001
PE031001
PE033502

RF025001
RF026001
RF101201
RF101205
RF111202
RF111203
RF121204
RF132001
RF138101
RL034101
RL132002
RL311101
RL311103
RL311104
RL313101
RL313201
RL313202
RL313203
RL313205
RL314202
RL315001
RL321101
RL321102
RL321104
RL321105
RL321112
RL321113
RL321114
RL321201
RL321204
RL321205
RL321211
RL321221
RL321701
RL322001
RL322101
RL323101
RL323301
RL324103
RL324105
RL327001
RL331001
RL331002
RL331003
RL332001
RL332002
RL332003
RL332004
RL332006
RL332008
RL332009
RL332010
RL332011
RL332012
RL332013
RL332014
RL334101
RL401203
RL401206
RL411101
RL413101
RL413201
RL413203
RL415003
RL421103
RL421104
RL421201
RL421207
RL421211
RL421215
RL421216
RL424102
RL424201
RL431001
RL432001
RL432002
RL432003
RL432004
RL438005
RL438601
RL439001
RL439005
RL439006
RL439007

SF121101
SF211104
SF211203
SF213201
SF213203
SF213204
SF213205
SF221101
SF221102
SF221205
SF221207
SF221208
SF221210
SF221211
SF223203
SF223401
SF224102
SF231001
SF234201
SF234202
SF234203

SR023101
SR104201
SR104202
SR113201
SR113202
SR121101
SR121102
SR121103
SR121105
SR121106
SR121107
SR121202
SR123201
SR123202
SR125001
SR128101
SR131000
SR131001
SR131002
SR132001
SR132002
SR132003
SR132004
SR134101
SR135002
SRNEW010

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OAK RIDGE NATIONAL LABORATORY TECHNOLOGY LOGIC DIAGRAM

INDEXES

000632

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1993
Edition

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7751

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Oak Ridge National Laboratory Technology Logic Diagram

Indexes

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000634

FOREWORD

The *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) was developed to provide a decision-support tool that relates environmental restoration (ER) and waste management (WM) problems at Oak Ridge National Laboratory (ORNL) to potential technologies that can remediate these problems. The TLD identifies the research, development, demonstration, testing, and evaluation needed to develop these technologies to a state that allows technology transfer and application to decontamination and decommissioning (D&D), remedial action (RA), and WM activities. It is essential that follow-on engineering studies be conducted to build on the output of this project. These studies will begin by selecting the most promising technologies identified in the TLD and finding an optimum mix of technologies that will provide a socially acceptable balance between cost and risk.

The TLD consists of three fundamentally separate volumes: Vol. 1 (*Technology Evaluation*), Vol. 2 (*Technology Logic Diagram*), and Vol. 3 (*Technology Evaluation Data Sheets*). Part A of Vols. 1 and 2 focuses on D&D. Part B of Vols. 1 and 2 focuses on RA. Part C of Vols. 1 and 2 focuses on WM. Each part of Vol. 1 contains an overview of the TLD, an explanation of the program-specific responsibilities, a review of identified technologies, and the rankings of remedial technologies. Volume 2 (Pts. A, B, and C) contains the logic linkages among EM goals, environmental problems, and the various technologies that have the potential to solve these problems. Volume 3 (Pts. A, B, and C) contains the TLD data sheets, which are expanded versions of logic paths from Vol. 2.

The focus of this volume is to provide a comprehensive index of ORNL problems, problem area/constituents, remedial technologies, and regulatory terms discussed in the TLD. This supplementary volume conists of three indexes that correspond to the organization of the TLD: Index A for the D&D volumes; Index B for the RA volumes; and Index C for the WM volumes. To facilitate the reader's use, explanatory notes are provided at the front of each index.

The technology evaluations contained in these volumes are based on the best information available during compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. L. Fellows, Editor, *Oak Ridge National Laboratory Technology Logic Diagram*, Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

INDEX A

Decontamination and Decommissioning

HOW TO USE THIS INDEX

The Decontamination and Decommissioning (D&D) Index provides a comprehensive list of site problems, problem area/constituents, remedial technologies, and regulatory terms discussed in the D&D sections of the *Oak Ridge National Laboratory Technology Logic Diagram*. All entries provide specific page numbers, or cross-reference entries that provide specific page numbers, in the D&D volumes (Vol. 1, Pt. A; Vol. 2, Pt. A; and appropriate parts of Vol. 3).

Page numbers are located at the end of main entries or at the end of subentries. References to the D&D Vol. 1, Pt. A (*Technology Evaluation*), are indicated by "V1:" and followed by a page number, while references to the D&D Vol. 2, Pt. A (*Technology Logic Diagrams*), are indicated by "V2:" and followed by a specific page number. Specific locations in Vol. 3 (*Technology Evaluation Data Sheets*) are given by the technology code numbers (e.g., roba-45) because pages in this volume are unnumbered.

Cross-references are indicated by a *See* at the end of the main entry. Following the *See* is a list of other main entries, which provide specific page numbers. The exception to this rule is found when any of the "ORNL Problems" are listed as main entries. In this case, a *See* refers to a list of facilities that provides additional information important to the ORNL Problem.

Examples of index entries are provided below.

- A main entry (a specific technology), which consists of a title in bold and a locator. The locator gives specific page numbers—"roba-45" (Vol. 3); "V1: 133, 141" (Vol. 1, Pt. A); and "V2: 119" (Vol. 2, Pt. A):

Technology name	Technology code no.	Vol. no.	Page nos.	Vol. no.	Page no.
⇓	⇓	⇓	⇓	⇓	⇓

Proximity probes, roba-45, V1: 133, 141; V2: 119

locator

- Two main entries that cross-reference. The first example consists of an ORNL Problem and a *See* reference, along with technology names and locators: the second example is the entry referenced, which provides a list of facilities directly related to the first example and a *See* reference to the first example:

Asphalt pavement problem areas, decontamination alternatives for.
For a complete list of facilities, see Asphalt pavement problem areas, facilities associated with
Chemical surface cleaning method technologies
ultrasonic cleaning, dcon-65, V1: 118; V2: 112
vacuum cleaning, dcon, V2: 112

Asphalt pavement problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Asphalt pavement problem areas, decontamination alternatives for
Other contaminated asphalt pavement surfaces—asphalt pavement (various radionuclides)
Pavement over 55-gal drum, Bldg. 7500 cells—asphalt pavement (fission products, corrosion products)

000637

INDEX A DECONTAMINATION AND DECOMMISSIONING

— A —

Abandoned hot cells, robotics and automation alternatives for
Controls—algorithm technologies
combined mobility/manipulation, roba-34, V1: 132, 140; V2: 118
control modes, roba-27, V1: 132, 140; V2: 117
emergency shutdown, roba-37, V1: 132, 140; V2: 118
manipulation (Cartesian control), roba-31, V1: 132, 140; V2: 117
manipulation (joint control), roba-30, V1: 132, 140; V2: 117
manipulation (redundancy control), roba-33, V1: 132, 140; V2: 118
manipulation (special purpose control), roba-32, V1: 132, 140; V2: 118
safety (collision avoidance), roba-35, V1: 132, 140; V2: 118
safety (load/rate limiting), roba-36, V1: 132, 140; V2: 118
vehicle/mobility driving, roba-28, V1: 132, 140; V2: 117
vehicle/mobility navigation, roba-29, V1: 132, 140; V2: 117
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 132, 140; V2: 118
console (fixed/mobile/suitcase), roba-38, V1: 132, 140; V2: 118
operator interface (command input), roba-40, V1: 132, 140; V2: 118
operator interface (operator assistance), roba-41, V1: 132, 140; V2: 119
operator interface (status/alert system), roba-42, V1: 132, 140; V2: 119
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 132, 140; V2: 117
end effectors/alternatives, roba-23, V1: 132, 140; V2: 117
force limiting/compliant mechanisms, roba-26, V1: 132, 140; V2: 117
general gripper/tool interface, roba-25, V1: 132, 140; V2: 117
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 131, 139; V2: 116
dexterous manipulators, roba-16, V1: 131, 139; V2: 116
long-reach manipulator (heavy duty), roba-15, V1: 131, 139; V2: 116
long-reach manipulator (light duty), roba-14, V1: 131, 139; V2: 116
Mechanical—mechanism technologies
precise programmable motions, roba-20, V1: 131, 140; V2: 116
stabilization/support mechanisms or booms, roba-22, V1: 131, 140; V2: 116
tool caddies, roba-21, V1: 131, 140; V2: 116
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 131, 139; V2: 116
external duct/pipe crawlers, roba-6, V1: 131, 139; V2: 115
failure recovery systems for mobile platforms, roba-11, V1: 131, 139; V2: 115
internal duct/pipe crawler, roba-5, V1: 131, 139; V2: 115
long-arm deployed robotic platforms, roba-9, V1: 131, 139; V2: 115
mounted robotic platforms, roba-8, V1: 131, 139; V2: 115
power sources for mobile platforms, roba-10, V1: 131, 139; V2: 115
specialized robotic deployment platforms, roba-7, V1: 131, 139; V2: 115
transportation systems for mobile platforms, roba-12, V1: 131, 139; V2: 116
wheeled/tracked vehicle, roba-1, V1: 131, 139; V2: 115
Other technologies
characterization sensor integration, roba-58, V1: 133, 141; V2: 120
field hardening, roba-53, V1: 133, 141; V2: 120
information management for sample handling, roba-56, V1: 133, 141; V2: 120
integrated automated analytical laboratory, roba-55, V1: 133, 141; V2: 120
radiation hardening, roba-54, V1: 133, 141; V2: 120
sample collection, roba-57, V1: 133, 141; V2: 120
sample preparation, roba-59, V1: 133, 141; V2: 120
Sensors—control technologies
force/torque, roba-50, V1: 133, 141; V2: 119
position/velocity sensors, roba-48, V1: 133, 141; V2: 119
proximity probes as sensors, roba-51, V1: 133, 141; V2: 119
tooling sensors, roba-52, V1: 133, 141; V2: 120
Sensors—perception technologies
force/torque sensors, roba-46, V1: 133, 141; V2: 119
proximity probes, roba-45, V1: 133, 141; V2: 119
range finders, roba-44, V1: 133, 140; V2: 119
visual/aural systems, roba-43, V1: 133, 140; V2: 119

Abrasive water jet (asbestos), dism-85, V1: 80; V2: 32

Abrasive water jet (steel structures, highly contaminated), dism-53, V1: 79; V2: 28

000638

Abrasive water jet (structural steel, mild contaminants), dism-72, V1: 80; V2: 30

Activation products. *For specific technologies to treat these contaminants, see*
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

Adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples, char-209, V1: 45; V2: 4

Advanced automated fixtures, bug-o, etc. (major equipment removal), dism-100, V1: 80; V2: 35

Advanced laser cutting (major equipment removal), dism-95, V1: 80; V2: 34

Advanced radiation monitors, char-269, V1: 48; V2: 11

Air monitoring, char-59, V1: 46; V2: 5

Alpha track etch detectors for surface alpha contamination, char-96, V1: 48; V2: 11

Am-241. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Analysis of censored data, char-249, V1: 47; V2: 9

Analytical methods for chelators and decontamination agents, char-206, V1: 50, 52; V2: 15, 19

Application of approximate reasoning to data analysis/evaluation, char-234, V1: 46; V2: 8

Aquatic resource alteration permits. *See*
Clean Water Act

Aquatic resources, V1: 167, 169

Archaeological and historic resources, V1: 170, 171

Asbestos emissions. *See*
Clean Air Act

Asbestos problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Asbestos problem areas, facilities associated with
Cutting technologies
abrasive water jet (asbestos), dism-85, V1: 80; V2: 32
laser cutting (asbestos), dism-84, V1: 80; V2: 32
Stripping technologies
CO_2 blasting (asbestos), dism-83, V1: 80; V2: 32
conventional (asbestos), dism-81, V2: 32
conventional/automated with vacuum system (asbestos), dism-82, V1: 80; V2: 32
glassification (asbestos), dism-86, V2: 32

Asbestos problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Asbestos problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Asphalt pavement problem areas, decontamination alternatives for. *For a complete list of facilities, see* Asphalt pavement problem areas, facilities associated with
Chemical surface cleaning method technologies
ultrasonic cleaning, dcon-65, V1: 118; V2: 112
vacuum cleaning, dcon, V2: 112
Mechanical surface removal method technologies
automated grinding, dcon-44, V1: 118; V2: 108
centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 107
concrete milling, dcon-47, V1: 118; V2: 108
explosive, dcon-48, V1: 118; V2: 109
grit blasting, dcon-38, V1: 118; V2: 107
hand grinding, honing, scraping, dcon-43, V1: 118; V2: 108
ice blasting, dcon-40, V1: 118; V2: 107
plastic pellet blasting, dcon-42, V1: 118; V2: 108
scabblers/scarifiers, dcon-37, V1: 117; V2: 107
supercritical CO_2 blasting, dcon-41, V1: 118; V2: 108
ultrahigh-pressure water, dcon-35, V1: 117; V2: 107

000639

Surface cleaning method technologies
automated brushing, dcon-57, V1: 118; V2: 111
solvent washing to remove radiological contamination, dcon-61, V1: 118; V2: 111
sponge blasting, dcon-58, V1: 118; V2: 111
strippable coatings, dcon-63, V1: 118; V2: 111
Thermal surface removal method technologies
compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 109
flashlamp cleaning, dcon-77
hand brushing used to remove surface contamination, dcon-56, V1: 118; V2: 110
high-pressure water, dcon-52, V1: 118; V2: 110
laser etching and ablation, dcon-74, V1: 119; V2: 109
steam cleaning, dcon-55, V1: 118; V2: 110
superheated water, dcon-53, V1: 118; V2: 110
water flushing, dcon-54, V1: 118; V2: 110

Asphalt pavement problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Asphalt pavement problem areas, decontamination alternatives for
Other contaminated asphalt pavement surfaces—asphalt pavement (various radionuclides)
Pavement over 55-gal drum, Bldg. 7500 cells—asphalt pavement (fission products, corrosion products)

Atomic emission spectroscopy, char-76, V1: 49; V2: 12, 13

Auger electron spectroscopy, char-2, V1: 50; V2: 14

Automated brushing, dcon-57, V1: 118; V2: 52, 65, 77, 91, 99, 111

Automated engineering system life cycle planning (needed enabling technologies), dism-174, V1: 48; V2: 43

Automated grinding, dcon-44, V1: 118; V2: 48, 57, 62, 73, 83, 88, 98, 108

Automated scanning and conversion of engineering drawings (needed enabling technologies), dism-155, V1: 47, 81; V2: 8, 42

Automated system reliability and safety analysis (needed enabling technologies), dism-175, V1: 48; V2: 43

— *B* —

Bar code/laser tooling location (needed enabling technologies), dism-140, V2: 40

Below regulatory concern levels, generic, for radioactive wastes, V1: 175–176

Beta/gamma emitters. *For specific technologies to treat these contaminants, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Biological surface cleaning, dcon-3, V2: 54

Block, concrete. *See*
Concrete block and tiled concrete problem areas, decontamination alternatives for

BRC. *See*
Below regulatory concern levels, generic, for radioactive wastes

Bubble dosimeters for neutron flux, char-216, V1: 48; V2: 11

Bldg. 3019. *For specific technologies to treat this facility, see*
Oil and purex chemical problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for

Bldg. 3028. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for

000640

Bldg. 3028 *(continued)*
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3029. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3030. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3031. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for

Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3032. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3033. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for

000642

Bldg. 3033 *(continued)*
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3036. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3038. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 3047. *For specific technologies to treat this facility, see*
Painted concrete problem areas, decontamination alternatives for

Bldg. 3505. *For specific technologies to treat this facility, see*
Painted concrete problem areas, decontamination alternatives for

Bldg. 3506. *For specific technologies to treat this facility, see*
Painted concrete problem areas, decontamination alternatives for

Bldg. 3515. *For specific technologies to treat this facility, see*
Painted concrete problem areas, decontamination alternatives for

Bldg. 3517. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for

Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Pipe interiors, decontamination alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 7500. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Asphalt pavement problem areas, decontamination alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Bldg. 7852. *For specific technologies to treat this facility, see*
Painted concrete problem areas, decontamination alternatives for

Bldg. 9201-3. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Organic problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Physical problem areas, characterization alternatives for
Pipe interiors, decontamination alternatives for
Radioactive elements, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for

000644

Bldg. 9201-3 *(continued)*
Tiled concrete problem areas, decontamination alternatives for

Bldg. 9219-1. *For specific technologies to treat this facility, see*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Entombment problem areas, dismantlement alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Reactor pool problem areas, dismantlement alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for

Bldg. 9419-1. *For specific technologies to treat this facility, see*
Concrete problem areas, decontamination alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Organic problem areas, characterization alternatives for
Physical problem areas, characterization alternatives for
Pipe interiors, decontamination alternatives for
Radioactive elements, characterization alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for

Buildings. *For complete lists of facilities and associated problem areas, see*
Asbestos problem areas, facilities associated with
Asphalt pavement problem areas, facilities associated with
Buried tank problem areas, facilities associated with
Concrete block and tiled concrete problem areas, facilities associated with
Concrete problem areas, facilities associated with
Entombment problem areas, facilities associated with
General problem areas, facilities associated with
Inorganic problem areas, facilities associated with
Major equipment removal problem areas, facilities associated with
Massive containment problem areas, facilities associated with
Needed enabling technology problem areas, facilities associated with
Oil and purex chemical problem areas, facilities associated with
Organic problem areas, facilities associated with
Painted concrete problem areas, facilities associated with
Physical problem areas, facilities associated with
Pipe interiors, facilities associated with
PCBs, facilities associated with
Radioactive constituents, facilities associated with
Reactor pool problem areas, facilities associated with
Reactors and support facilities, robotics and automation alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, list of facilities associated with
Steel containment structure (highly contaminated) problem areas, facilities associated with
Storage buildings, robotics and automation alternatives for
Structural-only concrete problem areas, facilities associated with
Structural steel problem areas, facilities associated with
Tiled concrete problem areas, facilities associated with
Wood/sheetrock, tar and felt roofing, and concrete problem areas, facilities associated with
Zincalloy, steel, and aluminum piping problem areas, facilities associated with

Buried tank problem areas, dismantlement alternatives for. *For a complete list of facilities, see*
Buried tank problem areas, facilities associated with
Cutting technologies
diamond wire cutting (buried tanks), dism-32, V2: 25
explosive cutting (buried tanks), dism-33, V1: 79; V2: 25
high-pressure abrasive water jet (buried tanks), dism-31, V1: 79; V2: 25
Demolition technologies
conventional demolition (buried tanks), dism-36, V2: 26
demolition compounds (buried tanks), dism-35, V1: 79; V2: 25
microwave demolition (buried tanks), dism-38, V2: 26

Buried tank problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Buried tank problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor

Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

— C —

Capillary zone electrophoresis, char-207, V1: 50; V2: 16

Capping—aboveground environmental barrier (entombment), dism-112, V1: 80; V2: 37
C-14. *For specific technologies to treat this contaminant, see*
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for

CO_2 blasting (asbestos), dism-83, V1: 80; V2: 32

Catalytic extraction process, dcon-6, V1: 117; V2: 71, 81, 86

Centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 39, 47, 61, 72, 82, 87, 97, 107

Cs-137. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Characterization
Discussion of implementation needs, V1: 43
Discussion of science and technology needs, V1: 42
Discussion of technology options, V1: 38–41
Introduction to, V1: 37
Technology rankings, V1: 44–52

Characterization alternatives. *See*
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Oil and purex chemical problem areas, characterization alternatives for
Organic problem areas, characterization alternatives for
Physical problem areas, characterization alternatives for
PCBs, characterization alternatives for
Radioactive elements, characterization alternatives for

Characterization sensor integration, roba-58, V1: 133, 141; V2: 120

Chelation treatment, dcon-21, V1: 117; V2: 55, 60, 71, 79, 86, 96, 104

Chemical. *See*
Oil and purex chemical problem areas, characterization alternatives for

Chemical foams, dcon-8, V1: 117; V2: 53, 68, 78, 93, 101

Chemical gels, dcon-9, V1: 117; V2: 68

Chemical leaching, dcon-5, V1: 117; V2: 81, 85

Clean Air Act
Asbestos demolition requirements, V1: 152–153, 166
Asbestos disposal, V1: 166
Asbestos emission controls, V1: 152–153, 166
Asbestos emissions, V1: 166
Fugitive dust emissions, V1: 156, 165–166
NESHAPs for asbestos, V1: 152–153, 166
Process emissions, V1: 165–166

Clean Water Act
Aquatic resource alteration permits, V1: 167, 171
Direct discharge to surface-water bodies, V1: 154–155, 164
NPDES permits, V1: 154–155, 164
Storm-water discharge, V1: 156, 164
Surface-water control, V1: 156

Client/server access to standards and regulatory guidelines (needed enabling technologies), dism-153, V1: 47, 81; V2: 7, 42

Client/server architecture for data base access (needed enabling technologies), dism-157, V1: 47; V2: 9, 42

Closure of tank systems. *See*
Resource Conservation and Recovery Act

Co-60. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for

Co-60 *(continued)*
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Cold vapor (mercury) analysis, char-24, V1: 49; V2: 14

Combined mobility/manipulation, roba-34, V1: 132, 140; V2: 118

Compact, high-capacity manipulators, roba-19, V1: 131, 139; V2: 116

Compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 51, 64, 76, 90, 98, 109

Computer-aided task analysis and procedure preparation (needed enabling technologies), dism-172, V1: 47, 81; V2: 8, 43

Computer-based D&D information retrieval (needed enabling technologies), dism-143, V1: 81; V2: 40

Computer-based training systems (needed enabling technologies), dism-191, V1: 47, 81; V2: 8, 44

Concrete. *For complete lists of facilities associated with, see*
Asbestos problem areas, facilities associated with
Buried waste problem areas, facilities associated with
Concrete block and tiled concrete problem areas, facilities associated with
Concrete problem areas, facilities associated with
Entombment problem areas, facilities associated with
Major equipment removal problem areas, facilities associated with
Massive containment problem areas, facilities associated with
Needed enabling technology problem areas, facilities associated with
Painted concrete problem areas, facilities associated with
Reactor pool problem areas, facilities associated with
Steel containment structure (highly contaminated) problem areas, facilities associated with
Structural-only concrete problem areas, facilities associated with
Structural steel problem areas, facilities associated with
Tiled concrete problem areas, facilities associated with
Wood/sheetrock, tar and felt, and concrete problem areas, facilities associated with

Concrete-based solidification/stabilization, dism-120, V2: 39

Concrete block and tiled concrete problem areas, decontamination alternatives for. *For a complete list of facilities, see* Concrete block and tiled concrete problem areas, facilities associated with
Bulk decontamination method technologies
catalytic extraction process, dcon-6, V1: 117; V2: 81
chemical leaching, dcon-5, V1: 117; V2: 81
dry heat (bulk roasting), dcon-4, V1: 117; V2: 80
incineration, dcon-2, V1: 117; V2: 80
solvent extraction, dcon-1, V1: 117; V2: 80
vacuum (low pressure), dcon-7, V1: 117; V2: 81
Chemical surface cleaning method technologies
automated brushing, dcon-57, V1: 118; V2: 77
chelation treatment, dcon-21, V1: 117; V2: 79
chemical foams, dcon-8, V1: 117; V2: 78
detergent treatments, dcon-13, V1: 117; V2: 79
electromigration, dcon-20, V1: 117; V2: 80
fluoboric acid treatment, dcon-11, V1: 117; V2: 78
hand brushing used to remove surface contamination, dcon-56, V1: 118; V2: 77
solvent washing to remove radiological contamination, dcon-61, V1: 118; V2: 77
sponge blasting, dcon-58, V1: 118; V2: 77
steam cleaning, dcon-55, V1: 118; V2: 77
Mechanical surface removal method technologies
automated grinding, dcon-44, V1: 118; V2: 73
centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 72
concrete milling, dcon-47, V1: 118; V2: 74
explosive, dcon-48, V1: 118; V2: 74
grit blasting, dcon-38, V1: 118; V2: 72
hand grinding, honing, scraping, dcon-43, V1: 118; V2: 73
ice blasting, dcon-40, V1: 118; V2: 73
plastic pellet blasting, dcon-42, V1: 118; V2: 73
scabblers/scarifiers, dcon-37, V1: 117; V2: 72
shot blasting, dcon-36, V1: 117; V2: 72
supercritical CO_2 blasting, dcon-41, V1: 118; V2: 73
ultrahigh-pressure water, dcon-35, V1: 117; V2: 72
Surface cleaning method technologies
compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 76
high-pressure water, dcon-52, V1: 118; V2: 76
strippable coatings, dcon-63, V1: 118; V2: 78
superheated water, dcon-53, V1: 118; V2: 76
vacuum (low pressure), dcon-7, V1: 117; V2: 78
water flushing, dcon-54, V1: 118; V2: 76

Thermal surface removal method technologies
flashlamp cleaning, dcon-77, V1: 119; V2: 75
laser etching and ablation, dcon-74, V1: 119; V2: 75
laser heating, dcon-73, V1: 119; V2: 75
microwave scabbling, dcon-71, V1: 119; V2: 74
plasma torch, dcon-72, V1: 119; V2: 75

Concrete block and tiled concrete problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Concrete block and tiled concrete problem areas, decontamination alternatives for
Bldg. 3028 floors—tiled concrete (fission products, TRU)
Bldg. 3028 interior/exterior walls—concrete block (fission products, TRU)
Bldg. 3029 floors—tiled concrete (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3029 interior/exterior walls—concrete block (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3030 floors—tiled concrete (43 beta/gamma emitters)
Bldg. 3031 floors—tiled concrete (Gd-153, Am-241)
Bldg. 3031 stacked shielding—concrete block (Gd-153, Am-241)
Bldg. 3032 floors—tiled concrete (P-32, Am-241)
Bldg. 3032 interior/exterior walls—concrete block (P-32, Am-241)
Bldg. 3033 floors—tiled concrete (H-3, Kr-85)
Bldg. 3036 floors—tiled concrete (Cs-137, Sr-90)
Bldg. 3036 interior walls—concrete block (Cs-137, Sr-90)
Bldg. 3038 floors—tiled concrete (Sr-90, Cs-137, Co-60, I-129)
Bldg. 3038 interior walls—concrete block (Sr-90, Cs-137, Co-60, I-129)
Bldg. 3517 floors—tiled concrete (Cs-137, Sr-90, Co-60)
Bldg. 3517 interior/exterior walls—concrete block (Cs-137, Sr-90, Co-60)
Bldg. 7500 floors—tiled concrete (Cs, Sr, TRU, Co-60)
Bldg. 7500 interior/exterior walls—concrete block (Cs, Sr, TRU, Co-60)
Bldg. 9201-3 coolant salt cell, floor—tiled concrete (U, Th, coolant salt)
Bldg. 9201-3 molten salt cells, floor—tiled concrete (U, Th, molten salt)
Molten Salt Reactor Experiment building floors—tiled concrete (fission products, corrosion products)
Molten Salt Reactor Experiment building interior/exterior walls—concrete block (fission products, corrosion products)
Oak Ridge Research Reactor building floors—tiled concrete (fission products)
Oak Ridge Research Reactor building interior/exterior walls—concrete block (fission products)

Concrete milling, dcon-47, V1: 118; V2: 49, 58, 74, 83, 108

Concrete problem areas, decontamination alternatives for. *For a complete list of facilities, see* Concrete problem areas, facilities associated with
Chemical surface cleaning method technologies
automated brushing, dcon-57, V1: 118; V2: 52
biological surface cleaning, dcon-3, V2: 54
chelation treatment, dcon-21, V1: 117; V2: 55
chemical foams, dcon-8, V1: 117; V2: 53
detergent treatments, dcon-13, V1: 117; V2: 54
electromigration, dcon-20, V1: 117; V2: 54
fluoboric acid treatment, dcon-11, V1: 117; V2: 53
hand brushing used to remove surface contamination, dcon-56, V1: 118; V2: 52
solvent washing to remove radiological contamination, dcon-61, V1: 118; V2: 52
sponge blasting, dcon-58, V1: 118; V2: 52
steam cleaning, dcon-55, V1: 118; V2: 52
Mechanical surface removal method technologies
automated grinding, dcon-44, V1: 118; V2: 48
centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 47
concrete milling, dcon-47, V1: 118; V2: 49
explosive, dcon-48, V1: 118; V2: 49
grit blasting, dcon-38, V1: 118; V2: 47
hand grinding, honing, scraping, dcon-43, V1: 118; V2: 48
ice blasting, dcon-40, V1: 118; V2: 48
plastic pellet blasting, dcon-42, V1: 118; V2: 48
scrabbler/scarifiers, dcon-37, V1: 117; V2: 47
shot blasting, dcon-36, V1: 117; V2: 47
supercritical CO_2 blasting, dcon-40, V1: 118; V2: 48
ultrahigh-pressure water, dcon-35, V1: 117; V2: 47
Surface cleaning method technologies
compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 51
high-pressure water, dcon-52, V1: 118; V2: 51
strippable coatings, dcon-63, V1: 118; V2: 53
superheated water, dcon-53, V1: 118; V2: 51
vacuum (low pressure), dcon-7, V1: 117; V2: 53
water flushing, dcon-54, V1: 118; V2: 51
Thermal surface removal method technologies
flashlamp cleaning, dcon-77, V1: 119; V2: 50
laser etching and ablation, dcon-74, V1: 119; V2: 50
laser heating, dcon-73, V1: 119; V2: 50
microwave scabbling, dcon-71, V1: 119; V2: 49
plasma torch, dcon-72, V1: 119; V2: 50

Concrete problem areas, facilities associated with. *For specific technologies to treat these facilities, see*
Concrete problem areas, decontamination alternatives for
Bldg. 3028 hot cell interiors—concrete (fission products, Cm-244, Pm-147, Am-241)
Bldg. 3029 hot cell interiors—concrete (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3030 hot cell interiors—concrete (43 beta/gamma emitters)
Bldg. 3031 hot cell interiors—concrete (Gd-153, Am-241)
Bldg. 3032 hot cell interiors—concrete (P-32, Am-241)
Bldg. 3036 floor—concrete (Cs-137, Sr-90)
Bldg. 3038 cell interiors—concrete (Sr-90, Cs-137, Co-60, I-129)
Bldg. 3517 hot cell interiors—concrete (C-137, Sr-90, Co-60)
Bldg. 9419-1 floor, first molten salt cells—concrete (U, Th, molten salt)
Graphite Reactor biological shields—concrete (fission products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, activation products)
Graphite Reactor canal—concrete (fission products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, activation products)
Graphite Reactor ductwork—concrete (fission products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, activation products)
Graphite Reactor stack—concrete (fission products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, activation products)
Homogeneous Reactor Test structure—high-density concrete (fission products, corrosion products, induced radiation)
Oak Ridge Reactor biological shield—concrete (fission products, corrosion products)
Slab supporting Low-Intensity Test Reactor components—concrete (fission products, corrosion products, activation products)

Console (data handling methods), roba-39, V1: 132, 140; V2: 118

Console (fixed/mobile/suitcase), roba-38, V1: 132, 140; V2: 118

Containment. *See*
Massive containment problem areas, dismantlement alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for

Contaminants
Summary of, V1: 14–16

Contamination control—analytical equipment, char-204, V1: 46; V2: 6

Control modes, roba-27, V1: 132, 140; V2: 117

Conventional (asbestos), dism-81, V2: 32

Conventional/automated with vacuum system (asbestos), dism-82, V1: 80; V2: 32

Conventional demolition (buried tanks), dism-36, V2: 26

Conventional demolition (reactor pools), dism-26, V2: 24

Conventional disassembly (major equipment removal), dism-102, V2: 36

Conventional disassembly (steel structures, highly contaminated), dism-60, V1: 79; V2: 29

Conventional disassembly (structural steel, mild contaminants), dism-76, V1: 80; V2: 31

Conventional—jack hammer, headache ball, etc. (structural-only concrete), dism-44, V1: 79; V2: 27

Coolant salt. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Oil and purex chemical problem areas, characterization alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for

Corrective Action Management Units. *See*
Resource Conservation and Recovery Act

Corrosion products. *For specific technologies to treat these contaminants, see*
Asphalt pavement problem areas, decontamination alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

Criticality indices, char-44, V1: 47; V2: 9

Cryogenic liquid cutting (steel structures, highly contaminated), dism-55, V2: 28

Cm-244. *For specific technologies to treat this contaminant, see*
Concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for

— D —

Data access services (needed enabling technologies), dism-154, V1: 47; V2: 7, 42

Data/signal transmission, roba-13, V1: 131, 139; V2: 116

Debris, hazardous. *See*
Resource Conservation and Recovery Act

Decontamination alternatives. *See*
Asphalt pavement problem areas, decontamination alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for
Tile concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for
Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

Decontamination and decommissioning of facilities. *See*
Isotope facilities scheduled for D&D program
ORNL facilities already in D&D program
ORNL special-case facilities

Decontamination, discussions of
Implementation needs, V1: 113–115
Introduction, V1: 91–103
Science and technology needs, V1: 111–112
Technology options, V1: 104–110
Technology rankings, V1: 116–122

Demolition compounds (buried tanks), dism-35, V1: 79; V2: 25

Demolition compounds (reactor pools), dism-25, V1: 79; V2: 24

Demolition compounds (structural-only concrete), dism-46, V1: 79; V2: 27

Department of Energy orders
DCG, V1: 173
Decommissioning, V1: 174–175
Derived concentration guides, V1: 173
Discharge of liquid radioactive waste, V1: 173
Occupational radiation exposure limits, V1: 175
Order 5400.5, V1: 173–174
Order 5480.11, V1: 175
Order 5820.2A, V1: 174–175
Public radiation exposure limits, V1: 173
Radioactive waste management, V1: 174–175
Residual radioactivity, V1: 173–174
Surface contamination guidelines, V1: 174

Detergent treatments, dcon-13, V1: 117; V2: 54, 70, 79, 94, 103

Dexterous manipulators, roba-16, V1: 131, 139; V2: 116

Diamond wire cutting (buried tanks), dism-32, V2: 25

Diamond wire cutting (major equipment removal), dism-94, V2: 34

Diamond wire cutting (massive containment), dism-12, V1: 79; V2: 23

Diamond wire cutting (reactor pools), dism-22, V2: 24

Diamond wire cutting (structural-only concrete), dism-42, V1: 79; V2: 26

Direct discharge to surface-water bodies. *See*
Clean Water Act
Department of Energy orders

Direct sampling ion trap mass spectrometry, char-90, V1: 50–52; V2: 15, 18, 19

Discharge to surface-water bodies. *See*
Clean Water Act
Department of Energy orders

Dismantlement
Discussion of implementation needs, V1: 77
Discussion of science and technology needs, V1: 76
Discussion of technology options, V1: 71–75
Introduction to, V1: 63–70
Technology rankings, V1: 78–83

Dismantlement alternatives. *See*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Entombment problem areas, dismantlement alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for

Dismantlement alternatives *(continued)*
Needed enabling technology problem areas, dismantlement alternatives for
Reactor pool problem areas, dismantlement alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problems, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for

Disposal, land, restrictions. *See*
Resource Conservation and Recovery Act

Dry heat (bulk roasting), dcon-4, V1: 117; V2: 80, 85, 91, 99

— *E* —

Electret passive surface alpha monitor, char-95, V1: 48; V2: 11

Electrochemical methods, char-10, V1: 46; V2: 6, 7

Electromigration, dcon-20, V1: 117; V2: 54, 80

Electron diffraction, char-37, V1: 49; V2: 13

Electronic catalog descriptions and source locations of site historical data (needed enabling technologies), dism-159, V1: 81; V2: 43

Electron spectroscopy for chemical analysis, char-1, V1: 50; V2: 14

Electropolishing, dcon-15, V1: 117; V2: 95, 103

Electrorefining, dcon-32, V1: 117; V2: 92, 67, 101, 105

Emergency shutdown, roba-37, V1: 132, 140; V2: 118

Emissions. *See*
Clean Air Act

Enabling technologies. *See*
Needed enabling technology problem areas, dismantlement alternatives for

Encasement—subsurface waste storage with void reduction (entombment), dism-113, V1: 80; V2: 37

End-effector changeout mechanisms, roba-24, V1: 132, 140; V2: 117

End effectors/alternatives, roba-23, V1: 132, 140; V2: 117

Energy dispersive X-ray spectroscopy, char-35, V1: 49; V2: 13

Engineered storage—for very "hot" items, future disposal (entombment), dism-115, V1: 80; V2: 38

Entombment problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Entombment problem areas, facilities associated with
Entombment technologies
capping—above ground environmental barrier (entombment), dism-112, V1: 80; V2: 37
concrete-based solidification/stabilization, dism-120, V2: 39
encasement—subsurface waste storage with void reduction (entombment), dism-113, V1: 80; V2: 37
engineered storage—for very "hot" items, future disposal (entombment), dism-115, V1: 80; V2: 38
ground-water diversion (entombment), dism-110, V2: 36
hydraulic isolation (entombment), dism-116, V2: 38
modular entombment—with provisions for future removal (entombment), dism-119, V2: 39
permanent entombment (entombment), dism-114, V1: 80; V2: 38
rubblization via crushing and/or shredding (entombment), dism-117, V2: 39
sensors for monitoring entombment integrity (entombment), dism-118, V1: 80; V2: 39
temporary entombment/clay fill (entombment), dism-111, V2: 37
thermoset polymer/thermal plastic stabilization (entombment), dism-109, V2: 36

Entombment problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Entombment problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Equipment removal. *See*
Major equipment removal problem areas, decontamination alternatives for

Explosive, dcon-48, V1: 118; V2: 49, 58, 74, 84, 109

Explosive cutting (buried tanks), dism-33, V1: 79; V2: 25

Explosive cutting (major equipment removal), dism-96, V2: 34

Explosive cutting (reactor pools), dism-23, V2: 24

Explosive cutting (steel structures, highly contaminated), dism-62, V1: 79; V2: 30

Explosive cutting (structural-only concrete), dism-45, V2: 27

Explosive cutting (structural steel, mild contaminants), dism-78, V2: 31

External duct/pipe crawlers, roba-6, V1: 131, 139; V2: 115

— F —

Facilities. *For complete lists of facilities and associated problem areas, see*
- Asbestos problem areas, facilities associated with
- Asphalt pavement problem areas, facilities associated with
- Buried tank problem areas, facilities associated with
- Concrete block and tiled concrete problem areas, facilities associated with
- Concrete problem areas, facilities associated with
- Entombment problem areas, facilities associated with
- General problem areas, facilities associated with
- Inorganic problem areas, facilities associated with
- Isotope facilities scheduled for D&D program
- Major equipment removal problem areas, facilities associated with
- Massive containment problem areas, facilities associated with
- Needed enabling technology problem areas, facilities associated with
- ORNL facilities already in D&D program
- ORNL special-case facilities
- Oil and purex chemical problem areas, facilities associated with
- Organic problem areas, facilities associated with
- Painted concrete problem areas, facilities associated with
- Physical problem areas, facilities associated with
- Pipe interiors, facilities associated with
- PCBs, facilities associated with
- Radioactive constituents, facilities associated with
- Reactor pool problem areas, facilities associated with
- Reactors and support facilities, robotics and automation alternatives for
- Stainless steel, steel plate, sheet steel, and structural steel problem areas, list of facilities associated with
- Steel containment structure (highly contaminated) problem areas, facilities associated with
- Storage buildings, robotics and automation alternatives for
- Structural-only concrete problem areas, facilities associated with
- Structural steel problem areas, facilities associated with
- Tiled concrete problem areas, facilities associated with
- Wood/sheetrock, tar and felt roofing, and concrete problem areas, facilities associated with
- Zincalloy, steel, and aluminum piping problem areas, facilities associated with

Facilities scheduled for decontamination and decommissioning. *See*
- Isotope facilities scheduled for D&D program
- ORNL facilities already in D&D program
- ORNL special-case facilities

Failure recovery systems for mobile platforms, roba-11, V1: 131, 139; V2: 115

Fe-55. *For specific technologies to treat this contaminant, see*
- Concrete problem areas, decontamination alternatives for

Fiber-optic chemical sensors, char-25, V1: 45, 51; V2: 5, 18

Fiber-optic systems for measuring multiple physical variables, char-248, V1: 51; V2: 17

Field hardening, roba-53, V1: 133, 141; V2: 120

Fission products. *For specific technologies to treat these contaminants, see*
- Asphalt pavement problem areas, decontamination alternatives for
- Concrete block and tiled concrete problem areas, decontamination alternatives for
- Concrete problem areas, decontamination alternatives for
- Oil and purex chemical problem areas, characterization alternatives for
- Painted concrete problem areas, decontamination alternatives for
- Pipe interiors, decontamination alternatives for
- Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
- Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for
- Tiled concrete problem areas, decontamination alternatives for
- Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for
- Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

Flashlamp cleaning, dcon-77, V1: 119; V2: 50, 59, 64, 75, 89

Flashlamp heating to release or desorb surface and subsurface contaminants, char-87, V1: 45; V2: 4

Floodplains, wetlands and, V1: 167, 168

Fluoboric acid treatment, dcon-11, V1: 117; V2: 53, 60, 69, 78, 94, 102

Fluorescence diagnosis of contaminated surfaces, char-110, V1: 50; V2: 14

Force limiting/compliant mechanisms, roba-26, V1: 132, 140; V2: 117

Force/torque, roba-50, V1: 133, 141; V2: 119

Force/torque sensors, roba-46, V1: 133, 141; V2: 119

Fourier transform infrared spectroscopy, char-8, V1: 46; V2: 6

Fractals used to select models for material transport in porous media, char-225, V1: 47; V2: 10

Fugitive dust emissions. *See*
Clean Air Act

— G —

Gd-153. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Gamma-ray spectrometry, char-268, V1: 49; V2: 12

Gas chromatography, char-94, V1: 51, 52; V2: 16, 19

Gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 50; V2: 16

Gas chromatography in the field, char-262, V1: 50, 51; V2: 15

Gas chromatography—mass spectrometry, char-88, V1: 50, 52; V2: 16, 18

Gas phase decontamination, dcon-16, V1: 117; V2: 95

General gripper/tool interface, roba-25, V1: 132, 140; V2: 117

Generalized object-oriented simulation software (needed enabling technologies), dism-173, V1: 48; V2: 43

General problem areas, characterization alternatives for. *For a complete list of facilities, see*
General problem areas, facilities associated with
Data analysis/management technologies
analysis of censored data, char-249, V1: 47; V2: 9
application of approximate reasoning to data analysis/evaluation, char-234, V1: 46; V2: 8
automated scanning and conversion of engineering drawings (needed enabling technologies), dism-155, V1: 47, 81; V2: 8
client/server access to standards and regulatory guidelines (needed enabling technologies), dism-153, V1: 47, 81; V2: 7
client/server architecture for data base access (needed enabling technologies), dism-157, V1: 47; V2: 9
computer-aided task analysis and procedure preparation (needed enabling technologies), dism-172, V1: 47, 81; V2: 8
computer-based training systems (needed enabling technologies), dism-191, V1: 47, 81; V2: 8
criticality indices, char-44, V1: 47; V2: 9
data access services (needed enabling technologies), dism-154, V1: 47; V2: 7
fractals used to select models for material transport in porous media, char-225, V1: 47; V2: 10
geographic information system for DOE sites (needed enabling technologies), dism-181, V1: 47; V2: 8
hazard analysis expert system, char-233, V1: 46; V2: 8
hypertext information systems (needed enabling technologies), dism-158, V1: 48; V2: 9
modeling of volatile organic compounds migration in porous materials, char-53, V1: 47; V2: 9
network architecture with integrated workstations, char-221, V1: 46; V2: 7
project information access services (needed enabling technologies), dism, 151, V2: 7
quality control for measurement processes, char-250, V1: 47; V2: 9
simulated walkthrough facility for robotics task sequence analysis (needed enabling technologies), dism-171, V1: 47, 81; V2: 8
spatial sample and data analysis plans, char-253, V1: 46; V2: 9
statistical methods for the analysis of large data sets, char-251, V1: 47; V2: 9

000653

task-scheduling aids, char-241, V1: 47; V2: 9
3-D CAD data base of buildings and structures (needed enabling technologies), dism-156, V1: 48, 81; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 46; V2: 5
electrochemical methods, char-10, V1: 46; V2: 6
fiber-optic chemical sensors, char-25, V1: 45, 51; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 46, 51; V2: 5
immunoassay detection, char-23, V1: 46; V2: 5
ion mobility mass spectrometry, char-264, V1: 45; V2: 5
laser photo acoustic spectroscopy, char-15, V1: 46, 51, 52; V2: 6
optical absorption spectroscopy, char-27, V1: 46; V2: 5
personnel monitoring, char-52, V1: 46; V2: 5
portable luminescence detection, char-92, V1: 46; V2: 6
portable Raman spectrometer, char-84, V1: 46; V2: 5
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 46; V2: 6
electrochemical methods, char-10, V1: 46; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 46; V2: 6
isotopic dilution mass spectrometry, char-48, V1: 46; V2: 6
laser ionization mass spectrometry, char-4, V1: 46; V2: 7
nuclear magnetic resonance, char-11, V1: 46; V2: 6
secondary ion mass spectroscopy, char-3, V1: 46; V2: 6
ultraviolet/visible spectroscopy, char-9, V1: 46; V2: 7
Sample collection technologies
flashlamp heating to release or desorb surface and subsurface contaminants, char-87, V1: 45; V2: 4
in situ solvent extraction, char-62, V1: 45; V2: 3
laser ablation for sample collection, char-86, V1: 45; V2: 4
membranes for sample collection and concentration, char-55, V2: 3
metallographic sectioning and preparation, char-67, V1: 45; V2: 3
multiangle drilling for depth profiling of contaminants, char-64, V1: 45; V2: 3
punch cores, char-82, V1: 45; V2: 3
sampling and mixing methods, char-81, V1: 45; V2: 3
sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 4
ultrasonic extraction, char-20, V1: 45; V2: 3
Sample preparation technologies
adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples, char-209, V1: 45; V2: 4
high-pressure ashing for sample preparation, char-203, V1: 45; V2: 4
microwave digestion, char-19, V1: 45; V2: 4
radioactive sample preparation, char-205, V1: 45; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 45; V2: 4
supercritical fluid extraction of organics, char-208, V1: 45; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 45; V2: 3
sampling program configuration management system, char-228, V1: 45; V2: 3
sequential sampling plans, char-252, V1: 45; V2: 3

General problem areas, facilities associated with. *For specific technologies to treat these facilities, see* General problem areas, characterization alternatives for
Bldgs. 3028, 3029, 3029E, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 9201-3, and 9419-1; drain lines; pulsefeeder pumps; pavement over 55-gal drum; and process piping and tankage

Generic BRC levels for radioactive wastes. *See* Below regulatory concern levels, generic, for radioactive waste

Geographic information system for DOE sites (needed enabling technologies), dism-181, V1: 47; V2: 8, 43

GIF images to augment as-built documentation (needed enabling technologies), dism-145, V2: 41

Glassification (asbestos), dism-86, V2: 32

Glow discharge ionization mass spectroscopy, char-56, V1: 50; V2: 14

Graphite Reactor. *See*
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for

Grappler/gross shearing and lifting (major equipment removal), dism-103, V2: 36

Grappler mobile shearing (steel structures, highly contaminated), dism-61, V1: 79; V2: 30

Grappler mobile shearing (structural steel, mild contaminants), dism-77, V1: 80; V2: 31

Grappler (structural-only concrete), dism-48, V1: 79; V2: 27

Grit blasting, dcon-38, V1: 118; V2: 47, 56, 61, 72, 82, 107

Ground-water diversion (entombment), dism-110, V2: 36

— H —

Hand brushing used to remove surface contamination, dcon-56, V1: 118; V2: 52, 65, 77, 110

Hand grinding, honing, scraping, dcon-43, V1: 118; V2: 48, 57, 62, 73, 83, 108

Hazard analysis expert system, char-233, V1: 46; V2: 8

Hazardous debris. *See*
Resource Conservation and Recovery Act

High-pressure abrasive water jet (buried tanks), dism-31, V1: 79; V2: 25

High-pressure abrasive water jet (major equipment removal), dism-97, V2: 34

High-pressure abrasive water jet (massive containment), dism-11, V1: 79; V2: 23

High-pressure abrasive water jet (reactor pools), dism-21, V1: 79; V2: 23

High-pressure abrasive water jet (structural-only concrete), dism-41, V1: 79; V2: 26

High-pressure ashing for sample preparation, char-203, V1: 45; V2: 4

High-pressure water, dcon-52, V1: 118; V2: 51, 64, 76, 110

High-pressure water jet (major equipment removal), dism-93, V1: 80; V2: 33

Historic and archaeological resources, V1: 170, 171

Holographic imaging, char-46, V1: 51; V2: 17

Homogeneous Reactor Test structure. *See*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Pipe interiors, decontamination alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

Hot cell problem areas. *See*
Abandoned hot cells, robotics and automation alternatives for
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Painted concrete problem areas, decontamination alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stabilized hot cells, robotics and automation alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for

Hydraulic isolation (entombment), dism-116, V2: 38

H-3. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Hypertext information systems (needed enabling technologies), dism-158, V1: 48; V2: 9, 43

— I —

Ice blasting, dcon-40, V1: 118; V2: 48, 57, 61, 73, 87, 107

Immunoassay detection, char-23, V1: 46; V2: 5

Incineration, dcon-2, V1: 117; V2: 80, 85

Inductively coupled plasma—mass spectroscopy, char-78, V1: 49; V2: 13

Inductively coupled plasma spectroscopy, char-77, V1: 49; V2: 13

Information management for sample handling, roba-56, V1: 133, 141; V2: 120

Infrared absorption (laser-based source), char-85, V1: 50, 51; V2: 14, 18

Infrared spectroscopy (wavelength dispersion), char-18, V1: 46, 51; V2: 5, 18

Inorganic acid treatments, dcon-12, V1: 117; V2: 69, 94, 102

Inorganic cementitious matrix composites model, char-39, V1: 51; V2: 17

Inorganic problem areas, characterization alternatives for. *For a complete list of facilities, see* Inorganic problem areas, facilities associated with
Field method technologies
atomic emission spectroscopy, char-76, V1: 49; V2: 12
laser ablation; inductively coupled plasma; atomic emission spectroscopy, char-111, V1: 49; V2: 13
portable X-ray fluorescence, char-6, V1: 49; V2: 13
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 49; V2: 13
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 49; V2: 13
auger electron spectroscopy, char-2, V1: 50; V2: 14
cold vapor (mercury) analysis, char-24, V1: 49; V2: 14
electron diffraction, char-37, V1: 49; V2: 13
electron spectroscopy for chemical analysis, char-1, V1: 50; V2: 14
energy dispersive X-ray spectroscopy, char-35, V1: 49; V2: 13
glow discharge ionization mass spectroscopy, char-56, V1: 50; V2: 14
inductively coupled plasma—mass spectroscopy, char-78, V1: 49; V2: 13
inductively coupled plasma spectroscopy, char-77, V1: 49; V2: 13
ion chromatography, char-50, V1: 49; V2: 13
neutron activation analysis, char-266, V1: 48, 49; V2: 14
particle-induced X-ray emission, char-17, V1: 49; V2: 14
powder X-ray diffraction, char-31, V1: 50; V2: 14
scanning electron microscopy, char-33, V1: 49; V2: 14
transmission electron microscopy, char-34, V1: 49; V2: 13
wavelength dispersive X-ray spectroscopy, char-36, V1: 49; V2: 13

Inorganic problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Inorganic problem areas, characterization alternatives for
Bldgs. 3028, 3029, 3029E, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 9201-3, and 9419-1; drain lines; pulsefeeder pumps; pavement over 55-gal drum; and process piping and tankage

In situ solvent extraction, char-62, V1: 45; V2: 3

Instrument response models for remote sensing, char-246, V1: 51; V2: 17

Integrated automated analytical laboratory, roba-55, V1: 133, 141; V2: 120

Internal duct/pipe crawler, roba-5, V1: 131, 139; V2: 115

I-129. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for

I-129 *(continued)*
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Ion chromatography, char-50, V1: 49; V2: 13

Ion mobility mass spectrometry, char-264, V1: 45; V2: 5

Ir-192. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Iron. *See*
Fe-55

Isotope facilities scheduled for D&D program, V1: 12, 14

Isotopic dilution mass spectrometry, char-48, V1: 46; V2: 6

— *K* —

Kr-85. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

— *L* —

Land disposal restrictions. *See*
Resource Conservation and Recovery Act

Laser ablation for sample collection, char-86, V1: 45; V2: 4

Laser ablation; inductively coupled plasma; atomic emission spectroscopy, char-111, V1: 49; V2: 13

Laser ablation organic mass spectrometry, char-93, V1: 51, 52; V2: 16, 19

Laser cutting (asbestos), dism-84, V1: 80; V2: 32

Laser cutting (major equipment removal), dism-91, V2: 33

Laser cutting (steel structures, highly contaminated), dism-51, V2: 28

Laser cutting (structural steel, mild contaminants), dism-71, V1: 80; V2: 30

Laser etching and ablation, dcon-74, V1: 119; V2: 50, 59, 63, 75, 88, 98, 109

Laser heating, dcon-73, V1: 119; V2: 50, 59, 63, 75, 88, 98

Laser ionization mass spectrometry, char-4, V1: 46; V2: 7

Laser photo acoustic spectroscopy, char-15, V1: 46, 51, 52; V2: 6

Laser triangular mapping of facilities (needed enabling technologies), dism-146, V2: 41

Leach/electrowinning, dcon-34, V1: 117; V2: 68, 93, 102, 105

Liquid chromatography—mass spectroscopy, char-89, V1: 50, 52; V2: 16

Liquid scintillation counting, char-267, V1: 49; V2: 12

Liquified cryogenic gas cutting (major equipment removal), dism-101, V2: 35

Location-specific regulations, V1: 168

Long-arm deployed robotic platforms, roba-9, V1: 131, 139; V2: 115

Long-range alpha detector, char-65, V1: 48; V2: 10

Long-reach manipulator (heavy duty), roba-15, V1: 131, 139; V2: 116

Long-reach manipulator (light duty), roba-14, V1: 131, 139; V2: 116

Low-Intesity Test Reactor. *See*
Concrete problem areas, decontamination alternatives for
Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

000657

— M —

Magnetic resonance imaging, char-58, V1: 51; V2: 17

Major equipment removal problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Major equipment removal problem areas, facilities associated with
- Automated conventional technologies
  - grappler/gross shearing and lifting (major equipment removal), dism-103, V2: 36
- Conventional technologies
  - conventional disassembly (major equipment removal), dism-102, V2: 36
- Cutting technologies
  - advanced automated fixtures, bug-o, et. (major equipment removal), dism-100, V1: 80; V2: 35
  - advanced laser cutting (major equipment removal), dism-95, V1: 80; V2: 34
  - diamond wire cutting (major equipment removal), dism-94, V2: 34
  - explosive cutting (major equipment removal), dism-96, V2: 34
  - high-pressure abrasive water jet (major equipment removal), dism-97, V2: 34
  - high-pressure water jet (major equipment removal), dism-93, V1: 80; V2: 33
  - laser cutting (major equipment removal), dism-91, V2: 33
  - liquified cryogenic gas cutting (major equipment removal), dism-101, V2: 35
  - mechanical saws (major equipment removal), dism-90, V1: 80; V2: 33
  - plasma arc cutting (major equipment removal), dism-92, V1: 80; V2: 33
  - plasma arc saw cutting (major equipment removal), dism-98, V2: 35
  - thermal arc water jet cutting (major equipment removal), dism-99, V2: 35
- Demolition technologies
  - oxyacetylene (major equipment removal), dism-89, V2: 33
  - thermite cutting (major equipment removal), dism-88, V2: 32

Major equipment removal problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Major equipment removal problem areas, dismantlement alternatives for
- Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Manipulation (Cartesian control), roba-31, V1: 132, 140; V2: 117

Manipulation (joint control), roba-30, V1: 132, 140; V2: 117

Manipulation (redundancy control), roba-33, V1: 132, 140; V2: 118

Manipulation (special purpose control), roba-32, V1: 132, 140; V2: 118

Massive containment problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Massive containment problem areas, facilities associated with
- Cutting technologies
  - diamond wire cutting (massive containment), dism-12, V1: 79; V2: 23
  - high-pressure abrasive water jet (massive containment), dism-11, V1: 79; V2: 23
- Demolition technologies
  - microwave demolition (massive containment), dism-16, V1: 79; V2: 23

Massive containment problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Massive containment problem areas, dismantlement alternatives for
- Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Mechanical saws (major equipment removal), dism-90, V1: 80; V2: 33

Membranes for sample collection and concentration, char-55, V2: 3

Metallographic sectioning and preparation, char-67, V1: 45; V2: 3

Metal milling, dcon-45, V1: 118; V2: 62

Microwave demolition (buried tanks), dism-38, V2: 26

Microwave demolition (massive containment), dism-16, V1: 79; V2: 23

Microwave demolition (reactor pools), dism-28, V1: 79; V2: 25

Microwave demolition (structural-only concrete), dism-47, V2: 27

Microwave digestion, char-19, V1: 45; V2: 4

Microwave scabbling, dcon-71, V1: 119; V2: 49, 58, 74

Modeling of heterogenous materials sampling, char-61, V1: 51; V2: 17

Modeling of volatile organic compounds migration in porous materials, char-53, V1: 47; V2: 9

Modular entombment—with provisions for future removal (entombment), dism-119, V2:

Molten salt. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for 39

Mounted robotic platforms, roba-8, V1: 131, 139; V2: 115

Multiangle drilling for depth profiling of contaminants, char-64, V1: 45; V2: 3

— *N* —

National Emission Standards for Hazardous Air Pollutants. *See*
Clean Air Act

National Emission Standards for Hazardous Air Pollutants for asbestos. *See*
Clean Air Act

National Environmental Policy Act, V1: 167

Needed enabling technology problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Needed enabling technology problem areas, facilities associated with
Needed enabling technologies
automated engineering system life cycle planning (needed enabling technologies), dism-174, V1: 48; V2: 43
automated scanning and conversion of engineering drawings (needed enabling technologies), dism-155, V1: 47, 81; V2: 42
automated system reliability and safety analysis (needed enabling technologies), dism-175, V1: 48; V2: 43
bar code/laser tooling location (needed enabling technologies), dism-140, V2: 40
client/server access to standards and regulatory guidelines (needed enabling technologies), dism-153, V1: 47, 81; V2: 42
client/server architecture for data base access (needed enabling technologies), dism-157, V1: 47; V2: 42
computer-aided task analysis and procedure preparation (needed enabling technologies), dism-172, V1: 47, 81; V2: 43
computer-based D&D information retrieval (needed enabling technologies), dism-143, V1: 81; V2: 40
computer-based training systems (needed enabling technologies), dism-191, V1: 47, 81; V2: 44
data access services (needed enabling technologies), dism-154, V1: 47; V2: 42
electronic catalog descriptions and source locations of site historical data (needed enabling technologies), dism-159, V1: 81; V2: 43
generalized object-oriented simulation software (needed enabling technologies), dism-173, V1: 48; V2: 43
geographic information system for DOE sites (needed enabling technologies), dism-181, V1: 47; V2: 43
GIF images to augment as-built documentation (needed enabling technologies), dism-145, V2: 41
hypertext information systems (needed enabling technologies), dism-158, V1: 48; V2: 43
laser triangular mapping of facilities (needed enabling technologies), dism-146, V2: 41
network architecture with integrated workstations (needed enabling technologies), dism-152, V2: 42
point-and-direct tooling positioning (needed enabling technologies), dism-142, V2: 40
project information access services (needed enabling technologies), dism-151, V1: 47, 81; V2: 42
3-D CAD data base of buildings and structures (needed enabling technologies), dism-156, V1: 48, 81; V2: 42
video mapping (needed enabling technologies), dism-147, V2: 41
zoning for containment—three zones (needed enabling technologies), dism-141, V2: 40

000659

Needed enabling technology problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Needed enabling technology problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

NESHAPs for asbestos. *See*
National Emission Standards for Hazardous Air Pollutants for asbestos

Network architecture with integrated workstations, char-221, V1: 46; V2: 7

Network architecture with integrated workstations (needed enabling technologies), dism-152, V2: 42

Neutron activation, char-107, V1: 48; V2: 11

Neutron activation analysis, char-266, V1: 48, 49; V2: 12, 14

Nondestructive testing for concrete, char-38, V1: 51; V2: 17

Nuclear magnetic resonance, char-11, V1: 46; V2: 6

— O —

Oak Ridge Research Reactor facility. *See*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Entombment problem areas, dismantlement alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Reactor pool problem areas, dismantlement alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt roofing, and concrete problem areas, decontamination alternatives for

Occupational Safety and Health Act,
Asbestos removal, V1: 172
General industry requirements, V1: 172
Hazardous waste operations, V1: 172
Permissible exposure limits (asbestos), V1: 172

Oil and purex chemical problem areas, characterization alternatives for. *For a complete list of facilities, see* Oil and purex chemical problem areas, facilities associated with
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 50–52; V2: 18
fiber-optic chemical sensors, char-25, V1: 45, 51; V2: 18
gas chromatography—mass spectrometry, char-88, V1: 50, 52; V2: 18
infrared absorption (laser-based source), char-,85, V2: 18
infrared spectroscopy (wavelength dispersion), char-18, V1: 46, 51; V2: 18
portable volatile organic compound detectors, char-5, V1: 50, 51; V2: 18
sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 18
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 50, 52; V2: 19
laser ablation organic mass spectrometry, char-93, V1: 51, 52; V2: 19
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50, 52; V2: 19

Oil and purex chemical problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Oil and purex chemical problem areas, characterization alternatives for
Painted sheet metal floor of coolant salt cell, Bldg. 9203-1; 3,000-gal stainless steel tank, Bldg. 9203-1; Fission Products Development Laboratory inactive cells, Bldg. 3019

000660

On-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50, 52; V2: 16, 19

Operator interface (command input), roba-40, V1: 132, 140; V2: 118

Operator interface (operator assistance), roba-41, V1: 132, 140; V2: 119

Operator interface (status/alert system), roba-42, V1: 132, 140; V2: 119

Optical absorption spectroscopy, char-27, V1: 46; V2: 5

Optical microscopy, char-32, V1: 51; V2: 17

Optimization of sampling designs, char-71, V1: 45; V2: 3

Organic acid treatments, dcon-10, V1: 117; V2: 69, 93, 102

Organic problem areas, characterization alternatives for. *For a complete list of facilities, see* Organic problem areas, facilities associated with
- Field method technologies
  - direct sampling ion trap mass spectrometry, char-90, V1: 50–52; V2: 15
  - fluorescence diagnosis of contaminated surfaces, char-110, V1: 50; V2: 14
  - gas chromatography in the field, char-262, V1: 50, 51; V2: 15
  - infrared absorption (laser-based source), char-85, V1: 50, 51; V2: 14
  - portable gas chromatograph/electron capture detection for analyzing PCBs, char-100, V1: 50, 52; V2: 15
  - portable volatile organic compound detectors, char-5, V1: 50, 51; V2: 15
  - synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 15
- Laboratory method technologies
  - analytical methods for chelators and decontamination agents, char-206, V1: 50, 52; V2: 15
  - capillary zone electrophoresis, char-207, V1: 50; V2: 16
  - gas chromatography, char-94, V1: 51, 52; V2: 16
  - gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 50; V2: 16
  - gas chromatography—mass spectroscopy, char-88, V1: 50, 52; V2: 16
  - laser ablation organic mass spectrometry, char-93, V1: 51, 52; V2: 16
  - liquid chromatography—mass spectroscopy, char-89, V1: 50, 52; V2: 16
  - on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50, 52; V2: 16
  - surface-enhanced Raman scattering, char-265, V1: 51; V2: 16
  - synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 16

Organic problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Organic problem areas, characterization alternatives for
- Bldgs. 3028, 3029, 3029E, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 9201-3, and 9419-1; drain lines, pulsefeeder pumps; pavement over 55-gal drum; and process piping and tankage

ORNL facilities already in D&D program, V1: 6-12

ORNL special-case facilities, V1: 14

OSHA. *See*
- Occupational, Safety, and Health Act

Oxyacetylene (major equipment removal), dism-89, V2: 33

Oxygen cutting (steel structures, highly contaminated), dism-57, V1: 79; V2: 29

Oxygen cutting (structural steel, mild contaminants), dism-75, V1: 80; V2: 31

— P —

Painted concrete problem areas, decontamination alternatives for. *For a complete list of facilities, see* Painted concrete problem areas, facilities associated with
- Chemical surface cleaning method technologies
  - chelation treatment, dcon-21, V1: 117; V2: 60
  - fluoboric acid treatment, dcon-11, V1: 117; V2: 60
- Mechanical surface removal method technologies
  - automated grinding, dcon-44, V1: 118; V2: 57
  - centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 39
  - concrete milling, dcon-47, V1: 118; V2: 58
  - explosive, dcon-48, V1: 118; V2: 58
  - grit blasting, dcon-38, V1: 118; V2: 56
  - hand grinding, honing, scraping, dcon-43, V1: 118; V2: 57
  - ice blasting, dcon-40, V1: 118; V2: 57
  - plastic pellet blasting, dcon-42, V1: 118; V2: 57
  - scabblers/scarifiers, dcon-37, V1: 117; V2: 56
  - shot blasting, dcon-36, V1: 117; V2: 56
  - supercritical CO_2 blasting, dcon-41, V1: 118; V2: 57
  - ultrahigh-pressure water, dcon-35, V1: 117; V2: 56

Surface cleaning method technologies
compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 60
Thermal surface removal method technologies
flashlamp cleaning, dcon-77, V1: 119; V2: 59
laser etching and ablation, dcon-74, V1: 119; V2: 59
laser heating, dcon-73, V1: 119; V2: 59
microwave scabbling, dcon-71, V1: 119; V2: 58
plasma torch, dcon-72, V1: 119; V2: 59

Painted concrete problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Painted concrete problem areas, decontamination alternatives for
Bldg. 3019 hot cell interiors, floors, and cell faces—painted concrete (U-233, Pu-239, fission products)
Bldg. 3028 hot cell interiors, floors, cell faces—painted concrete (fission products, Cm-147, Pm-241, Am)
Bldg. 3029 cell faces—painted concrete (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3030 floors and cell faces—painted concrete (43 beta/gamma emitters)
Bldg. 3031 floors and cell faces—painted concrete (Gd-153, Am-241)
Bldg. 3032 floors and cell faces—painted concrete (P-32, Am-241)
Bldg. 3033 cell faces—painted concrete (H-3, Kr-85)
Bldg. 3036 floors—painted concrete (Cs-137, Sr-90)
Bldg. 3038 cell floor and surfaces—painted concrete (Sr-90, Cs-137, Co-60, I-129)
Bldg. 3047 floors and cell faces—painted concrete (Cs, Sr, Co, Cm, Eu, Am, Pu)
Bldg. 3505 floors and cell faces—painted concrete (fission products, TRU)
Bldg. 3506 hot cell interiors—painted concrete (fission products)
Bldg. 3515 floors and cell faces—painted concrete (fission products)
Bldg. 3517 high-bay floors and cell faces—painted concrete (Cs-137, Sr-90, Co-60)
Bldg. 7852 floors and cell faces—painted concrete (fission products, corrosion products, Cs, Sr, TRU, Co, Cm, Eu, Am, Pu)
Bldg. 9201-3 coolant salt cell—painted concrete (U, Th, coolant salt)
Bldg. 9201-3 molten salt cell—painted concrete (U, Th, molten salt)
Graphite Reactor biological shield exterior—painted concrete (fission products, Pu, C-14, F3-55, Cs-137, Sr-90, C0-60, activation products)
Oak Ridge Research Reactor hot cell interiors, floors, cell faces—painted concrete (fission products, TRU)

Particle-induced X-ray emission, char-17, V1: 49; V2: 14

Particle size analysis, char-26, V1: 51; V2: 17

Passive monitors for weak beta radionuclides, char-102, V1: 48; V2: 10

Pavement problem areas. *See*
Asphalt pavement problem areas, decontamination alternatives for

PCB immunoassay kit, char-99, V2: 19

Permanent entombment (entombment), dism-114, V1: 80; V2: 38

Personnel monitoring, char-52, V1: 46; V2: 5

P-32. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Photon electron rejecting alpha liquid scintillation, char-97, V1: 49; V2: 12

Physical problem areas, characterization alternatives for. *For a complete list of facilities, see* Physical problem areas, facilities associated with
Field method technologies
fiber-optic systems for measuring multiple physical variables, char-248, V1: 51; V2: 17
instrument response models for remote sensing, char-246, V1: 51; V2: 17
Laboratory method technologies
holographic imaging, char-46, V1: 51; V2: 17
inorganic cementitious matrix composites model, char-39, V1: 51; V2: 17
magnetic resonance imaging, char-58, V1: 51; V2: 17
modeling of heterogenous materials sampling, char-61, V1: 51; V2: 17
nondestructive testing for concrete, char-38, V1: 51; V2: 17
optical microscopy, char-32, V1: 51; V2: 17
particle size analysis, char-26, V1: 51; V2: 17
radiation-induced segregation model, char-42, V1: 51; V2: 18

Physical problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Physical problem areas, characterization alternatives for
Bldgs. 3028, 3029, 3029E, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 9201-3, and 9419-1; drain lines, pulsefeeder pumps; pavement over 55-gal drum; and process piping and tankage

Pipe interiors, decontamination alternatives for. *For a complete list of facilities, see* Pipe interiors, facilities associated with
Chemical surface cleaning technologies
chelation treatment, dcon-21, V1: 117; V2: 96
chemical foams, dcon-8, V1: 117; V2: 93
detergent treatment, dcon-13, V1: 117; V2: 94
electropolishing, dcon-15, V1: 117; V2: 95
fluoboric acid treatment, dcon-11, V1: 117; V2: 94
gas phase decontamination, dcon-16, V1: 117; V2: 95
inorganic acid treatments, dcon-12, V1: 117; V2: 94
organic acid treatments, dcon-10, V1: 117; V2: 93
REDOX treatments, dcon-14, V1: 117; V2: 95
Mechanical surface removal method technologies
automated grinding, dcon-44, V1: 118; V2: 88
centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 87
ice blasting, dcon-40, V1: 118; V2: 87
plastic pellet blasting, dcon-42, V1: 118; V2: 88
supercritical CO_2 blasting, dcon-41, V1: 118; V2: 87
ultrahigh-pressure water, dcon-35, V1: 117; V2: 87
Metal refining method technologies
electrorefining, dcon-32, V1: 117; V2: 92
leach/electrowinning, dcon-34, V1: 117; V2: 93
smelt purification, dcon-31, V1: 117; V2: 92
Surface cleaning method technologies
automated brushing, dcon-57, V1: 118; V2: 91
compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 90
dry heat (bulk roasting), dcon-4, V1: 117; V2: 91
solvent washing to remove radiological contamination, dcon-61, V1: 118; V2: 91
steam cleaning, dcon-55, V1: 118; V2: 90
superheated water, dcon-53, V1: 118; V2: 90
vacuum cleaning, dcon-64, V1: 118; V2: 91
water flushing, dcon-54, V1: 118; V2: 90
ultrasonic cleaning, dcon-65, V1: 118; V2: 92
Thermal surface removal method technologies
flashlamp cleaning, dcon-77, V1: 119; V2: 89
laser etching and ablation, dcon-74, V1: 119; V2: 88
laser heating, dcon-73, V1: 119; V2: 88
plasma etching/fluorination, dcon-76, V1: 119; V2: 89
plasma surface cleaning, dcon-75, V1: 119; V2: 89

Pipe interiors, facilities associated with. *For specific technologies to treat these facilities, see* Pipe interiors, decontamination alternatives for
Bldg. 3517 process piping and tankage—stainless steel pipe interior (Cs-137, Sr-90)
Drain lines from Bldg. 9419-1—steel pipe interior (U, Th, molten salt)
Drain lines from coolant salt cell, Bldg. 9201-3—steel pipe interior (U, Th, coolant salt)
Drain lines from molten salt cells, Bldg. 9201-3—steel pipe interior (U, Th, molten salt)
Homogeneous Reactor Test process piping—stainless steel pipe interior (UO_2SO_4, fission products, corrosion products)
Instrument air lines and air lines in coolant salt cell, Bldg. 9201-3—copper tubing interior (U, Th, H-3, molten salt)
Molten Salt Reactor Experiment Off-Gas System—steel pipe interior
Molten Salt Reactor Experiment reactor piping—INOR piping interior (U, Be, L, F, TiF_3)
Oak Ridge Research Reactor demineralizer piping (outside pool)—stainless steel pipe interior (fission products, corrosion products)
Oak Ridge Research Reactor primary coolant piping—aluminum piping interior (fission products, corrosion products)
Pulse-feeder pumps—metal (heavy water)

Plasma arc cutting (major equipment removal), dism-92, V1: 80; V2: 33

Plasma arc cutting (steel structures, highly contaminated), dism-56, V1: 79; V2: 28

Plasma arc cutting (structural steel, mild contaminants), dism-74, V1: 80; V2: 31

Plasma arc saw cutting (major equipment removal), dism-98, V2: 35

Plasma arc saw (steel structures, highly contaminated), dism-58, V2: 29

Plasma etching/fluorination, dcon-76, V1: 119; V2: 89

Plasma surface cleaning, dcon-75, V1: 119; V2: 63, 89

Plasma torch, dcon-72, V1: 119; V2: 50, 59, 63, 75

Plastic pellet blasting, dcon-42, V1: 118; V2: 48, 57, 62, 73, 88, 97, 108

Plate, steel. *See*
Stainless steel, steel plate, and structural steel problem areas, decontamination alternatives for

Pu. *For specific technologies to treat this contaminant, see*
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for

Point-and-direct tooling positioning (needed enabling technologies), dism-142, V2: 40

Polychlorinated biphenyls (PCBs)
Characterization alternatives for. *For a complete list of facilities, see* Polychlorinated biphenyls (PCBs), facilities associated with Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 50–52; V2: 19
PCB immunoassay kit, char-99, V2: 19
portable gas chromatograph/electron capture detection for analyzing PCBs, char-100, V1: 50, 52; V2: 19
sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 19
Laboratory method technologies
gas chromatography, char-94, V1: 51, 52; V2: 19
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50, 52; V2: 19

Polychlorinated biphenyls (PCBs), facilities associated with. *For specific technologies to treat these facilities, see* PCBs, characterization alternatives for
Asbestos pipe insulation, Bldg. 9201-3

Pool. *See*
Reactor pool problem areas, dismantlement alternatives for

Portable gamma-ray scintillometers, char-263, V1: 48; V2: 11

Portable gas chromatograph/electron capture detection for analyzing PCBs, char-100, V1: 50, 52; V2: 15, 19

Portable luminescence detection, char-92, V1: 46; V2: 6

Portable Raman spectrometer, char-84, V1: 46; V2: 5

Portable volatile organic compound detectors, char-5, V1: 50, 51; V2: 15, 18

Portable X-ray fluorescence, char-6, V1: 49; V2: 13

Position/velocity sensors, roba-48, V1: 133, 141; V2: 119

Powder X-ray diffraction, char-31, V1: 50; V2: 14

Power sources for mobile platforms, roba-10, V1: 131, 139; V2: 115

Precise programmable motions, roba-20, V1: 131, 140; V2: 116

Process emissions. *See*
Clean Air Act

Project information access services (needed enabling technologies), dism-151, V : 47, 81; V2: 7, 42

Pm-147. *For specific technologies to treat this contaminant, see*
Concrete problem areas, decontamination alternatives for

Proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 10, 12

Proximity probes, roba-45, V1: 133, 141; V2: 119

Proximity probes as sensors, roba-51, V1: 133, 141; V2: 119

Punch cores, char-82, V1: 45; V2: 3

Purex. *See*
Oil and purex chemical problem areas, characterization alternatives for

— Q —

Quality control for measurement processes, char-250, V1: 47; V2: 9

— R —

Radiation hardening, roba-54, V1: 133, 141; V2: 120

Radiation-induced segregation model, char-42, V1: 51; V2: 18

Radiation Protection Standards
DOE orders, V1: 173–175
Generic BRC levels for radioactive wastes, V1: 175–176

Radioactive elements, characterization alternatives for. *For a complete list of facilities, see* Radioactive elements, facilities associated with
Field method technologies
advanced radiation monitors, char-269, V1: 48; V2: 11
alpha track etch detectors for surface alpha contamination, char-96, V1: 48; V2: 11
bubble dosimeters for neutron flux, char-216, V1: 48; V2: 11
electret passive surface alpha monitor, char-95, V1: 48; V2: 11
long-range alpha detector, char-65, V1: 48; V2: 10
passive monitors for weak beta radionuclides, char-102, V1: 48; V2: 10
portable gamma-ray scintillometers, char-263, V1: 48; V2: 11
proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 10
thermoluminescence dosimeter array for spatial characterization of surface alpha contamination, char-103, V1: 48; V2: 10
tritium/beta/gamma floor scanner, char-105, V1: 48; V2: 11
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 49; V2: 12
liquid scintillation counting, char-267, V1: 49; V2: 12
neutron activation, char-107, V1: 48; V2: 11
neutron activation analysis, char-266, V1: 48; V2: 12
photon electron rejecting alpha liquid scintillation, char-97, V1: 49; V2: 12
proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 12
radioanalytical procedures, char-202, V1: 49; V2: 12
radiographic imaging, char-40, V1: 49; V2: 12
sodium iodide-germanium gamma spectroscopy, char-106, V1: 48; V2: 12

Radioactive elements, facilities associated with. *For specific technologies to treat these facilities, see* Radioactive elements, characterization alternatives for
Bldgs. 3028, 3029, 3029E, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 9201-3, and 9419-1; drain lines, pulsefeeder pumps; pavement over 55-gal drum; and process piping and tankage

Radioactive sample preparation, char-205, V1: 45; V2: 4

Radioactive wastes, generic BRC levels for. *See* Radiation Protection Standards

Radioanalytical procedures, char-202, V1: 49; V2: 12

Radiographic imaging, char-40, V1: 49; V2: 12

Range finders, roba-44, V1: 133, 140; V2: 119

Rankings, technology
Descriptions of criteria, V1: 30–32
for characterization technologies, V1: 45–52; V2: 3–19
for decontamination technologies, V1: 117–119; V2: 47–112
for dismantlement technologies, V1: 79–81; V2: 23–44
for robotics and automation, V1: 139–141; V2: 115–120

Rare, threatened, or endangered species, V1: 169, 171

RCRA. *See* Resource Conservation and Recovery Act

Reactor pool problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Reactor pool problem areas, facilities associated with
Cutting technologies
diamond wire cutting (reactor pools), dism-22, V2: 24
explosive cutting (reactor pools), dism-23, V2: 24
high-pressure abrasive water jet (reactor pools), dism-21, V1: 79; V2: 23
Demolition technologies
conventional demolition (reactor pools), dism-26, V2: 24
demolition compounds (reactor pools), dism-25, V1: 79; V2: 24
microwave demolition (reactor pools), dism-28, V1: 79; V2: 25

Reactor pool problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Reactor pool problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Reactors and support facilities, robotics and automation alternatives for
Controls—algorithm technologies
combined mobility/manipulation, roba-34, V1: 132, 140; V2: 118
control modes, roba-27, V1: 132, 140; V2: 117
emergency shutdown, roba-37, V1: 132, 140; V2: 118
manipulation (Cartesian control), roba-31, V1: 132, 140; V2: 117
manipulation (joint control), roba-30, V1: 132, 140; V2: 117

000665

manipulation (redundancy control), roba-33, V1: 132, 140; V2: 118
manipulation (special purpose control), roba-32, V1: 132, 140; V2: 118
safety (collision avoidance), roba-35, V1: 132, 140; V2: 118
safety (load/rate limiting), roba-36, V1: 132, 140; V2: 118
vehicle/mobility driving, roba-28, V1: 132, 140; V2: 117
vehicle/mobility navigation, roba-29, V1: 132, 140; V2: 117
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 132, 140; V2: 118
console (fixed/mobile/suitcase), roba-38, V1: 132, 140; V2: 118
operator interface (command input), roba-40, V1: 132, 140; V2: 118
operator interface (operator assistance), roba-41, V1: 132, 140; V2: 119
operator interface (status/alert system), roba-42, V1: 132, 140; V2: 119
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 132, 140; V2: 117
end effectors/alternatives, roba-23, V1: 132, 140; V2: 117
force limiting/compliant mechanisms, roba-26, V1: 132, 140; V2: 117
general gripper/tool interface, roba-25, V1: 132, 140; V2: 117
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 131, 139; V2: 116
dexterous manipulators, roba-16, V1: 131, 139; V2: 116
long-reach manipulator (heavy duty), roba-15, V1: 131, 139; V2: 116
long-reach manipulator (light duty), roba-14, V1: 131, 139; V2: 116
Mechanical—mechanism technologies
precise programmable motions, roba-20, V1: 131, 140; V2: 116
stabilization/support mechanisms or booms, roba-22, V1: 131, 140; V2: 116
tool caddies, roba-21, V1: 131, 140; V2: 116
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 131, 139; V2: 116
external duct/pipe crawlers, roba-6, V1: 131, 139; V2: 115
failure recovery systems for mobile platforms, roba-11, V1: 131, 139; V2: 115
internal duct/pipe crawler, roba-5, V1: 131, 139; V2: 115
long-arm deployed robotic platforms, roba-9, V1: 131, 139; V2: 115
mounted robotic platforms, roba-8, V1: 131, 139; V2: 115
power sources for mobile platforms, roba-10, V1: 131, 139; V2: 115
specialized robotic deployment platforms, roba-7, V1: 131, 139; V2: 115
transportation systems for mobile platforms, roba-12, V1: 131, 139; V2: 116
wheeled/tracked vehicle, roba-1, V1: 131, 139; V2: 115
Other technologies
characterization sensor integration, roba-58, V1: 133, 141; V2: 120
field hardening, roba-53, V1: 133, 141; V2: 120
information management for sample handling, roba-56, V1: 133, 141; V2: 120
integrated automated analytical laboratory, roba-55, V1: 133, 141; V2: 120
radiation hardening, roba-54, V1: 133, 141; V2: 120
sample collection, roba-57, V1: 133, 141; V2: 120
sample preparation, roba-59, V1: 133, 141; V2: 120
Sensors—control technologies
force/torque, roba-50, V1: 133, 141; V2: 119
position/velocity sensors, roba-48, V1: 133, 141; V2: 119
proximity probes as sensors, roba-51, V1: 133, 141; V2: 119
tooling sensors, roba-52, V1: 133, 141; V2: 120
Sensors—perception technologies
force/torque sensors, roba-46, V1: 133, 141; V2: 119
proximity probes, roba-45, V1: 133, 141; V2: 119
range finders, roba-44, V1: 133, 140; V2: 119
visual/aural systems, roba-43, V1: 133, 140; V2: 119

REDOX treatments, dcon-14, V1: 117; V2: 70, 95, 103

Regulatory compliance. *See*
Clean Air Act
Clean Water Act
Department of Energy orders
National Environmental Policy Act
Occupational Safety and Health Administration
Radiation Protection Standards
Resource Conservation and Recovery Act

Resource Conservation and Recovery Act
Chemical, physical, biological treatment, V1: 157
Closure of containers, V1: 152, 160
Closure of tank systems, V1: 151, 160, 152
Containment building, V1: 158–159, 161
Corrective Action Management Units (CAMU), V1: 162–163
Hazardous debris, V1: 160–162
Land disposal restrictions, V1: 156–159, 160–162
LDR, V1: 156–159, 160–162
Miscellaneous treatment units, V1: 157
Overview, V1: 151
Permits for treatment units, V1: 161–162
Sampling/analysis, V1: 156
Treatment units, V1: 157–159, 161–162

Restrictions, land disposal. *See*
Resource Conservation and Recovery Act

Robotics and automation. *See*
Abandoned hot cells, robotics and automation alternatives for
Reactors and support facilities, robitics and autmomation alternatives for
Stabilized hot cells, robotics and automation aternatives for
Storage buildings, robitics and automation alternatives for

Robotics and automation, discussions of
Implementation needs, V1: 138
Introduction, V1: 129
Science and technology needs, V1: 136–137
Technology options, V1: 130–135
Technology rankings, V1: 139–141

Rubblization via crushing and/or shredding (entombment), dism-117, V2: 39

— S —

Safety (collision avoidance), roba-35, V1: 132, 140; V2: 118

Safety (load/rate limiting), roba-36, V1: 132, 140; V2: 118

Sample collection, roba-57, V1: 133, 141; V2: 120

Sample preparation, roba-59, V1: 133, 141; V2: 120

Sampling and mixing methods, char-81, V1: 45; V2: 3

Sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 4, 18, 19

Sampling program configuration management system, char-228, V1: 45; V2: 3

Scabblers/scarifiers, dcon-37, V1: 117; V2: 47, 56, 72, 82, 107

Scanning electron microscopy, char-33, V1: 49; V2: 14

Secondary ion mass spectroscopy, char-3, V1: 46; V2: 6

Sensors for monitoring entombment integrity (entombment), dism-118, V1: 80; V2: 39

Sequential sampling plans, char-252, V1: 45; V2: 3

Sheet steel. *See*
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for

Shot blasting, dcon-36, V1: 117; V2: 47, 56, 61, 72, 82

Simulated walkthrough facility for robotics task sequence analysis (needed enabling technologies), dism-171, V1: 47, 81; V2: 8

Smelt purification, dcon-31, V1: 117; V2: 67, 92, 100, 105

Sodium iodide-germanium gamma spectroscopy, char-106, V1: 48; V2: 12

Solvent extraction, dcon-1, V1: 117; V2: 80, 85

Solvent washing to remove organics, dcon-62, V1: 118; V2: 66

Solvent washing to remove radiological contamination, dcon-61, V1: 118; V2: 52, 66, 77, 91, 111

Spatial sample and data analysis plans, char-253, V1: 46; V2: 9

Specialized robotic deployment platforms, roba-7, V1: 131, 139; V2: 115

Species, rare, threatened, or endangered species, V1: 169, 171

Sponge blasting, dcon-58, V1: 118; V2: 52, 65, 77, 111

Stabilization/support mechanisms or booms, roba-22, V1: 131, 140; V2: 116

Stabilized hot cells, robotics and automation alternatives for
Controls—algorithm technologies
combined mobility/manipulation, roba-34, V1: 132, 140; V2: 118
control modes, roba-27, V1: 132, 140; V2: 117
emergency shutdown, roba-37, V1: 132, 140; V2: 118
manipulation (Cartesian control), roba-31, V1: 132, 140; V2: 117
manipulation (joint control), roba-30, V1: 132, 140; V2: 117
manipulation (redundancy control), roba-33, V1: 132, 140; V2: 118
manipulation (special purpose control), roba-32, V1: 132, 140; V2: 118
safety (collision avoidance), roba-35, V1: 132, 140; V2: 118
safety (load/rate limiting), roba-36, V1: 132, 140; V2: 118
vehicle/mobility driving, roba-28, V1: 132, 140; V2: 117
vehicle/mobility navigation, roba-29, V1: 132, 140; V2: 117
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 132, 140; V2: 118

000667

console (fixed/mobile/suitcase), roba-38, V1: 132, 140; V2: 118
operator interface (command input), roba-40, V1: 132, 140; V2: 118
operator interface (operator assistance), roba-41, V1: 132, 140; V2: 119
operator interface (status/alert system), roba-42, V1: 132, 140; V2: 119
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 132, 140; V2: 117
end effectors/alternatives, roba-23, V1: 132, 140; V2: 117
force limiting/compliant mechanisms, roba-26, V1: 132, 140; V2: 117
general gripper/tool interface, roba-25, V1: 132, 140; V2: 117
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 131, 139; V2: 116
dexterous manipulators, roba-16, V1: 131, 139; V2: 116
long-reach manipulator (heavy duty), roba-15, V1: 131, 139; V2: 116
long-reach manipulator (light duty), roba-14, V1: 131, 139; V2: 116
Mechanical—mechanism technologies
precise programmable motions, roba-20, V1: 131, 140; V2: 116
stabilization/support mechanisms or booms, roba-22, V1: 131, 140; V2: 116
tool caddies, roba-21, V1: 131, 140; V2: 116
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 131, 139; V2: 116
external duct/pipe crawlers, roba-6, V1: 131, 139; V2: 115
failure recovery systems for mobile platforms, roba-11, V1: 131, 139; V2: 115
internal duct/pipe crawler, roba-5, V1: 131, 139; V2: 115
long-arm deployed robotic platforms, roba-9, V1: 131, 139; V2: 115
mounted robotic platforms, roba-8, V1: 131, 139; V2: 115
power sources for mobile platforms, roba-10, V1: 131, 139; V2: 115
specialized robotic deployment platforms, roba-7, V1: 131, 139; V2: 115
transportation systems for mobile platforms, roba-12, V1: 131, 139; V2: 116
wheeled/tracked vehicle, roba-1, V1: 131, 139; V2: 115
Other technologies
characterization sensor integration, roba-58, V1: 133, 141; V2: 120
field hardening, roba-53, V1: 133, 141; V2: 120
information management for sample handling, roba-56, V1: 133, 141; V2: 120
integrated automated analytical laboratory, roba-55, V1: 133, 141; V2: 120
radiation hardening, roba-54, V1: 133, 141; V2: 120
sample collection, roba-57, V1: 133, 141; V2: 120
sample preparation, roba-59, V1: 133, 141; V2: 120
Sensors—control technologies
force/torque, roba-50, V1: 133, 141; V2: 119
position/velocity sensors, roba-48, V1: 133, 141; V2: 119
proximity probes as sensors, roba-51, V1: 133, 141; V2: 119
tooling sensors, roba-52, V1: 133, 141; V2: 120
Sensors—perception technologies
force/torque sensors, roba-46, V1: 133, 141; V2: 119
proximity probes, roba-45, V1: 133, 141; V2: 119
range finders, roba-44, V1: 133, 140; V2: 119
visual/aural systems, roba-43, V1: 133, 140; V2: 119

Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for. *For a complete list of facilities, see* Stainless steel, steel plate, sheet steel, and structural steel problem areas, facilities associated with
Chemical surface cleaning method technologies
catalytic extraction process, dcon-6, V1: 117; V2: 71
chelation treatment, dcon-21, V1: 117; V2: 71
chemical gels, dcon-9, V1: 117; V2: 68
chemical foams, dcon-8, V1: 117; V2: 68
detergent treatments, dcon-13, V1: 117; V2: 70
fluoboric acid treatment, dcon-11, V1: 117; V2: 69
inorganic acid treatments, dcon-12, V1: 117; V2: 69
organic acid treatments, dcon-10, V1: 117; V2: 69
REDOX treatments, dcon-14, V1: 117; V2: 70
Mechanical surface removal method technologies
automated grinding, dcon-44, V1: 118; V2: 62
centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 61
grit blasting, dcon-38, V1: 118; V2: 61
hand grinding, honing, scraping, dcon-43, V1: 118; V2: 62
ice blasting, dcon-40, V1: 118; V2: 61
metal milling, dcon-45, V1: 118; V2: 62
plastic pellet blasting, dcon-42, V1: 118; V2: 62
shot blasting, dcon-36, V1: 117; V2: 61
supercritical CO_2 blasting, dcon-41, V1: 118; V2: 62
ultrahigh-pressure water, dcon-35, V1: 117; V2: 61
Metal refining method technologies
electrorefining, dcon-32, V1: 117; V2: 67
leach/electrowinning, dcon-34, V1: 117; V2: 68
smelt purification, dcon-31, V1: 117; V2: 67

Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for *(continued)*
Surface cleaning method technologies
automated brushing, dcon-57, V1: 118; V2: 65
compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 64
hand brushing used to remove surface contamination, dcon-56, V1: 118; V2: 65
high-pressure water, dcon-52, V1: 118; V2: 64
solvent washing to remove organics, dcon-62, V1: 118; V2: 66
solvent washing to remove radiological contamination, dcon-61, V1: 118; V2: 66
sponge blasting, dcon-58, V1: 118; V2: 65
steam cleaning, dcon-55, V1: 118; V2: 65
strippable coatings, dcon-63, V1: 118; V2: 66
superheated water, dcon-53, V1: 118; V2: 64
ultrasonic cleaning, dcon-65, V1: 118; V2: 67
vacuum (low pressure), dcon-64, V1: 118; V2: 66
water flushing, dcon-54, V1: 118; V2: 65
Thermal surface removal method technologies
flashlamp cleaning, dcon-77, V1: 119; V2: 64
laser etching and ablation, dcon-74, V1: 119; V2: 63
laser heating, dcon-73, V1: 119; V2: 63
plasma surface cleaning, dcon-75, V1: 119; V2: 63
plasma torch, dcon-72, V1: 119; V2: 63

Stainless steel, steel plate, sheet steel, and structural steel problem areas, list of facilities associated with. *For specific technologies to treat these facilities, see* Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Bldg. 3028 hot cell liners—stainless steel (fission products, Cm-147, Pm-241, Am)
Bldg. 3028E charging area—sheet steel (fission products, TRU)
Bldg. 3028E steel structure—structural steel (fission products, TRU)
Bldg. 3029 cell 2 wall—steel plate (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3029 exterior walls—sheet steel (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3029 hot cell liners—stainless steel (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3029 structure—structural steel (Cs-137, Sr-90, Co-60, Ir-92)
Bldg. 3030 hot cell liners—stainless steel (43 beta/gamma emitters)
Bldg. 3030 siding/interior walls—sheet steel (43 beta/gamma emitters)
Bldg. 3030 steel building structure—structural steel (43 beta/gamma emitters)
Bldg. 3031 hot cell liners—stainless steel (Gd-153, Am-241)
Bldg. 3031 siding/interior walls—sheet steel (Gd-153, Am-241)
Bldg. 3031 structure—structural steel (Gd-153, Am-241)
Bldg. 3032 hot cell liners—stainless steel (P-32, Am-241)
Bldg. 3032 siding/interior walls—sheet steel (P-32, Am-241)
Bldg. 3032 structure—structural steel (P-32, Am-241)
Bldg. 3033 process piping—stainless steel (H-3, Kr-85)
Bldg. 3033 siding/interior walls—sheet steel (H-3, Kr-85)
Bldg. 3036 siding/interior walls—sheet steel (Cs-137, Sr-90)
Bldg. 3038 glove boxes and cell interior—stainless steel (pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I)
Bldg. 3038 glove boxes—stainless steel (Pu-238, Am-241, Cm-244)
Bldg. 3517 hot cell liners—stainless steel (Cs-137, Sr-90, Co-60)
Bldg. 3517 interior/exterior walls—stainless steel (Cs-137, Sr-90, Co-60)
Bldg. 7500 high-bay area—sheet steel (Cs, Sr, TRU, Co-60)
Bldg. 9201-3 three walls and upper floors of molten salt cells—sheet steel (U, Th, molten salt)
Bldg. 9201-3 walls and roof of coolant salt cells—sheet steel (U, Th, coolant salt)
Bldg. 9419-1 handrail—painted steel pipe exterior (U, Th, molten salt)
Graphite Reactor process piping—stainless steel pipe exterior
Homogeneous Reactor Test process piping—stainless steel pipe exterior (uranyl sulfate, fission products, corrosion products)
Instrument and air lines in coolant salt cell, Bldg. 9201-3—copper tubing exterior (U, Th, H-3, molten salt)
Membrane between Homogeneous Reactor Test concrete—steel plate (fission products, corrosion products)
Molten Salt Reactor building structure—structural steel (Cs, Sr, TRU, Co-60)
Molten Salt Reactor Experiment exterior siding—sheet steel (Cs, Sr, TRU, Co-60)
Molten Salt Reactor Experiment off-gas system—stainless steel pipe exterior (fission products, corrosion products)
Molten Salt Reactor Experiment piping—INOR-8 pipe exterior (U, Be, LiF, TiF_3)
Oak Ridge Research Reactor building siding—sheet steel (fission products)
Oak Ridge Research Reactor demineralizer piping (outside pool)—stainless steel pipe exterior (fission products, corrosion products)
Oak Ridge Research Reactor hot cell liners—stainless steel (fission products, corrosion products)

Oak Ridge Research Reactor primary coolant piping—aluminum piping exterior (fission products, corrosion products)
Oak Ridge Research Reactor steel building structure—structural steel (fission products)

State regulations
Air emissions, V1: 165–166
Aquatic resource alteration, V1: 167, 171
Fugitive dust emissions, V1: 165–166
NPDES permits, V1: 164
RCRA, V1: 152–159
Stormwater discharge, V1: 164

Statistical methods for the analysis of large data sets, char-251, V1: 47; V2: 9

Steam cleaning, dcon-55, V1: 118; V2: 52, 65, 77, 90, 99, 110

Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Steel containment structure (highly contaminated) problem areas, facilities associated with
Cutting technologies
abrasive water jet (steel structures, highly contaminated), dism-53, V1: 79; V2: 28
conventional disassembly (steel structures, highly contaminated), dism-60, V1: 79; V2: 29
cryogenic liquid cutting (steel structures, highly contaminated), dism-55, V2: 28
explosive cutting (steel structures, highly contaminated), dism-62, V1: 79; V2: 30
grappler mobile shearing (steel structures, highly contaminated), dism-61, V1: 79; V2: 30
laser cutting (steel structures, highly contaminated), dism, 51, V2: 28
oxygen cutting (steel structures, highly contaminated), dism-57, V1: 79; V2: 29
plasma arc cutting (steel structures, highly contaminated), dism-56, V1: 79; V2: 28
plasma arc saw (steel structures, highly contaminated), dism-58, V2: 29
thermal arc water jet (steel structures, highly contaminated), dism-59, V2: 29

Steel containment structure (highly contaminated) problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Steel problem areas. *See*
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for
Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

Storage buildings, robotics and automation alternatives for
Controls—algorithm technologies
combined mobility/manipulation, roba-34, V1: 132, 140; V2: 118
control modes, roba-27, V1: 132, 140; V2: 117
emergency shutdown, roba-37, V1: 132, 140; V2: 118
manipulation (Cartesian control), roba-31, V1: 132, 140; V2: 117
manipulation (joint control), roba-30, V1: 132, 140; V2: 117
manipulation (redundancy control), roba-33, V1: 132, 140; V2: 118
manipulation (special purpose control), roba-32, V1: 132, 140; V2: 118
safety (collision avoidance), roba-35, V1: 132, 140; V2: 118
safety (load/rate limiting), roba-36, V1: 132, 140; V2: 118
vehicle/mobility driving, roba-28, V1: 132, 140; V2: 117
vehicle/mobility navigation, roba-29, V1: 132, 140; V2: 117
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 132, 140; V2: 118
console (fixed/mobile/suitcase), roba-38, V1: 132, 140; V2: 118
operator interface (command input), roba-40, V1: 132, 140; V2: 118
operator interface (operator assistance), roba-41, V1: 132, 140; V2: 119
operator interface (status/alert system), roba-42, V1: 132, 140; V2: 119
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 132, 140; V2: 117
end effectors/alternatives, roba-23, V1: 132, 140; V2: 117
force limiting/compliant mechanisms, roba-26, V1: 132, 140; V2: 117
general gripper/tool interface, roba-25, V1: 132, 140; V2: 117

000670

Storage buildings, robotics and automation alternatives for *(continued)*
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 131, 139; V2: 116
dexterous manipulators, roba-16, V1: 131, 139; V2: 116
long-reach manipulator (heavy duty), roba-15, V1: 131, 139; V2: 116
long-reach manipulator (light duty), roba-14, V1: 131, 139; V2: 116
Mechanical—mechanism technologies
precise programmable motions, roba-20, V1: 131, 140; V2: 116
stabilization/support mechanisms or booms, roba-22, V1: 131, 140; V2: 116
tool caddies, roba-21, V1: 131, 140; V2: 116
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 131, 139; V2: 116
external duct/pipe crawlers, roba-6, V1: 131, 139; V2: 115
failure recovery systems for mobile platforms, roba-11, V1: 131, 139; V2: 115
internal duct/pipe crawler, roba-5, V1: 131, 139; V2: 115
long-arm deployed robotic platforms, roba-9, V1: 131, 139; V2: 115
mounted robotic platforms, roba-8, V1: 131, 139; V2: 115
power sources for mobile platforms, roba-10, V1: 131, 139; V2: 115
specialized robotic deployment platforms, roba-7, V1: 131, 139; V2: 115
transportation systems for mobile platforms, roba-12, V1: 131, 139; V2: 116
wheeled/tracked vehicle, roba-1, V1: 131, 139; V2: 115
Other technologies
characterization sensor integration, roba-58, V1: 133, 141; V2: 120
field hardening, roba-53, V1: 133, 141; V2: 120
information management for sample handling, roba-56, V1: 133, 141; V2: 120
integrated automated analytical laboratory, roba-55, V1: 133, 141; V2: 120
radiation hardening, roba-54, V1: 133, 141; V2: 120
sample collection, roba-57, V1: 133, 141; V2: 120
sample preparation, roba-59, V1: 133, 141; V2: 120
Sensors—control technologies
force/torque, roba-50, V1: 133, 141; V2: 119
position/velocity sensors, roba-48, V1: 133, 141; V2: 119
proximity probes as sensors, roba-51, V1: 133, 141; V2: 119
tooling sensors, roba-52, V1: 133, 141; V2: 120
Sensors—perception technologies
force/torque sensors, roba-46, V1: 133, 141; V2: 119
proximity probes, roba-45, V1: 133, 141; V2: 119
range finders, roba-44, V1: 133, 140; V2: 119
visual/aural systems, roba-43, V1: 133, 140; V2: 119

Storm-water discharge. *See*
Clean Water Act

Streambed modifications, V1: 167, 171

Strippable coatings, dcon-63, V1: 118; V2: 111

Sr-90. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Structural-only concrete problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Structural-only concrete problem areas, facilities associated with
Cutting technologies
diamond wire cutting (structural-only concrete), dism-42, V1: 79; V2: 26
high-pressure abrasive water jet (structural-only concrete), dism-41, V1: 79; V2: 26
Demolition technologies
conventional—jack hammer, headache ball, etc. (structural-only concrete), dism-44, V1: 79; V2: 27
demolition compounds (structural-only concrete), dism-46, V1: 79; V2: 27
explosive cutting (structural-only concrete), dism-45, V2: 27
grappler (structural-only concrete), dism-48, V1: 79; V2: 27
microwave demolition (structural-only concrete), dism-47, V2: 27

Structural-only concrete problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Structural—only concrete problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge

Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Structural steel problem areas, dismantlement alternatives for. *For a complete list of facilities, see* Structural steel problem areas, facilities associated with
Cutting technologies
abrasive water jet (structural steel, mild contaminants), dism-72, V1: 80; V2: 30
laser cutting (structural steel, mild contaminants), dism-71, V1: 80; V2: 30
oxygen cutting (structural steel, mild contaminants), dism-75, V1: 80; V2: 31
plasma arc cutting (structural steel, mild contaminants), dism-74, V1: 80; V2: 31
thermite lance (structural steel, mild contaminants), dism-79, V2: 31
Demolition technologies
conventional disassembly (structural steel, mild contaminants), dism-76, V1: 80; V2: 31
explosive cutting (structural steel, mild contaminants), dism-78, V2: 31
grappler mobile shearing (structural steel, mild contaminants), dism-77, V1: 80; V2: 31

Structural steel problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Structural steel problem areas, dismantlement alternatives for
Bldgs. 3028, 3028E, 3029, 3030, 3031, 3032, 3033, 3036, 3038, 3517, 7500, 9219-1, 9201-3, and 9419-1; drain lines; Homogeneous Reactor Test structure; membrane between Homogeneous Reactor Test concrete; Oak Ridge Research Reactor biological shield; Oak Ridge Research Reactor hot cell liners; pavement over 55-gal drum; process piping and tankage; and pulsefeeder pumps

Supercritical CO_2 blasting, dcon-41, V1: 118; V2: 48, 57, 62, 73, 83, 87, 97, 108

Supercritical fluid extraction of inorganics, char-201, V1: 45; V2: 4

Supercritical fluid extraction of organics, char-208, V1: 45; V2: 4

Superheated water, dcon-53, V1: 118; V2: 51, 64, 76, 90, 99, 110

Support facilities. *See*
Reactors and support facilities, robotics and automation alternatives for

Surface-enhanced Raman scattering, char-265, V1: 51; V2: 16

Surface-water bodies, direct discharge to. *See*
Clean Water Act
Department of Energy orders

Synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 15, 16

— T —

Tank problem areas. *See*
Asbestos problem areas, dismantlement alternatives for
Buried tank problem areas, dismantlement alternatives for
Buried waste problem areas, dismantlement alternatives for
Entombment problem areas, dismantlement alternatives for
General problem areas, characterization alternatives for
Inorganic problem areas, characterization alternatives for
Major equipment removal problem areas, dismantlement alternatives for
Massive containment problem areas, dismantlement alternatives for
Needed enabling technology problem areas, dismantlement alternatives for
Oil and purex chemical problem areas, characterization alternatives for
Organic problem areas, characterization alternatives for
Physical problem areas, characterization alternatives for
Pipe interiors, decontamination alternatives for
Radioactive constituents, characterization alternatives for
Reactor pool problem areas, dismantlement alternatives for
Steel containment structure (highly contaminated) problem areas, dismantlement alternatives for
Structural-only concrete problem areas, dismantlement alternatives for
Structural steel problem areas, dismantlement alternatives for
Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for
Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for

Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for. *For a complete list of facilities, see* Tank (southeast of Bldg. 7500), facilities associated with
Chemical surface cleaning technologies
chelation treatment, dcon-21, V1: 117; V2: 104
chemical foams, dcon-8, V1: 117; V2: 101
detergent treatment, dcon-13, V1: 117; V2: 103
electropolishing, dcon-15, V1: 117; V2: 103

Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for *(continued)*
fluoboric acid treatment, dcon-11, V1: 117; V2: 102
inorganic acid treatments, dcon-12, V1: 117; V2: 102
organic acid treatments, dcon-9, V1: 117; V2: 102
REDOX treatments, dcon-14, V1: 117; V2: 103
Mechanical surface removal method technologies
automated grinding, dcon-44, V1: 118; V2: 98
centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 97
plastic pellet blasting, dcon-42, V1: 118; V2: 97
supercritical CO_2 blasting, dcon-41, V1: 118; V2: 97
ultrahigh-pressure water, dcon-35, V1: 117; V2: 97
Metal refining method technologies
electrorefining, dcon-32, V1: 117; V2: 101
leach/electrowinning, dcon-34, V1: 117; V2: 101
smelt purification, dcon-31, V1: 117; V2: 100
Thermal surface removal method technologies
automated brushing, dcon-57, V1: 118; V2: 99
compressed-air cryogenic CO_2 pellet blasting, dcon-51, V1: 118; V2: 98
dry heat (bulk roasting), dcon-4, V1: 117; V2: 99
laser etching and ablation, dcon-74, V1: 119; V2: 98
laser heating, dcon-73, V1: 119; V2: 98
solvent washing to remove radiological contamination, dcon-61, V1: 118; V2: 100
steam cleaning, dcon-55, V1: 118; V2: 99
superheated water, dcon-53, V1: 118; V2: 99
ultrasonic cleaning, dcon-65, V1: 118; V2: 100
vacuum cleaning, dcon-65, V1: 118; V2: 100
water flushing, dcon-54, V1: 118; V2: 99

Tank (southeast of Bldg. 7500) problem areas, facilities associated with. *For specific technologies to treat the facility see* Tank (southeast of Bldg. 7500) problem areas, decontamination alternatives for
Tanks southeast of Bldg. 7500—stainless steel (fission products, corrosion products)

Tank systems, closure of. *See*
Resource Conservation and Recovery Act

Task-scheduling aids, char-241, V1: 47; V2: 9

Technical Task Plans
relevance to characterization technologies, V1: 54–60
relevance to decontamination technologies, V1: 124
relevance to dismantlement technologies, V1: 85–87
relevance to robotics and automation technologies, V1: 143–145
search data-base listing, V1: 181–182

Technological problems. *See*
Needed enabling technology, dismantlement alternatives for

Temporary entombment/clay fill (entombment), dism-111, V2: 37

Thermal arc water jet cutting (major equipment removal), dism-99, V2: 35

Thermal arc water jet (steel structures, highly contaminated), dism-59, V2: 29

Thermite cutting (major equipment removal), dism-88, V2: 32

Thermite lance (structural steel, mild contaminants), dism-79, V2: 31

Thermoluminescence dosimeter array for spatial characterization of surface alpha contamination, char-103, V1: 48; V2: 10

Thermoset polymer/thermal plastic stabilization (entombment), dism-109, V2: 36

Th. *For specific technologies to treat this contaminant, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Pipe interiors, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for

Threatened, rare, or endangered species, V1: 169, 171

3-D CAD data base of buildings and structures (needed enabling technologies), dism-156, V1: 48, 81; V2: 10, 42

Tiled concrete problem areas, decontamination alternatives for. *For a complete list of facilities, see* Tiled concrete problem areas, facilities associated with
Mechanical surface removal method technologies
automated grinding, dcon-44, V1: 118; V2: 83
centrifuge cryogenic CO_2 pellet blasting, dcon-39, V1: 118; V2: 82
concrete milling, dcon-47, V1: 118; V2: 83
explosive, dcon-48, V1: 118; V2: 84
grit blasting, dcon-38, V1: 118; V2: 82

000673

hand grinding, honing, scraping, dcon-43, V1: 118; V2: 83
scabblers/scarifiers, dcon-37, V1: 117; V2: 82
shot blasting, dcon-36, V2: 82
supercritical CO_2 blasting, dcon-41, V1: 118; V2: 83
ultrahigh-pressure water, dcon-35, V1: 117; V2: 82

Tiled concrete problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Tiled concrete problem areas, decontamination alternatives for
Bldg. 3028 floors—tiled concrete (fission products, TRU)
Bldg. 3029 floors—tiled concrete (Cs-137, Sr-90, Co-60, Ir-192)
Bldg. 3030 floors—tiled concrete (43 beta/gamma emitters)
Bldg. 3031 floors—tiled concrete (Gd-153, Am-241)
Bldg. 3032 floors—tiled concrete (P-32, Am-241)
Bldg. 3033 floors—tiled concrete (H-3, Kr-85)
Bldg. 3036 floors—tiled concrete (Cs-137, Sr-90)
Bldg. 3038 floors—tiled concrete (Sr-90, Cs-137, Co-60, I-129)
Bldg. 3517 floors—tiled concrete (Cs-137, Sr-90, Co-60)
Bldg. 7500 floors—tiled concrete (Cs, Sr, TRU, Co-60)
Bldg. 9201-3 coolant salt cell, floor—tiled concrete (U, Th, coolant salt)
Bldg. 9201-3 molten salt cells, floor—tiled concrete (U, Th, molten salt)
Molten Salt Reactor Experiment building floors—tiled concrete (fission products, corrosion products)
Oak Ridge Research Reactor building floors—tiled concrete (fission products)

Tool caddies, roba-21, V1: 131, 140; V2: 116

Tooling sensors, roba-52, V1: 133, 141; V2: 120

Transmission electron microscopy, char-34, V1: 49; V2: 13

Transmutation, dcon-78, V1: 117; V2: 106

Transportation systems for mobile platforms, roba-12, V1: 131, 139; V2: 116

TRU. *For specific technologies to treat these contaminants, see*
Concrete block and tiled concrete problem areas, decontamination alternatives for
Painted concrete problem areas, decontamination alternatives for
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for
Tiled concrete problem areas, decontamination alternatives for
Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for

Treatment units. *See*
Resource Conservation and Recovery Act

Tritium/beta/gamma floor scanner, char-105, V1: 48; V2: 11

— U —

Ultrahigh-pressure water, dcon-35, V1: 117; V2: 47, 56, 61, 72, 82, 87, 97, 107

Ultrasonic cleaning, dcon-65, V1: 118; V2: 67, 92, 100, 112

Ultrasonic extraction, char-20, V1: 45; V2: 3

Ultraviolet/visible spectroscopy, char-9, V1: 46; V2: 7

U. *For specific technologies to treat this contaminant, see*
Stainless steel, steel plate, sheet steel, and structural steel problem areas, decontamination alternatives for

— V —

Vacuum cleaning, dcon-64, V1: 118; V2: 66, 91, 100, 112

Vacuum (low pressure), dcon-7, V1: 117; V2: 53, 78, 81, 86

Vehicle/mobility driving, roba-28, V1: 132, 140; V2: 117

Vehicle/mobility navigation, roba-29, V1: 132, 140; V2: 117

Video mapping (needed enabling technologies), dism-147, V2: 41

Visual/aural systems, roba-43, V1: 133, 140; V2: 119

— W —

Water flushing, dcon-54, V1: 118; V2: 51, 76, 90, 99, 110

Wavelength dispersive X-ray spectroscopy, char-36, V1: 49; V2: 13

Wetlands and floodplains, V1: 167, 168

000674

Wheeled/tracked vehicle, roba-1, V1: 131, 139; V2: 115

Wood/sheetrock, tar and felt, and concrete problem areas, decontamination alternatives for. *For a complete list of facilities, see* Wood/sheetrock, tar and felt roofing, concrete problem areas, facilities associated with
- Bulk decontamination method technologies
  - catalytic extraction process, dcon-6, V1: 117; V2: 86
  - chemical leaching, dcon-5, V1: 117; V2: 85
  - dry heat (bulk roasting), dcon-4, V1: 117; V2: 85
  - incineration, dcon-2, V1: 117; V2: 85
  - solvent extraction, dcon-1, V1: 117; V2: 85
  - vacuum (low pressure), dcon-7, V1: 117; V2: 86
- Chemical surface cleaning method technologies
  - chelation treatment, dcon-21, V1: 117; V2: 86

Wood/sheetrock, tar and felt roofing, and concrete problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Wood/sheetrock tar and felt roofing, and concrete problem areas, decontamination alternatives for
- Bldg. 3028 interior walls—wood/sheetrock (fission products, TRU)
- Bldg. 3028 roof—tar and felt roofing (fission products, TRU)
- Bldg. 3029 interior walls—wood/sheetrock (Cs-137, Sr-90, Co-60, Ir-192)
- Bldg. 3029 roof—tar and felt roofing (Cs-137, Sr-90, Co-60, Ir-192)
- Bldg. 3030 interior walls—wood/sheetrock (43 beta/gamma emitters)
- Bldg. 3030 roof—tar and felt roofing (43 beta/gamma emitters)
- Bldg. 3031 interior walls—wood/sheetrock (Gd-153, Am-241)
- Bldg. 3031 roof—tar and felt roofing (Gd-153, Am-241)
- Bldg. 3032 interior walls—wood/sheetrock (P-32, Am-241)
- Bldg. 3032 roof—tar and felt roofing (P-32, Am-241)
- Bldg. 3033 roof—tar and felt roofing (H-3, Kr-85)
- Bldg. 3036 interior walls—wood/sheetrock (Cs-137, Sr-90)
- Bldg. 3036 roof—tar and felt roofing (Cs-137, Sr-90)
- Bldg. 3038 roof—tar and felt roofing (Sr-90, Cs-137, Co-60, I-129)
- Bldg. 3517 interior walls—wood/sheetrock (Cs-137, Sr-90, Co-60)
- Bldg. 3517 roof—tar and felt roofing (Cs-137, Sr-90, Co-60)
- Bldg. 7500 floor under and shield around evaporator—concrete (uranyl sulfate, fission products)
- Bldg. 7500 interior walls—wood/sheetrock (Cs, Sr, TRU, Co-60)
- Bldg. 7500 roof—tar and felt roofing (Cs, Sr, TRU, Co-60)
- Molten Salt Reactor Experiment building interior walls—wood/sheetrock (Cs, Sr, TRU, Co-60)
- Molten Salt Reactor Experiment building roof—tar and felt roofing (Cs, Sr, TRU, Co-60)
- Oak Ridge Research Reactor building interior walls—wood/sheetrock (fission products)
- Oak Ridge Research Reactor building roof—tar and felt roofing (fission products)

— X —

X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 49; V2: 13

— Z —

Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for. *For a complete list of facilities, see* Zincalloy, steel, and aluminum piping problem areas, facilities associated with
- Metal refining method technologies
  - electrorefining, dcon-32, V1: 117; V2: 105
  - leach/electrowinning, dcon-34, V1: 117; V2: 105
  - smelt purification, dcon-31, V1: 117; V2: 105
  - transmutation, dcon-78, V1: 117; V2: 106

Zincalloy, steel, and aluminum piping problem areas, facilities associated with. *For specific technologies to treat these facilities, see* Zincalloy, steel, and aluminum piping problem areas, decontamination alternatives for
- Homogeneous Reactor Test Reactor—zincalloy (UO_2SO_4, fission products, corrosion products, activation products)
- Low-Intensity Test Reactor tank internal surfaces—steel (corrosion products, fission products, activation products)
- Low-Intensity Test Reactor water piping—aluminum piping (fission products, corrosion products, activation products)

Zoning for containment—three zones (needed enabling technologies), dism-141, V2: 40

000675

INDEX B

Remedial Action

HOW TO USE THIS INDEX

The Remedial Action (RA) Index provides a comprehensive list of site problems, problem area/constituents, remedial technologies, and regulatory terms discussed in the RA sections of the *Oak Ridge National Laboratory Technology Logic Diagram*. All entries provide specific page numbers, or cross-reference entries that provide specific page numbers, in the RA volumes (Vol. 1, Pt. B; Vol. 2, Pt. B; and appropriate parts of Vol. 3).

Page numbers are located at the end of main entries or at the end of subentries. References to the RA Vol. 1, Pt. B (*Technology Evaluation*), are indicated by "V1:" and followed by a page number, while references to the RA Vol. 2, Pt. B (*Technology Logic Diagrams*), are indicated by "V2:" and followed by a specific page number. Specific locations in Vol. 3 (*Technology Evaluation Data Sheets*) are given by the technology code numbers (e.g., rema-41) because pages in this volume are unnumbered.

Cross-references are indicated by a *See* at the end of the main entry. Following the *See* is a list of other main entries, which provide specific page numbers.

Examples of index entries are provided below.

- A main entry (a specific technology), which consists of a title in bold and a locator. The locator gives specific page numbers—"rema-41" (Vol. 3); "V1: 95, 100" (Vol. 1, Pt. B); and "V2: 24, 41" (Vol. 2, Pt. B):

Technology name	Technology code no.	Vol. no.	Page nos.	Vol. no.	Page nos.
⇓	⇓	⇓	⇓	⇓	⇓

Sheet pile walls, rema-41, V1: 95, 100; V2: 24, 41

locator

- Two main entries that cross-reference. The first example consists of an ORNL Problem and a *See* reference; the second example is the entry referenced, which provides specific page numbers:

Radioactive elements, technologies for. *See*
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (radioactive elements), characterization technologies for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10

Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62, V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62, V2: 12

000677

INDEX B REMEDIAL ACTION

— A —

Action-specific regulations. *See*
Resource Conservation and Recovery Act

Activated carbon, rema-66, V1: 100; V2: 43

Adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4

Adsorption on biomedia, rema-73, V1: 100; V2: 43

Advanced radiation monitors, char-269, V1: 62;V2: 12

Air monitoring, char-59, V1: 60; V2: 6

Air standards. *See*
Clean Air Act

Air stripping, rema-76, V1: 100; V2: 44

Alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13

Anaerobic dechlorination, rema-69, V1: 100; V2: 46

Analysis of censored data, char-249, V1: 61; V2: 10

Analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17

Application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9

Archaeological findings, historic sites and, V1: 216

Artificial wetlands, rema-63, V1: 101; V2: 46

As low as reasonably achievable (ALARA), V1: 162

Atomic emission spectroscopy, char-76, V1: 63; V2: 14, 15

Atomic Energy Act, V1: 156

Auger electron spectroscopy, char-2, V1: 64; V2: 16

Automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9

— B —

Below regulatory concern policy, V1: 156

Biological denitrification, rema-75, V1: 100, 101; V2: 44

Biological oxidation, rema-68, V1: 100; V2: 45

Biological waste (in all problems), characterization alternatives for
Laboratory method technologies
pathogen surveillance, char-215, V1: 65; V2: 19

Biopolymer drains, rema-44, V1: 95, 99; V2: 25, 40

Borehole mining, rema-4, V1: 96; V2: 31

Bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12

Bulk item exhumation, rema-126, V1: 95–96; V2: 32

Buried bulk equipment items, technologies for. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Buried pipes, robotics and automation alternatives for
Controls—algorithms technologies
combined mobility/manipulation, roba-34, V1: 115, 122; V2: 53
control modes, roba-27, V1: 115, 122; V2: 52
emergency shutdown, roba-37, V1: 115, 122; V2: 53
manipulation (Cartesian control), roba-31, V1: 115, 122; V2: 53
manipulation (joint control), roba-30, V1: 115, 122; V2: 53
manipulation (redundancy control), roba-33, V1: 115, 122; V2: 53
manipulation (special purpose control), roba-32, V1: 115, 122; V2: 53
safety (collision avoidance), roba-35, V1: 115, 122; V2: 53
safety (load/rate limiting), roba-36, V2: 53
vehicle/mobility driving, roba-28, V1: 115, 122; V2: 52
vehicle/mobility navigation, roba-29, V1: 115, 122; V2: 53
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 116, 122; V2: 54
console (fixed/mobile/suitcase), roba-38, V1: 116, 122; V2: 54
operator interface (command input), roba-40, V1: 116, 122; V2: 54

000678

Buried pipes, robotics and automation alternatives for *(continued)*
operator interface (operator assistance), roba-41, V1: 116, 123; V2: 54
operator interface (status/alert system), roba-42, V1: 116, 123; V2: 54
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 115, 122; V2: 52
end effectors/alternatives, roba-23, V1: 115, 122; V2: 52
force limiting/compliant mechanisms, roba-26, V1: 115, 122; V2: 52
general gripper/tool interface, roba-25, V1: 115, 122; V2: 52
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 115, 122; V2: 52
dexterous manipulators, roba-16, V1: 115, 122; V2: 51
Mechanical—mechanism technologies
stabilization/support mechanisms or booms, roba-22, V1: 115, 122; V2: 52
tool caddies, roba-21, V1: 115, 122; V2: 52
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 115, 122; V2: 51
failure recovery systems for mobile platforms, roba-11, V1: 115, 122; V2: 51
long-arm deployed robotic platforms, roba-9, V1: 115, 122; V2: 51
power sources for mobile platforms, roba-10, V1: 115, 122; V2: 51
specialized robotic deployment platforms, roba-7, V1: 115, 122; V2: 51
transportation methods for mobile platforms, roba-12, V1: 115, 122; V2: 51
wheeled/tracked vehicle, roba-1, V1: 115, 122; V2: 51
Other technologies
characterization sensor integration, roba-58, V1: 116, 123; V2: 56
field hardening, roba-53, V1: 116, 123; V2: 55
information management for sample handling, roba-56, V1: 116, 123; V2: 56
integrated automated analytical, roba-55, V1: 116, 123; V2: 55
radiation hardening, roba-54, V1: 116, 123; V2: 55
sample collection, roba-57, V1: 116, 123; V2: 56
sample preparation, roba-59, V1: 116, 123; V2: 56
Sensors—control technologies
force/torque, roba-50, V1: 116, 123; V2: 55
position/velocity sensors, roba-48, V1: 116, 123; V2: 55
proximity probes as control sensors, roba-51, V1: 116, 123; V2: 55
tooling sensors, roba-52, V1: 116, 123; V2: 55
Sensors—perception technologies
force/torque sensors, roba-46, V1: 116, 123; V2: 55
proximity probes, roba-45, V1: 116, 123; V2: 54
range finders, roba-44, V1: 116, 123; V2: 54
visual/aural, roba-43, V1: 116, 123; V2: 54

Buried waste
Description of implementation needs for remedial action alternatives, V1: 90
Description of remedial action alternatives for, V1: 78
Description of science and technology needs for remedial action alternatives, V1: 86
Problem definition, V1: 14

Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Excavation technologies
bulk item exhumation, rema-126, V1: 95–96; V2: 32

Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Field method technologies
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground-water monitoring, char-274, V1: 65; V2: 19
SEAMIST inverted membrane, char-273, V1: 65; V2: 19
Sample collection technologies
SEAMIST inverted membrane, char-273, V1: 65; V2: 19

Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Data analysis management technologies
analysis of censored data, char-249, V1: 61; V2: 10
application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
client/server architecture for data base access, dism-157, V1: 61; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
computer-based training systems, dism-191, V1: 61; V2: 9
configuration management system, char-229, V1: 62; V2: 11
criticality indices, char-44, V1: 61; V2: 10
data access services, dism-154, V1: 61; V2: 8
detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11

dynamic modeling of material transport, char-255, V1: 62; V2: 11
fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
geographic information system for DOE sites, dism-181, V1: 61; V2: 8
hazard analysis expert system, char-233, V1: 61; V2: 9
hypertext information systems, dism-158, V1: 61; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
multisensor fusion measurement systems, char-222, V1: 62; V2: 11
network architecture with integrated workstations, char-221, V2: 8
project information access services, dism-151, V1: 61; V2: 8
quality control for measurement processes, char-250, V1: 61; V2: 10
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9
spatial sample and data analysis, char-253, V1: 61; V2: 10
statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
stored material neural net identification system, char-242, V1: 62; V2: 11
subsurface complexation model, char-45, V1: 62; V2: 11
task scheduling aids, char-241, V1: 61; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 60; V2: 6
electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
electrochemical methods, char-10, V1: 60; V2: 7
fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
ground-penetrating radar, char-124, V1: 60; V2: 6
immunoassay detection, char-23, V1: 60, V1: 60; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
ion mobility mass spectrometry, char-264, V1: 59; V2: 5
magnetics, char-128, V1: 60; V2: 6
microgravity methods, char-127, V1: 60; V2: 6
optical absorption spectroscopy, char-27, V1: 60; V2: 5
personnel monitoring, char-52, V1: 60; V2: 6
portable luminescence detection, char-92, V1: 60; V2: 7
portable Raman spectrometer, char-84, V1: 60; V2: 5
seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
tomographic seismic monitoring, char-60, V1: 60; V2: 6
ultrasonic ranging and data system, char-123, V1: 60; V2: 6
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 60; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
isotopic dilution mass spectroscopy, char- 48, V1: 60; V2: 7
laser ionization mass spectrometry, char-4, V1: 61; V2: 8
nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4
multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3
sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
SEAMIST inverted membrane, char-273, V1: 65; V2: 19
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

000680

7751

Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Excavation technologies
overshot drilling, rema-123, V1: 96; V2: 32
wireline basket recovery, rema-125, V1: 96; V2: 32

Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Conversion technologies
transmutation, rema-127, V1: 97; V2: 29

Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63–64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Buried waste (low-level waste), remedial action alternatives, in WAGs 1, 3, 4, 5, 6, and 7 for
Bottom seal technologies
jet grouting, rema-85, V1: 95; V2: 26
microtunneled high-density polyethylene, rema-86, V1: 95; V2: 26
vibrated plastic tube bottom seal, rema-87, V1: 95; V2: 26
Capping technologies
capping, rema-46, V1: 95; V2: 24
intruder barriers, rema-94, V2: 24
Destruction technologies
calcining/sintering, rema-98, V1: 97; V2: 27
in situ vitrification (buried waste), rema-100, V1: 96; V2: 29
vitrification, rema-117, V1: 97; V2: 29
Excavation technologies
borehole mining, rema-4, V1: 96; V2: 31
modular excavation, rema-122, V1: 96; V2: 32
precision excavation, rema-90, V1: 96; V2: 31
remote excavation, rema-38, V1: 96; V2: 31
solidify and mine (freeze and mine), rema-10, V1: 96; V2: 32
vacuum loader (buried waste), rema-101, V1: 96; V2: 33
Fixation technologies
cementitious solidification, rema-9, V1: 97; V2: 28
ceramic encapsulation, rema-116, V1: 97; V2: 29
in situ chemical grouting, rema-2, V1: 96; V2: 28
in situ particulate grouting, rema-3, V1: 96; V2: 27
in situ vitrification (buried waste), rema-100, V1: 96; V2: 29
polymer-impregnated concrete/polymer modified concrete, rema-115, V1: 97; V2: 29
sulfur polymer cement, rema-114, V1: 97; V2: 28
thermoplastic encapsulation, rema-112, V1: 97; V2: 28
thermoset encapsulation, rema-113, V1: 97; V2: 28
vitrification, rema-117, V1: 97; V2: 29
Physical separation
freeze separation, rema-91, V1: 96; V2: 31
gravity sorting, rema-8, V1: 96; V2: 31
physical sorting, rema-121, V1: 96; V2: 30
shredding and magnetic separation, rema-93, V1: 96; V2: 30
soil washing, rema-6, V2: 30
Wall technologies
hydromill, rema-84, V1: 95; V2: 25
slurry wall with high-density polyethylene insert, rema-83, V1: 95; V2: 24

Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Barrier technologies
cryogenic barriers, rema-58, V1: 95; V2: 25
grout curtains, rema-42, V1: 95; V2: 24
sheet pile walls, rema-41, V1: 95; V2: 24
soil saw, rema-88, V1: 95; V2: 25
Bottom seal technologies
jet grouting, rema-85, V1: 95; V2: 26
microtunneled high-density polyethylene, rema-86, V1: 95; V2: 26
vibrated plastic tube bottom seal, rema-87, V1: 95; V2: 26

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Capping technologies
capping, rema-46, V1: 95; V2: 24
intruder barriers, rema-94, V2: 24
Destruction technologies
calcining/sintering, rema-98, V1: 97; V2: 27
in situ vitrification (buried waste), rema-100, V1: 96; V2: 29
vitrification, rema-117, V1: 97; V2: 29
Drain technologies
biopolymer drains, rema-44, V1: 95; V2: 25
french drains, rema-43, V1: 95; V2: 25
horizontal wells, rema-45, V1: 95; V2: 25
Excavation technologies
borehole mining, rema-4, V1: 96; V2: 31
modular excavation, rema-122, V1: 96; V2: 32
precision excavation, rema-90, V1: 96; V2: 31
remote excavation, rema-38, V1: 96; V2: 31
solidify and mine (freeze and mine), rema-10, V1: 96; V2: 32
vacuum loader (buried waste), rema-101, V1: 96; V2: 33
Fixation technologies
cementitious solidification, rema-9, V1: 97; V2: 28
ceramic encapsulation, rema-116, V1: 97; V2: 29
in situ chemical grouting, rema-2, V1: 96; V2: 28
in situ particulate grouting, rema-3, V1: 96; V2: 27
in situ vitrification (buried waste), rema-100, V1: 96; V2: 29
polymer-impregnated concrete/polymer modified concrete, rema-115, V1: 97; V2: 29
sulfur polymer cement, rema-114, V1: 97; V2: 28
thermoplastic encapsulation, rema-112, V1: 97; V2: 28
thermoset encapsulation, rema-113, V1: 97; V2: 28
vitrification, rema-117, V1: 97; V2: 29
Physical separation
freeze purification, rema-91, V1: 96; V2: 31
gravity sorting, rema-8, V1: 96; V2: 31
physical sorting, rema-121, V1: 96; V2: 30
shredding and magnetic separation, rema-93, V1: 96; V2: 30
soil washing, rema-6, V2: 30
Recovery technologies
smelting, wpro-111, V1: 97; V2: 30
Wall technologies
cryogenic barriers, rema-58, V1: 95; V2: 25
hydromill, rema-84, V1: 95; V2: 25
slurry wall with high-density polyethylene insert, rema-83, V1: 95; V2: 24
soil saw, rema-88, V1: 95; V2: 25

Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Bottom seal technologies
jet grouting, rema-85, V1: 95; V2: 26
microtunneled high-density polyethylene, rema-86, V1: 95; V2: 26
vibrated plastic tube bottom seal, rema-87, V1: 95; V2: 26
Capping technologies
capping, rema-46, V1: 95; V2: 24
intruder barriers, rema-94, V2: 24
Destruction technologies
calcining/sintering, rema-98, V1: 97; V2: 27
Excavation technologies
borehole mining, rema-4, V1: 96; V2: 31
modular excavation, rema-122, V1: 96; V2: 32
precision excavation, rema-90, V1: 96; V2: 31
remote excavation, rema-38, V1: 96; V2: 31
solidify and mine (freeze and mine), rema-10, V1: 96; V2: 32
vacuum loader (buried waste), rema-101, V1: 96; V2: 33
Fixation technologies
cementitious solidification, rema-9, V1: 97; V2: 28
ceramic encapsulation, rema-116, V1: 97; V2: 29
in situ chemical grouting, rema-2, V1: 96; V2: 28
in situ particulate grouting, rema-3, V1: 96; V2: 27
in situ vitrification (buried waste), rema-100, V1: 96; V2: 29
polymer-impregnated concrete/polymer modified concrete, rema-115, V1: 97; V2: 29
sulfur polymer cement, rema-114, V1: 97; V2: 28
thermoplastic encapsulation, rema-112, V1: 97; V2: 28
thermoset encapsulation, rema-113, V1: 97; V2: 28
vitrification, rema-117, V1: 97; V2: 29
Physical separation
freeze purification, rema-91, V1: 96; V2: 31
thermal desorption, rema-92, V1: 96; V2: 30
Wall technologies
hydromill, rema-84, V1: 95; V2: 25
slurry wall with high-density polyethylene insert, rema-83, V1: 95; V2: 24

Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17

000682

Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7 *(continued)*
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17
gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17
solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Barrier technologies
cryogenic barriers, rema-58, V1: 95; V2: 25
grout curtains, rema-42, V1: 95; V2: 24
sheet pile walls, rema-41, V1: 95; V2: 24
soil saw, rema-88, V1: 95; V2: 25
Bottom seal technologies
jet grouting, rema-85, V1: 95; V2: 26
microtunneled high-density polyethylene, rema-86, V1: 95; V2: 26
vibrated plastic tube bottom seal, rema-87, V1: 95; V2: 26
Capping technologies
capping, rema-46, V1: 95; V2: 24
intruder barriers, rema-94, V2: 24
Destruction technologies
calcining/sintering, rema-98, V1: 97; V2: 27
incineration, rema-95, V1: 97; V2: 27
in situ biodegradation, rema-110, V1: 96; V2: 26
in situ heating, rema-99, V2: 26
in situ vitrification (buried waste), rema-100, V1: 96; V2: 29
low-temperature ashing, rema-7, V1: 97; V2: 27
vitrification, rema-117, V1: 97; V2: 29
Drain technologies
biopolymer drains, rema-44, V1: 95; V2: 25
french drains, rema-43, V1: 95; V2: 25
horizontal wells, rema-45, V1: 95; V2: 25
Excavation technologies
borehole mining, rema-4, V1: 96; V2: 31
modular excavation, rema-122, V1: 96; V2: 32
precision excavation, rema-90, V1: 96; V2: 31
remote excavation, rema-38, V1: 96; V2: 31
solidify and mine (freeze and mine), rema-10, V1: 96; V2: 32
vacuum loader (buried waste), rema-101, V1: 96; V2: 33
Fixation technologies
cementitious solidification, rema-9, V1: 97; V2: 28
ceramic encapsulation, rema-116, V1: 97; V2: 29
in situ chemical grouting, rema-2, V1: 96; V2: 28
in situ particulate grouting, rema-3, V1: 96; V2: 27
in situ vitrification (buried waste), rema-100, V1: 96; V2: 29
polymer-impregnated concrete/polymer modified concrete, rema-115, V1: 97; V2: 29
sulfur polymer cement, rema-114, V1: 97; V2: 28
thermoplastic encapsulation, rema-112, V1: 97; V2: 28
thermoset encapsulation, rema-113, V1: 97; V2: 28
vitrification, rema-117, V1: 97; V2: 29
Physical separation
fracted air stripping, rema-89, V1: 96; V2: 30
freeze purification, rema-91, V1: 96; V2: 31
gravity sorting, rema-8, V1: 96; V2: 31
physical sorting, rema-121, V1: 96; V2: 30
shredding and magnetic separation, rema-93, V1: 96; V2: 30
soil washing, rema-6, V2: 30
thermal desorption, rema-92, V1: 96; V2: 30
Wall technologies
cryogenic barriers, rema-58, V1: 95; V2: 25
hydromill, rema-84, V1: 95; V2: 25
slurry wall with high-density polyethylene insert, rema-83, V1: 95; V2: 24
soil saw, rema-88, V1: 95; V2: 25

Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13

000683

electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13
proportional counter for alpha and beta activity, char-108, V1: 62, 63; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63-64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 63, V1: 62; V2: 13

Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Barrier technologies
grout curtains, rema-42, V1: 95; V2: 24
sheet pile walls, rema-41, V1: 95; V2: 24
slurry walls, rema-40, V1: 95; V2: 24
Drain technologies
biopolymer drains, rema-44, V1: 95; V2: 25
french drains, rema-43, V1: 95; V2: 25
horizontal wells, rema-45, V1: 95; V2: 25

Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Controls—algorithms technologies
combined mobility /manipulation, roba-34, V1: 115, 122; V2: 53
control modes, roba-27, V1: 115, 122; V2: 52
emergency shutdown, roba-37, V1: 115, 122; V2: 53
manipulation (Cartesian control), roba-31, V1: 115, 122; V2: 53
manipulation (joint control), roba-30, V1: 115, 122; V2: 53
manipulation (redundancy control), roba-33, V1: 115, 122; V2: 53
manipulation (special purpose control), roba-32, V1: 115, 122; V2: 53
safety (collision avoidance), roba-35, V1: 115, 122; V2: 53
safety (load/rate limiting), roba-36, V2: 53
vehicle/mobility driving, roba-28, V1: 115, 122; V2: 52
vehicle/mobility navigation, roba-29, V1: 115, 122; V2: 53
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 116, 122; V2: 54
console (fixed/mobile/suitcase), roba-38, V1: 116, 122; V2: 54
operator interface (command input), roba-40, V1: 116, 122; V2: 54
operator interface (operator assistance), roba-41, V1: 116, 123; V2: 54
operator interface (status/alert system), roba-42, V1: 116, 123; V2: 54
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 115, 122; V2: 52
end effectors/alternatives, roba-23, V1: 115, 122; V2: 52
force limiting/compliant mechanisms, roba-26, V1: 115, 122; V2: 52
general gripper/tool interface, roba-25, V1: 115, 122; V2: 52
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 115, 122; V2: 52
dexterous manipulators, roba-16, V1: 115, 122; V2: 51
Mechanical—mechanism technologies
stabilization/support mechanisms or booms, roba-22, V1: 115, 122; V2: 52
tool caddies, roba-21, V1: 115, 122; V2: 52
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 115, 122; V2: 51
failure recovery systems for mobile platforms, roba-11, V1: 115, 122; V2: 51
long-arm deployed robotic platforms, roba-9, V1: 115, 122; V2: 51
power sources for mobile platforms, roba-10, V1: 115, 122; V2: 51
specialized robotic deployment platforms, roba-7, V1: 115, 122; V2: 51
transportation methods for mobile platforms, roba-12, V1: 115, 122; V2: 51
wheeled/tracked vehicle, roba-1, V1: 115, 122; V2: 51
Other technologies
characterization sensor integration, roba-58, V1: 116, 123; V2: 56
field hardening, roba-53, V1: 116, 123; V2: 55
information management for sample handling, roba-56, V1: 116, 123; V2: 56
integrated automated analytical, roba-55, V1: 116, 123; V2: 55
radiation hardening, roba-54, V1: 116, 123; V2: 55
sample collection, roba-57, V1: 116, 123; V2: 56
sample preparation, roba-59, V1: 116, 123; V2: 56

Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7 *(continued)*
Sensors—control technologies
force/torque, roba-50, V1: 116, 123; V2: 55
position/velocity sensors, roba-48, V1: 116, 123; V2: 55
proximity probes as control sensors, roba-51, V1: 116, 123; V2: 55
tooling sensors, roba-52, V1: 116, 123; V2: 55
Sensors—perception technologies
force/torque sensors, roba-46, V1: 116, 123; V2: 55
proximity probes, roba-45, V1: 116, 123; V2: 54
range finders, roba-44, V1: 116, 123; V2: 54
visual/aural, roba-43, V1: 116, 123; V2: 54

Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Structural stabilization technologies
dynamic compaction, rema-1, V1: 95; V2: 23
horizontal mixed in-place, rema-81, V1: 95; V2: 23
in situ solidification, rema-5, V1: 95; V2: 23
structural caps, rema-96, V1: 95; V2: 23
surcharge, rema-82, V1: 95; V2: 23
thermal set resin impregnation, rema-97, V1: 95; V2: 23

— C —

Capillary zone electrophoresis, char-207, V1: 64; V2: 17

Capping, rema-46, V1: 95, 98, 99; V2: 24, 33, 40

Capping (pits/trenches), rema-36, V1: 98; V2: 37

Capping, RCRA requirements for, V1: 177–179

Calcining/sintering, rema-98, V1: 97; V2: 27

Caves, salt-dome formations, salt-bed formations, and underground mines, V1: 207

Cementitious solidification, rema-9, V1: 97; V2: 28

Ceramic encapsulation, rema-116, V1: 97; V2: 29

CERCLA. *See*
Comprehensive Environmental Response, Compensation, and Liability Act

Characteristic waste. *See*
Resource Conservation and Recovery Act

Characterization alternatives. *See*
Biological waste (in all problems), characterization alternatives for
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (general problem areas), characterization alternatives for, in WAG 10
Hydrofracture (inorganics), characterization alternatives for, in WAG 10
Hydrofracture (organics), characterization alternatives for, in WAG 10
Hydrofracture (physical problem areas), characterization alternatives for, in WAG 10
Hydrofracture (radioactive elements), characterization alternatives for, in WAG 10
Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9

000685

Impoundments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radioactive elements), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (general problem areas), characterization alternatives for, in WAG 7
Pits and trenches (inorganics), characterization alternatives for, in WAG 7
Pits and trenches (organics), characterization alternatives for, in WAG 7
Pits and trenches (physical problem areas), characterization alternatives for, in WAG 7
Pits and trenches (radioactive elements), characterization alternatives for, in WAG 7
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9

Characterization sensor integration, roba-58, V1: 116, 123; V2: 56

Chem char process, rema-20, V1: 99; V2: 34

Chemical oxidation, rema-72, V1: 100; V2: 45

Clay/bentonite additives, rema-60, V1: 100; V2: 41

Clean Air Act
Air emissions, V1: 176
Fugitive dust emissions, V1: 174
National Ambient Air Quality Standards, V1: 146, 174
National Emission Standards for Hazardous Air Pollutants (NESHAPs), V1: 154, 158
TDEC air standards, V1: 174

Clean Water Act
Discharge of dredge or fill material, V1: 175, 184–185, 211
Dredging, V1: 175, 185
Federal ambient water quality criteria, V1: 145, 147–153
Health advisories, V1: 155
National Pollutant Discharge Elimination System (NPDES) permits, V1: 175, 182–185
TDEC ambient water quality criteria, V1: 146

Cleanup criteria. *See*
Residual radioactive material

Client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8

Client/server architecture for data base access, dism-157, V1: 61; V2: 9

Cold vapor (mercury) analysis, char-24, V1: 64; V2: 15

Combined mobility/manipulation, roba-34, V1: 115, 122; V2: 53

Compact, high-capacity manipulators, roba-19, V1: 115, 122; V2: 52

Composition determination, technologies for. *See*
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Comprehensive Environmental Response, Compensation, and Liability Act
Natural Resource Damage Assessments, V1: 133
Natural resource trustees, V1: 133
Permit requirements, V1: 169

Computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9

Computer-based training systems, dism-191, V1: 61; V2: 9

Configuration management system, char-229, V1: 62; V2: 11

Console (data handling methods), roba-39, V1: 116, 122; V2: 54

Console (fixed/mobile/suitcase), roba-38, V1: 116, 122; V2: 54

Containers
RCRA storage and closure requirements, V1: 180–181

000686

Containment building. *See*
Resource Conservation and Recovery Act

Contaminated sludge/soil, technologies for. *See*
Pits and trenches (contaminated sludge/soil), remedial action alternatives for, in WAG 7

Contaminated soil. *See*
Land disposal restrictions

Contamination, char-103, V1: 62; V2: 12

Contamination control—analytical equipment, char-204, V1: 60; V2: 7

Control modes, roba-27, V1: 115, 122; V2: 52

Control plates. *See*
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Corrective action. *See*
Resource Conservation and Recovery Act

Corrective Action Management Unit (CAMU). *See*
Resource Conservation and Recovery Act

Criticality indices, char-44, V1: 61; V2: 10

Cryogenic barriers, rema-58, V1: 95, 98, 99; V2: 25, 33, 41

Cryogenic immobilization, rema-79, V1: 101; V2: 46

— D —

Data access services, dism-154, V1: 61; V2: 8

Data/signal transmission, roba-13, V1: 115, 122; V2: 51

Debris
Containment building, V1: 195–196
Hazardous debris, V1: 170, 172

Deep rock drainage curtain, rema-24, V1: 99; V2: 46

De minimis risk, V1: 157

Department of Energy requirements
Discharge of liquid waste to surface waters, V1: 163
Disposal of radioactive waste, V1: 163
Management of radioactive waste, V1: 163, 168
Occupational exposure limits, V1: 162
Public radiation exposure limits, V1: 162
Residual radioactivity, V1: 165, 168

Department of Transportation regulations
Radioactive materials, V1: 161
Hazardous materials, V1: 161

Detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11

Dexterous manipulators, roba-16, V1: 115, 122; V2: 51

Direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16

Discharge of dredge or fill materials. *See*
Clean Water Act

Discharge of liquid waste to surface waters. *See*
Department of Energy requirements

Disposal of radioactive waste. *See*
Department of Energy requirements

Dose limits. *See*
Radionuclides, regulatory compliance for

Dredging, rema-48, V1: 100; V2: 42

Dredging. *See*
Clean Water Act

Dynamic compaction, rema-1, V1: 95; V2: 23

Dynamic modeling of material transport, char-255, V1: 62; V2: 11

— E —

Electret passive surface alpha monitor, char-95, V1: 62; V2: 13

Electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6

Electrochemical methods, char-10, V1: 60; V2: 7

Electrokinetic removal, rema-19, V1: 98; V2: 36

Electromagnetic offset log survey, char-272, V2: 19

Electron diffraction, char-37, V1: 63; V2: 15

Electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16

Emergency shutdown, roba-37, V1: 115, 122; V2: 53

End-effector changeout mechanisms, roba-24, V1: 115, 122; V2: 52

End effectors/alternatives, roba-23, V1: 115, 122; V2: 52

Energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15

Entombed clamshell, rema-124, V1: 99; V2: 36

— F —

Failure recovery systems for mobile platforms, roba-11, V1: 115, 122; V2: 51

Federal ambient water quality criteria. *See*
Clean Water Act

Federal Facilities Agreement, V1: 131

Federal Facilities Compliance Act, V1: 132, 158

Federal Facilities Compliance Agreement
LDR-FFCA/ORR, V1: 132, 157
Mixed waste FFCA/ORR, V1: 132, 157

Federal Insecticide, Fungicide, and Rodenticide Act
Pesticides, V1: 205
Disposal, V1: 205

Fiber-optic chemical sensors, char-25, V1: 59, 65; V2: 5, 19

Field hardening, roba-53, V1: 116, 123; V2: 55

Flood plains, wetlands and, V1: 207

Force limiting/compliant mechanisms, roba-26, V1: 115, 122; V2: 52

Force/torque, roba-50, V1: 116, 123; V2: 55

Force/torque sensors, roba-46, V1: 116, 123; V2: 55

Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7

Fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11

Fracted air stripping, rema-89, V1: 96; V2: 30

Freeze separation, rema-91, V1: 96; V2: 31

French drains, rema-43, V1: 95, 99; V2: 25, 40

Fugitive dust emission. *See*
Clean Air Act

— G —

Gamma-ray spectrometry, char-268, V1: 63; V2: 14

Gas chromatography, char-94, V1: 64; V2: 18

Gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17

Gas chromatography in the field, char-262, V1: 64; V2: 17

Gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18

General gripper/tool interface, roba-25, V1: 115, 122; V2: 52

General problem areas. *See*
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (general problem areas), characterization alternatives for, in WAG 10
Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (general problem areas), characterization alternatives for, in WAG 7
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9

Geographic information system for DOE sites, dism-181, V1: 61; V2: 8

Glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16

Gravity sorting, rema-8, V1: 96; V2: 31

Ground-penetrating radar, char-124, V1: 60; V2: 6

Ground water and surface water
Description of implementation needs for remedial action alternatives, V1: 93
Description of remedial action alternatives for, V1: 84–85

Ground water and surface water *(continued)*
Description of science and technology needs for remedial action alternatives, V1: 89
Problem definition, V1: 23
Regulatory requirements for cleanup, V1: 137–146

Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Data analysis management technologies
analysis of censored data, char-249, V1: 61; V2: 10
application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
client/server architecture for data base access, dism-157, V1: 61; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
computer-based training systems, dism-191, V1: 61; V2: 9
configuration management system, char-229, V1: 62; V2: 11
criticality indices, char-44, V1: 61; V2: 10
data access services, dism-154, V1: 61; V2: 8
detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11
dynamic modeling of material transport, char-255, V1: 62; V2: 11
fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
geographic information system for DOE sites, dism-181, V1: 61; V2: 8
hazard analysis expert system, char-233, V1: 61; V2: 9
hypertext information systems, dism-158, V1: 61; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
multisensor fusion measurement systems, char-222, V1: 62; V2: 11
network architecture with integrated workstations, char-221, V2: 8
project information access services, dism-151, V1: 61; V2: 8
quality control for measurement processes, char-250, V1: 61; V2: 10
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9
spatial sample and data analysis, char-253, V1: 61; V2: 10
statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
stored material neural net identification system, char-242, V1: 62; V2: 11
subsurface complexation model, char-45, V1: 62; V2: 11
task scheduling aids, char-241, V1: 61; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 60; V2: 6
electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
electrochemical methods, char-10, V1: 60; V2: 7
fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
ground-penetrating radar, char-124, V1: 60; V2: 6
immunoassay detection, char-23, V1: 60; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
ion mobility mass spectrometry, char-264, V1: 59; V2: 5
magnetics, char-128, V1: 60; V2: 6
microgravity methods, char-127, V1: 60; V2: 6
optical absorption spectroscopy, char-27, V1: 60; V2: 5
personnel monitoring, char-52, V1: 60; V2: 6
portable luminescence detection, char-92, V1: 60; V2: 7
portable Raman spectrometer, char-84, V1: 60; V2: 5
seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
tomographic seismic monitoring, char-60, V1: 60; V2: 6
ultrasonic ranging and data system, char-123, V1: 60; V2: 6
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 60; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7
laser ionization mass spectrometry, char-4, V1: 61; V2: 8
nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4
multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3

000689

sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63–64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Destruction technologies
artificial wetlands, rema-63, V1: 101; V2: 46
Physical separation technologies
adsorption on biomedia, rema-73, V1: 100; V2: 43
in situ activated carbon, rema-67, V1: 101; V2: 43
in situ biomedia adsorption, rema-74, V1: 101; V2: 43
in situ ion exchange, rema-64, V1: 101; V2: 43
in situ precipitation, rema-62, V1: 101; V2: 62
ion exchange, rema-65, V1: 100; V2: 42
precipitation, rema-34, V1: 100; V2: 44

Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Destruction technologies
biological denitrification, rema-75, V1: 100, 101; V2: 44
in situ biological denitrification, rema-111, V2: 45

Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18

000690

Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11 *(continued)*
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17
gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17
solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Destruction technologies
artificial wetlands, rema-63, V1: 101; V2: 46
biological oxidation, rema-68, V1: 100; V2: 45
chemical oxidation, rema-72, V1: 100; V2: 45
in situ biological oxidation, rema-70, V1: 101; V2: 45
in situ chemical oxidation, rema-61, V1: 101; V2: 45
Physical separation technologies
activated carbon, rema-66, V1: 100; V2: 43

Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Destruction technologies
anaerobic dechlorination, rema-69, V1: 100; V2: 46
in situ anaerobic degradation, rema-71, V1: 101; V2: 46

Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63–64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 63, V1: 62; V2: 13

Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Physical separation technologies
adsorption on biomedia, rema-73, V1: 100; V2: 43
in situ activated carbon, rema-67, V1: 101; V2: 43
in situ biomedia adsorption, rema-74, V1: 101; V2: 43
in situ ion exchange, rema-64, V1: 101; V2: 43
in situ precipitation, rema-62, V1: 101; V2: 62
ion exchange, rema-65, V1: 100; V2: 42
precipitation, rema-34, V1: 100; V2: 44

Ground-water and surface-water regulations, V1: 137–146

Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Controls—algorithms technologies
combined mobility /manipulation, roba-34, V1: 115, 122; V2: 53

000691

control modes, roba-27, V1: 115, 122; V2: 52
emergency shutdown, roba-37, V1: 115, 122; V2: 53
manipulation (Cartesian control), roba-31, V1: 115, 122; V2: 53
manipulation (joint control), roba-30, V1: 115, 122; V2: 53
manipulation (redundancy control), roba-33, V1: 115, 122; V2: 53
manipulation (special purpose control), roba-32, V1: 115, 122; V2: 53
safety (collision avoidance), roba-35, V1: 115, 122; V2: 53
safety (load/rate limiting), roba-36, V2: 53
vehicle/mobility driving, roba-28, V1: 115, 122; V2: 52
vehicle/mobility navigation, roba-29, V1: 115, 122; V2: 53
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 116, 122; V2: 54
console (fixed/mobile/suitcase), roba-38, V1: 116, 122; V2: 54
operator interface (command input), roba-40, V1: 116, 122; V2: 54
operator interface (operator assistance), roba-41, V1: 116, 123; V2: 54
operator interface (status/alert system), roba-42, V1: 116, 123; V2: 54
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 115, 122; V2: 52
end effectors/alternatives, roba-23, V1: 115, 122; V2: 52
force limiting/compliant mechanisms, roba-26, V1: 115, 122; V2: 52
general gripper/tool interface, roba-25, V1: 115, 122; V2: 52
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 115, 122; V2: 52
dexterous manipulators, roba-16, V1: 115, 122; V2: 51
Mechanical—mechanism technologies
stabilization/support mechanisms or booms, roba-22, V1: 115, 122; V2: 52
tool caddies, roba-21, V1: 115, 122; V2: 52
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 115, 122; V2: 51
failure recovery systems for mobile platforms, roba-11, V1: 115, 122; V2: 51
long-arm deployed robotic platforms, roba-9, V1: 115, 122; V2: 51
power sources for mobile platforms, roba-10, V1: 115, 122; V2: 51
specialized robotic deployment platforms, roba-7, V1: 115, 122; V2: 51
transportation methods for mobile platforms, roba-12, V1: 115, 122; V2: 51
wheeled/tracked vehicle, roba-1, V1: 115, 122; V2: 51
Other technologies
characterization sensor integration, roba-58, V1: 116, 123; V2: 56
field hardening, roba-53, V1: 116, 123; V2: 55
information management for sample handling, roba-56, V1: 116, 123; V2: 56
integrated automated analytical, roba-55, V1: 116, 123; V2: 55
radiation hardening, roba-54, V1: 116, 123; V2: 55
sample collection, roba-57, V1: 116, 123; V2: 56
sample preparation, roba-59, V1: 116, 123; V2: 56
Sensors—control technologies
force/torque, roba-50, V1: 116, 123; V2: 55
position/velocity sensors, roba-48, V1: 116, 123; V2: 55
proximity probes as control sensors, roba-51, V1: 116, 123; V2: 55
tooling sensors, roba-52, V1: 116, 123; V2: 55
Sensors—perception technologies
force/torque sensors, roba-46, V1: 116, 123; V2: 55
proximity probes, roba-45, V1: 116, 123; V2: 54
range finders, roba-44, V1: 116, 123; V2: 54
visual/aural, roba-43, V1: 116, 123; V2: 54

Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Fixation technologies
cryogenic immobilization, rema-79, V1: 101; V2: 46

Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Physical separation technologies
air stripping, rema-76, V1: 100; V2: 44
steam stripping, rema-77, V1: 100; V2: 44

Ground-water classification, V1: 137

Ground-water cleanup, V1: 137

Ground-water discharge location, char-259, V1: 65; V2: 18

Grout curtains, rema-42, V1: 95, 100; V2: 24, 40

Grout sheets, technologies for. *See*
Hydrofracture (grout sheets), remedial action alternatives for, in WAG 10

— H —

Hazard analysis expert system, char-233, V1: 61; V2: 9

Hazardous debris. *See*
Land disposal restrictions

000692

Hazardous debris. *See*
Resource Conservation and Recovery Act

Hazardous materials. *See*
Department of Transportation

Hazardous waste. *See*
Resource Conservation and Recovery Act

Health Advisories. *See*
Clean Water Act

HFIR control plates, technologies for. *See*
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

High-level waste. *See*
Radionuclides, regulatory compliance for

High-level waste disposal. *See*
Department of Energy requirements

High-pressure ashing, char-203, V1: 59; V2: 5

High-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste, technologies for. *See*
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level technologies), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Historic sites and archaeological findings, V1: 216

Horizontal mixed in-place, rema-81, V1: 95; V2: 23

Horizontal wells, rema-45, V1: 95, 99; V2: 25, 40

Hydrofracture
Description of implementation needs for remedial action alternatives, V1: 93
Description of remedial action alternatives for, V1: 84
Description of science and technology needs for remedial action alternatives, V1: 89
Problem definition, V1: 17

Hydrofracture (general problem areas), characterization alternatives for, in WAG 10
Data analysis management technologies
analysis of censored data, char-249, V1: 61; V2: 10
application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
client/server architecture for data base access, dism-157, V1: 61; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
computer-based training systems, dism-191, V1: 61; V2: 9
configuration management system, char-229, V1: 62; V2: 11
criticality indices, char-44, V1: 61; V2: 10
data access services, dism-154, V1: 61; V2: 8
detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11
dynamic modeling of material transport, char-255, V1: 62; V2: 11
fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
geographic information system for DOE sites, dism-181, V1: 61; V2: 8
hazard analysis expert system, char-233, V1: 61; V2: 9
hypertext information systems, dism-158, V1: 61; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
multisensor fusion measurement systems, char-222, V1: 62; V2: 11
network architecture with integrated workstations, char-221, V2: 8
project information access services, dism-151, V1: 61; V2: 8
quality control for measurement processes, char-250, V1: 61; V2: 10
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9
spatial sample and data analysis, char-253, V1: 61; V2: 10
statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
stored material neural net identification system, char-242, V1: 62; V2: 11
subsurface complexation model, char-45, V1: 62; V2: 11
task scheduling aids, char-241, V1: 61; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 60; V2: 6
electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
electrochemical methods, char-10, V1: 60; V2: 7
fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
ground-penetrating radar, char-124, V1: 60; V2: 6
immunoassay detection, char-23, V1: 60; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
ion mobility mass spectrometry, char-264, V1: 59; V2: 5
magnetics, char-128, V1: 60; V2: 6

microgravity methods, char-127, V1: 60; V2: 6
optical absorption spectroscopy, char-27, V1: 60; V2: 5
personnel monitoring, char-52, V1: 60; V2: 6
portable luminescence detection, char-92, V1: 60; V2: 7
portable Raman spectrometer, char-84, V1: 60; V2: 5
seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
tomographic seismic monitoring, char-60, V1: 60; V2: 6
ultrasonic ranging and data system, char-123, V1: 60; V2: 6
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 60; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7
laser ionization mass spectrometry, char-4, V1: 61; V2: 8
nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4
multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3
sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
SEAMIST inverted membrane, char-273, V1: 65; V2: 19
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

Hydrofracture ground-water monitoring, char-274, V1: 65; V2: 19

Hydrofracture grouting, rema-23, V1: 99; V2: 47

Hydrofracture (grout sheets), remedial action alternatives for, in WAG 10
Barrier technologies
water proofing cave with hydraulic cage, rema-21, V1: 99; V2: 46
Drainage technologies
deep rock drainage curtain, rema-24, V1: 99; V2: 46
Fixation technologies
hydrofracture grouting, rema-23, V1: 99; V2: 47

Hydrofracture (inorganics), characterization alternatives for, in WAG 10
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63–64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16

000694

Hydrofracture (inorganics), characterization alternatives for, in WAG 10 *(continued)*
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Hydrofracture (organics), characterization alternatives for, in WAG 10
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17
gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17
solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Hydrofracture (physical problem areas), characterization alternatives for, in WAG 10
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Hydrofracture (radioactive elements), characterization alternatives for, in WAG 10
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63–64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 63, V1: 62; V2: 13

Hydromill, rema-84, V1: 95; V2: 25

Hypertext information systems, dism-158, V1: 61; V2: 10

— I —

Impoundments
Description of implementation needs for remedial action alternatives, V1: 93
Description of remedial action alternatives for, V1: 83
Description of science and technology needs for remedial action alternatives, V1: 88
Problem definition, V1: 16
RCRA closure requirements, V1: 177–179

Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Data analysis management technologies
analysis of censored data, char-249, V1: 61; V2: 10
application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
client/server architecture for data base access, dism-157, V1: 61; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
computer-based training systems, dism-191, V1: 61; V2: 9
configuration management system, char-229, V1: 62; V2: 11
criticality indices, char-44, V1: 61; V2: 10
data access services, dism-154, V1: 61; V2: 8
detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11
dynamic modeling of material transport, char-255, V1: 62; V2: 11
fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
geographic information system for DOE sites, dism-181, V1: 61; V2: 8
hazard analysis expert system, char-233, V1: 61; V2: 9
hypertext information systems, dism-158, V1: 61; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
multisensor fusion measurement systems, char-222, V1: 62; V2: 11
network architecture with integrated workstations, char-221, V2: 8
project information access services, dism-151, V1: 61; V2: 8
quality control for measurement processes, char-250, V1: 61; V2: 10
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9
spatial sample and data analysis, char-253, V1: 61; V2: 10
statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
stored material neural net identification system, char-242, V1: 62; V2: 11
subsurface complexation model, char-45, V1: 62; V2: 11
task scheduling aids, char-241, V1: 61; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 60; V2: 6
electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
electrochemical methods, char-10, V1: 60; V2: 7
fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
ground-penetrating radar, char-124, V1: 60; V2: 6
immunoassay detection, char-23, V1: 60; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
ion mobility mass spectrometry, char-264, V1: 59; V2: 5
magnetics, char-128, V1: 60; V2: 6
microgravity methods, char-127, V1: 60; V2: 6
optical absorption spectroscopy, char-27, V1: 60; V2: 5
personnel monitoring, char-52, V1: 60; V2: 6
portable luminescence detection, char-92, V1: 60; V2: 7
portable Raman spectrometer, char-84, V1: 60; V2: 5
seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
tomographic seismic monitoring, char-60, V1: 60; V2: 6
ultrasonic ranging and data system, char-123, V1: 60; V2: 6
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 60; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7
laser ionization mass spectrometry, char-4, V1: 61; V2: 8
nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4
multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3
sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
SEAMIST inverted membrane, char-273, V1: 65; V2: 19

000696

Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9 *(continued)*
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

Impoundments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63-64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Impoundments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Barrier technologies
clay/bentonite additives, rema-60, V1: 100; V2: 41
cryogenic barriers, rema-58, V1: 99; V2: 41
grout curtains, rema-42, V1: 100; V2: 40
sheet pile walls, rema-41, V1: 100; V2: 41
slurry walls, rema-40, V1: 100; V2: 41
Chemical separation technologies
soil washing, rema-51, V1: 100; V2: 41
Drain technologies
biopolymer drains, rema-44, V1: 99; V2: 40
french drains, rema-43, V1: 99; V2: 40
horizontal wells, rema-45, V1: 99; V2: 40
Excavation technologies
dredging, rema-48, V1: 100; V2: 42
mechanical excavation, rema-50, V1: 100; V2: 42
vacuum loaders, rema-49, V1: 100; V2: 42
Fixation technologies
in situ fixation, rema-57, V1: 100; V2: 42
in situ vitrification (impoundments), rema-59, V1: 100; V2: 42
Physical separation technologies
in situ soil flushing, rema-47, V1: 100; V2: 41
sludge drying, rema-56, V1: 100; V2: 41
soil washing, rema-51, V1: 100; V2: 41

Impoundments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17

000697

gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17
solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Impoundments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Barrier technologies
clay/bentonite additives, rema-60, V1: 100; V2: 41
cryogenic barriers, rema-58, V1: 99; V2: 41
grout curtains, rema-42, V1: 100; V2: 40
sheet pile walls, rema-41, V1: 100; V2: 41
slurry walls, rema-40, V1: 100; V2: 41
Chemical separation technologies
soil washing, rema-51, V1: 100; V2: 41
Drain technologies
biopolymer drains, rema-44, V1: 99; V2: 40
french drains, rema-43, V1: 99; V2: 40
horizontal wells, rema-45, V1: 99; V2: 40
Excavation technologies
dredging, rema-48, V1: 100; V2: 42
mechanical excavation, rema-50, V1: 100; V2: 42
vacuum loaders, rema-49, V1: 100; V2: 42
Fixation technologies
in situ fixation, rema-57, V1: 100; V2: 42
in situ vitrification (impoundments), rema-59, V1: 100; V2: 42
Physical separation technologies
in situ soil flushing, rema-47, V1: 100; V2: 41
sludge drying, rema-56, V1: 100; V2: 41
soil washing, rema-51, V1: 100; V2: 41

Impoundments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Impoundments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63–64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 63, V1: 62; V2: 13

Impoundments (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Physical separation technologies
in situ solidification using sorbents, rema-31, V2: 40

Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Barrier technologies
clay/bentonite additives, rema-60, V1: 100; V2: 41
cryogenic barriers, rema-58, V1: 99; V2: 41
grout curtains, rema-42, V1: 100; V2: 40
sheet pile walls, rema-41, V1: 100; V2: 41
slurry walls, rema-40, V1: 100; V2: 41
Capping technologies
capping, rema-46, V1: 99; V2: 40
Chemical separation technologies
soil washing, rema-51, V1: 100; V2: 41
Drain technologies
biopolymer drains, rema-44, V1: 99; V2: 40
french drains, rema-43, V1: 99; V2: 40
horizontal wells, rema-45, V1: 99; V2: 40

Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9 *(continued)*
Excavation technologies
dredging, rema-48, V1: 100; V2: 42
mechanical excavation, rema-50, V1: 100; V2: 42
vacuum loaders, rema-49, V1: 100; V2: 42
Fixation technologies
in situ fixation, rema-57, V1: 100; V2: 42
in situ vitrification (impoundments), rema-59, V1: 100; V2: 42
Physical separation technologies
in situ soil flushing, rema-47, V1: 100; V2: 41
sludge drying, rema-56, V1: 100; V2: 41
soil washing, rema-51, V1: 100; V2: 41

Impoundments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Controls—algorithms technologies
combined mobility /manipulation, roba-34, V1: 115, 122; V2: 53
control modes, roba-27, V1: 115, 122; V2: 52
emergency shutdown, roba-37, V1: 115, 122; V2: 53
manipulation (Cartesian control), roba-31, V1: 115, 122; V2: 53
manipulation (joint control), roba-30, V1: 115, 122; V2: 53
manipulation (redundancy control), roba-33, V1: 115, 122; V2: 53
manipulation (special purpose control), roba-32, V1: 115, 122; V2: 53
safety (collision avoidance), roba-35, V1: 115, 122; V2: 53
safety (load/rate limiting), roba-36, V2: 53
vehicle/mobility driving, roba-28, V1: 115, 122; V2: 52
vehicle/mobility navigation, roba-29, V1: 115, 122; V2: 53
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 116, 122; V2: 54
console (fixed/mobile/suitcase), roba-38, V1: 116, 122; V2: 54
operator interface (command input), roba-40, V1: 116, 122; V2: 54
operator interface (operator assistance), roba-41, V1: 116, 123; V2: 54
operator interface (status/alert system), roba-42, V1: 116, 123; V2: 54
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 115, 122; V2: 52
end effectors/alternatives, roba-23, V1: 115, 122; V2: 52
force limiting/compliant mechanisms, roba-26, V1: 115, 122; V2: 52
general gripper/tool interface, roba-25, V1: 115, 122; V2: 52
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 115, 122; V2: 52
dexterous manipulators, roba-16, V1: 115, 122; V2: 51
Mechanical—mechanism technologies
stabilization/support mechanisms or booms, roba-22, V1: 115, 122; V2: 52
tool caddies, roba-21, V1: 115, 122; V2: 52
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 115, 122; V2: 51
failure recovery systems for mobile platforms, roba-11, V1: 115, 122; V2: 51
long-arm deployed robotic platforms, roba-9, V1: 115, 122; V2: 51
power sources for mobile platforms, roba-10, V1: 115, 122; V2: 51
specialized robotic deployment platforms, roba-7, V1: 115, 122; V2: 51
transportation methods for mobile platforms, roba-12, V1: 115, 122; V2: 51
wheeled/tracked vehicle, roba-1, V1: 115, 122; V2: 51
Other technologies
characterization sensor integration, roba-58, V1: 116, 123; V2: 56
field hardening, roba-53, V1: 116, 123; V2: 55
information management for sample handling, roba-56, V1: 116, 123; V2: 56
integrated automated analytical, roba-55, V1: 116, 123; V2: 55
radiation hardening, roba-54, V1: 116, 123; V2: 55
sample collection, roba-57, V1: 116, 123; V2: 56
sample preparation, roba-59, V1: 116, 123; V2: 56
Sensors—control technologies
force/torque, roba-50, V1: 116, 123; V2: 55
position/velocity sensors, roba-48, V1: 116, 123; V2: 55
proximity probes as control sensors, roba-51, V1: 116, 123; V2: 55
tooling sensors, roba-52, V1: 116, 123; V2: 55
Sensors—perception technologies
force/torque sensors, roba-46, V1: 116, 123; V2: 55
proximity probes, roba-45, V1: 116, 123; V2: 54
range finders, roba-44, V1: 116, 123; V2: 54
visual/aural, roba-43, V1: 116, 123; V2: 54

Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Contents retrieval technologies
tank contents removal using hydraulic techniques, rema-29, V1: 97; V2: 38
tank contents removal using mechanical mining, rema-27, V1: 97; V2: 38
tank contents removal using pneumatic techniques, rema-28, V1: 97; V2: 38
Fixation technologies
in situ solidification using cement-based grouting, rema-25, V1: 97; V2: 38
in situ solidification using polymer grouting, rema-32, V1: 98; V2: 39

in situ solidification using silicate-based formulations, rema-26, V1: 98; V2: 39
in situ solidification using thermoplastic techniques, rema-33, V1: 98; V2: 39
in situ treatment using in situ vitrification, rema-30, V1: 98; V2: 39

Incineration, cement kiln, rema-14, V1: 99; V2: 35

Incineration, rema-12, V1: 99; V2: 34

Incineration, rema-95, V1: 97; V2: 27

Incineration, RCRA requirements for, V1: 186–188

Inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14

Inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14

Information management for sample handling, roba-56, V1: 116, 123; V2: 56

Infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6

Inorganics, technologies for. *See*
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (inorganics), characterization alternatives for, in WAG 10
Impoundments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (inorganics), characterization alternatives for, in WAG 7
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9

In situ activated carbon, rema-67, V1: 101; V2: 43

In situ anaerobic degradation, rema-71, V1: 101; V2: 46

In situ biodegradation, rema-110, V1: 96; V2: 26

In situ biological denitrification, rema-111, V2: 45

In situ biological oxidation, rema-70, V1: 101; V2: 45

In situ biomedia adsorption, rema-74, V1: 101; V2: 43

In situ chemical grouting, rema-2, V1: 96; V2: 28

In situ chemical oxidation, rema-61, V1: 101; V2: 45

In situ extraction, rema-39, V1: 98; V2: 37

In situ fixation, rema-57, V1: 100; V2: 42

In situ ground-water flow meter, char-258, V1: 65; V2: 18

In situ grouting (pipelines), rema-52, V1: 99; V2: 47

In situ grouting (pits/trenches), rema-37, V1: 98; V2: 37

In situ heating, rema-99, V2: 26

In situ ion exchange, rema-64, V1: 101; V2: 43

In situ solid phase microextraction of organics, char-210, V1: 59; V2: 3

In situ particulate grouting, rema-3, V1: 96; V2: 27

In situ precipitation, rema-62, V1: 101; V2: 62

In situ soil flushing, rema-47, V1: 100; V2: 41

In situ solidification, rema-5, V1: 95; V2: 23

In situ solidification using cement-based grouting, rema-25, V1: 97; V2: 38

In situ solidification using polymer grouting, rema-32, V1: 98; V2: 39

In situ solidification using silicate-based formulations, rema-26, V1: 98; V2: 39

In situ solidification using thermoplastic techniques, rema-33, V1: 98; V2: 39

In situ treatment using in situ vitrification, rema-30, V1: 98; V2: 39

In situ vitrification, rema-18, V1: 99; V2: 36

In situ vitrification (buried waste), rema-100, V1: 96; V2: 29

In situ vitrification (impoundments), rema-59, V1: 100; V2: 42

In situ vitrification (pits/trenches), rema-35, V1: 98; V2: 37

Integrated automated analytical, roba-55, V1: 116, 123; V2: 55

Intruder barriers, rema-94, V2: 24

Ion chromatography, char-50, V1: 63; V2: 15

Ion exchange, rema-65, V1: 100; V2: 42

Ion mobility mass spectrometry, char-264, V1: 59; V2: 5

Isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7

— J —

Jet grouting, rema-85, V1: 95; V2: 26

— L —

Land disposal restrictions
Contaminated soil, V1: 172
Hazardous debris, V1: 170, 172
RCRA hazardous waste, V1: 170

Land disposal restrictions. *See*
Resource Conservation and Recovery Act

Laser ionization mass spectrometry, char-4, V1: 61; V2: 8

Laws, environmental, affecting remedial action activities
Overview of, V1: 133–136

LDR. *See*
Land disposal restrictions

Liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17

Liquid scintillation counting, char-267, V1: 63; V2: 14

Listed waste. *See*
Resource Conservation and Recovery Act

Long-arm deployed robotic platforms, roba-9, V1: 115, 122; V2: 51

Long-range alpha detector, char-65, V1: 62; V2: 12

Low-level waste. *See*
Radionuclides, regulatory compliance for

Low-level waste regulations. *See*
Department of Energy requirements

Low-level waste, technologies for. *See*
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6 and 7
Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Pits and trenches (low-level waste), remedial action alternatives for, in WAG 7
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Low-level waste tanks, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Controls—algorithms technologies
combined mobility/manipulation, roba-34, V1: 115, 122; V2: 53
control modes, roba-27, V1: 115, 122; V2: 52
emergency shutdown, roba-37, V1: 115, 122; V2: 53
manipulation (Cartesian control), roba-31, V1: 115, 122; V2: 53
manipulation (joint control), roba-30, V1: 115, 122; V2: 53
manipulation (redundancy control), roba-33, V1: 115, 122; V2: 53
manipulation (special purpose control), roba-32, V1: 115, 122; V2: 53
safety (collision avoidance), roba-35, V1: 115, 122; V2: 53
safety (load/rate limiting), roba-36, V2: 53
vehicle/mobility driving, roba-28, V1: 115, 122; V2: 52
vehicle/mobility navigation, roba-29, V1: 115, 122; V2: 53
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 116, 122; V2: 54
console (fixed/mobile/suitcase), roba-38, V1: 116, 122; V2: 54
operator interface (command input), roba-40, V1: 116, 122; V2: 54
operator interface (operator assistance), roba-41, V1: 116, 123; V2: 54
operator interface (status/alert system), roba-42, V1: 116, 123; V2: 54
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 115, 122; V2: 52
end effectors/alternatives, roba-23, V1: 115, 122; V2: 52
force limiting/compliant mechanisms, roba-26, V1: 115, 122; V2: 52
general gripper/tool interface, roba-25, V1: 115, 122; V2: 52
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 115, 122; V2: 52
dexterous manipulators, roba-16, V1: 115, 122; V2: 51
Mechanical—mechanism technologies
stabilization/support mechanisms or booms, roba-22, V1: 115, 122; V2: 52
tool caddies, roba-21, V1: 115, 122; V2: 52
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 115, 122; V2: 51
failure recovery systems for mobile platforms, roba-11, V1: 115, 122; V2: 51
long-arm deployed robotic platforms, roba-9, V1: 115, 122; V2: 51
power sources for mobile platforms, roba-10, V1: 115, 122; V2: 51

specialized robotic deployment platforms, roba-7, V1: 115, 122; V2: 51
transportation methods for mobile platforms, roba-12, V1: 115, 122; V2: 51
wheeled/tracked vehicle, roba-1, V1: 115, 122; V2: 51
Other technologies
characterization sensor integration, roba-58, V1: 116, 123; V2: 56
field hardening, roba-53, V1: 116, 123; V2: 55
information management for sample handling, roba-56, V1: 116, 123; V2: 56
integrated automated analytical, roba-55, V1: 116, 123; V2: 55
radiation hardening, roba-54, V1: 116, 123; V2: 55
sample collection, roba-57, V1: 116, 123; V2: 56
sample preparation, roba-59, V1: 116, 123; V2: 56
Sensors—control technologies
force/torque, roba-50, V1: 116, 123; V2: 55
position/velocity sensors, roba-48, V1: 116, 123; V2: 55
proximity probes as control sensors, roba-51, V1: 116, 123; V2: 55
tooling sensors, roba-52, V1: 116, 123; V2: 55
Sensors—perception technologies
force/torque sensors, roba-46, V1: 116, 123; V2: 55
proximity probes, roba-45, V1: 116, 123; V2: 54
range finders, roba-44, V1: 116, 123; V2: 54
visual/aural, roba-43, V1: 116, 123; V2: 54

Low-temperature ashing, rema-7, V1: 97; V2: 27

Low-temperature thermal treatment, rema-13, V1: 98; V2: 33

— M —

Magnetics, char-128, V1: 60; V2: 6

Management of residual radioactive material. *See* Residual radioactive material

Management of radioactive waste. *See* Department of Energy requirements

Manipulation (Cartesian control), roba-31, V1: 115, 122; V2: 53

Manipulation (joint control), roba-30, V1: 115, 122; V2: 53

Manipulation (redundancy control), roba-33, V1: 115, 122; V2: 53

Manipulation (special purpose control), roba-32, V1: 115, 122; V2: 53

Maximum concentration levels. *See* Radionuclides, regulatory compliance for
Resource Conservation and Recovery Act

Maximum contaminant level goals. *See* Safe Drinking Water Act

Maximum contaminant levels. *See* Safe Drinking Water Act

Mechanical excavation, rema-50, V1: 100; V2: 42

Membranes for sample collection and concentration, char-55, V1: 59; V2: 4

Metallographic sectioning and preparation, char-67, V1: 59; V2: 4

Metals, technologies for. *See*
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Impoundments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (metals), remedial action alternatives for, in WAG 7
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Microgravity methods, char-127, V1: 60; V2: 6

Microtunneled high-density polyethylene, rema-86, V1: 95; V2: 26

Microwave digestion, char-19, V1: 59; V2: 4

Mixed-waste regulations
Definitions of, V1: 156
LDR-FFCA/ORR, V1: 132, 157

Mixed waste, technologies for. *See*
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10

Modular excavation, rema-122, V1: 96; V2: 32

Molten glass combustor, rema-15, V1: 99; V2: 34

Multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4

Multisensor fusion measurement systems, char-222, V1: 62; V2: 11

— N —

National Ambient Air Quality Standards. *See*
Clean Air Act

National Emission Standards. *See*
Clean Air Act

National Pollutant Discharge Elimination System. *See*
Clean Water Act

Natural Resource Damage Assessments. *See*
CERCLA

Natural resource trustees. *See*
CERCLA

NESHAPs. *See*
Radionuclides, regulatory compliance for

Network architecture with integrated workstations, char-221, V2: 8

Neutron activation, char-107, V1: 63; V2: 13

Neutron activation analysis, char-266, V1: 63–64; V2: 14

Nitrates, technologies for. *See*
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Nuclear magnetic resonance, char-11, V1: 60; V2: 7

— O —

Occupational exposure limits. *See*
Department of Energy requirements

Occupational radiation exposure limits. *See*
Department of Energy requirements

Occupational Safety and Health Administration
Asbestos, V1: 206
Hazardous-waste operations, V1: 206
Worker protection, V1: 206

On-line supercritical fluid extraction multidetector gas chromatography, char-115, V1: 64; V2: 17

Operator interface (command input), roba-40, V1: 116, 122; V2: 54

Operator interface (operator assistance), roba-41, V1: 116, 123; V2: 54

Operator interface (status/alert system), roba-42, V1: 116, 123; V2: 54

Optical absorption spectroscopy, char-27, V1: 60; V2: 5

Optical microscopy, char-32, V1: 65; V2: 18

Optimization of sampling designs, char-71, V1: 59; V2: 3

Organics, technologies for. *See*
Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (organics), characterization alternatives for, in WAG 10
Impoundments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (organics), characterization alternatives for, in WAG 7
Pits and trenches (organics), remedial action alternatives for, in WAG 7
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Tanks (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9

Overshot drilling, rema-123, V1: 96; V2: 32

— P —

Particle-induced X-ray emission, char-17, V1: 63; V2: 15

Particle size analysis, char-26, V1: 65; V2: 18

Passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12

Pathogen surveillance, char-215, V1: 65; V2: 19

PCB immunoassay kit, char-99, V2: 16

PCBs. *See*
Polychorinated biphenyls

Permits under CERCLA. *See*
CERCLA

Personnel monitoring, char-52, V1: 60; V2: 6

Pesticides. *See*
Federal Insecticide, Fungicide, and Rodenticide Act

Photon electron rejecting alpha liquid scintillation, char-97, V2: 14

Physical problem areas, technologies for. *See*
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (physical problem areas), characterization alternatives for, in WAG 10
Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (physical problem areas), characterization alternatives for, in WAG 7
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9

Physical sorting, rema-121, V1: 96; V2: 30

Pipelines
Description of implementation needs for remedial action alternatives, V1: 92
Description of remedial action alternatives for, V1: 83
Description of science and technology needs for remedial action alternatives, V1: 88
Problem definition, V1: 17

Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Data analysis management technologies
analysis of censored data, char-249, V1: 61; V2: 10
application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
client/server architecture for data base access, dism-157, V1: 61; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
computer-based training systems, dism-191, V1: 61; V2: 9
configuration management system, char-229, V1: 62; V2: 11
criticality indices, char-44, V1: 61; V2: 10
data access services, dism-154, V1: 61; V2: 8
detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11
dynamic modeling of material transport, char-255, V1: 62; V2: 11
fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
geographic information system for DOE sites, dism-181, V1: 61; V2: 8
hazard analysis expert system, char-233, V1: 61; V2: 9
hypertext information systems, dism-158, V1: 61; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
multisensor fusion measurement systems, char-222, V1: 62; V2: 11
network architecture with integrated workstations, char-221, V2: 8
project information access services, dism-151, V1: 61; V2: 8
quality control for measurement processes, char-250, V1: 61; V2: 10
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9
spatial sample and data analysis, char-253, V1: 61; V2: 10
statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
stored material neural net identification system, char-242, V1: 62; V2: 11
subsurface complexation model, char-45, V1: 62; V2: 11
task scheduling aids, char-241, V1: 61; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 60; V2: 6
electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
electrochemical methods, char-10, V1: 60; V2: 7
fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
ground-penetrating radar, char-124, V1: 60; V2: 6
immunoassay detection, char-23, V1: 60; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
ion mobility mass spectrometry, char-264, V1: 59; V2: 5
magnetics, char-128, V1: 60; V2: 6
microgravity methods, char-127, V1: 60; V2: 6

000704

Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8 *(continued)*
optical absorption spectroscopy, char-27, V1: 60; V2: 5
personnel monitoring, char-52, V1: 60; V2: 6
portable luminescence detection, char-92, V1: 60; V2: 7
portable Raman spectrometer, char-84, V1: 60; V2: 5
seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
tomographic seismic monitoring, char-60, V1: 60; V2: 6
ultrasonic ranging and data system, char-123, V1: 60; V2: 6
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 60; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7
laser ionization mass spectrometry, char-4, V1: 61; V2: 8
nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4
multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3
sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
SEAMIST inverted membrane, char-273, V1: 65; V2: 19
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63-64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Excavation technologies
pipeline excavation, rema-53, V1: 99; V2: 47
Fixation technologies
in situ grouting (pipelines), rema-52, V1: 99; V2: 47

000705

Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17
gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17
solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Excavation technologies
pipeline excavation, rema-53, V1: 99; V2: 47
Fixation technologies
in situ grouting (pipelines), rema-52, V1: 99; V2: 47

Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Pipelines (radioactive elements), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63-64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 63, V1: 62; V2: 13

Pipelines (radionuclides), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Excavation technologies
pipeline excavation, rema-53, V1: 99; V2: 47
Fixation technologies
in situ grouting (pipelines), rema-52, V1: 99; V2: 47

Pipelines (well bores), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Plug and abandon technologies
well plugging and abandonment, rema-22, V2: 47

Pits and trenches
Description of implementation needs for remedial action alternatives, V1: 92
Description of remedial action alternatives for, V1: 80
Description of science and technology needs for remedial action alternatives, V1: 87
Problem definition, V1: 16

000706

Pits and trenches (contaminated sludge/soil), remedial action alternatives for, in WAG 7
Excavation technologies
remote excavation, rema-38, V1: 98; V2: 37
Fixation technologies
in situ grouting (pits/trenches), rema-37, V1: 98; V2: 37
in situ vitrification (pits/trenches), rema-35, V1: 98; V2: 37
Physical separation technologies
in situ extraction, rema-39, V1: 98; V2: 37

Pits and trenches (general problem areas), characterization alternatives for, in WAG 7
Data analysis management technologies
analysis of censored data, char-249, V1: 61; V2: 10
application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
client/server architecture for data base access, dism-157, V1: 61; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
computer-based training systems, dism-191, V1: 61; V2: 9
configuration management system, char-229, V1: 62; V2: 11
criticality indices, char-44, V1: 61; V2: 10
data access services, dism-154, V1: 61; V2: 8
detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11
dynamic modeling of material transport, char-255, V1: 62; V2: 11
fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
geographic information system for DOE sites, dism-181, V1: 61; V2: 8
hazard analysis expert system, char-233, V1: 61; V2: 9
hypertext information systems, dism-158, V1: 61; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
multisensor fusion measurement systems, char-222, V1: 62; V2: 11
network architecture with integrated workstations, char-221, V2: 8
project information access services, dism-151, V1: 61; V2: 8
quality control for measurement processes, char-250, V1: 61; V2: 10
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9
spatial sample and data analysis, char-253, V1: 61; V2: 10
statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
stored material neural net identification system, char-242, V1: 62; V2: 11
subsurface complexation model, char-45, V1: 62; V2: 1[illegible]
task scheduling aids, char-241, V1: 61; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 60; V2: 6
electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
electrochemical methods, char-10, V1: 60; V2: 7
fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
ground-penetrating radar, char-124, V1: 60; V2: 6
immunoassay detection, char-23, V1: 60; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
ion mobility mass spectrometry, char-264, V1: 59; V2: 5
magnetics, char-128, V1: 60; V2: 6
microgravity methods, char-127, V1: 60; V2: 6
optical absorption spectroscopy, char-27, V1: 60; V2: 5
personnel monitoring, char-52, V1: 60; V2: 6
portable luminescence detection, char-92, V1: 60; V2: 7
portable Raman spectrometer, char-84, V1: 60; V2: 5
seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
tomographic seismic monitoring, char-60, V1: 60; V2: 6
ultrasonic ranging and data system, char-123, V1: 60; V2: 6
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 60; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7
laser ionization mass spectrometry, char-4, V1: 61; V2: 8
nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4

multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3
sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
SEAMIST inverted membrane, char-273, V1: 65; V2: 19
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

Pits and trenches (inorganics), characterization alternatives for, in WAG 7
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63–64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Pits and trenches (low-level waste), remedial action alternatives for, in WAG 7
Excavation technologies
remote excavation, rema-38, V1: 98; V2: 37
Fixation technologies
in situ grouting (pits/trenches), rema-37, V1: 98; V2: 37
in situ vitrification (pits/trenches), rema-35, V1: 98; V2: 37
Physical separation technologies
in situ extraction, rema-39, V1: 98; V2: 37

Pits and trenches (metals), remedial action alternatives for, in WAG 7
Capping technologies
capping (pits/trenches), rema-36, V1: 98; V2: 37

Pits and trenches (organics), characterization alternatives for, in WAG 7
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17
gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17

Pits and trenches (organics), characterization alternatives for, in WAG 7 *(continued)*
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17
solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Pits and trenches (organics), remedial action alternatives for, in WAG 7
Capping technologies
capping (pits/trenches), rema-36, V1: 98; V2: 37

Pits and trenches (physical problem areas), characterization alternatives for, in WAG 7
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Pits and trenches (radioactive elements), characterization alternatives for, in WAG 7
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63-64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 63, V1: 62; V2: 13

Pits and trenches (radionuclides), remedial action alternatives for, in WAG 7
Capping technologies
capping (pits/trenches), rema-36, V1: 98; V2: 37

Plasma arc furnace, rema-17, V1: 99; V2: 35

Plates. *See*
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Polychlorinated biphenyls regulations. *See*
Toxic Substances Control Act

Polychlorinated biphenyls, technologies for
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Polymer-impregnated concrete/polymer modified concrete, rema-115, V1: 97; V2: 29

Portable gamma-ray scintillometers, char-263, V1: 62; V2: 13

Portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16

Portable luminescence detection, char-92, V1: 60; V2: 7

Portable Raman spectrometer, char-84, V1: 60; V2: 5

Portable volatile organic compounds detectors, char-5, V1: 64; V2: 16

Portable X-ray fluorescence, char-6, V1: 63; V2: 14

Position/velocity sensors, roba-48, V1: 116, 123; V2: 55

Powder X-ray diffraction, char-31, V1: 64; V2: 16

Power sources for mobile platforms, roba-10, V1: 115, 122; V2: 51

Precipitation, rema-34, V1: 100; V2: 44

Precision excavation, rema-90, V1: 96; V2: 31

Primary drinking water standards. *See*
Safe Drinking Water Act

Project information access services, dism-151, V1: 61; V2: 8

Proportional counter for alpha and beta activity, char-108, V1: 63, V1: 62; V2: 12

Proximity probes, roba-45, V1: 116, 123; V2: 54

Proximity probes as control sensors, roba-51, V1: 116, 123; V2: 55

Public radiation exposure limits. *See*
Department of Energy requirements

Public Radiation Protection Standards. *See*
Department of Energy requirements

— Q —

Quality control for measurement processes, char-250, V1: 61; V2: 10

— R —

Radiation hardening, roba-54, V1: 116, 123; V2: 55

Radiation protection standards
Department of Energy orders, V1: 162–168
Department of Transportation regulations, V1: 161
Environmental Protection Agency regulations, V1: 158–161
Federal agreements and legislation, V1: 157–158
Generic below regulatory concern levels for radioactive wastes, V1: 156–157

Radioactive elements, technologies for. *See*
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (radioactive elements), characterization alternatives for, in WAG 10
Impoundments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (radioactive elements), characterization technologies for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (radioactive elements), characterization alternatives for, in WAG 7
Soils and sediments (radioactive elements), characterization technologies for, in WAGs 1, 5, 8, and 9
Tanks (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9

Radioactive materials. *See*
Department of Transportation

Radioactive sample preparation, char-205, V1: 59; V2: 4

Radioanalytical procedures, char-202, V1: 63; V2: 13

Radiologically contaminated tank contents, technologies for. *See*
Impoundments (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Radionuclides. *See*
Safe Drinking Water Act

Radionuclides, regulatory compliance for
Dose limits, V1: 162
High-level waste, V1: 159, 162–163
Low-level waste, V1: 160, 162, 164, 168
Maximum contaminant levels, V1: 205
NESHAPS. *See*
Clean Air Act
Spent nuclear fuel, V1: 159, 162–163
Transportation requirements, V1: 161
Transuranic waste, V1: 159, 162, 163, 168

Radionuclides, technologies for. *See*
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (radionuclides), remedial action technologies for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (radionuclides), remedial action alternatives for, in WAG 7
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Range finders, roba-44, V1: 116, 123; V2: 54

Rankings, technology
Characterization technologies, V1: 59–65
Descriptions of criteria, V1: 44–46
Remedial action technologies, V1: 95–101
Robotics and automation technologies, V1: 122–123

Rare, threatened, or endangered species, V1: 215

000710

RCRA. *See*
Resource Conservation and Recovery Act

Remote excavation, rema-38, V1: 96, 98; V2: 31, 37

Refractory organics, technologies for. *See*
Soils and sediments, remedial action alternatives for, in WAGs 1, 5, 8, and 9

Regulatory compliance. *See Specific Acts*
Laws, environmental, affecting remedial action activities
Radiation Protection Standards

Remedial action alternatives. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (grout sheets), remedial action alternatives for, in WAG 10
Impoundments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radionuclides), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (well bores), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (contaminated sludge/soil), remedial action alternatives for, in WAG 7
Pits and trenches (low-level waste), remedial action alternatives for, in WAG 7
Pits and trenches (metals), remedial action alternatives for, in WAG 7
Pits and trenches (organics), remedial action alternatives for, in WAG 7
Pits and trenches (radionuclides), remedial action alternatives for, in WAG 7
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Residual radioactive material
Cleanup criteria, V1: 161, 165–166
Management of, V1: 166–167

Residual radioactivity. *See*
Department of Energy requirements

Resource Conservation and Recovery Act
Action-specific regulations, V1: 176–204
Characteristic waste, V1: 143
Containment building, V1: 195–196
Corrective Action, V1: 154, 172
Corrective Action Management Unit (CAMU), V1: 172
Hazardous debris, V1: 170, 172
Hazardous waste, V1: 143, 169
Land disposal restrictions (LDR), V1: 170
Listed waste, V1: 143
Maximum concentration levels, V1: 138, 143
Soil cleanup, V1: 154, 172
Solid waste, V1: 143
Subtitle C, V1: 169, 176–204
Subtitle D, V1: 174
Subtitle I, V1: 173

RCRA hazardous waste. *See*
Land disposal restrictions

Roadmapping methodology, V1: 25

Robotics and automation alternatives. *See*
Buried pipes, robotics and automation alternatives for
Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Impoundments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Low-level waste tanks, robotics and automation alternatives for
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9

— S —

Safe Drinking Water Act
Maximum contaminant levels, V1: 138–143, 158
Maximum contaminant level goals, V1: 138–143
Primary drinking water standards, V1: 138–143
Radionuclides, V1: 158
Secondary drinking water standards, V1: 144–145
Underground injection control, V1: 198–201, 205

Safety (collision avoidance), roba-35, V1: 115, 122; V2: 53

Safety (load/rate limiting), roba-36, V2: 53

Salt-bed formations, V1: 207

Salt-dome formations, V1: 207

Sample collection, roba-57, V1: 116, 123; V2: 56

Sample preparation, roba-59, V1: 116, 123; V2: 56

Sampling and mixing methods, char-81, V1: 59; V2: 3

Sampling of heterogeneous wastes, char-270, V1: 59; V2: 4

Sampling program configuration management system, char-228, V1: 59; V2: 3

Sampling USTs for volatile organics, char-257, V1: 59; V2: 3

Scanning electron microscopy, char-33, V1: 63; V2: 15

Scenic rivers V1: 215

SEAMIST inverted membrane, char-273, V1: 65; V2: 19

Secondary drinking water standards. *See*
Safe Drinking Water Act

Secondary ion mass spectroscopy, char-3, V1: 60; V2: 7

Sediment sampling from restricted access locations, char-276, V1: 59; V2: 4

Seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6

Sequential sampling plans, char-252, V1: 59; V2: 3

Sheet pile walls, rema-41, V1: 95, 100; V2: 24, 41

Shredding and magnetic separation, rema-93, V1: 96; V2: 30

Simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9

Sludge drying, rema-56, V1: 100; V2: 41

Slurry wall with high-density polyethylene insert, rema-83, V1: 95; V2: 24

Slurry walls, rema-40, V1: 95, 100; V2: 24, 41

Smelting, wpro-111, V1: 97; V2: 30

Sodium iodide-germanium gamma spectroscopy, char-106, V1: 62, 63; V2: 13

Soil cleanup. *See*
Resource Conservation and Recovery Act

Soil cleanup regulations
PCBs, V1: 154–155
Lead, V1: 155

Soil cleanup regulations, corrective action. *See*
RCRA

000712

Soil cleanup regulations, LDR for soil. *See* RCRA

Soil saw, rema-88, V1: 95; V2: 25

Soil vapor extraction, rema-78, V1: 98; V2: 33

Soil washing, rema-6, V2: 30

Soil washing, rema-51, V1: 100; V2: 41

Soil washing, rema-55, V1: 98; V2: 33

Soils and sediments
Description of implementation needs for remedial action alternatives, V1: 92
Description of remedial action alternatives for, V1: 81–82
Description of science and technology needs for remedial action alternatives, V1: 87
Problem definition, V1: 18, 20–23

Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Data analysis management technologies
analysis of censored data, char-249, V1: 61; V2: 10
application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
client/server architecture for data base access, dism-157, V1: 61; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
computer-based training systems, dism-191, V1: 61; V2: 9
configuration management system, char-229, V1: 62; V2: 11
criticality indices, char-44, V1: 61; V2: 10
data access services, dism-154, V1: 61; V2: 8
detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11
dynamic modeling of material transport, char-255, V1: 62; V2: 11
fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
geographic information system for DOE sites, dism-181, V1: 61; V2: 8
hazard analysis expert system, char-233, V1: 61; V2: 9
hypertext information systems, dism-158, V1: 61; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
multisensor fusion measurement systems, char-222, V1: 62; V2: 11
network architecture with integrated workstations, char-221, V2: 8
project information access services, dism-151, V1: 61; V2: 8
quality control for measurement processes, char-250, V1: 61; V2: 10
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 61; V2: 9
spatial sample and data analysis, char-253, V1: 61; V2: 10
statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
stored material neural net identification system, char-242, V1: 62; V2: 11
subsurface complexation model, char-45, V1: 62; V2: 11
task scheduling aids, char-241, V1: 61; V2: 10
Detection/measurement—field method technologies
air monitoring, char-59, V1: 60; V2: 6
electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
electrochemical methods, char-10, V1: 60; V2: 7
fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
ground-penetrating radar, char-124, V1: 60; V2: 6
immunoassay detection, char-23, V1: 60; V2: 5
infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
ion mobility mass spectrometry, char-264, V1: 59; V2: 5
magnetics, char-128, V1: 60; V2: 6
microgravity methods, char-127, V1: 60; V2: 6
optical absorption spectroscopy, char-27, V1: 60; V2: 5
personnel monitoring, char-52, V1: 60; V2: 6
portable luminescence detection, char-92, V1: 60; V2: 7
portable Raman spectrometer, char-84, V1: 60; V2: 5
seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
tomographic seismic monitoring, char-60, V1: 60; V2: 6
ultrasonic ranging and data system, char-123, V1: 60; V2: 6
Detection/measurement—laboratory method technologies
contamination control—analytical equipment, char-204, V1: 60; V2: 7
Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7
laser ionization mass spectrometry, char-4, V1: 61; V2: 8

000713

nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4
multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3
sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
SEAMIST inverted membrane, char-273, V1: 65; V2: 19
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63–64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Capping technologies
capping, rema-46, V1: 98; V2: 33

Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Barrier technologies
cryogenic barriers, rema-58, V1: 98; V2: 33
Capping technologies
capping, rema-46, V1: 98; V2: 33
Chemical separation technologies
electrokinetic removal, rema-19, V1: 98; V2: 36
soils treatment using solvent extraction, rema-119, V1: 98; V2: 36
Destruction technologies
chem char process, rema-20, V1: 99; V2: 34
plasma arc furnace, rema-17, V1: 99; V2: 35
soils treatment using oxidation or reduction, rema-120, V1: 98; V2: 35
Excavation technologies
entombed clamshell, rema-124, V1: 99; V2: 36
Fixation technologies
in situ vitrification, rema-18, V1: 99; V2: 36
stabilization/fixation by grouting, rema-54, V2: 36
Wall technologies
cryogenic barriers, rema-58, V1: 98; V2: 33

Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Capping technologies
capping, rema-46, V1: 98; V2: 33

Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Destruction technologies
molten glass combustor, rema-15, V1: 99; V2: 34

Soils and sediments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17
gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17
solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Barrier technologies
cryogenic barriers, rema-58, V1: 98; V2: 33
Capping technologies
capping, rema-46, V1: 98; V2: 33
Chemical separation technologies
soils treatment using solvent extraction, rema-119, V1: 98; V2: 36
Destruction technologies
molten glass combustor, rema-15, V1: 99; V2: 34
plasma arc furnace, rema-17, V1: 99; V2: 35
soils treatment using bioremediation, rema-118, V1: 99; V2: 35
soils treatment using oxidation or reduction, rema-120, V1: 98; V2: 35
Excavation technologies
entombed clamshell, rema-124, V1: 99; V2: 36
Fixation technologies
in situ vitrification, rema-18, V1: 99; V2: 36
stabilization/fixation by grouting, rema-54; V2: 36
Physical separation technologies
incineration, rema-12, V1: 99; V2: 34
Wall technologies
cryogenic barriers, rema-58, V1: 98; V2: 33

Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Destruction technologies
incineration, rema-12, V1: 99; V2: 34
molten glass combustor, rema-15, V1: 99; V2: 34
plasma arc furnace, rema-17, V1: 99; V2: 35
Physical separation technologies
low-temperature thermal treatment, rema-13, V1: 98; V2: 33
thermal desorption, rema-16, V1: 98; V2: 34
thermally enhanced soil vapor extraction, rema-80, V1: 98; V2: 34

Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13

000715

proportional counter for alpha and beta activity, char-108, V1: 62, 63; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63-64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 62, 63; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 62, 63; V2: 13

Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Barrier technologies
cryogenic barriers, rema-58, V1: 98; V2: 33
Chemical separation technologies
electrokinetic removal, rema-19, V1: 98; V2: 36
soils treatment using solvent extraction, rema-119, V1: 98; V2: 36
Destruction technologies
chem char process, rema-20, V1: 99; V2: 34
plasma arc furnace, rema-17, V1: 99; V2: 35
Excavation technologies
entombed clamshell, rema-124, V1: 99; V2: 36
Fixation technologies
in situ vitrification, rema-18, V1: 99; V2: 36
stabilization/fixation by grouting, rema-54, V2: 36
Wall technologies
cryogenic barriers, rema-58, V1: 98; V2: 33

Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Destruction technologies
chem char process, rema-20, V1: 99; V2: 34

Soils and sediments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Controls—algorithms technologies
combined mobility /manipulation, roba-34, V1: 115, 122; V2: 53
control modes, roba-27, V1: 115, 122; V2: 52
emergency shutdown, roba-37, V1: 115, 122; V2: 53
manipulation (Cartesian control), roba-31, V1: 115, 122; V2: 53
manipulation (joint control), roba-30, V1: 115, 122; V2: 53
manipulation (redundancy control), roba-33, V1: 115, 122; V2: 53
manipulation (special purpose control), roba-32, V1: 115, 122; V2: 53
safety (collision avoidance), roba-35, V1: 115, 122; V2: 53
safety (load/rate limiting), roba-36, V2: 53
vehicle/mobility driving, roba-28, V1: 115, 122; V2: 52
vehicle/mobility navigation, roba-29, V1: 115, 122; V2: 53
Controls—human/machine interface technologies
console (data handling methods), roba-39, V1: 116, 122; V2: 54
console (fixed/mobile/suitcase), roba-38, V1: 116, 122; V2: 54
operator interface (command input), roba-40, V1: 116, 122; V2: 54
operator interface (operator assistance), roba-41, V1: 116, 123; V2: 54
operator interface (status/alert system), roba-42, V1: 116, 123; V2: 54
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 115, 122; V2: 52
end effectors/alternatives, roba-23, V1: 115, 122; V2: 52
force limiting/compliant mechanisms, roba-26, V1: 115, 122; V2: 52
general gripper/tool interface, roba-25, V1: 115, 122; V2: 52
Mechanical—manipulation technologies
compact, high-capacity manipulators, roba-19, V1: 115, 122; V2: 52
dexterous manipulators, roba-16, V1: 115, 122; V2: 51
Mechanical—mechanism technologies
stabilization/support mechanisms or booms, roba-22, V1: 115, 122; V2: 52
tool caddies, roba-21, V1: 115, 122; V2: 52
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 115, 122; V2: 51
failure recovery systems for mobile platforms, roba-11, V1: 115, 122; V2: 51
long-arm deployed robotic platforms, roba-9, V1: 115, 122; V2: 51
power sources for mobile platforms, roba-10, V1: 115, 122; V2: 51
specialized robotic deployment platforms, roba-7, V1: 115, 122; V2: 51
transportation methods for mobile platforms, roba-12, V1: 115, 122; V2: 51
wheeled/tracked vehicle, roba-1, V1: 115, 122; V2: 51
Other technologies
characterization sensor integration, roba-58, V1: 116, 123; V2: 56
field hardening, roba-53, V1: 116, 123; V2: 55
integrated automated analytical, roba-55, V1: 116, 123; V2: 55
information management for sample handling, roba-56, V1: 116, 123; V2: 56
radiation hardening, roba-54, V1: 116, 123; V2: 55

000716

Soils and sediments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9 *(continued)*
sample collection, roba-57, V1: 116, 123; V2: 56
sample preparation, roba-59, V1: 116, 123; V2: 56
Sensors—control technologies
force/torque, roba-50, V1: 116, 123; V2: 55
position/velocity sensors, roba-48, V1: 116, 123; V2: 55
proximity probes as control sensors, roba-51, V1: 116, 123; V2: 55
tooling sensors, roba-52, V1: 116, 123; V2: 55
Sensors—perception technologies
force/torque sensors, roba-46, V1: 116, 123; V2: 55
proximity probes, roba-45, V1: 116, 123; V2: 54
range finders, roba-44, V1: 116, 123; V2: 54
visual/aural, roba-43, V1: 116, 123; V2: 54

Soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3

Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Chemical separation
soil washing, rema-55, V1: 98; V2: 33
Destruction technologies
incineration, cement kiln, rema-14, V1: 99; V2: 35
Physical separation
soil vapor extraction, rema-78, V1: 98; V2: 33
soil washing, rema-55, V1: 98; V2: 33
thermal desorption, rema-16, V1: 98; V2: 34
vapor extraction with radio frequency, rema-11, V1: 98; V2: 34

Soils treatment using bioremediation, rema-118, V1: 99; V2: 35

Soils treatment using oxidation or reduction, rema-120, V1: 98; V2: 35

Soils treatment using solvent extraction, rema-119, V1: 98; V2: 36

Solidify and mine (freeze and mine), rema-10, V1: 96; V2: 32

Solid phase microextraction analytical method, char-211, V1: 65; V2: 18

Solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3

Solid waste. *See*
Resource Conservation and Recovery Act

Solid waste landfills, V1: 174

Spatial sample and data analysis, char-253, V1: 61; V2: 10

Specialized robotic deployment platforms, roba-7, V1: 115, 122; V2: 51

Species, rare, threatened, or endangered, V1: 215

Spent nuclear fuel. *See*
Radionuclides, regulatory compliance for

Spent nuclear fuel, disposal standards. *See*
DOE requirements

Stabilization/fixation by grouting, rema-54, V2: 36

Stabilization/support mechanisms or booms, roba-22, V1: 115, 122; V2: 52

State regulations.
Air, V1: 174
Ground water, V1: 137
Hazardous waste, V1: 176–204
Solid waste, V1: 174
Surface water, V1: 146, 205

Statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10

Steam stripping, rema-77, V1: 100; V2: 44

Stored material neural net identification system, char-242, V1: 62; V2: 11

Structural caps. *See*
RCRA closure requirements. *See*
Capping

Structural caps, rema-96, V1: 95; V2: 23

Subsurface complexation model, char-45, V1: 62; V2: 11

Subtitle C. *See*
Resource Conservation and Recovery Act

Subtitle D. *See*
Resource Conservation and Recovery Act

Subtitle I. *See*
Resource Conservation and Recovery Act

Sulfur polymer cement, rema-114, V1: 97; V2: 28

Supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5

Supercritical fluid extraction of organics, char-208, V1: 59; V2: 4

Surcharge, rema-82, V1: 95; V2: 23

Surface water cleanup, V1: 137

Synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17, 18

000717

— T —

Tank contents removal using hydraulic techniques, rema-29, V1: 97; V2: 38

Tank contents removal using mechanical mining, rema-27, V1: 97; V2: 38

Tank contents removal using pneumatic techniques, rema-28, V1: 97; V2: 38

Tanks
- Description of implementation needs for remedial action alternatives, V1: 90
- Description of remedial action alternatives for, V1: 80
- Description of science and technology needs for remedial action alternatives, V1: 86
- Problem definition, V1: 16
- RCRA tank storage and closure requirements, V1: 191–193

Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
- Data analysis management technologies
  - analysis of censored data, char-249, V1: 61; V2: 10
  - application of approximate reasoning to data analysis/evaluation, char-234, V1: 61; V2: 9
  - automated scanning and conversion of engineering drawings, dism-155, V1: 61; V2: 9
  - client/server access to standards and regulatory guidelines, dism-153, V1: 61; V2: 8
  - client/server architecture for data base access, dism-157, V1: 61; V2: 9
  - computer-aided task analysis and procedure preparation, dism-172, V1: 61; V2: 9
  - computer-based training systems, dism-191, V1: 61; V2: 9
  - configuration management system, char-229, V1: 62; V2: 11
  - criticality indices, char-44, V1: 61; V2: 10
  - data access services, dism-154, V1: 61; V2: 8
  - detection and measurement systems with feature extraction, char-223, V1: 62; V2: 11
  - dynamic modeling of material transport, char-255, V1: 62; V2: 11
  - fractals used to select models for material transport in porous media, char-225, V1: 62; V2: 11
  - geographic information system for DOE sites, dism-181, V1: 61; V2: 8
  - hazard analysis expert system, char-233, V1: 61; V2: 9
  - hypertext information systems, dism-158, V1: 61; V2: 10
  - modeling of volatile organic compounds migration in porous materials, char-53, V1: 61; V2: 10
  - multisensor fusion measurement systems, char-222, V1: 62; V2: 11
  - network architecture with integrated workstations, char-221, V2: 8
  - project information access services, dism-151, V1: 61; V2: 8
  - quality control for measurement processes, char-250, V1: 61; V2: 10
  - simulated walkthrough facility for robotics task sequence analysis, dism-71, V1: 61; V2: 9
  - spatial sample and data analysis, char-253, V1: 61; V2: 10
  - statistical methods for the analysis of large data sets, char-251, V1: 61; V2: 10
  - stored material neural net identification system, char-242, V1: 62; V2: 11
  - subsurface complexation model, char-45, V1: 62; V2: 11
  - task scheduling aids, char-241, V1: 61; V2: 10
- Detection/measurement—field method technologies
  - air monitoring, char-59, V1: 60; V2: 6
  - electrical and electromagnetic detection of ground and geologic features, char-125, V1: 60; V2: 6
  - electrochemical methods, char-10, V1: 60; V2: 7
  - fiber-optic chemical sensors, char-25, V1: 65, V1: 59; V2: 5
  - ground-penetrating radar, char-124, V1: 60; V2: 6
  - immunoassay detection, char-23, V1: 60; V2: 5
  - infrared spectroscopy (wavelength dispersion), char-18, V1: 60; V2: 6
  - ion mobility mass spectrometry, char-264, V1: 59; V2: 5
  - magnetics, char-128, V1: 60; V2: 6
  - microgravity methods, char-127, V1: 60; V2: 6
  - optical absorption spectroscopy, char-27, V1: 60; V2: 5
  - personnel monitoring, char-52, V1: 60; V2: 6
  - portable luminescence detection, char-92, V1: 60; V2: 7
  - portable Raman spectrometer, char-84, V1: 60; V2: 5
  - seismic methods (retraction, profiling, reflection), char-126, V1: 60; V2: 6
  - tomographic seismic monitoring, char-60, V1: 60; V2: 6
  - ultrasonic ranging and data system, char-123, V1: 60; V2: 6
- Detection/measurement—laboratory method technologies
  - contamination control—analytical equipment, char-204, V1: 60; V2: 7
  - Fourier transform infrared spectroscopy, char-8, V1: 60; V2: 7
  - isotopic dilution mass spectroscopy, char-48, V1: 60; V2: 7
  - laser ionization mass spectrometry, char-4, V1: 61; V2: 8

000718

Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9 *(continued)*
nuclear magnetic resonance, char-11, V1: 60; V2: 7
secondary ion mass spectroscopy, char-3, V1: 60; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 59; V2: 3
membranes for sample collection and concentration, char-55, V1: 59; V2: 4
multiangle drilling for depth profiling of contaminants, char-64, V1: 59; V2: 4
sampling and mixing methods, char-81, V1: 59; V2: 3
sampling of heterogeneous wastes, char-270, V1: 59; V2: 4
sampling USTs for volatile organics, char-257, V1: 59; V2: 3
SEAMIST inverted membrane, char-273, V1: 65; V2: 19
sediment sampling from restricted access locations, char-276, V1: 59; V2: 4
soil/sediment sampling for volatile organics analysis, char-256, V1: 59; V2: 3
solid sorbent sampling in airborne organics, char-254, V1: 59; V2: 3
Sample preparation technologies
adaptation of the EPA TCLP leaching test for use with radioactive samples, char-209, V1: 59; V2: 4
high-pressure ashing, char-203, V1: 59; V2: 5
metallographic sectioning and preparation, char-67, V1: 59; V2: 4
microwave digestion, char-19, V1: 59; V2: 4
radioactive sample preparation, char-205, V1: 59; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 59; V2: 5
supercritical fluid extraction of organics, char-208, V1: 59; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 59; V2: 3
sampling program configuration management system, char-228, V1: 59; V2: 3
sequential sampling plans, char-252, V1: 59; V2: 3

Tanks (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 14
portable X-ray fluorescence, char-6, V1: 63; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14
Laboratory method technologies
atomic emission spectroscopy, char-76, V1: 63; V2: 15
auger electron spectroscopy, char-2, V1: 64; V2: 16
cold vapor (mercury) analysis, char-24, V1: 64; V2: 15
electron diffraction, char-37, V1: 63; V2: 15
electron spectroscopy for chemical analysis, char-1, V1: 64; V2: 16
energy dispersive X-ray spectroscopy, char-35, V1: 63; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 63; V2: 16
inductively coupled plasma—mass spectroscopy, char-78, V1: 63; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 63; V2: 14
ion chromatography, char-50, V1: 63; V2: 15
neutron activation analysis, char-266, V1: 63–64; V2: 14
particle-induced X-ray emission, char-17, V1: 63; V2: 15
powder X-ray diffraction, char-31, V1: 64; V2: 16
scanning electron microscopy, char-33, V1: 63; V2: 15
transmission electron microscopy, char-34, V1: 63; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Tanks (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
direct sampling ion trap mass spectrometry, char-90, V1: 64; V2: 16
gas chromatography in the field, char-262, V1: 64; V2: 17
PCB immunoassay kit, char-99, V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 64; V2: 16
portable volatile organic compounds detectors, char-5, V1: 64; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 17
Laboratory method technologies
analytical methods for chelators and decontamination agents, char-206, V1: 64; V2: 17
capillary zone electrophoresis, char-207, V1: 64; V2: 17
gas chromatography, char-94, V1: 64; V2: 18
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 64; V2: 17
gas chromatography—mass spectroscopy, char-88, V1: 64; V2: 18
liquid chromatography—mass spectroscopy, char-89, V1: 64; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 64; V2: 17

000719

solid phase microextraction analytical method, char-211, V1: 65; V2: 18
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 64; V2: 18

Tanks (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
ground-water discharge location, char-259, V1: 65; V2: 18
in situ ground-water flow meter, char-258, V1: 65; V2: 18
Laboratory method technologies
optical microscopy, char-32, V1: 65; V2: 18
particle size analysis, char-26, V1: 65; V2: 18

Tanks (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Field method technologies
advanced radiation monitors, char-269, V1: 62; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 62; V2: 13
bubble dosimeters for neutron flux, char-216, V1: 62; V2: 12
electret passive surface alpha monitor, char-95, V1: 62; V2: 13
electromagnetic offset log survey, char-272, V2: 19
fiber-optic chemical sensors, char-25, V1: 65; V2: 19
hydrofracture ground water monitoring, char-274, V1: 65; V2: 19
long-range alpha detector, char-65, V1: 62; V2: 12
passive monitors for weak beta radionuclides, char-102, V1: 62; V2: 12
portable gamma-ray scintillometers, char-263, V1: 62; V2: 13
proportional counter for alpha and beta activity, char-108, V1: 62, 63; V2: 12
thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12
Laboratory method technologies
gamma-ray spectrometry, char-268, V1: 63; V2: 14
liquid scintillation counting, char-267, V1: 63; V2: 14
neutron activation, char-107, V1: 63; V2: 13
neutron activation analysis, char-266, V1: 63–64; V2: 14
photon electron rejecting alpha liquid scintillation, char-97, V2: 14
proportional counter for alpha and beta activity, char-108, V1: 62, 63; V2: 13
radioanalytical procedures, char-202, V1: 63; V2: 13
sodium iodide-germanium gamma spectroscopy, char-106, V1: 62, 63; V2: 13

Task scheduling aids, char-241, V1: 61; V2: 10

TDEC. *See*
Tennessee Department of Environment and Conservation

Technical Task Plans
Relevance to characterization technologies, V1: 67–73
Relevance to remedial action technologies, V1: 106–110
Relevance to robotics and automation technologies, V1: 125–127
Search data-base listing, V1: 221–222

Tennessee Department of Environment and Conservation air standards. *See*
Clean Air Act

Tennessee Department of Environment and Conservation ambient water quality criteria. *See*
Clean Water Act

Tennessee Oversight Agreement, V1: 131

Thermal desorption, rema-16, V1: 98; V2: 34

Thermal desorption, rema-92, V1: 96; V2: 30

Thermal set resin impregnation, rema-97, V1: 95; V2: 23

Thermally enhanced soil vapor extraction, rema-80, V1: 98; V2: 34

Thermoluminescence dosimeter array for spatial characterization of alpha contamination, char-103, V1: 62; V2: 12

Thermoplastic encapsulation, rema-112, V1: 97; V2: 28

Thermoset encapsulation, rema-113, V1: 97; V2: 28

Tomographic seismic monitoring, char-60, V1: 60; V2: 6

Tool caddies, roba-21, V1: 115, 122; V2: 52

Tooling sensors, roba-52, V1: 116, 123; V2: 55

Toxic Substances Control Act
PCBs, V1: 154–155, 205
Soil cleanup, V1: 154
Spill cleanup policy, V1: 155

Transmission electron microscopy, char-34, V1: 63; V2: 15

Transmutation, rema-127, V1: 97; V2: 29

Transportation methods for mobile platforms, roba-12, V1: 115, 122; V2: 51

Transportation requirements. *See*
Radionuclides, regulatory compliance for

000720

Transuranic waste. *See*
Radionuclides, regulatory compliance for

Transuranic wastes
Disposal standards, V1: 159

Transuranic wastes. *See*
Department of Energy requirements

Trench subsidence, technologies for. *See*
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Tritium, technologies for. *See*
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11

— *U* —

Ultrasonic ranging and data system, char-123, V1: 60; V2: 6

Ultraviolet/visible spectroscopy, char-9, V1: 60; V2: 8

Underground injection control. *See*
Safe Drinking Water Act

Underground mines, V1: 207

Underground storage tanks, V1: 173, 201–202

— *V* —

Vacuum loader (buried waste), rema-101, V1: 96; V2: 33

Vacuum loaders, rema-49, V1: 100; V2: 42

Vapor extraction with radio frequency, rema-11, V1: 98; V2: 34

Vehicle/mobility driving, roba-28, V1: 115, 122; V2: 52

Vehicle/mobility navigation, roba-29, V1: 115, 122; V2: 53

Vibrated plastic tube bottom seal, rema-87, V1: 95; V2: 26

Visual/aural, roba-43, V1: 116, 123; V2: 54

Vitrification, rema-117, V1: 97; V2: 29

VOCs. *See*
Volatile organic compounds

VOHs. *See*
Volatile organic hydrocarbons

Volatile organic compounds, technologies for. *See*
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Soils and sediments (volatile organic compounds), remedial action alternatives for, in WAGs 1, 5, 8, and 9

Volatile organic hydrocarbons, technologies for. *See*
Soils and sediments, remedial action alternatives for, in WAGs 1, 5, 8, and 9

— *W* —

WAG 1. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), characterization alternatives alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Low-level waste tanks, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radioactive elements), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radionuclides), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (well bores), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9

WAG 2. *See*
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11

WAG 2 *(continued)*
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11

WAG 3. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

WAG 4. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11

WAG 4 *(continued)*
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radioactive elements), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radionuclides), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (well bores), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

WAG 5. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7

Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Low-level waste tanks, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radioactive elements), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radionuclides), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (well bores), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

WAG 5 *(continued)*
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9

WAG 6. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

WAG 7. *See*
Buried waste (buried bulk equipment items), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (composition determination), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (general problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (HFIR control plates), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (high-specific activity europium in HFIR, TRU oxides, and concentrated low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (inorganics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (low-level waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (metals), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (mixed waste), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (organics), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (physical problem areas), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radioactive elements), characterization alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (radionuclides), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste, robotics and automation alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Buried waste (trench subsidence), remedial action alternatives for, in WAGs 1, 3, 4, 5, 6, and 7
Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radioactive elements), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radionuclides), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (well bores), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pits and trenches (contaminated sludge/soil), remedial action alternatives for, in WAG 7
Pits and trenches (general problem areas), characterization alternatives for, in WAG 7
Pits and trenches (inorganics), characterization alternatives for, in WAG 7
Pits and trenches (low-level waste), remedial action alternatives for, in WAG 7
Pits and trenches (metals), remedial action alternatives for, in WAG 7
Pits and trenches (organics), characterization alternatives for, in WAG 7
Pits and trenches (organics), remedial action alternatives for, in WAG 7
Pits and trenches (physical problem areas), characterization alternatives for, in WAG 7
Pits and trenches (radioactive elements), characterization alternatives for, in WAG 7
Pits and trenches (radionuclides), remedial action alternatives for, in WAG 7

WAG 7 *(continued)*
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

WAG 8. *See*
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Low-level waste tanks, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Pipelines (general problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (inorganics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (metals), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8

Pipelines (organics), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (organics), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (physical problem areas), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radioactive elements), characterization alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (radionuclides), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Pipelines (well bores), remedial action alternatives for, in WAGs 1, 4, 5, 7, and 8
Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9

WAG 9. *See*
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Impoundments (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (metals), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (organics), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments (radionuclides), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Impoundments, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Inactive low-level waste tanks (radiologically contaminated tank contents), remedial action alternatives for, in WAGs 1, 5, 8, and 9
Low-level waste tanks, robotics and automation alternatives for, in WAGs 1, 5, 8, and 9
Tanks (general problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (inorganics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (organics), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (physical problem areas), characterization alternatives for, in WAGs 1, 5, 8, and 9
Tanks (radioactive elements), characterization alternatives for, in WAGs 1, 5, 8, and 9

WAG 10. *See*
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11

WAG 10 *(continued)*
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Hydrofracture (general problem areas), characterization alternatives for, in WAG 10
Hydrofracture (grout sheets), remedial action alternatives for, in WAG 10
Hydrofracture (inorganics), characterization alternatives for, in WAG 10
Hydrofracture (organics), characterization alternatives for, in WAG 10
Hydrofracture (physical problem areas), characterization alternatives for, in WAG 10
Hydrofracture (radioactive elements), characterization alternatives for, in WAG 10

WAG 11. *See*
Ground water and surface water (general problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (inorganics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (nitrates), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (organics), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (physical problem areas), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (PCBs), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radioactive elements), characterization alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (radionuclides), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water, robotics and automation alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (tritium), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Ground water and surface water (volatile organic compounds), remedial action alternatives for, in WAGs 2, 3, 4, 5, 6, 8, 9, 10, and 11
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

WAG 13. *See*
Soils and sediments (general problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (inorganics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (low-level waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (metals), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (mixed waste), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (nitrates), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (physical problem areas), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (PCBs), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radioactive elements), characterization alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (radionuclides), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (refractory organics), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments, robotics and automation alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13
Soils and sediments (volatile organic hydrocarbons), remedial action alternatives for, in WAGs 1, 2, 3, 4, 5, 6, 7, 11, and 13

WAGs, descriptions of, V1: 7–14

Water proofing cave with hydraulic cage, rema-21, V1: 99; V2: 46

Wavelength dispersive X-ray spectroscopy, char-36, V1: 63; V2: 15

Well bores, technologies for. *See*
Pipelines (well bores), remedial action technologies for, in WAGs 1, 4, 5, 7, and 8

Well plugging and abandonment, rema-22, V2: 47

Wireline basket recovery, rema-125, V1: 96; V2: 32

Wheeled/tracked vehicle, roba-1, V1: 115, 122; V2: 51

— X —

X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219, V1: 63; V2: 14

000732

HOW TO USE THIS INDEX

The Waste Management (WM) Index provides a comprehensive list of site problems, problem area/constituents, remedial technologies, and regulatory terms discussed in the WM sections of the *Oak Ridge National Laboratory Technology Logic Diagram*. All entries provide specific page numbers, or cross-reference entries that provide specific page numbers, in the WM volumes (Vol. 1, Pt. C; Vol. 2, Pt. C; and appropriate parts of Vol. 3).

Page numbers are located at the end of main entries or at the end of subentries. References to the WM Vol. 1, Pt. C (*Technology Evaluation*), are indicated by "V1:" and followed by a page number, while references to the WM Vol. 2, Pt. C (*Technology Logic Diagrams*), are indicated by "V2:" and followed by a specific page number. Specific locations in Vols. 3 (*Technology Evaluation Data Sheets*) are given by the technology code numbers (e.g., wpro-117) because pages in this volume are unnumbered.

Cross-references are indicated by a *See* at the end of the main entry. Following the *See* is a list of other main entries, which provide specific page numbers.

Examples of index entries are provided below.

- A main entry (a specific technology), which consists of a title in bold and a locator. The locator gives specific page numbers—"wpro-117" (Vol. 3); "V1: 111" (Vol. 1, Pt. C); and "V2: 44, 143" (Vol. 2, Pt. C).

Technology name	Technology code no.	Vol. no.	Page no.	Vol. no.	Page nos.
⇓	⇓	⇓	⇓	⇓	⇓
Biodegradation,	wpro-117,	V1:	111;	V2:	44, 143

locator

- Two main entries that cross-reference. The first example consists of an ORNL Problem and a *See* reference; the second example is the entry referenced, which provides specific page numbers:

Nitrogen oxide criteria pollutant. *See*
Waste off-gases (NO_x criteria pollutant), waste management alternatives for

Waste off-gases (NO_x criteria pollutant), waste management alternatives for
Chemical treatment technologies
deNO$_x$ processes, wpro-307, V1: 123, 126; V2: 132
Thermal treatment technologies
incineration, wpro-108, V1: 124, 127; V2: 133
molten salt oxidation, wpro-113, V1: 127; V2: 133

000734

— A —

Acid. *See*
Melton Valley and REDC caustic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Melton Valley and REDC caustic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
REDC acidic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
REDC acidic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
Waste off-gases (entrained vapors/acids), waste management alternatives for

Acid digestion, wpro-127, V1: 109; V2: 137

Acid pits. *See*
Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for

Adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples, char-209, V1: 45; V2: 4

Adsorbable RAD constituents. *See*
Waste off-gases (adsorbable RAD constituents), waste management alternatives for

Adsorption, wpro-202/203, V1: 109, 116, 118, 119, 121, 123, 125; V2: 89, 96, 100, 108, 114, 124, 126, 127, 129, 130, 133, 134

Advanced electric thermolysis, wpro-120, V1: 117, 120; V2: 117

Advanced radiation monitors, char-269, V1: 48; V2: 12

Aerobic digestion, wpro-224, V1: 111, 118, 122; V2: 35, 94, 104, 118, 121, 139

Air monitoring, char-59, V1: 46; V2: 6

Air quality laws (Tennessee)
Compliance with, V1: 188–189

Air stripping, wpro-200, V1: 116; V2: 100, 108, 111, 114, 121

Alpha track etch detectors for surface alpha contamination, char-96, V1: 48; V2: 12

Anaerobic digestion, wpro-225, V1: 101, 111, 118, 122, V2: 36, 94, 104, 118, 121, 140

Analysis of censored data, char-249, V1: 47; V2: 9

Analytical methods for chelators and decontamination agents, char-206, V1: 50; V2: 17

Animal carcasses. *See*
Biological wastes, animal carcasses and bedding material (contaminated and uncontaminated), waste management alternatives for

Application of approximate reasoning to data analysis/evaluation, char-234, V1: 47; V2: 8

Aqueous waste, caustic. *See*
Melton Valley and REDC caustic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Melton Valley and REDC caustic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
REDC acidic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
REDC acidic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for

Asbestos regulations
Clean Air Act, V1: 200–201
DOE orders, V1: 202
OSHA, V1: 201
Tennessee regulations, V1: 201–202

Asbestos, waste shipment alternatives for
Waste packaging technologies
POP PGIII and POP PGII, wpht-108, V2: 150

Asphalt. *See*
Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Asphalt and building materials, TRU contamination only, waste management alternatives for
Asphalt and building materials, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for

000735

Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
Chemical treatment technologies
electropolishing/osmosis/migration, dcon-20, V1: 99; V2: 27
gamma radiolysis, wpro-100, V1: 99; V2: 27
leaching and stripping, wpro-213, V1: 99; V2: 27
solvent extraction, wpro-111, V1: 100; V2: 26
supercritical fluid extraction, wpro-118, V1: 100; V2: 26
Thermal treatment technologies
calcination/roasting, dcon-60, V1: 100; V2: 25
chem char process, wpro-114, V1: 100; V2: 25
incineration, wpro-108, V1: 100; V2: 24
molten glass combustor, wpro-116, V1: 100; V2: 26
plasma arc furnace, wpro-107, V1: 101; V2: 25
pyrolysis, wpro-110, V1: 101; V2: 25
thermal desorption, wpro-106, V1: 101; V2: 25
Waste stabilization technologies
encapsulation, V1: 99; V2: 24

Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 99; V2: 27
supercritical fluid extraction, wpro-118, V1: 100; V2: 27
Waste stabilization technologies
encapsulation, V1: 99; V2: 27

Asphalt and building materials, TRU contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 70
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 69
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 70
molten glass combustor, wpro-116, V1: 104; V2: 70
plasma arc furnace, wpro-107, V1: 104; V2: 70
Waste stabilization technologies
encapsulation, V1: 102; V2: 69

Asphalt and building materials, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 135
recycle/reuse, wpro-130, V1: 106; V2: 135

Atomic emission spectroscopy, char-76, V1: 49; V2: 14

Auger electron spectroscopy, char-2, V1: 50; V2: 15

Autoclaving, wpro-119, V1: 112, 113; V2: 104

Automated engineering system life cycle planning, dism-174, V1: 48; V2: 11

Automated scanning and conversion of engineering drawings, dism-154, V1: 47; V2: 8

Automated system reliability and safety analysis, dism-175, V1: 48; V2: 11

— B —

Basins, retention. *See*
Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for

Bedding material. *See*
Biological wastes, animal carcasses and bedding material (contaminated and uncontaminated), waste management alternatives for

Biodegradation, wpro-117, V1: 111; V2: 44, 143

Biodenitrification, wpro-229, V1: 117, 121; V2: 114

Biological wastes, animal carcasses and bedding material (contaminated and uncontaminated), waste management alternatives for
Thermal treatment technologies
incineration, wpro-108, V1: 100; V2: 137
molten glass combustor, wpro-116, V1: 100; V2: 137
molten salt oxidation, wpro-113, V1: 101; V2: 137
plasma arc furnace, wpro-107, V1: 101; V2: 138

Biosorption, wpro-226, V1: 101, 104, 111, 121; V2: 35, 39, 57, 60, 64, 82, 110

Borehole disposal, wdis-100, V2: 152, 153

Bradtec process, wpro-228, V1: 116, 119; V2: 112

Bubble dosimeters for neutron flux, char-216, V1: 48; V2: 12

Bucky ball chemistry, wpro-101, V1: 116, 125; V2: 117, 130

000736

Burial grounds. *See*
Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for

— C —

CAA. *See*
Asbestos regulations

Calcination/roasting, dcon-60, V1: 100, 103; V2: 24, 25, 50, 69

CAMUs/TUs. *See*
Corrective Action Management Unit/Temporary Unit

Capillary zone electrophoresis, char-207, V1: 50; V2: 17

Carcasses, animal. *See*
Biological wastes, animal carcasses and bedding material (contaminated and uncontaminated), waste management alternatives for

Catalytic destruction, wpro-109, V1: 99, 109, 116, 121, 123; V2: 22, 86, 100, 103, 106, 125, 126

Cementitious solidification/stabilization, wsta-100, V2: 147

Characteristics of hazardous waste, V1: 162–163

Characterization
Discussion of implementation needs, V1: 43
Discussion of science and technology needs, V1: 42
Discussion of technology options, V1: 38–41
Technology rankings, V1: 44–51

Characterization alternatives for waste management. *See*
Gaseous waste (general problem area/constituents), characterization alternatives for
Gaseous waste (inorganic constituents), characterization alternatives for
Gaseous waste (organic constituents), characterization alternatives for
Gaseous waste (pathogenic constituents), characterization alternatives for
Gaseous waste (physical characteristics), characterization alternatives for
Gaseous waste (radioactive constituents), characterization alternatives for
Liquid wastes (general problem area/constituents), characterization alternatives for
Liquid wastes (inorganic constituents), characterization alternatives for
Liquid wastes (organic constituents), characterization alternatives for
Liquid wastes (pathogenic constituents), characterization alternatives for
Liquid wastes (physical characteristics), characterization alternatives for
Liquid wastes (radioactive constituents), characterization alternatives for
Solid-liquid wastes (general problem area/constituents), characterization alternatives for
Solid-liquid wastes (inorganic constituents), characterization alternatives for
Solid-liquid wastes (organic constituents), characterization alternatives for
Solid-liquid wastes (pathogenic constituents), characterization alternatives for
Solid-liquid wastes (physical characteristics), characterization alternatives for
Solid-liquid wastes (radioactive constituents), characterization alternatives for
Solid wastes (general problem areas/constituents), characterization alternatives for
Solid wastes (inorganic constituents), characterization alternatives for
Solid wastes (organic constituents), characterization alternatives for
Solid wastes (pathogenic constituents), characterization alternatives for
Solid wastes (physical characteristics), characterization alternatives for
Solid wastes (radioactive constituents), characterization alternatives for

Characterization sensor integration, roba-58, V1: 141, 147; V2: 162

Chem char process, wpro-114, V1: 100, 117, 120, 122; V2: 25, 28, 34, 39, 42, 43, 46, 62, 104, 118, 139

Chemical dechlorination, wpro-209, V1: 116; V2: 98

Chemical oxidation/reduction, wpro-209, V1: 109, 113, 116, 119; V2: 112, 115

Chemical precipitation, wpro-210, V1: 109, 116, 119; V2: 87, 89, 112, 115

Chemical reduction, wpro-209, V2: 110

Clean Air Act. *See*
Asbestos regulations

Clean Air Act and Tennessee Air Quality Laws, V1: 188–190

Clean Water Act
Dredge or fill material activites and permitting, V1: 205

000737

Clean Water Act *(continued)*
NPDES permits, V1: 205–206
Radioactive materials, V1: 205–206
Tennessee Water Quality Control Act, V1: 205

Client/server access to standards and regulatory guidelines, dism-152, V1: 46; V2: 7

Client/server architecture for data base access, dism-157, V1: 47; V2: 9

Coal yard runoff sludge, uncontaminated waste, waste management alternatives for
Physical treatment technologies
recycle/reuse (reuse in steam boiler), wpro-130, V1: 112; V2: 107
recycle/reuse (sell as roadbed aggregate/filler), wpro-130, V1: 112; V2: 107
shallow land burial, wpro-132, V1: 113; V2: 142

Cold vapor (mercury) analysis, char-24, V1: 49; V2: 15

Combined mobility/manipulation, roba-34, V1: 140, 146; V2: 159

Combustible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V2: 35
anaerobic digestion, wpro-225, V1: 101; V2: 36
biosorption, wpro-226, V1: 101; V2: 35
Chemical treatment technologies
gamma radiolysis, wpro-100, V1: 99; V2: 34
leaching and stripping, wpro-213, V1: 99; V2: 33
supercritical fluid extraction, wpro-118, V1: 100; V2: 33
Thermal treatment technologies
chem char process, wpro-114, V1: 100; V2: 34
incineration, wpro-108, V1: 100; V2: 34
microwave treatment, wpro-115, V1: 100; V2: 35
molten glass combustor, wpro-116, V1: 100; V2: 35
molten salt oxidation, wpro-113, V1: 101; V2: 34
plasma arc furnace, wpro-107, V1: 101; V2: 35
Waste stabilization technologies
encapsulation, V1: 99; V2: 33

Combustible debris, RAD contamination only, waste management alternatives for
Biological treatment technologies
biosorption, wpro-226, V1: 104; V2: 57
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 56
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 56
microwave treatment, wpro-115, V1: 103; V2: 57
molten glass combustor, wpro-116, V1: 104; V2: 57
molten salt oxidation, wpro-113, V1: 104; V2: 56
plasma arc furnace, wpro-107, V1: 104; V2: 57
Waste stabilization technologies
encapsulation, V1: 102; V2: 56

Combustible debris, TRU contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 75
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 75
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 75
microwave treatment, wpro-115, V1: 103; V2: 75
molten glass combustor, wpro-116, V1: 104; V2: 76
molten salt oxidation, wpro-113, V1: 104; V2: 75
plasma arc furnace, wpro-107, V1: 104; V2: 76
Waste stabilization technologies
encapsulation, V1: 102; V2: 75

Combustible debris, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V2: 139
anaerobic digestion, wpro-225, V2: 140
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 138
recycle/reuse, wpro-130, V1: 106; V2: 138
sell as scrap, wpro-130, V1: 106; V2: 138
Thermal treatment technologies
chem char process, wpro-114, V2: 139
incineration, wpro-108, V1: 106; V2: 138
microwave treatment, wpro-115, V1: 106; V2: 139
molten salt oxidation, wpro-113, V1: 107; V2: 139
plasma arc furnace, wpro-107, V1: 107; V2: 139

Commercial RCRA landfill sites, wdis-103, V2: 152

Compact high-capacity manipulators, roba-19, V1: 139, 145; V2: 158

Compactible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Chemical treatment technologies
gamma radiolysis, wpro-100, V1: 99; V2: 36

000738

leaching and stripping, wpro-213, V1: 99; V2: 36
supercritical fluid extraction, wpro-118, V1: 100; V2: 36
Thermal treatment technologies
incineration, wpro-108, V1: 100; V2: 37
microwave treatment, wpro-115, V1: 100; V2: 37
molten glass combustor, wpro-116, V1: 100; V2: 37
plasma arc furnace, wpro-107, V1: 101; V2: 37
Waste stabilization technologies
encapsulation, V1: 99; V2: 36

Compactible debris, RAD contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 57
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 58
microwave treatment, wpro-115, V1: 103; V2: 58
molten glass combustor, wpro-116, V1: 104; V2: 58
plasma arc furnace, wpro-107, V1: 104; V2: 58
Waste stabilization technologies
encapsulation, V1: 102; V2: 57

Compactible debris, TRU contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 76
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 76
Thermal treatment technologies
microwave treatment, wpro-115, V1: 103; V2: 77
molten glass combustor, wpro-116, V1: 104; V2: 77
plasma arc furnace, wpro-107, V1: 104; V2: 77
Waste stabilization technologies
encapsulation, V1: 102; V2: 76

Compactible debris, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Physical treatment technologies
recycle/reuse, wpro-130, V1: 106; V2: 140
sell as scrap, wpro-130, V1: 106; V2: 140
Thermal treatment technologies
microwave treatment, V1: 106; wpro-115, V2: 141
molten glass combustor, wpro-116, V1: 107; V2: 140
plasma arc furnace, wpro-107, V1: 107; V2: 140

Computer-aided task analysis and procedure preparation, dism-172, V1: 47; V2: 9

Computer-based training systems, dism-191, V1: 47; V2: 9

Computer tomography, char-41, V1: 51; V2: 18

Concrete. *See*
Concrete rubble and gravel, TRU contamination only, waste management alternatives for
Concrete rubble and gravel, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Concrete rubble, RAD contamination only, waste management alternatives for

Concrete rubble and gravel, TRU contamination only, waste management alternatives for
Chemical treatment technologies
electropolishing/osmosis/migration, dcon-20, V1: 102; V2: 67
gamma radiolysis, wpro-100, V2: 67
leaching and stripping, wpro-213, V1: 103; V2: 67
Thermal treatment technologies
microwave treatment, wpro-115, V1: 103; V2: 67
plasma arc furnace, wpro-107, V1: 104; V2: 66
thermal desorption, wpro-106, V1: 104; V2: 66
Waste stabilization technologies
encapsulation, V1: 102; V2: 66

Concrete rubble and gravel, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 135
recycle/reuse, wpro-130, V1: 106; V2: 135

Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Chemical treatment technologies
catalytic destruction, wpro-109, V1: 99; V2: 22
electropolishing/osmosis/migration, dcon-20, V1: 99; V2: 22
Waste stabilization technologies
encapsulation, V1: 99; V2: 22

Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Chemical treatment technologies
electropolishing/osmosis/migration, dcon-20, V1: 99; V2: 22
gamma radiolysis, wpro-100, V1: 99; V2: 22

Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for *(continued)*
leaching and stripping, wpro-213, V1: 99; V2: 22
supercritical fluid extraction, wpro-118, V1: 100; V2: 21
Thermal treatment technologies
microwave treatment, wpro-115, V1: 100; V2: 21
plasma arc furnace, wpro-107, V1: 101; V2: 21
thermal desorption, wpro-106, V1: 101; V2: 21
Waste stabilization technologies
encapsulation, V2: 21

Concrete rubble, RAD contamination only, waste management alternatives for
Chemical treatment technologies
electropolishing/osmosis/migration, dcon-20, V1: 102; V2: 49
gamma radiolysis, wpro-100, V2: 48
leaching and stripping, wpro-213, V1: 103; V2: 48
Thermal treatment technologies
microwave treatment, wpro-115, V1: 103; V2: 48
plasma arc furnace, wpro-107, V1: 104; V2: 48
thermal desorption, wpro-106, V1: 104; V2: 48
Waste stabilization technologies
encapsulation, V1: 102; V2: 48

Console (data handling methods), roba-39, V1: 140, 146; V2: 160

Console (fixed/mobile/suitcase), roba-38, V1: 140, 146; V2: 160

Contamination control—analytical equipment, char-204, V1: 46; V2: 6

Control modes, roba-27, V1: 139, 146; V2: 158

Corrective action management unit/temporary unit, V1: 171–172

Corrective action requirements, V1: 170–172

Corrosive wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Chemical treatment technologies
chemical precipitation, wpro-210, V2: 87
electrochemical metal removal, wpro-205, V1: 99; V2: 88
ion exchange, wpro-217/218, V2: 87
neutralization, wpro-230, V1: 110; V2: 87
Physical treatment technologies
inorganic microporous filters, wpro-207, V1: 109; V2: 87
reverse osmosis, wpro-206, V1: 109; V2: 87
Thermal treatment technologies
evaporation, wpro-223, V1: 110; V2: 88
Waste stabilization technologies
encapsulation, V1: 109

Corrosive wastes, RAD and/or TRU contamination only, waste management alternatives for
Chemical treatment technologies
ion exchange, wpro-217/218, V1: 111
neutralization, wpro-230, V1: 111

Corrosive wastes, uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants), only, waste management alternatives for
Physical treatment technologies
inorganic microporous filters, wpro-207, V1: 112
recycle/reuse, wpro-130, V1: 112
reverse osmosis, wpro-206, V1:
Chemical treatment technologies
ion exchange, wpro-217/218, V1: 113
neutralization, wpro-230, V1: 113

Criticality indices, char-44, V1: 47; V2: 9

CWA. *See*
Clean Water Act

Cyclone separation, wpro-302, V1: 123, 126, 129; V2: 128

— D —

Data access services, dism-153, V1: 46; V2: 8

Data/signal transmission, roba-13, V1: 139, 145; V2: 157

Debris. *See*
Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
Combustible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Combustible debris, RAD contamination only, waste management alternatives for
Combustible debris, TRU contamination only, waste management alternatives for
Combustible debris, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Compactible debris, TRU contamination only, waste management alternatives for
Compactible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Compactible debris, RAD contamination only, waste management alternatives for
Compactible debris, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for

Final residues from D&D, ER, and WM operations (clean debris), waste disposal alternatives for

Delisting petitions, V1: 164

Demolition, V2: 145

DeNO$_x$ processes, wpro-307, V1: 123, 126; V2: 132

Department of Energy orders, V1: 182–188

Department of Energy orders
Asbestos, V1: 202
High-level radioactive waste, V1: 193
Low-level radioactive waste, V1: 194
Mixed-waste management, V1: 197–198
NEPA, V1: 212
Radioactive-waste management, V1: 182–188
TRU waste, V1: 191
Waste minimization , V1: 204

Develop cask to ship spent fuel elements to Savannah River Site for storage, wpro-125, V1: 105; V2: 121

Dexterous manipulators, roba-16, V1: 139, 145; V2: 157

Direct sampling ion trap mass spectrometry, char-90, V1: 50; V2: 16

Discarded asbestos transite, TRU contamination only, waste management alternatives for
Chemical treatment technologies
electropolishing/osmosis/migration, dcon-20, V1: 102; V2: 68
gamma radiolysis, wpro-100, V2: 68
solvent extraction, wpro-211/212, V1: 103; V2: 68
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 67
Thermal treatment technologies
calcination/roasting, dcon-60, V1: 103; V2: 69
incineration, wpro-108, V1: 103; V2: 69
plasma arc furnace, wpro-107, V1: 104; V2: 69
Waste stabilization technologies
encapsulation, V1: 102; V2: 67

Discarded filters, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Biological treatment technologies
biosorption, wpro-226, V1: 101; V2: 39
microbial dechlorination, wpro-227, V2: 39
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 99; V2: 38
supercritical fluid extraction, wpro-118, V1: 100; V2: 38
Thermal treatment technologies
chem char process, wpro-114, V1: 100; V2: 39
incineration, wpro-108, V1: 100; V2: 38
microwave treatment, wpro-115, V1: 100; V2: 38
molten glass combustor, wpro-116, V1: 100; V2: 39
molten salt oxidation, wpro-113, V1: 101; V2: 38
plasma arc furnace, wpro-107, V1: 101; V2: 39
Waste stabilization technologies
encapsulation, V1: 99; V2: 38

Discarded filters, RAD contamination only, waste management alternatives for
Biological treatment
biosorption, wpro-226, V1: 104; V2: 60
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 59
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 59
microwave treatment, wpro-115, V1: 103; V2: 59
molten glass combustor, wpro-116, V1: 104; V2: 59
molten salt oxidation, wpro-113, V1: 104; V2: 59
Waste stabilization technologies
encapsulation, V1: 102; V2: 59

Discarded filters, TRU contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 77
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 77
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 78
microwave treatment, wpro-115, V1: 103; V2: 78
molten glass combustor, wpro-116, V1: 104; V2: 78
plasma arc furnace, wpro-107, V1: 104; V2: 78
Waste stabilization technologies
encapsulation, V1: 102; V2: 77

Discarded filters, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 141
sell as scrap, wpro-130, V1: 106; V2: 141
Thermal treatment technologies
incineration, wpro-108, V1: 106; V2: 141
microwave treatment, wpro-115, V1: 106; V2: 142

Discarded filters, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for *(continued)*
molten salt oxidation, wpro-113, V1: 107; V2: 141
plasma arc furnace, wpro-107, V1: 107; V2: 142

Distillation, wpro-222, V1: 110, 117, 120, 122; V2: 93, 99, 103, 110, 118

DOE orders. *See*
Department of Energy orders

Dry storage, wpro-123, V1: 105; V2: 121

— E —

Electrochemical metal removal, wpro-205, V1: 99, 102, 119; V2: 30, 31, 53, 55, 72, 74, 88, 110, 113

Electrochemical methods, char-10, V1: 46; V2: 6

Electrolysis, wpro-205, V1: 116, 119; V2: 108, 111

Electron beam destruction, wpro-304, V1: 124; V2: 125

Electron diffraction, char-37, V1: 49; V2: 14

Electron spectroscopy for chemical analysis, char-1, V1: 50; V2: 15

Electropolishing/osmosis/migration, dcon-20, V1: 99, 102; V2: 22, 27, 49, 67, 68

Emergency shutdown, roba-37, V1: 140, 146; V2: 160

Encapsulation, V1: 99, 102, 109, 112; V2: 21, 22, 24, 27, 29, 31, 33, 36, 38, 40, 42, 44, 48, 49, 51, 52, 53, 54, 56, 57, 59, 60, 62, 64, 66, 67, 69, 71, 72, 73, 75, 76, 77, 79, 80, 83, 143

End-effector changeout mechanisms, roba-24, V1: 139, 145; V2: 158

End effectors/alternatives, roba-23, V1: 139, 145; V2: 158

Energy dispersive X-ray spectroscopy, char-35, V1: 49; V2: 15

Entrained vapors/acids. *See*
Waste off-gases (entrained vapors/acids), waste management alternatives for

Envirocare, Utah Landfill, wdis-104, V2: 153

Evaporation, wpro-223, V1: 110, 117, 120; V2: 82, 88, 90, 110, 113, 121

— F —

Failure recovery systems for mobile platforms, roba-11, V1: 139, 145; V2: 157

Federal Insecticide, Fungicide, and Rodenticide Act
Regulation of pesticides, V1: 208

Fiberglass insulation. *See*
Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Fiberglass insulation, RAD contamination only, waste management alternatives for
Fiberglass insulation, TRU contamination only, waste management alternatives for
Fiberglass insulation, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for

Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Thermal treatment technologies
chem char process, wpro-114, V1: 100; V2: 28
microwave treatment, wpro-115, V1: 100; V2: 28
molten glass combustor, wpro-116, V1: 100; V2: 28
plasma arc furnace, wpro-107, V1: 101; V2: 28
thermal desorption, wpro-106, V1: 101; V2: 28

Fiberglass insulation, RAD contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 52
Thermal treatment technologies
microwave treatment, wpro-115, V1: 103; V2: 52
molten glass combustor, wpro-116, V1: 104; V2: 52
plasma arc furnace, wpro-107, V1: 104; V2: 52
Waste stabilization technologies
encapsulation, V1: 102; V2: 52

Fiberglass insulation, TRU contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 71
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 71

000742

Thermal treatment technologies
microwave treatment, wpro-115, V1: 103; V2: 71
molten glass combustor, wpro-116, V1: 104; V2: 71
plasma arc furnace, wpro-107, V1: 104; V2: 71
Waste stabilization technologies
Encapsulation, V1: 102; V2: 71

Fiberglass insulation, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 135
recycle/reuse, wpro-130, V1: 106; V2: 135
Thermal treatment technologies
microwave treatment, wpro-115, V1: 106; V2: 136
molten glass combustor, wpro-116, V1: 107; V2: 135
plasma arc furnace, wpro-107, V1: 107; V2: 136

Fiber-optic chemical sensors, char-25, V1: 46; V2: 5

Fiber-optic detection and monitoring system (intelligent materials), char-240, V1: 48; V2: 10

Fiber-optic systems for measuring multiple physical variables, char-248, V1: 51; V2: 18

Field hardening, roba-53, V1: 140, 147; V2: 161

Filtration, wpro-201, V1: 109, 116, 118, 123, 125, 126; V2: 91, 96, 100, 107, 109, 111, 114, 119, 125, 128, 129, 130

Final residues from D&D, ER, and WM operations (clean debris), waste disposal alternatives for
Landfill technologies
Y-12 Plant Industrial Landfill, wdis-101, V2: 151

Final residues from D&D, ER, and WM operations (low-level mixed waste), waste disposal alternatives for
Landfill technologies
Envirocare, Utah Landfill, wdis-104, V2: 153
Underground disposal technologies
borehole disposal, wdis-100, V2: 153

Final residues from D&D, ER, and WM operations (low-level RAD waste), waste disposal alternatives for
Trench disposal technologies
Nevada test site, wdis-102, V2: 151

Final residues from D&D, ER, and WM operations (RCRA waste), waste disposal alternatives for
Landfill technologies
commercial RCRA landfill sites, wdis-103, V2: 152
Underground disposal technologies
borehole disposal, wdis-100, V2: 152

Final residues from D&D, ER, and WM operations (scrap asbestos), waste disposal alternatives for
Landfill technologies
Y-12 Plant industrial landfill, wdis-101, V2: 151

Final residues from D&D, ER, and WM operations (TRU waste), waste disposal alternatives for
Underground waste retrieval facilities
Waste Isolation Pilot Plant, New Mexico, wdis-105, V2: 153

Fissile materials, RAD contaminated, waste management alternatives for
Chemical treatment technologies
transmutation, wpro-219, V1: 105; V2: 123

Flameless thermal oxidizers, wpro-305, V1: 124; V2: 125, 127

Flue gas desulfurization process, wpro-308, V1: 124, 126; V2: 132

Fluid systems, V2: 145

Force limiting/compliant mechanisms, roba-26, V1: 139, 146; V2: 158

Force/torque sensors, roba-50, V1: 140, 146, 147; V2: 161

Fourier transform infrared spectroscopy, char-8, V1: 46; V2: 6

Fugitive atmospheric discharge, wpro-306, V2: 134

— G —

Gamma radiolysis, wpro-100, V1: 99, 109, 111, 117, 119; V2: 22, 23, 27, 31, 34, 36, 48, 50, 67, 68, 92, 89, 98, 101, 106, 120

Gamma-ray spectrometry, char-268, V1: 49; V2: 13

Gas chromatography, char-94, V1: 50; V2: 17

Gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 50; V2: 17

Gas chromatography in the field, char-262, V1: 50; V2: 16

Gas chromatography—mass spectrometry, char-88, V1: 50; V2: 17

Gaseous waste (general problem area/ constituents), characterization alternatives for
Data analysis/management technologies
analysis of censored data, char-249, V1: 47; V2: 9
application of approximate reasoning to data analysis/evaluation, char-234, V1: 47; V2: 8
automated engineering system life cycle planning, dism-174, V1: 48; V2: 11
automated scanning and conversion of engineering drawings, dism-154, V1: 47; V2: 8
automated system reliability and safety analysis, dism-175, V1: 48; V2: 11
client/server access to standards and regulatory guidelines, dism-152, V1: 46; V2: 7
client/server architecture for data base access, dism-157, V1: 47; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 47; V2: 9
computer-based training systems, dism-191, V1: 47; V2: 9
criticality indices, char-44, V1: 47; V2: 9
data access services, dism-153, V1: 46; V2: 8
fiber-optic detection and monitoring system (intelligent materials), char-240, V1: 48; V2: 10
generalized object-oriented simulation software, dism-173, V1: 48; V2: 11
geographic information system for DOE sites, dism-181, V1: 47; V2: 8
hazard analysis expert system, char-233, V1: 47; V2: 8
hypertext information systems, dism-158, V1: 47; V2: 9
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-260, V1: 48; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 47; V2: 10
network architecture with integrated workstations, char-221, V1: 46; V2: 7
project information access services, char-220, V2: 7
quality control for measurement process, char-250, V1: 47; V2: 9
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 47; V2: 8
spatial sample and data analysis plans, char-253, V1: 47; V2: 9
statistical methods for the analysis of large data sets, char-251, V1: 47; V2: 9
task scheduling aids, char-241, V1: 47; V2: 10
3-D CAD data base of buildings and other structures, dism-156, V1: 48; V2: 10
waste management configuration management system, char-230, V2: 10
Detection/measurement field methods
air monitoring, char-59, V1: 46; V2: 6
electrochemical methods, char-10, V1: 46; V2: 6
fiber-optic chemical sensors, char-25, V1: 46; V2: 5
immunoassay detection, char-23, V1: 46; V2: 5
infrared spectroscopy, char-18, V1: 46; V2: 6
ion mobility mass spectrometry, char-264, V1: 46; V2: 5
luminescence detection, char-92, V1: 46; V2: 6
optical absorption spectroscopy, char-27, V1: 46; V2: 5
personnel monitoring, char-52, V1: 46; V2: 6
portable Raman spectrometer, char-84, V1: 46; V2: 5
Detection/measurement laboratory methods
contamination control—analytical equipment, char-204, V1: 46; V2: 6
Fourier transform infrared spectroscopy, char-8, V1: 46; V2: 6
isotopic dilution mass spectroscopy, char-48, V1: 46; V2: 7
laser ionization mass spectrometry, char-4, V1: 46; V2: 7
nuclear magnetic resonance, char-11, V1: 46; V2: 7
secondary ion mass spectroscopy, char-3, V1: 46; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 46; V2: 7
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 45; V2: 3
membranes for sample collection and concentration, char-55, V1: 45; V2: 3
multiangle drilling for depth profiling of contaminants, char-64, V1: 45; V2: 4
sampling and mixing methods, char-81, V1: 45; V2: 3
sampling heterogenous wastes, char-270, V1: 45; V2: 4
sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 4
sampling underground storage tanks for volatile organics, char-257, V1: 45; V2: 3
sediment sampling from restricted access locations, char-276, V1: 45; V2: 4
solid sorbent sampling for airborne organics, char-254, V1: 45; V2: 4
ultrasonic extraction, char-20, V1: 45; V2: 3
vacuum-assisted reverse flow, solvent extraction methods, char-62, V1: 45; V2: 3
Sample preparation technologies
adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples, char-209, V1: 45; V2: 4
high-pressure ashing for sample preparation, char-203, V1: 45; V2: 5
metallographic sectioning and preparation, char-67, V1: 45; V2: 4
microwave digestion, char-19, V1: 45; V2: 4

000744

radioactive sample preparation, char-205, V1: 45; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 45; V2: 5
supercritical fluid extraction of organics, char-208, V1: 45; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 45; V2: 3
sampling program configuration management system, char-228, V1: 45; V2: 3
sequential sampling plans, char-252, V1: 45; V2: 3

Gaseous waste (inorganic constituents), characterization alternatives for
Field methods
atomic emission spectroscopy, char-76, V1: 49; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219 and char-6, V1: 49; V2: 14
Laboratory methods
atomic emission spectroscopy, char-76, V1: 49; V2: 14
auger electron spectroscopy, char-2, V1: 50; V2: 15
cold vapor (mercury) analysis, char-24, V1: 49; V2: 15
electron diffraction, char-37, V1: 49; V2: 14
electron spectroscopy for chemical analysis, char-1, V1: 50; V2: 15
energy dispersive X-ray spectroscopy, char-35, V1: 49; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 50; V2: 15
inductively coupled plasma—mass spectroscopy, char-78, V1: 49; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 49; V2: 14
ion chromatography, char-50, V1: 49; V2: 14
neutron activation analysis, char-266, V1: 50; V2: 15
particle-induced X-ray emission, char-17, V1: 49; V2: 15
powder X-ray diffraction, char-31, V1: 50; V2: 15
scanning electron microscopy, char-33, V1: 49; V2: 15
transmission electron microscopy, char-34, V1: 49; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 49; V2: 14

Gaseous waste (organic constituents), characterization alternatives for
Field methods
direct sampling ion trap mass spectrometry, char-90, V1: 50; V2: 16
gas chromatography in the field, char-262, V1: 50; V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 50; V2: 16
portable volatile organic compound detectors, char-5, V1: 50; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 16
Laboratory methods
analytical methods for chelators and decontamination agents, char-206, V1: 50; V2: 17
capillary zone electrophoresis, char-207, V1: 50; V2: 17
gas chromatography, char-94, V1: 50; V2: 17
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 50; V2: 17
gas chromatography—mass spectrometry, char-88, V1: 50; V2: 17
liquid chromatography—mass spectrometry, char-89, V1: 50; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50; V2: 17
solid phase microextraction method, char-211, V1: 50; V2: 17

Gaseous waste (pathogenic constituents), characterization alternatives for
Laboratory methods
pathogen surveillance, char-215, V1: 51; V2: 18

Gaseous waste (physical characteristics), characterization alternatives for
Field methods
fiber-optic systems for measuring multiple physical variables, char-248, V1: 51; V2: 18
instrument response models for remote sensing, char-246, V1: 50; V2: 18
Laboratory methods
computer tomography, char-41, V1: 51; V2: 18
optical microscopy, char-32, V1: 51; V2: 18
particle size analysis, char-26, V1: 51; V2: 18

Gaseous waste (radioactive constituents), characterization alternatives for
Field methods
advanced radiation monitors, char-269, V1: 48; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 48; V2: 12
bubble dosimeters for neutron flux, char-216, V1: 48; V2: 12
gamma-ray spectrometry, char-268, V1: 49; V2: 13
gross fissile analysis by neutron activation and delayed neutron counting, char-200, V2: 13
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-250, V1: 47; V2: 12
long-range alpha detector, char-65, V1: 48; V2: 11

Gaseous waste (radioactive constituents), characterization alternatives for *(continued)*
neutron activation, char-266, V1: 49, 50; V2: 13
passive monitors for weak beta radionuclides, char-102, V1: 48; V2: 11
passive neutron detection, char-104, V1: 49; V2: 13
photon electron rejecting alpha liquid scintillation, char-97, V1: 49; V2: 13
portable gamma ray scintillometers, char-263, V1: 48; V2: 12
proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 11, 13
radioanalytical procedures, char-202, V1: 49; V2: 13
sodium iodide-germanium gamma spectroscopy, char-196, V2: 13
thermoluminescence dosimeter array for spatial characterization of alpha-contamination, char-103, V1: 48; V2: 11
waste curie monitor (bag or barrel counter for low-level gamma radioactivity), char-109, V2: 12
Laboratory methods
liquid scintillation counting, char-267, V1: 49; V2: 14

Gaseous-waste regulations
mixed-gaseous wastes, V1: 188–190

Gas phase (ClF_3) treatment, dcon-16, V1: 103; V2: 55

Gas phase treatment, dcon-16, V1: 99; V2: 32

General gripper/tool interface, roba-25, V1: 139, 146; V2: 158

Generalized object-oriented simulation software, dism-173, V1: 48; V2: 11

Generation of hazardous and mixed wastes, waste management alternatives for
Waste minimization technology
waste minimization evaluation system, wmin-100, V2: 146

Generator requirements under Subtitle C, V1: 166–167

Geographic information system for DOE sites, dism-181, V1: 47; V2: 8

Glow discharge ionization mass spectroscopy, char-56, V1: 50; V2: 15

Graphite moderator, RAD contaminated, waste management alternatives for
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 122
molten glass combustor, wpro-116, V1: 104; V2: 123
molten salt oxidation, wpro-113, V1: 104; V2: 122
plasma arc furnace, wpro-107, V1: 104; V2: 122

Gravel. *See*
Concrete rubble and gravel, TRU contamination only, waste management alternatives for
Concrete rubble and gravel, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for

Gross fissile analysis by neutron activation and delayed neutron counting, char-200, V2: 13

— H —

Hazard analysis expert system, char-233, V1: 47; V2: 8

Hazardous constituents regulated under RCRA, V1: 163–164

Hazardous Materials Transportation Act
DOE orders, V1: 209–210
Regulatory requirements, V1: 209

Hazardous waste regulations, V1: 158–181

High-gradient magnetic separation, wpro-204, V1: 109, 118, 123, 126; V2: 88, 108, 128, 129

High-level radioactive waste, V1: 193

High-level radioactive-waste regulations, V1: 193

High-pressure ashing for sample preparation, char-203, V1: 45; V2: 5

High-temperature crystalline materials, wsta-105, V2: 148

High-temperature noncrystalline materials, wsta-106, V2: 148

Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for
Hydraulic retrieval technologies
fluid systems, V2: 145
Mechanical retrieval technologies
demolition, V2: 145
wheeled tracked vehicles, V2: 145

Hypertext information systems, dism-158, V1: 47; V2: 9

000746

— I —

Ignitable reactive wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
biodegradation, wpro-117, V1: 111
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 110; V2: 85
solvent extraction, wpro-211/212, V1: 110; V2: 85
supercritical fluid extraction, wpro-118, V1: 110; V2: 85
wet air oxidation, wpro-215, V2: 97
Thermal treatment technologies
catalytic destruction, wpro-109, V1: 109; V2: 86
incineration, wpro-108, V1: 110; V2: 85
molten glass combustor, wpro-116, V1: 110; V2: 86
molten salt oxidation, wpro-113, V1: 110; V2: 86
plasma arc furnace, wpro-107, V1: 110; V2: 86
thermal desorption, wpro-106, V1: 111
Waste stabilization technologies
encapsulation, V1: 109

Ignitable reactive wastes, uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants), waste management alternatives for
Physical treatment technologies
recycle/reuse, wpro-130, V1: 112
sell as scrap, wpro-130, V1: 113
Thermal treatment technologies
incineration, wpro-108, V1: 114
molten glass combustor, wpro-116, V1: 114
molten salt oxidation, wpro-113, V1: 114
plasma arc furnace, wpro-107, V1: 114
Waste stabilization technologies
encapsulation, V1: 112

Immunoassay detection, char-23, V1: 46; V2: 5

Incineration, wpro-108, V1: 100, 103, 106, 110, 112, 114, 118, 120, 122, 124, 127, 207; V2: 24, 32, 34, 37, 38, 40, 43, 45, 50, 51, 55, 56, 58, 59, 61, 63, 65, 69, 70, 74, 75, 78, 80, 81, 83, 85, 90, 93, 95, 102, 104, 105, 122, 125, 127, 132, 133, 137, 138, 141, 143, 144

Inductively coupled plasma—mass spectroscopy, char-78, V1: 49; V2: 14

Inductively coupled plasma spectroscopy, char-77, V1: 49; V2: 14

Infectious and medical wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Thermal treatment technologies
autoclaving, wpro-119, V1: 112; V2: 104
incineration, wpro-108, V1: 112; V2: 104
molten glass combustor, wpro-116, V1: 112; V2: 105
molten salt oxidation, wpro-113, V1: 112; V2: 104
plasma arc furnace, wpro-107, V1: 112; V2: 105

Infectious and medical wastes, RAD and/or TRU contaminated only, waste management alternatives for
Chemical treatment technologies
gamma radiolysis, wpro-100, V1: 111
ion exchange, wpro-217/218, V1: 111
Thermal treatment technologies
autoclaving, wpro-119, V1: 112
incineration, wpro-108, V1: 112
molten glass combustor, wpro-116, V1: 112
molten salt oxidation, wpro-113, V1: 112
plasma arc furnace, wpro-107, V1: 112

Infectious and medical wastes, uncontaminated waste, waste management alternatives for
Chemical treatment technologies
chemical oxidation/reduction, wpro-209, V1: 113
ion exchange, wpro-217/218, V1: 113
Thermal treatment technologies
autoclaving, wpro-119, V1: 113
incineration, wpro-108, V1: 114
molten glass combustor, wpro-116, V1: 114
molten salt oxidation, wpro-113, V1: 114
plasma arc furnace, wpro-107, V1: 114

Information management for sample handling, roba-56, V1: 141, 147; V2: 162

Infrared spectroscopy, char-18, V1: 46; V2: 6

Inorganic membrane separation, wpro-300, V1: 123, 125, 126; V2: 124, 125, 126, 127, 129

Inorganic microporous filters, wpro-207, V1: 109, 112, 116, 119; V2: 87, 88, 91, 97, 107, 111, 114, 118, 133

Inorganics. *See*
Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Combustible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Compactible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for

Inorganics *(continued)*
Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Discarded filters, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Gaseous waste (inorganic constituents), characterization alternatives for
Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for
Lab packs (organics, inorganics, RAD), waste management alternatives for
Liquid wastes (inorganic constituents), characterization alternatives for
Scrap ferrous metals, mixed waste contaminated (steel, RAD, organics, inorganics, PCBs), waste management alternatives for
Scrap nonferrous metals, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Scrap transite and scrap asbestos pipe and insulation, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Solid-liquid wastes (inorganic constituents), characterization alternatives for
Solid wastes (inorganic constituents), characterization alternatives for
Spent ion exchange media, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Waste off-gases (inorganic constituents), waste management alternatives for
Waste processing sludges, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Waste processing solid residuals, mixed waste contaminated (RAD, organics, inorganics), waste management alternatives for

In situ solid phase microextraction of organics, char-210, V1: 45; V2: 3

Instrument response models for remote sensing, char-246, V1: 50; V2: 18

Integrated automated analytical laboratory, roba-55, V1: 140, 147; V2: 162

Integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-250, V1: 47, 48; V2: 10, 12

Ion chromatography, char-50, V1: 49; V2: 14

Ion exchange, wpro-217/218, V1: 109, 111, 113, 117, 119; V2: 87, 89, 108, 111

Ion mobility mass spectrometry, char-264, V1: 46; V2: 5

Isotopic dilution mass spectroscopy, char-48, V1: 46; V2: 7

— L —

Lab packs (organics, inorganics, RAD), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 99; V2: 94
solvent extraction, wpro-211/212, V1: 100, 103; V2: 95
Thermal treatment technologies
incineration, wpro-108, V1: 100, 103; V2: 95
molten glass combustor, wpro-116, V1: 100; V2: 96
molten salt oxidation, wpro-113, V1: 101; V2: 95
plasma arc furnace, wpro-107, V1: 101; V2: 96

Land disposal restrictions, V1: 172–177

Landfill disposal, wpro-131, V1: 106; V2: 138, 135, 136, 141, 143

Laser ionization mass spectrometry, char-4, V1: 46; V2: 7

Leaching and stripping, wpro-213, V1: 99, 103, 108, 110, 117, 123, 124, 125, 126; V2: 22, 27, 30, 31, 33, 36, 38, 40, 42, 44, 48, 52, 54, 56, 57, 59, 60, 63, 64, 67, 70, 71, 73, 75, 76, 77, 79, 81, 83, 85, 92, 94, 98, 124, 125, 126, 128, 129, 130 134, 144

Liquid chromatography—mass spectrometry, char-89, V1: 50; V2: 17

Liquid scintillation counting, char-267, V1: 49; V2: 14

Liquid wastes (general problem area/ constituents), characterization alternatives for
Data analysis/management technologies
analysis of censored data, char-249, V1: 47; V2: 9
application of approximate reasoning to data analysis/evaluation, char-234, V1: 47; V2: 8
automated engineering system life cycle planning, dism-174, V1: 48; V2: 11

automated scanning and conversion of engineering drawings, dism-154, V1: 47; V2: 8
automated system reliability and safety analysis, dism-175, V1: 48; V2: 11
client/server access to standards and regulatory guidelines, dism-152, V1: 46; V2: 7
client/server architecture for data base access, dism-157, V1: 47; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 47; V2: 9
computer-based training systems, dism-191, V1: 47; V2: 9
criticality indices, char-44, V1: 47; V2: 9
data access services, dism-153, V1: 46; V2: 8
fiber-optic detection and monitoring system (intelligent materials), char-240, V1: 48; V2: 10
generalized object-oriented simulation software, dism-173, V1: 48; V2: 11
geographic information system for DOE sites, dism-181, V1: 47; V2: 8
hazard analysis expert system, char-233, V1: 47; V2: 8
hypertext information systems, dism-158, V1: 47; V2: 9
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-260, V1: 48; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 47; V2: 10
network architecture with integrated workstations, char-221, V1: 46; V2: 7
project information access services, char-220, V2: 7
quality control for measurement process, char-250, V1: 47; V2: 9
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 47; V2: 8
spatial sample and data analysis plans, char-253, V1: 47; V2: 9
statistical methods for the analysis of large data sets, char-251, V1: 47; V2: 9
task scheduling aids, char-241, V1: 47; V2: 10
3-D CAD data base of buildings and other structures, dism-156, V1: 48; V2: 10
waste management configuration management system, char-230, V2: 10
Detection/measurement field methods
air monitoring, char-59, V1: 46; V2: 6
electrochemical methods, char-10, V1: 46; V2: 6
fiber-optic chemical sensors, char-25, V1: 46; V2: 5
infrared spectroscopy, char-18, V1: 46; V2: 6
immunoassay detection, char-23, V1: 46; V2: 5
ion mobility mass spectrometry, char-264, V1: 46; V2: 5
luminescence detection, char-92, V1: 46; V2: 6
optical absorption spectroscopy, char-27, V1: 46; V2: 5
personnel monitoring, char-52, V1: 46; V2: 6
portable Raman spectrometer, char-84, V1: 46; V2: 5
Detection/measurement laboratory methods
contamination control—analytical equipment, char-204, V1: 46; V2: 6
Fourier transform infrared spectroscopy, char-8, V1: 46; V2: 6
isotopic dilution mass spectroscopy, char-48, V1: 46; V2: 7
laser ionization mass spectrometry, char-4, V1: 46; V2: 7
nuclear magnetic resonance, char-11, V1: 46; V2: 7
secondary ion mass spectroscopy, char-3, V1: 46; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 46; V2: 7
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 45; V2: 3
membranes for sample collection and concentration, char-55, V1: 45; V2: 3
multiangle drilling for depth profiling of contaminants, char-64, V1: 45; V2: 4
sampling and mixing methods, char-81, V1: 45; V2: 3
sampling heterogenous wastes, char-270, V1: 45; V2: 4
sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 4
sampling underground storage tanks for volatile organics, char-257, V1: 45; V2: 3
sediment sampling from restricted access locations, char-276, V1: 45; V2: 4
solid sorbent sampling for airborne organics, char-254, V1: 45; V2: 4
ultrasonic extraction, char-20, V1: 45; V2: 3
vacuum-assisted reverse flow, solvent extraction methods, char-62, V1: 45; V2: 3
Sample preparation technologies
adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples, char-209, V1: 45; V2: 4
high-pressure ashing for sample preparation, char-203, V1: 45; V2: 5
metallographic sectioning and preparation, char-67, V1: 45; V2: 4
microwave digestion, char-19, V1: 45; V2: 4
radioactive sample preparation, char-205, V1: 45; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 45; V2: 5
supercritical fluid extraction of organics, char-208, V1: 45; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 45; V2: 3
sampling program configuration management system, char-228, V1: 45; V2: 3
sequential sampling plans, char-252, V1: 45; V2: 3

Liquid wastes (inorganic constituents), characterization alternatives for
Field methods
atomic emission spectroscopy, char-76, V1: 49; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219 and char-6, V1: 49; V2: 14
Laboratory methods
auger electron spectroscopy, char-2, V1: 50; V2: 15
cold vapor (mercury) analysis, char-24, V1: 49; V2: 15
electron diffraction, char-37, V1: 49; V2: 14
electron spectroscopy for chemical analysis, char-1, V1: 50; V2: 15
energy dispersive X-ray spectroscopy, char-35, V1: 49; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 50; V2: 15
inductively coupled plasma—mass spectroscopy, char-78, V1: 49; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 49; V2: 14
ion chromatography, char-50, V1: 49; V2: 14
neutron activation analysis, char-266, V1: 49, 50; V2: 15
particle-induced X-ray emission, char-17, V1: 49; V2: 15
powder X-ray diffraction, char-31, V1: 50; V2: 15
scanning electron microscopy, char-33, V1: 49; V2: 15
transmission electron microscopy, char-34, V1: 49; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 49; V2: 14

Liquid wastes (organic constituents), characterization alternatives for
Field methods
direct sampling ion trap mass spectrometry, char-90, V1: 50; V2: 16
gas chromatography in the field, char-262, V1: 50; V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 50; V2: 16
portable volatile organic compound detectors, char-5, V1: 50; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 16
Laboratory methods
analytical methods for chelators and decontamination agents, char-206, V1: 50; V2: 17
capillary zone electrophoresis, char-207, V1: 50; V2: 17
gas chromatography, char-94, V1: 50; V2: 17
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 50; V2: 17
gas chromatography—mass spectrometry, char-88, V1: 50; V2: 17
liquid chromatography—mass spectrometry, char-89, V1: 50; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50; V2: 17
solid phase microextraction method, char-211, V1: 50; V2: 17

Liquid wastes (pathogenic constituents), characterization alternatives for
Laboratory methods
pathogen surveillance, char-215, V1: 51; V2: 18

Liquid wastes (physical characteristics), characterization alternatives for
Field methods
fiber-optic systems for measuring multiple physical variables, char-248, V1: 51; V2: 18
instrument response models for remote sensing, char-246, V1: 50; V2: 18
Laboratory methods
computer tomography, char-41, V1: 51; V2: 18
optical microscopy, char-32, V1: 51; V2: 18
particle size analysis, char-26, V1: 51; V2: 18

Liquid wastes (radioactive constituents), characterization alternatives for
Field methods
advanced radiation monitors, char-269, V1: 48; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 48; V2: 12
bubble dosimeters for neutron flux, char-216, V1: 48; V2: 12
gamma-ray spectrometry, char-268, V1: 49; V2: 13
gross fissile analysis by neutron activation and delayed neutron counting, char-200, V2: 13
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-250, V1: 47; V2: 12
long-range alpha detector, char-65, V1: 48; V2: 11
neutron activation, char-266, V1: 49, 50; V2: 13
passive monitors for weak beta radionuclides, char-102, V1: 48; V2: 11
passive neutron detection, char-104, V1: 49; V2: 13
photon electron rejecting alpha liquid scintillation, char-97, V1: 49; V2: 13
portable gamma ray scintillometers, char-263, V1: 48; V2: 12
proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 11, 13
radioanalytical procedures, char-202, V1: 49; V2: 13
sodium iodide-germanium gamma spectroscopy, char-196, V2: 13

000750

thermoluminescence dosimeter array for spatial characterization of alpha- contamination, char-103, V1: 48; V2: 11
waste curie monitor (bag or barrel counter for low-level gamma radioactivity), char-109, V2: 12
Laboratory methods
liquid scintillation counting, char-267, V1: 49; V2: 14

Listed solid waste, V1: 163

Listed wastes (halogenated solvents), mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
microbial dechlorination, wpro-227, V1: 118; V2: 100
Chemical treatment technologies
chemical dechlorination, wpro-209, V1: 116; V2: 98
gamma radiolysis, wpro-100, V1: 117; V2: 98
leaching and stripping, wpro-213, V1: 117; V2: 98
ozonation photolysis, wpro-214, V1: 117; V2: 99
solvent extraction, wpro-211/212, V1: 117; V2: 97
supercritical water oxidation, wpro-216, V1: 117; V2: 98
wet air oxidation, wpro-215, V1: 117; V2: 97
Physical treatment technologies
adsorption, wpro-202/203, V1: 116; V2: 96
filtration, wpro-201, V2: 96
inorganic microporous filters, wpro-207, V2: 97
Thermal treatment technologies
catalytic destruction, wpro-109, V1: 116; V2: 100
distillation, wpro-222, V1: 117; V2: 99
incineration, wpro-108, V1: 118
molten glass combustor, wpro-116, V2: 100
molten salt oxidation, wpro-113, V1: 118; V2: 99
plasma arc furnace, wpro-107, V1: 118; V2: 99

Listed wastes (nonhalogenated solvents), mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V1: 118; V2: 104
anaerobic digestion, wpro-225, V1: 118; V2: 104
Chemical treatment technologies
gamma radiolysis, wpro-100, V2: 101
ozonation photolysis, wpro-214, V1: 117; V2: 102
solvent extraction, wpro-211/212, V1: 117; V2: 101
supercritical water oxidation, wpro-216, V1: 117; V2: 101
wet air oxidation, wpro-215, V1: 117; V2: 101
Physical treatment technologies
adsorption, wpro-202/203, V1: 116; V2: 100
air stripping, wpro-200, V1: 116; V2: 100
filtration, wpro-201, V2: 100
Thermal treatment technologies
catalytic destruction, wpro-109, V1: 116; V2: 103
chem char process, wpro-114, V1: 117; V2: 104
distillation, wpro-222, V1: 117; V2: 103
incineration, wpro-108, V1: 118; V2: 102
low-temperature separation, wpro-220, V1: 118; V2: 103
molten glass combustor, wpro-116, V1: 118; V2: 103
molten salt oxidation, wpro-113, V1: 118; V2: 103

Listed wastes (nonhalogenated solvents), uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V1: 122
anaerobic digestion, wpro-225, V1: 122
Chemical treatment technologies
ozonation photolysis, wpro-214, V1: 121
solvent extraction, wpro-211/212, V1: 121
supercritical water oxidation, wpro-216, V1: 121
wet air oxidation, wpro-215, V1: 122
Physical treatment technologies
adsorption, wpro-202/203, V1: 121
air stripping, wpro-200, V1: 121
recycle/reuse, wpro-130, V1: 121
Thermal treatment technologies
catalytic destruction, wpro-109, V1: 121
chem char process, wpro-114, V1: 122
distillation, wpro-222, V1: 122
incineration, wpro-108, V1: 122
low-temperature separation, wpro-220, V1: 122
molten glass combustor, wpro-116, V1: 122
molten salt oxidation, wpro-113, V1: 122

Long-arm deployed robotic platforms, roba-9, V2: 157

Long-range alpha detector, char-65, V1: 48; V2: 11

Low-level radioactive waste, V1: 193–194

Low-level radioactive-waste regulations, V1: 193–194

Low specific activity materials processing, preparation, and packaging, wpht-102, V2: 149

Low-temperature separation, wpro-220, V1: 118, 124; V2: 103, 122, 124, 125, 127

Luminescence detection, char-92, V1: 46; V2: 6

000751

— M —

Manipulation (Cartesian control), roba-31, V1: 140, 146; V2: 159

Manipulation (joint control), roba-30, V1: 139, 146; V2: 159

Manipulation (redundancy control), roba-33, V1: 140, 146; V2: 159

Manipulation (special purpose control), roba-31, V1: 140, 146; V2: 159

Marking and labeling requirements, V1: 207

Medical waste. *See*
- Infectious and medical wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
- Infectious and medical wastes, RAD and/or TRU contaminated only, waste management alternatives for
- Infectious and medical wastes, uncontaminated waste, waste management alternatives for

Melton Valley and REDC caustic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
- Biological treatment technologies
  - biodenitrification, wpro-229, V1: 117; V2: 114
- Chemical treatment technologies
  - Bradtec process, wpro-228, V1: 116; V2: 112
  - chemical oxidation/reduction, wpro-209, V1: 116; V2: 112
  - chemical precipitation, wpro-210, V1: 116; V2: 112
  - electrochemical metal removal, wpro-205, V2: 113
  - ion exchange, wpro-217/218, V1: 117; V2: 111
  - neutralization, wpro-230, V1: 117
  - nitrate-ammonia-ceramic (NAC) process, wpro-106, V1: 117; V2: 112
  - ozonation photolysis, wpro-214, V2: 113
  - solvent extraction, wpro-211/212, V2: 113
- Physical treatment technologies
  - air stripping, wpro-200, V2: 111
  - electrolysis, wpro-205, V1: 116; V2: 111
  - filtration, wpro-201, V1: 116; V2: 111
  - inorganic microporous filters, wpro-207, V1: 116; V2: 111
  - reverse osmosis, wpro-206, V1: 116; V2: 111
- Thermal treatment technologies
  - evaporation, wpro-223, V1: 117; V2: 113
  - microwave treatment, wpro-115, V2: 114

Melton Valley and REDC caustic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
- Biological treatment technologies
  - biodenitrification, wpro-229, V1: 121
- Chemical treatment technologies
  - Bradtec process, wpro-228, V1: 119
  - chemical oxidation/reduction, wpro-209, V1: 119
  - chemical precipitation, wpro-210, V1: 119
  - electrochemical metal removal, wpro-205, V1: 119
  - ion exchange, wpro-217/218, V1: 119
  - neutralization, wpro-230, V1: 120
  - nitrate-ammonia-ceramic (NAC) process, wpro-106, V1: 120
  - ozonation photolysis, wpro-214, V1: 120
  - solvent extraction, wpro-211/212, V1: 120
- Physical treatment technologies
  - adsorption, wpro-202/203, V1: 118
  - electrolysis, wpro-205, V1: 119
  - filtration, wpro-201, V1: 118
  - high-gradient magnetic separation, wpro-204, V1: 118
  - inorganic microporous filters, wpro-207, V1: 119
  - reverse osmosis, wpro-206, V1: 119
- Thermal treatment technologies
  - evaporation, wpro-223, V1: 120
  - microwave treatment, wpro-115, V1: 120

Membranes for sample collection and concentration, char-55, V1: 45; V2: 3

Metallographic sectioning and preparation, char-67, V1: 45; V2: 4

Microbial dechlorination, wpro-227, V1: 118; V2: 39, 100

Microwave digestion, char-19, V1: 45; V2: 4

Microwave treatment, wpro-115, V1: 100, 103, 106, 120; V2: 21, 28, 35, 37, 38, 43, 46, 48, 52, 57, 58, 59, 63, 65, 67, 71, 75, 77, 78, 81, 83, 114, 117, 120, 136, 139, 141, 142, 143

Mixed waste. *See*
- Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
- Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
- Combustible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Compactible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
- Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Discarded filters, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for

000752

Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Final residues from D&D, ER, and WM operations (low-level mixed waste), waste disposal alternatives for
Generation of hazardous and mixed wastes, waste management alternatives for
Scrap ferrous metal, mixed waste contaminated (steel, RAD, organics, inorganics, PCBs), waste management alternatives for
Scrap nonferrous metals, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Scrap transite and scrap asbestos pipe and insulation, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Spent ion exchange media, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Waste management, definitions of problems for
Waste processing sludges, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Waste processing solid residuals, mixed waste contaminated (RAD, organics, inorganics), waste management alternatives for

Mixed-waste regulations
DOE orders, V1: 198
DOE's National Compliance Plan, V1: 197
Federal Facilities Compliance Act of 1992, V1: 196–197
LDR-FFCA/ORR, V1: 196
Mixed-gaseous waste, V1: 188–189
Mixed-waste oils, V1: 199
Treatment, V1: 196

Modeling of volatile organic compounds migration in porous materials, char-53, V1: 47; V2: 10

Molten glass combustor, wpro-116, V1: 100, 104, 107, 110, 112, 114, 118, 121, 122,; V2: 26, 28, 35, 37, 39, 41, 44, 47, 51, 52, 57, 58, 59, 61, 63, 65, 70, 71, 76, 77, 78, 80, 82, 84, 86, 94, 96, 100, 103, 105, 106, 123, 135, 137, 140

Molten salt oxidation, wpro-113, V1: 101, 104, 107, 110, 112, 114, 118, 121, 122, 127,; V2: 34, 38, 41, 46, 56, 59, 61, 75, 86, 91, 93, 95, 99, 103, 104, 105, 122, 125, 127, 128, 132, 133, 137, 139, 141

Mond process, wpro-112, V1: 100, 103; V2: 32, 55, 74

Mounted robotic platform, roba-8, V1: 139, 145; V2: 157

Multiangle drilling for depth profiling of contaminants, char-64, V1: 45; V2: 4

— N —

National Environmental Policy Act
Categorical exclusions, V1: 211–212
DOE Order 5440.1E, V1: 212
Environmental Assessments, V1: 212
Environmental Impact Statements, V1: 212

Network architecture with integrated workstations, char-221, V1: 46; V2: 7

Neutralization, wpro-230, V1: 110, 111, 113, 117, 120; V2: 87

Neutron activation, char-266, V1: 49, 50; V2: 13

Neutron activation analysis, char-266, V1: 49, 50; V2: 13, 15

Nevada Test Site, wdis-102, V2: 151

Nitrate-ammonia-ceramic (NAC) process, wpro-106, V1: 100, 103, 117, 120; V2: 32, 55, 74, 112

Nitrogen oxide criteria pollutant. *See*
Waste off-gases (NO_x criteria pollutant), waste management alternatives for

Nonadsorbable RAD constituents. *See*
Waste off-gases (nonadsorbable RAD constituents), waste management alternatives for

Nonfissile concentrated wastes having total activities greater than Type-A package limits, waste shipment alternatives for
Waste packaging technologies
Type-B radioactive material transport packages, wpht-105, V2: 149

Nonfissile concentrated wastes having total activities less than Type-A package limits, waste shipment alternatives for
Waste packaging technologies
Type-A radioactive material transport packages, wpht-104, V2: 149

Nonfissile radioactive materials having low specific activity, waste shipment alternatives for
Waste packaging technologies
low-specific-activity materials processing, preparation, and packaging, wpht-102, V2: 149

Nonfissile radioactive materials, surface contaminated objects, waste shipment alternatives for
Waste packaging technologies
surface-contaminated objects processing, preparation, and packaging, wpht-103, V2: 149

Nonradioactive hazardous waste, waste shipment alternatives for
Waste packaging technologies
RCRA nonbulk: POP PGI, II, III specification packaging bulk—strong tight containers, wpht-109, V2: 150

NO_x. *See*
Waste off-gases (NO_x criteria pollutant), waste management alternatives for

Nuclear magnetic resonance, char-11, V1: 46; V2: 7

— O —

Occupational Safety and Health Administration
Asbestos, V1: 201
Worker protection, V1: 214

Oils. *See*
Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Scrap transite and scrap asbestos pipe and insulation, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for

On-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50; V2: 17

Operator interface (command input), roba-40, V1: 140, 146; V2: 160

Operator interface (operator assistance), roba-41, V1: 140, 146; V2: 160

Operator interface (status/alert system), roba-42, V1: 140, 146; V2: 160

Optical absorption spectroscopy, char-27, V1: 46; V2: 5

Optical microscopy, char-32, V1: 51; V2: 18

Optimization of sampling designs, char-71, V1: 45; V2: 3

Organics. *See*
Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Combustible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Compactible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Discarded filters, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Gaseous waste (organic constituents), characterization alternatives for
Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for
Lab packs (organics, inorganics, RAD), waste management alternatives for
Liquid wastes (organic constituents), characterization alternatives for
REDC liquid organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Scrap ferrous metals, mixed waste contaminated (steel, RAD, organics, inorganics, PCBs), waste management alternatives for
Scrap nonferrous metals, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Scrap transite and scrap asbestos pipe and insulation, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Solid-liquid wastes (organic constituents), characterization alternatives for
Solid wastes (organic constituents), characterization alternatives for
Spent ion exchange media, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Toxic organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for

Waste off-gases (semivolatile organic constituents), waste management alternatives for
Waste processing sludges, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Waste processing solid residuals, mixed waste contaminated (RAD, organics, inorganics), waste management alternatives for

Other RCRA hazardous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V1: 111
anaerobic digestion, wpro-225, V1: 111
Chemical treatment technologies
chemical oxidation/reduction, wpro-209, V1: 109
gamma radiolysis, wpro-100, V1: 109; V2: 106
supercritical water oxidation, wpro-216, V1: 110
wet air oxidation, wpro-215, V1: 110
Thermal treatment technologies
catalytic destruction, wpro-109, V1: 109; V2: 106
incineration, wpro-108, V1: 110; V2: 105
molten glass combustor, wpro-116, V1: 110; V2: 106
molten salt oxidation, wpro-113, V1: 110; V2: 105
plasma arc furnace, wpro-107, V1: 110; V2: 106

Other uncategorized unknown wastes, waste management alternatives for
Physical treatment technologies
recharacterize and dispose of/reuse, wpro-130, V2: 106

Ozonation photolysis, wpro-214, V1: 117, 121, 120, 124; V2: 99, 102, 109, 113, 120, 124, 126

— P —

Package to meet WIPP WAC, wpro-128, V1: 105; V2: 67, 69, 71, 72, 73, 75, 76, 77, 79, 83

Packaging technologies. *See*
Asbestos, waste shipment alternatives for
Asphalt and building materials, TRU contamination only, waste management alternatives for
Combustible debris, TRU contamination only, waste management alternatives for
Compactible debris, TRU contamination only, waste management alternatives for
Discarded asbestos transite, TRU contamination only, waste management alternatives for
Discarded filters, TRU contamination only, waste management alternatives for
Fiberglass insulation, TRU contamination only, waste management alternatives for
Nonfissile concentrated wastes having total activities greater than Type-A package limits, waste shipment alternatives for
Nonfissile concentrated wastes having total activities less than Type-A package limits, waste shipment alternatives for
Nonfissile radioactive materials having low specific activity, waste shipment alternatives for
Nonfissile radioactive materials, surface-contaminated objects, waste shipment alternatives for
Nonradioactive hazardous waste, waste shipment alternatives for
PCB-contaminated wastes, waste shipment alternatives for
Scrap ferrous metals, TRU contamination only, waste management alternatives for
Scrap nonferrous metals, TRU contamination only, waste management alternatives for
Spent ion exchange media, TRU contamination only, waste management alternatives for
Waste handling and packaging, robotics and automation alternatives for
Waste processing solid residuals, TRU contamination only, waste management alternatives for
Wastes containing fissile material, waste shipment alternatives for

Particle-induced X-ray emission, char-17, V1: 49; V2: 15

Particle size analysis, char-26, V1: 51; V2: 18

Particulate constituents. *See*
Waste off-gases (particulate constituents), waste management alternatives for

Passive monitors for weak beta radionuclides, char-102, V1: 48; V2: 11

Passive neutron detection, char-104, V1: 49; V2: 13

Pathogen surveillance, char-215, V1: 51; V2: 18

PCB-contaminated wastes, waste shipment alternatives for. *See*
Polychlorinated biphenyl-contaminates wastes, waste shipment alternatives for

PCB regulations. *See*
Toxic Substances Control Act

PCBs. *See*
Polychlorinated biphenyls

Performance Oriented Packaging (POP) Packaging Group (PG) II, PGIII, bulk, wpht-107, V2: 150

000755

Personnel monitoring, char-52, V1: 46; V2: 6

Photon electron rejecting alpha liquid scintillation, char-97, V1: 49; V2: 13

Plasma arc furnace, wpro-107, V1: 101, 104, 107, 110, 112, 114, 118, 121; V2: 21, 24, 25, 28, 29, 35, 37, 39, 41, 44, 47, 48, 51, 52, 53, 57, 58, 62, 64, 65, 66, 69, 70, 71, 72, 76, 77, 78, 82, 84, 86, 91, 94, 96, 99, 105, 106, 122, 136, 138, 139, 140, 142

Polychlorinated biphenyl-contaminated wastes, waste shipment alternatives for
- Waste packaging technologies
  - Performance Oriented Packaging (POP)
    - Packaging Group (PG) II, PGIII, bulk, wpht-107, V2: 150

Polychlorinated biphenyl regulations. *See* Toxic Substances Control Act

Polychlorianted biphenyls. *See*
- Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
- Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
- Combustible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Compactible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
- Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Discarded filters, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
- Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for
- PCB-contaminated wastes, waste shipment alternatives for
- Scrap ferrous metals, mixed waste contaminated (steel, RAD, organics, inorganics, PCBs), waste management alternatives for
- Scrap nonferrous metals, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Scrap transite and scrap asbestos pipe and insulation, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
- Spent ion exchange media, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
- Waste processing sludges, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for

Polymer-impregnated concrete, wsta-101, V2: 147

Pool storage, wpro-124, V1: 105; V2: 121

POP PGIII and POP PGII, wpht-108, V2: 150

Portable gamma ray scintillometers, char-263, V1: 48; V2: 12

Portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 50; V2: 16

Portable Raman spectrometer, char-84, V1: 46; V2: 5

Portable volatile organic compound detectors, char-5, V1: 50; V2: 16

Position/velocity sensors, roba-48, V1: 140, 147; V2: 161

Powder X-ray diffraction, char-31, V1: 50; V2: 15

Power sources for mobile platforms, roba-10, V1: 139, 145; V2: 157

Precise programmable motions, roba-20, V1: 139, 145; V2: 158

Process/dilute liquid low-level waste, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
- Biological treatment technologies
  - biosorption, wpro-226, V2: 110
- Chemical treatment technologies
  - chemical precipitation, wpro-210, V2: 109
  - chemical reduction, wpro-209, V2: 110
  - electrochemical metal removal, wpro-205, V2: 110
  - ion exchange, wpro-217/218, V2: 108
  - ozonation photolysis, wpro-214, V2: 109
  - solvent extraction, wpro-211/212, V2: 109
- Physical treatment technologies
  - adsorption, wpro-202/203, V2: 108
  - air stripping, wpro-200, V2: 108
  - electrolysis, wpro-205, V2: 108
  - filtration, wpro-201, V2: 107
  - high-gradient magnetic separation, wpro-204, V2: 108

000756

inorganic microporous filters, wpro-207, V2: 107
reverse osmosis, wpro-206, V2: 107
Thermal treatment technologies
distillation, wpro-22, V2: 110
evaporation, wpro-223, V2: 110

Process/dilute liquid low-level waste, RAD and/or TRU contaminants only, waste management alternatives for
Biological treatment technologies
biosorption, wpro-226, V1: 121
Chemical treatment technologies
chemical oxidation/reduction, wpro-209, V1: 119
chemical precipitation, wpro-210, V1: 119
electrochemical metal removal, wpro-205, V1: 119
ion exchange, wpro-217/218, V1: 119
ozonation photolysis, wpro-214, V1: 120
solvent extraction, wpro-211/212, V1: 120
Physical treatment technologies
adsorption, wpro-202/203, V1: 118
electrolysis, wpro-205, V1: 119
filtration, wpro-201, V1: 118
high-gradient magnetic separation, wpro-204, V1: 118
inorganic microporous filters, wpro-207, V1: 119
reverse osmosis, wpro-206, V1: 119
Thermal treatment technologies
evaporation, wpro-223, V1: 120

Project information access services, char-220, V2: 7

Proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 11, 13

Proximity probes, roba-45, V1: 140, 146; V2: 161

Proximity probes as control sensors, roba-51, V1: 140, 147; V2: 161

Pyrolysis, wpro-110, V1: 101; V2: 25

— Q —

Quality control for measurement process, char-250, V1: 47; V2: 9

— R —

Radiation hardening, roba-54, V1: 140, 147; V2: 161

Radioactive sample preparation, char-205, V1: 45; V2: 4

Radioactive waste. *See*
Asphalt and building materials, mixed waste contaminated (debris, RAD, PCBs, organics, inorganics), waste management alternatives for
Asphalt and building materials, mixed waste contaminated (fiberglass insulation, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Combustible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Combustible debris, RAD contamination only, waste management alternatives for
Compactible debris, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Compactible debris, RAD contamination only, waste management alternatives for
Concrete rubble, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Concrete rubble, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Concrete rubble, RAD contamination only, waste management alternatives for
Corrosive wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Discarded filters, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Discarded filters, RAD contamination only, waste management alternatives for
Fiberglass insulation, mixed waste contaminated (fiberglass, RAD, PCBs, oils, organics, inorganics), waste management alternatives for
Fiberglass insulation, RAD contamination only, waste management alternatives for
Final residues from D&D, ER, and WM operations (low-level RAD waste), waste disposal alternatives for
Fissile materials, RAD contaminated, waste management alternatives for
Gaseous waste (radioactive constituents), characterization alternatives for
Graphite moderator, RAD contaminated, waste management alternatives for
Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for
Ignitable reactive wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for

000757

Radioactive waste *(continued)*
Infectious and medical wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Lab packs (organics, inorganics, RAD), waste management alternatives for
Liquid wastes (radioactive constituents), characterization alternatives for
Listed wastes (halogenated solvents), mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Listed wastes (nonhalogenated solvents), mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Melton Valley and REDC caustic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Melton Valley and REDC caustic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
Nonfissile radioactive materials having low specific activity, waste shipment alternatives for
Nonfissile radioactive materials, surface contaminated objects, waste shipment alternatives for
Other RCRA hazardous wastes, mixed waste contaminated, waste management alternatives for
Process/dilute liquid low-level waste, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
REDC acidic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
REDC acidic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
REDC liquid organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Sanitary/industrial wastewater, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Scrap building materials, RAD contamination only, waste management alternatives for
Scrap ferrous metals, mixed waste contaminated (steel, RAD, organics, inorganics, PCBs), waste management alternatives for
Scrap ferrous metals, RAD contamination only, waste management alternatives for
Scrap nonferrous metals, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Scrap nonferrous metals, RAD contamination only, waste management alternatives for
Scrap transite and scrap asbestos pipe and insulation, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Solid-liquid wastes (radioactive constituents), characterization alternatives for
Solid wastes (radioactive constituents), characterization alternatives for
Spent ion exchange media, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Spent ion exchange media, RAD contamination only, waste management alternatives for
Toxic metal wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Toxic organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Waste management, definitions of problems for
Waste off-gases (adsorbable RAD constituents), waste management alternatives for
Waste off-gases (nonadsorbable RAD constituents), waste management alternatives for
Waste off-gases (radioactive constituents), waste management alternatives for
Waste processing sludges, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Waste processing sludges, RAD contamination only, waste management alternatives for
Waste processing solid residuals, mixed waste contaminated (RAD, organics, inorganics), waste management alternatives for
Waste processing solid residuals, RAD contamination only, waste management alternatives for

Radioactive-waste management regulations
General Requirements
Clean Air Act and Tennessee Air Quality Laws, V1: 188–190
DOE orders, V1: 182–188
Regulation of radioactive waste
high-level radioactive waste, V1: 193
low-level radioactive waste, V1: 193–194
special-case waste, V1: 194
spent nuclear fuel, V1; 194–195
TRU waste, V1: 190–193

Radioanalytical procedures, char-202, V1: 49; V2: 13

Radiochemical Engineering Development Center (REDC). *See*
Melton Valley and REDC caustic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for

000758

Melton Valley and REDC caustic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
REDC acidic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
REDC acidic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
REDC liquid organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
REDC liquid organic wastes, RAD and/or TRU contaminants only, waste management alternatives for

Range finders, roba-44, V1: 140, 146; V2: 160

Rankings, technology
Description of criteria, V1: 30–32

RCRA. *See*
Resource Conservation and Recovery Act

RCRA Hazardous waste. *See*
Corrosive wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Generation of hazardous and mixed wastes, waste management alternatives for
Ignitable reactive wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Infectious and medical wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Listed wastes (halogenated solvents), mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Listed wastes (nonhalogenated solvents), mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Melton Valley and REDC caustic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Nonradioactive hazardous waste, waste shipment alternatives for
Other RCRA hazardous wastes, mixed waste contaminated, (RCRA hazardous and/or RAD contaminated) waste management alternatives for
Process/dilute liquid low-level waste, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
REDC acidic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Sanitary/industrial wastewater, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Toxic metal wastes, mixed waste contaminated, (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Toxic organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Waste management, definitions of problems for

RCRA nonbulk: POP PGI, II, III specification packaging bulk—strong tight containers, wpht-109, V2: 150

Recharacterization and disposal, wpro-303, V2: 131

Recharacterize and dispose of/reuse, wpro-130, V1: 123, 130; V2: 106

Recordkeeping and reporting requirements, V1: 207

Recycle/reuse (sell as roadbed aggregate/filler), wpro-130, V1: 106, 112, 121, 125; V2: 107, 131, 135, 136, 138, 140, 142

Reprocessing, wpro-122, V1: 105; V2: 121

Resource Conservation and Recovery Act
Division by subtitles, V1: 158
Hazardous-waste management regulations
CAMUs/TUs, V1: 171–172
characteristics of hazardous waste, V1: 162–163
corrective action requirements, V1: 170–172
delisting petitions, V1: 164
generator requirements under Subtitle C, V1: 166–167
hazardous constituents regulated under RCRA , V1: 163–164
land disposal restrictions, V1: 172–177
listed solid waste, V1: 163
transporter requirements under Subtitle C, V1: 167
treatment, storage, disposal facility permitting requirements under RCRA, V1: 169
treatment, storage, disposal facility requirements under Subtitle C, V1: 168–170
underground storage tanks under Subtitle I, V1: 176–181
waste mixtures (mixture rule, derived-from rule, contained-in policy, and mixed waste), V1: 164–166
wastes excluded from Subtitle C, V1: 164

Resource Conservation and Recovery Act *(continued)*
Mixed-waste V1: 196–199
Solid-waste regulations, V1: 159–162
Tennessee regulations, V1: 159
Waste minimization, V1: 203

REDC acidic aqueous wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
biodenitrification, wpro-229, V1: 117; V2: 114
Chemical treatment technologies
Bradtec process, wpro-228, V1: 116; V2: 112
chemical oxidation/reduction, wpro-209, V1: 116; V2: 112
chemical precipitation, wpro-210, V1: 116; V2: 112
electrochemical metal removal, wpro-205, V2: 113
ion exchange, wpro-217/218, V1: 117; V2: 111
neutralization, wpro-230, V1: 117
nitrate-ammonia-ceramic (NAC) process, wpro-106, V1: 117; V2: 112
ozonation photolysis, wpro-214, V2: 113
solvent extraction, wpro-211/212, V2: 113
Physical treatment technologies
air stripping, wpro-200, V2: 111
electrolysis, wpro-205, V1: 116; V2: 111
filtration, wpro-201, V1: 116; V2: 111
inorganic microporous filters, wpro-207, V1: 116; V2: 111
reverse osmosis, wpro-206, V1: 116; V2: 111
Thermal treatment technologies
evaporation, wpro-223, V1: 117; V2: 113
microwave treatment, wpro-115, V2: 114

REDC acidic aqueous wastes, RAD and/or TRU contaminants only, waste management alternatives for
Biological treatment technologies
biodenitrification, wpro-229, V1: 121
Chemical treatment technologies
Bradtec process, wpro-228, V1: 119
chemical oxidation/reduction, wpro-209, V1: 119
chemical precipitation, wpro-210, V1: 119
electrochemical metal removal, wpro-205, V1: 119
ion exchange, wpro-217/218, V1: 119
neutralization, wpro-230, V1: 120
nitrate-ammonia-ceramic (NAC) process, wpro-106, V1: 120
ozonation photolysis, wpro-214, V1: 120
solvent extraction, wpro-211/212, V1: 120
Physical treatment technologies
electrolysis, wpro-205, V1: 119
filtration, wpro-201, V1: 118
inorganic microporous filters, wpro-207, V1: 119
reverse osmosis, wpro-206, V1: 119
Thermal treatment technologies
evaporation, wpro-223, V1: 120
microwave treatment, wpro-115, V1: 120

REDC liquid organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V1: 118
anaerobic digestion, wpro-225, V1: 118
Chemical treatment technologies
chemical oxidation/reduction, wpro-209, V1: 116; V2: 115
chemical precipitation, wpro-210, V1: 116; V2: 115
solvent extraction, wpro-211/212, V1: 117; V2: 115
Physical treatment technologies
adsorption, wpro-202/203, V1: 116; V2: 114
air stripping, wpro-200, V2: 114
filtration, wpro-201, V2: 114
inorganic microporous filters, wpro-207, V2: 114
Thermal treatment technologies
advanced electric thermolysis, wpro-120, V1: 117; V2: 117
Bucky ball chemistry, wpro-101, V1: 116; V2: 117
chem char process, wpro-114, V1: 117
distillation, wpro-222, V1: 117
incineration, wpro-108, V1: 118
microwave treatment, wpro-115, V2: 117
molten glass combustor, wpro-116, V1: 118
molten salt oxidation, wpro-113, V1: 118
plasma arc furnace, wpro-107, V1: 118
supercritical fluid extraction, wpro-118, V1: 117; V2: 117
wet air oxidation, wpro-215, V1: 117; V2: 116

REDC liquid organic wastes, RAD and/or TRU contaminants only, waste management alternatives for
Chemical treatment technologies
chemical oxidation/reduction, wpro-209, V1: 119
chemical precipitation, wpro-210, V1: 119
solvent extraction, wpro-211/212, V1: 120
Physical treatment technologies
adsorption, wpro-202/203, V1: 118
filtration, wpro-201, V1: 118
inorganic microporous filters, wpro-207, V1: 119
Thermal treatment technologies
advanced electric thermolysis, wpro-120, V1: 120
Bucky ball chemistry, wpro-101, V1: 119
chem char process, wpro-114, V1: 120
distillation, wpro-222, V1: 120
incineration, wpro-108, V1: 120
molten glass combustor, wpro-116, V1: 121
molten salt oxidation, wpro-113, V1: 121
plasma arc furnace, wpro-107, V1: 121
supercritical fluid extraction, wpro-118, V1: 120

Residues. *See*
Final residues from D&D, ER, and WM operations (clean debris), waste disposal alternatives for
Final residues from D&D, ER, and WM operations (low-level mixed waste), waste disposal alternatives for
Final residues from D&D, ER, and WM operations (low-level RAD waste), waste disposal alternatives for
Final residues from D&D, ER, and WM operations (RCRA waste), waste disposal alternatives for
Final residues from D&D, ER, and WM operations (scrap asbestos), waste disposal alternatives for
Final residues from D&D, ER, and WM operations (TRU waste), waste disposal alternatives for

Reverse osmosis, wpro-206, V1: 109, 116, 119; V2: 87, 88, 107, 111, 118

Robotics and automation
Discussion of implementation needs, V1: 144
Discussion of science and technology needs, V1: 142–143
Discussion of technology options, V1: 138–141
Technology rankings, V1: 145–147

Robotics and automation alternatives for waste management. *See*
Waste handling and packaging, robotics and automation alternatives for
Waste surveillance and inspection, robotics and automation alternatives for

— S —

Safety (collision avoidance), roba-35, V1: 140, 146; V2: 159

Safety (load/rate limiting), roba-35, V1: 140, 146; V2: 159

Sample collection, roba-57, V1: 141, 147; V2: 162

Sample preparation, roba-59, V1: 141, 147; V2: 162

Sampling and mixing methods, char-81, V1: 45; V2: 3

Sampling heterogenous wastes, char-270, V1: 45; V2: 4

Sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 4

Sampling program configuration management system, char-228, V1: 45; V2: 3

Sampling underground storage tanks for volatile organics, char-257, V1: 45; V2: 3

Sanitary/industrial wastewater, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V2: 118
anaerobic digestion, wpro-225, V2: 118
Chemical treatment technologies
gamma radiolysis, wpro-100, V2: 120
ozonation photolysis, wpro-214, V2: 120
solvent extraction, wpro-211/212, V2: 119
supercritical water oxidation, wpro-216, V2: 120
wet air oxidation, wpro-215, V2: 120
Physical treatment technologies
adsorption, wpro-202/203, V2: 119
filtration, wpro-201, V2: 119
inorganic microporous filters, wpro-207, V2: 118
reverse osmosis, wpro-206, V2: 118
Thermal treatment technologies
chem char process, wpro-114, V2: 118
distillation, wpro-222, V2: 118
evaporation, wpro-223, V2: 121

Sanitary/industrial wastewater, RAD and/or TRU contaminants only, waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V2: 121
anaerobic digestion, wpro-225, V2: 121
Chemical treatment technologies
gamma radiolysis, wpro-100, V1: 119
solvent extraction, wpro-211/212, V1: 120
supercritical water oxidation, wpro-216, V1: 120
wet air oxidation, wpro-215, V1: 120
Physical treatment technologies
adsorption, wpro-202/203, V1: 118
filtration, wpro-201, V1: 118
inorganic microporous filters, wpro-207, V1: 119
reverse osmosis, wpro-206, V1: 119
Thermal treatment technologies
evaporation, wpro-223, V1: 120

Scanning electron microscopy, char-33, V1: 49; V2: 15

Scrap asbestos pipe insulation and transite, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 135

Scrap building materials, RAD contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 52
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 51

Scrap building materials, RAD contamination only, waste management alternatives for *(continued)*
molten glass combustor, wpro-116, V1: 104; V2: 51
plasma arc furnace, wpro-107, V1: 104; V2: 51
Waste stabilization technologies
encapsulation, V1: 102; V2: 51

Scrap ferrous metals, mixed waste contaminated (steel, RAD, organics, inorganics, PCBs), waste management alternatives for
Chemical treatment technologies
electrochemical metal removal, wpro-205, V1: 99; V2: 30
leaching and stripping, wpro-213, V1: 99; V2: 30
solvent extraction, wpro-211, V1: 100; V2: 30
supercritical fluid extraction, wpro-118, V1: 100; V2: 30
Physical treatment technologies
sonification, wpro-121, V1: 99; V2: 29
Thermal treatment technologies
plasma arc furnace, wpro-107, V1: 101; V2: 29
smelting, wpro-111, V1: 101; V2: 29
thermal desorption, wpro-106, V1: 101; V2: 29
Waste stabilization technologies
encapsulation, V1: 99; V2: 29

Scrap ferrous metals, RAD contamination only, waste management alternatives for
Chemical treatment technologies
electrochemical metal removal, wpro-205, V1: 102; V2: 53
leaching and stripping, wpro-213, V1: 103; V2: 54
solvent extraction, wpro-211/212, V1: 103; V2: 54
Physical treatment technologies
sonification, wpro-121, V1: 102; V2: 53
Thermal treatment technologies
plasma arc furnace, wpro-107, V1: 104; V2: 53
smelting, wpro-111, V1: 104; V2: 53
Waste stabilization technologies
encapsulation, V1: 102; V2: 53

Scrap ferrous metals, TRU contamination only, waste management alternatives for
Chemical treatment technologies
electrochemical metal removal, wpro-205, V1: 102; V2: 72
leaching and stripping, wpro-213, V1: 103; V2: 73
solvent extraction, wpro-211/212, V1: 103; V2: 73
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 72
Thermal treatment technologies
plasma arc furnace, wpro-107, V1: 104; V2: 72
smelting, wpro-111, V1: 104; V2: 72
Waste stabilization technologies
encapsulation, V1: 102; V2: 72

Scrap ferrous metals, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 136
recycle/reuse, wpro-130, V1: 106; V2: 136
sell as scrap, wpro-130, V1: 106; V2: 136

Scrap nonferrous metals, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Chemical treatment technologies
electrochemical metal removal, wpro-205, V1: 99; V2: 31
gamma radiolysis, wpro-100, V1: 99; V2: 31
gas phase treatment, dcon-16, V1: 99; V2: 32
leaching and stripping, wpro-213, V1: 99; V2: 31
mond process, wpro-112, V1: 100; V2: 32
nitrate-ammonia-ceramic (NAC) process, wpro-105, V1: 100; V2: 32
supercritical fluid extraction, V1: 100; V2: 31
Physical treatment technologies
sonification, wpro-121, V1: 99; V2: 31
Thermal treatment technologies
incineration, wpro-108, V1: 100; V2: 32
smelting, wpro-111, V1: 101; V2: 33
thermal desorption, wpro-106, V1: 101; V2: 33
Waste stabilization technologies
encapsulation, V1: 99; V2: 31

Scrap nonferrous metals, RAD contamination only, waste management alternatives for
Chemical treatment technologies
electrochemical metal removal, wpro-205, V1: 102; V2: 55
gas phase (ClF_3) treatment, dcon-16, V1: 103; V2: 55
leaching and stripping, wpro-213, V1: 103; V2: 54
mond process, wpro-112, V1: 103; V2: 55
nitrate-ammonia-ceramic (NAC) process, wpro-105, V1: 103; V2: 55
Physical treatment technologies
sonification, wpro-121, V1: 102; V2: 54
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 55
smelting, wpro-111, V1: 104; V2: 56
Waste stabilization technologies
encapsulation, V1: 102; V2: 54

Scrap nonferrous metals, TRU contamination only, waste management alternatives for
Chemical treatment technologies
electrochemical metal removal, wpro-205, V1: 102; V2: 74
leaching and stripping, wpro-213, V1: 103; V2: 73
mond process, wpro-112, V1: 103; V2: 74
nitrate-ammonia-ceramic (NAC) process, wpro-106, V1: 103; V2: 74

000762

Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 73
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 74
smelting, wpro-111, V1: 104; V2: 74
Waste stabilization technologies
encapsulation, V1: 102; V2: 73

Scrap nonferrous metals, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Chemical treatment technologies
acid digestion, wpro-127, V2: 137
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 136
recycle/reuse, wpro-130, V1: 106; V2: 136
sell as scrap, wpro-130, V1: 106; V2: 136

Scrap transite and scrap asbestos pipe and insulation, mixed waste contaminated (asbestos, PCBs, oils, RAD, organics, inorganics), waste management alternatives for
Chemical treatment technologies
gamma radiolysis, wpro-100, V1: 99; V2: 23
solvent extraction (general), wpro-211/212, V1: 100; V2: 23
supercritical fluid extraction, wpro-118, V1: 100; V2: 23
Thermal treatment technologies
calcination/roasting, dcon-60, V1: 100; V2: 24
incineration, wpro-108, V1: 100; V2: 24
plasma arc furnace, wpro-107, V1: 101; V2: 24

Scrap transite and scrap asbestos pipe and insulation, RAD contamination only, waste management alternatives for
Chemical treatment technologies
electropolishing/osmosis/migration, dcon-20, V1: 102; V2: 49
gamma radiolysis, wpro-100, V2: 50
solvent extraction, wpro-211/212, V1: 103; V2: 49
Thermal treatment technologies
calcination/roasting, dcon-60, V1: 103; V2: 50
incineration, wpro-108, V1: 103; V2: 50
plasma arc furnace, wpro-107, V1: 104; V2: 51
Waste stabilization technologies
encapsulation, V1: 102; V2: 49

Scrubbers, wpro-211/212, V1: 123; V2: 131

Scrubbers, wpro-301, V1: 123, 125, 126; V2: 124, 126, 128, 130

Secondary ion mass spectroscopy, char-3, V1: 46; V2: 7

Sediment sampling from restricted access locations, char-276, V1: 45; V2: 4

Sell as scrap, wpro-130, V1: 106, 113; V2: 136, 138, 140, 141

Semivolatile organic constituents. *See*
Waste off-gases (semivolatile organic constituents), waste management alternatives for

Sequential sampling plans, char-252, V1: 45; V2: 3

Shallow land burial, wpro-132, V1: 108, 113, 142; V2: 107, 142

Simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 47; V2: 8

Sludge. *See*
Coal yard runoff sludge, waste management alternatives for
Waste processing sludges, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Waste processing sludges, RAD contamination only, waste management alternatives for
Waste processing sludges, TRU contamination only, waste management alternatives for
Waste processing sludges, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for

Smelting, wpro-111, V1: 101,104; V2: 29, 33, 53, 56, 72, 74

Sodium iodide-germanium gamma spectroscopy, char-196, V2: 13

Solid-liquid wastes (general problem area/ constituents), characterization alternatives for
Data analysis/management technologies
analysis of censored data, char-249, V1: 47; V2: 9
application of approximate reasoning to data analysis/evaluation, char-234, V1: 47; V2: 8
automated engineering system life-cycle planning, dism-174, V1: 48; V2: 11
automated scanning and conversion of engineering drawings, dism-154, V1: 47; V2: 8
automated system reliability and safety analysis, dism-175, V1: 48; V2: 11
client/server access to standards and regulatory guidelines, dism-152, V1: 46; V2: 7
client/server architecture for data base access, dism-157, V1: 47; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 47; V2: 9
computer-based training systems, dism-191, V1: 47; V2: 9
criticality indices, char-44, V1: 47; V2: 9
data access services, dism-153, V1: 46; V2: 8

000763

Solid-liquid wastes (general problem area/ constituents), characterization alternatives for *(continued)*
fiber-optic detection and monitoring system (intelligent materials), char-240, V1: 48; V2: 10
generalized object-oriented simulation software, dism-173, V1: 48; V2: 11
geographic information system for DOE sites, dism-181, V1: 47; V2: 8
hazard analysis expert system, char-233, V1: 47; V2: 8
hypertext information systems, dism-158, V1: 47; V2: 9
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-260, V1: 48; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 47; V2: 10
network architecture with integrated workstations, char-221, V1: 46; V2: 7
project information access services, char-220, V2: 7
quality control for measurement process, char-250, V1: 47; V2: 9
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 47; V2: 8
spatial sample and data analysis plans, char-253, V1: 47; V2: 9
statistical methods for the analysis of large data sets, char-251, V1: 47; V2: 9
task scheduling aids, char-241, V1: 47; V2: 10
3-D CAD data base of buildings and other structures, dism-156, V1: 48; V2: 10
waste management configuration management system, char-230, V2: 10
Detection/measurement field methods
air monitoring, char-59, V1: 46; V2: 6
electrochemical methods, char-10, V1: 46; V2: 6
fiber-optic chemical sensors, char-25, V1: 46; V2: 5
infrared spectroscopy, char-18, V1: 46; V2: 6
immunoassay detection, char-23, V1: 46; V2: 5
ion mobility mass spectrometry, char-264, V1: 46; V2: 5
luminescence detection, char-92, V1: 46; V2: 6
optical absorption spectroscopy, char-27, V1: 46; V2: 5
personnel monitoring, char-52, V1: 46; V2: 6
portable Raman spectrometer, char-84, V1: 46; V2: 5
Detection/measurement laboratory methods
contamination control—analytical equipment, char-204, V1: 46; V2: 6
Fourier transform infrared spectroscopy, char-8, V1: 46; V2: 6
isotopic dilution mass spectroscopy, char-48, V1: 46; V2: 7
laser ionization mass spectrometry, char-4, V1: 46; V2: 7
nuclear magnetic resonance, char-11, V1: 46; V2: 7
secondary ion mass spectroscopy, char-3, V1: 46; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 46; V2: 5
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 45; V2: 3
membranes for sample collection and concentration, char-55, V1: 45; V2: 3
multiangle drilling for depth profiling of contaminants, char-64, V1: 45; V2: 4
sampling and mixing methods, char-81, V1: 45; V2: 3
sampling heterogenous wastes, char-270, V1: 45; V2: 4
sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 4
sampling underground storage tanks for volatile organics, char-257, V1: 45; V2: 3
sediment sampling from restricted access locations, char-276, V1: 45; V2: 4
solid sorbent sampling for airborne organics, char-254, V1: 45; V2: 4
ultrasonic extraction, char-20, V1: 45; V2: 3
vacuum-assisted reverse flow, solvent extraction methods, char-62, V1: 45; V2: 3
Sample preparation technologies
adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples, char-209, V1: 45; V2: 4
high-pressure ashing for sample preparation, char-203, V1: 45; V2: 5
metallographic sectioning and preparation, char-67, V1: 45; V2: 4
microwave digestion, char-19, V1: 45; V2: 4
radioactive sample preparation, char-205, V1: 45; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 45; V2: 5
supercritical fluid extraction of organics, char-208, V1: 45; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 45; V2: 3
sampling program configuration management system, char-228, V1: 45; V2: 3
sequential sampling plans, char-252, V1: 45; V2: 3

Solid-liquid wastes (inorganic constituents), characterization alternatives for
Field methods
atomic emission spectroscopy, char-76, V1: 49; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219 and char-6, V1: 49; V2: 14

000764

Laboratory methods
auger electron spectroscopy, char-2, V1: 50; V2: 15
atomic emission spectroscopy, char-76, V1: 49; V2: 14
cold vapor (mercury) analysis, char-24, V1: 49; V2: 15
electron diffraction, char-37, V1: 49; V2: 14
electron spectroscopy for chemical analysis, char-1, V1: 50; V2: 15
energy dispersive X-ray spectroscopy, char-35, V1: 49; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 50; V2: 15
inductively coupled plasma—mass spectroscopy, char-78, V1: 49; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 49; V2: 14
ion chromatography, char-50, V1: 49; V2: 14
neutron activation analysis, char-266, V1: 49, 50; V2: 15
particle-induced X-ray emission, char-17, V1: 49; V2: 15
powder X-ray diffraction, char-31, V1: 50; V2: 15
scanning electron microscopy, char-33, V1: 49; V2: 15
transmission electron microscopy, char-34, V1: 49; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 49; V2: 14

Solid-liquid wastes (organic constituents), characterization alternatives for
Field methods
direct sampling ion trap mass spectrometry, char-90, V1: 50; V2: 16
gas chromatography in the field, char-262, V1: 50; V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 50; V2: 16
portable volatile organic compound detectors, char-5, V1: 50; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 16
Laboratory methods
analytical methods for chelators and decontamination agents, char-206, V1: 50; V2: 17
capillary zone electrophoresis, char-207, V1: 50; V2: 17
gas chromatography, char-94, V1: 50; V2: 17
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 50; V2: 17
gas chromatography—mass spectrometry, char-88, V1: 50; V2: 17
liquid chromatography—mass spectrometry, char-89, V1: 50; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50; V2: 17
solid phase microextraction method, char-211, V1: 50; V2: 17

Solid-liquid wastes (pathogenic constituents), characterization alternatives for
Laboratory methods
pathogen surveillance, char-215, V1: 51; V2: 18

Solid-liquid wastes (physical characteristics), characterization alternatives for
Field methods
fiber-optic systems for measuring multiple physical variables, char-248, V1: 51; V2: 18
instrument response models for remote sensing, char-246, V1: 50; V2: 18
Laboratory methods
computer tomography, char-41, V1: 51; V2: 18
optical microscopy, char-32, V1: 51; V2: 18
particle size analysis, char-26, V1: 51; V2: 18

Solid-liquid wastes (radioactive constituents), characterization alternatives for
Field methods
advanced radiation monitors, char-269, V1: 48; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 48; V2: 12
bubble dosimeters for neutron flux, char-216, V1: 48; V2: 12
gamma-ray spectrometry, char-268, V1: 49; V2: 13
gross fissile analysis by neutron activation and delayed neutron counting, char-200, V2: 13
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-250, V1: 47; V2: 12
long-range alpha detector, char-65, V1: 48; V2: 11
neutron activation, char-266, V1: 49, 50; V2: 13
passive monitors for weak beta radionuclides, char-102, V1: 48; V2: 11
passive neutron detection, char-104, V1: 49; V2: 13
photon electron rejecting alpha liquid scintillation, char-97, V1: 49; V2: 13
portable gamma ray scintillometers, char-263, V1: 48; V2: 12
proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 11, 13
radioanalytical procedures, char-202, V1: 49; V2: 13
sodium iodide-germanium gamma spectroscopy, char-196, V2: 13
thermoluminescence dosimeter array for spatial characterization of alpha-contamination, char-103, V1: 48; V2: 11
waste curie monitor (bag or barrel counter for low-level gamma radioactivity), char-109, V2: 12

000765

Solid-liquid wastes (radioactive constituents), characterization alternatives for *(continued)*
Laboratory methods
liquid scintillation counting, char-267, V1: 49; V2: 14

Solid phase microextraction method, char-211, V1: 50; V2: 17

Solid sorbent sampling for airborne organics, char-254, V1: 45; V2: 4

Solid Waste Disposal Act
As amended by the FFCA, V1: 196–199
Mixed waste, V1: 196

Solid Waste Disposal Act. *See*
Resource Conservation and Recovery Act

Solid-waste regulations, V1: 159–162

Solid wastes (general problem areas/constituents), characterization alternatives for
Data analysis/management technologies
analysis of censored data, char-249, V1: 47; V2: 9
application of approximate reasoning to data analysis/evaluation, char-234, V1: 47; V2: 8
automated engineering system life cycle planning, dism-174, V1: 48; V2: 11
automated scanning and conversion of engineering drawings, dism-154, V1: 47; V2: 8
automated system reliability and safety analysis, dism-175, V1: 48; V2: 11
client/server access to standards and regulatory guidelines, dism-152, V1: 46; V2: 7
client/server architecture for data base access, dism-157, V1: 47; V2: 9
computer-aided task analysis and procedure preparation, dism-172, V1: 47; V2: 9
computer-based training systems, dism-191, V1: 47; V2: 9
criticality indices, char-44, V1: 47; V2: 9
data access services, dism-153, V1: 46; V2: 8
fiber-optic detection and monitoring system (intelligent materials), char-240, V1: 48; V2: 10
generalized object-oriented simulation software, dism-173, V1: 48; V2: 11
geographic information system for DOE sites, dism-181, V1: 47; V2: 8
hazard analysis expert system, char-233, V1: 47; V2: 8
hypertext information systems, dism-158, V1: 47; V2: 9
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-260, V1: 48; V2: 10
modeling of volatile organic compounds migration in porous materials, char-53, V1: 47; V2: 10
network architecture with integrated workstations, char-221, V1: 46; V2: 7
project information access services, char-220, V2: 7
quality control for measurement process, char-250, V1: 47; V2: 9
simulated walkthrough facility for robotics task sequence analysis, dism-171, V1: 47; V2: 8
spatial sample and data analysis plans, char-253, V1: 47; V2: 9
statistical methods for the analysis of large data sets, char-251, V1: 47; V2: 9
task scheduling aids, char-241, V1: 47; V2: 10
3-D CAD data base of buildings and other structures, dism-156, V1: 48; V2: 10
waste management configuration management system, char-230, V2: 10
Detection/measurement field methods
air monitoring, char-59, V1: 46; V2: 6
electrochemical methods, char-10, V1: 46; V2: 6
fiber-optic chemical sensors, char-25, V1: 46; V2: 5
infrared spectroscopy, char-18, V1: 46; V2: 6
ion mobility mass spectrometry, char-264, V1: 46; V2: 5
immunoassay detection, char-23, V1: 46; V2: 5
luminescence detection, char-92, V1: 46; V2: 6
optical absorption spectroscopy, char-27, V1: 46; V2: 5
personnel monitoring, char-52, V1: 46; V2: 6
portable Raman spectrometer, char-84, V1: 46; V2: 5
Detection/measurement laboratory methods
contamination control—analytical equipment, char-204, V1: 46; V2: 6
Fourier transform infrared spectroscopy, char-8, V1: 46; V2: 6
isotopic dilution mass spectroscopy, char-48, V1: 46; V2: 7
laser ionization mass spectrometry, char-4, V1: 46; V2: 7
nuclear magnetic resonance, char-11, V1: 46; V2: 7
secondary ion mass spectroscopy, char-3, V1: 46; V2: 7
ultraviolet/visible spectroscopy, char-9, V1: 46; V2: 7
Sample collection technologies
in situ solid phase microextraction of organics, char-210, V1: 45; V2: 3
membranes for sample collection and concentration, char-55, V1: 45; V2: 3
multiangle drilling for depth profiling of contaminants, char-64, V1: 45; V2: 4
sampling and mixing methods, char-81, V1: 45; V2: 3
sampling heterogenous wastes, char-270, V1: 45; V2: 4
sampling interface system for surface contamination by organics, char-271, V1: 45; V2: 4

000766

sampling underground storage tanks for volatile organics, char-257, V1: 45; V2: 3
sediment sampling from restricted access locations, char-276, V1: 45; V2: 4
solid sorbent sampling for airborne organics, char-254, V1: 45; V2: 4
ultrasonic extraction, char-20, V1: 45; V2: 3
vacuum-assisted reverse flow, solvent extraction methods, char-62, V1: 45; V2: 3
Sample preparation technologies
adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples, char-209, V1: 45; V2: 4
high-pressure ashing for sample preparation, char-203, V1: 45; V2: 5
metallographic sectioning and preparation, char-67, V1: 45; V2: 4
microwave digestion, char-19, V1: 45; V2: 4
radioactive sample preparation, char-205, V1: 45; V2: 4
supercritical fluid extraction of inorganics, char-201, V1: 45; V2: 5
supercritical fluid extraction of organics, char-208, V1: 45; V2: 4
Sampling design technologies
optimization of sampling designs, char-71, V1: 45; V2: 3
sampling program configuration management system, char-228, V1: 45; V2: 3
sequential sampling plans, char-252, V1: 45; V2: 3

Solid wastes (inorganic constituents), characterization alternatives for
Field methods
atomic emission spectroscopy, char-76, V1: 49; V2: 14
X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219 and char-6, V1: 49; V2: 14
Laboratory methods
atomic emission spectroscopy, char-76, V1: 49; V2: 14
auger electron spectroscopy, char-2, V1: 50; V2: 15
cold vapor (mercury) analysis, char-24, V1: 49; V2: 15
electron diffraction, char-37, V1: 49; V2: 14
electron spectroscopy for chemical analysis, char-1, V1: 50; V2: 15
energy dispersive X-ray spectroscopy, char-35, V1: 49; V2: 15
glow discharge ionization mass spectroscopy, char-56, V1: 50; V2: 15
inductively coupled plasma—mass spectroscopy, char-78, V1: 49; V2: 14
inductively coupled plasma spectroscopy, char-77, V1: 49; V2: 14
ion chromatography, char-50, V1: 49; V2: 14
neutron activation analysis, char-266, V1: 49, 50; V2: 15
particle-induced X-ray emission, char-17, V1: 49; V2: 15
powder X-ray diffraction, char-31, V1: 50; V2: 15
scanning electron microscopy, char-33, V1: 49; V2: 15
transmission electron microscopy, char-34, V1: 49; V2: 15
wavelength dispersive X-ray spectroscopy, char-36, V1: 49; V2: 14

Solid wastes (organic constituents), characterization alternatives for
Field methods
direct sampling ion trap mass spectrometry, char-90, V1: 50; V2: 16
gas chromatography in the field, char-262, V1: 50; V2: 16
portable gas chromatograph/electron capture detector for analyzing PCBs, char-100, V1: 50; V2: 16
portable volatile organic compound detectors, char-5, V1: 50; V2: 16
synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 16
Laboratory methods
analytical methods for chelators and decontamination agents, char-206, V1: 50; V2: 17
capillary zone electrophoresis, char-207, V1: 50; V2: 17
gas chromatography, char-94, V1: 50; V2: 17
gas chromatography—Fourier transform infrared spectroscopy, char-66, V1: 50; V2: 17
gas chromatography—mass spectrometry, char-88, V1: 50; V2: 17
liquid chromatography—mass spectrometry, char-89, V1: 50; V2: 17
on-line supercritical fluid extraction—multidetector gas chromatography, char-115, V1: 50; V2: 17
solid phase microextraction method, char-211, V1: 50; V2: 17

Solid wastes (pathogenic constituents), characterization alternatives for
Laboratory methods
pathogen surveillance, char-215, V1: 51; V2: 18

Solid wastes (physical characteristics), characterization alternatives for
Field methods
fiber-optic systems for measuring multiple physical variables, char-248, V1: 51; V2: 18
instrument response models for remote sensing, char-246, V1: 50; V2: 18
Laboratory methods
computer tomography, char-41, V1: 51; V2: 18
optical microscopy, char-32, V1: 51; V2: 18
particle size analysis, char-26, V1: 51; V2: 18

Solid wastes (radioactive constituents), characterization alternatives for
Field methods
advanced radiation monitors, char-269, V1: 48; V2: 12
alpha track etch detectors for surface alpha contamination, char-96, V1: 48; V2: 12
bubble dosimeters for neutron flux, char-216, V1: 48; V2: 12
gamma-ray spectrometry, char-268, V1: 49; V2: 13
gross fissile analysis by neutron activation and delayed neutron counting, char-200, V2: 13
integrated microprocessor/sensor monitoring for radioactive waste storage containers, char-250, V1: 47; V2: 12
long-range alpha detector, char-65, V1: 48; V2: 11
neutron activation, char-266, V1: 49, 50; V2: 13
passive monitors for weak beta radionuclides, char-102, V1: 48; V2: 11
passive neutron detection, char-104, V1: 49; V2: 13
photon electron rejecting alpha liquid scintillation, char-97, V1: 49; V2: 13
portable gamma ray scintillometers, char-263, V1: 48; V2: 12
proportional counter for alpha and beta activity, char-108, V1: 48, 49; V2: 11, 13
radioanalytical procedures, char-202, V1: 49; V2: 13
sodium iodide-germanium gamma spectroscopy, char-196, V2: 13
thermoluminescence dosimeter array for spatial characterization of alpha-contamination, char-103, V1: 48; V2: 11
waste curie monitor (bag or barrel counter for low-level gamma radioactivity), char-109, V2: 12
Laboratory methods
liquid scintillation counting, char-267, V1: 49; V2: 14

Solid wastes, waste management alternatives for
Waste stabilization technologies (solidification, macroencapsulation, microencapsulation, and chemical fixation)
cementitious solidification/stabilization, wsta-100, V2: 147
high-temperature crystalline materials, wsta-105, V2: 148
high-temperature noncrystalline materials, wsta-106, V2: 148
polymer-impregnated concrete, wsta-101, V2: 147
thermoplastic encapsulation, wsta-102/103, V2: 147
thermosetting plastics encapsulation, wsta-104, V2: 147

Solvent extraction (general), wpro-211/212, V1: 100, 103, 110, 117, 120, 121; V2: 23, 26, 29, 30, 31, 42, 45, 49, 53, 54, 62, 68, 85, 73, 81, 90, 92, 95, 97, 101, 109, 113, 115, 119

Sonification, wpro-121, V1: 99, 102; V2: 29, 31, 53, 54

Spatial sample and data analysis plans, char-253, V1: 47; V2: 9

Special-case waste, V1: 194

Special-case waste regulations, V1: 194

Spent fuel elements and components, waste management alternatives for
Physical treatment technologies
develop cask to ship spent fuel elements to Savannah River Site for storage, wpro-125, V1: 105; V2: 121
dry storage, wpro-123, V1: 105; V2: 121
pool storage, wpro-124, V1: 105; V2: 121
reprocessing, wpro-122, V1: 105; V2: 121

Spent ion exchange media, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 99; V2: 40
supercritical fluid extraction, wpro-118, V1: 100; V2: 40
supercritical water oxidation, wpro-216, V1: 102; V2: 40
Thermal treatment technologies
chem char process, wpro-114, V1: 100; V2: 42
incineration, wpro-108, V1: 100; V2: 40
molten glass combustor, wpro-116, V1: 100; V2: 41
molten salt oxidation, wpro-113, V1: 101; V2: 41
plasma arc furnace, wpro-107, V1: 101; V2: 41
thermal desorption, wpro-106, V1: 101; V2: 41
Waste stabilization technologies
encapsulation, V1: 99; V2: 40

Spent ion exchange media, RAD contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 60
Thermal treatment technologies
chem char process, wpro-114, V2: 62
incineration, wpro-108, V1: 103; V2: 61
molten glass combustor, wpro-116, V1: 104; V2: 61
molten salt oxidation, wpro-113, V1: 104; V2: 61
plasma arc furnace, wpro-107, V1: 104; V2: 62
thermal desorption, wpro-106, V1: 104; V2: 61

Waste stabilization technologies
encapsulation, V1: 102; V2: 60

Spent ion exchange media, TRU contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 79
supercritical water oxidation, wpro-216, V1: 105; V2: 79
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 79
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 80
molten glass combustor, wpro-116, V1: 104; V2: 80
Waste stabilization technologies
encapsulation, V1: 102; V2: 79

Spent nuclear fuel, V1: 194–195

Spent nuclear fuel regulations, V1: 194–195

Stabilization/support mechanisms or booms, roba-22, V1: 139, 145; V2: 158

Statistical methods for the analysis of large data sets, char-251, V1: 47; V2: 9

Steam plant ash (coal ash), waste management alternatives for
Physical treatment technologies
shallow land burial, wpro-132, V1: 108; V2: 107

Storage and disposal, V1: 207

Sulfer oxide criteria pollutant. *See*
Waste off-gases (SO_x criteria pollutant), waste management alternatives for

Supercritical fluid extraction, wpro-118, V1: 110, 120; V2: 21, 23, 26, 27, 30, 31, 33, 36, 38, 40, 42, 44, 85, 117

Supercritical fluid extraction of inorganics, char-201, V1: 45; V2: 5

Supercritical fluid extraction of organics, char-208, V1: 45; V2: 4

Supercritical water oxidation, wpro-216, V1: 102, 105, 110, 117, 120, 121; V2: 40, 79, 98, 101, 120

Surface contaminated objects processing, preparation, and packaging, wpht-103, V2: 149

Synchronous fluorescence screening for polycyclic aromatic hydrocarbons, char-101, V1: 50; V2: 16

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Tanks, storage. *See*
Historical waste disposal sites, burial grounds, acid pits, retention basins, and bulk waste in storage tanks (RAD, scrap wood, scrap metals, asbestos, PCB, organic, and inorganic constituents), waste management alternatives for
Underground storage tanks

Task scheduling aids, char-241, V1: 47; V2: 10

Thermal desorption, wpro-106, V1: 101, 104, 111; V2: 21, 25, 28, 29, 33, 41, 43, 46, 48, 61, 66, 142, 144

Thermoluminescence dosimeter array for spatial characterization of alpha-contamination, char-103, V1: 48; V2: 11

Thermoplastic encapsulation, wsta-102/103, V2: 147

Thermosetting plastics encapsulation, wsta-104, V2: 147

Tool caddies, roba-21, V1: 139, 145; V2: 158

Tooling sensors, roba-52, V1: 140, 147; V2: 161

Toxic metal wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
biosorption, wpro-226, V1: 111
Chemical treatment technologies
chemical precipitation, wpro-210, V1: 109; V2: 89
gamma radiolysis, wpro-100, V2: 89
ion exchange, wpro-217/218, V1: 109; V2: 89
solvent extraction, wpro-211/212, V1: 110; V2: 90
Physical treatment technologies
adsorption, wpro-202/203, V1: 109; V2: 89
filtration, wpro-201, V2: 109
high-gradient magnetic separation, wpro-204, V1: 109; V2: 88
inorganic microporous filters, wpro-207, V1: 109; V2: 88
reverse osmosis, wpro-206, V1: 109; V2: 88
Thermal treatment technologies
evaporation, wpro-223, V1: 110; V2: 90
incineration, wpro-108, V1: 110; V2: 90
molten salt oxidation, wpro-113, V1: 110; V2: 91
plasma arc furnace, wpro-107, V1: 110; V2: 91

Toxic organic wastes, mixed waste contaminated (RCRA hazardous and/or RAD contaminated), waste management alternatives for
Biological treatment technologies
aerobic digestion, wpro-224, V1: 111; V2: 94
anaerobic digestion, wpro-225, V1: 111; V2: 94
Chemical treatment technologies
acid digestion, wpro-127, V1: 109; V2: 137
gamma radiolysis, wpro-100, V1: 109; V2: 92
leaching and stripping, wpro-213, V1: 110; V2: 92
solvent extraction, wpro-211/212, V2: 92
supercritical water oxidation, wpro-216, V1: 110
Physical treatment technologies
adsorption, wpro-202/203, V1: 109
filtration, wpro-201, V1: 109; V2: 91
inorganic microporous filters, wpro-207, V1: 109; V2: 91
Thermal treatment technologies
distillation, wpro-222, V1: 110; V2: 93
incineration, wpro-108, V1: 110; V2: 93
molten glass combustor, wpro-116, V1: 110; V2: 94
molten salt oxidation, wpro-113, V2: 93
plasma arc furnace, wpro-107, V1: 110; V2: 94

Toxic Substances Control Act
Regulation of PCBs
incineration, V1: 207
marking and labeling requirements, V1: 207
recordkeeping and reporting requirements, V1: 207
storage and disposal, V1: 207

Transmission electron microscopy, char-34, V1: 49; V2: 15

Transmutation, wpro-219, V1: 102, 105; V2: 45, 64, 83, 123

Transportation off-site, regulations for. *See* Hazardous Materials Transportation Act

Transportation systems for mobile platforms, roba-12, V1: 139, 145; V2: 157

Transporter requirements under Subtitle C, V1: 167

Treatment, storage, disposal facility permitting requirements under RCRA, V1: 169

Treatment, storage, disposal facility requirements under Subtitle C, V1: 168–170

TRU waste. *See*
Asphalt and building materials, TRU contamination only, waste management alternatives for
Combustible debris, TRU contamination only, waste management alternatives for
Compactible debris, TRU contamination only, waste management alternatives for
Concrete rubble and gravel, TRU contamination only, waste management alternatives for
Discarded asbestos transite, TRU contamination only, waste management alternatives for
Discarded filters, TRU contamination only, waste management alternatives for
Fiberglass insulation, TRU contamination only, waste management alternatives for
Final residues from D&D, ER, and WM operations (TRU waste), waste disposal alternatives for
Scrap ferrous metals, TRU contamination only, waste management alternatives for
Scrap nonferrous metals, TRU contamination only, waste management alternatives for
Spent ion exchange media, TRU contamination only, waste management alternatives for
Waste processing sludges, TRU contamination only, waste management alternatives for
Waste processing solid residuals, TRU contamination only, waste management alternatives for

TRU waste regulations, V1: 190–193

Type-A or Type-B fissile radioactive material packages, wpht-106, V2: 149

Type-A radioactive material transport packages, wpht-104, V2: 149

Type-B radioactive material transport packages, wpht-105, V2: 149

— U —

Ultrasonic extraction, char-20, V1: 45; V2: 3

Ultraviolet/visible spectroscopy, char-9, V1: 46; V2: 7

Underground storage tanks, V1: 176–181

Underground storage tanks under Subtitle I, V1: 176–181

— V —

Vacuum-assisted reverse flow, solvent extraction methods, char-62, V1: 45; V2: 3

Vehicle/mobility driving, roba-28, V1: 139, 146; V2: 159

Vehicle/mobility navigation, roba-29, V1: 139, 146; V2: 159

Visual/aural systems, roba-43, V1: 140, 146; V2: 160

Volatile organic compounds in gases. *See*
Waste off-gases (VOC constituents), waste management alternatives for

— *W* —

Waste containing fissile material, waste shipment alternatives for
Waste packaging technologies
Type-A or Type-B fissile radioactive material packages, wpht-106, V2: 149

Waste curie monitor (bag or barrel counter for low-level gamma radioactivity), char-109, V2: 12

Waste handling and packaging, robotics and automation alternatives for
Controls—algorithms
combined mobility/manipulation, roba-34, V1: 140, 146; V2: 159
control modes, roba-27, V1: 139, 146; V2: 158
emergency shutdown, roba-37, V1: 140, 146; V2: 160
manipulation (Cartesian control), roba-31, V1: 140, 146; V2: 159
manipulation (joint control), roba-30, V1: 139, 146; V2: 159
manipulation (redundancy control), roba-33, V1: 140, 146; V2: 159
manipulation (special purpose control), roba-31, V1: 140, 146; V2: 159
safety (collision avoidance), roba-35, V1: 140, 146; V2: 159
safety (load/rate limiting), roba-35, V1: 140, 146; V2: 159
vehicle/mobility driving, roba-28, V1: 139, 146; V2: 159
vehicle/mobility navigation, roba-29, V1: 139, 146; V2: 159
Controls—human/machine interface
console (data handling methods), roba-39, V1: 140, 146; V2: 160
console (fixed/mobile/suitcase), roba-38, V1: 140, 146; V2: 160
operator interface (command input), roba-40, V1: 140, 146; V2: 160
operator interface (operator assistance), roba-41, V1: 140, 146; V2: 160
operator interface (status/alert system), roba-42, V1: 140, 146; V2: 160
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 139, 145; V2: 158
end effectors/alternatives, roba-23, V1: 139, 145; V2: 158
force limiting/compliant mechanisms, roba-26, V1: 139, 146; V2: 158
general gripper/tool interface, roba-25, V1: 139, 146; V2: 158
Mechanical—manipulation technologies
compact high-capacity manipulators, roba-19, V1: 139, 145; V2: 158
dexterous manipulators, roba-16, V1: 139, 145; V2: 157
Mechanical—mechanism technologies
precise programmable motions, roba-20, V1: 139, 145; V2: 158
stabilization/support mechanisms or booms, roba-22, V1: 139, 145; V2: 158
tool caddies, roba-21, V1: 139, 145; V2: 158
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 139, 145; V2: 157
failure recovery systems for mobile platforms, roba-11, V1: 139, 145; V2: 157
long-arm deployed robotic platforms, roba-9, V2: 157
mounted robotic platform, roba-8, V1: 139, 145; V2: 157
power sources for mobile platforms, roba-10, V1: 139, 145; V2: 157
transportation systems for mobile platforms, roba-12, V1: 139, 145; V2: 157
wheeled/tracked vehicle, roba-1, V1: 139, 145; V2: 157
Other technologies
characterization sensor integration, roba-58, V1: 141, 147; V2: 162
field hardening, roba-53, V1: 140, 147; V2: 161
information management for sample handling, roba-56, V1: 141, 147; V2: 162
integrated automated analytical laboratory, roba-55, V1: 140, 147; V2: 162
radiation hardening, roba-54, V1: 140, 147; V2: 161
sample collection, roba-57, V1: 141, 147; V2: 162
sample preparation, roba-59, V1: 141, 147; V2: 162
Sensors—control
force/torque sensors, roba-50, V1: 140, 147; V2: 161
position/velocity sensors, roba-48, V1: 140, 147; V2: 161
proximity probes as control sensors, roba-51, V1: 140, 147; V2: 161
tooling sensors, roba-52, V1: 140, 147; V2: 161
Sensors—perception
force/torque sensors, roba-46, V1: 140, 146; V2: 161
proximity probes, roba-45, V1: 140, 146; V2: 161
range finders, roba-44, V1: 140, 146; V2: 160
visual/aural systems, roba-43, V1: 140, 146; V2: 160

Waste Isolation Pilot Plant, New Mexico, wdis-105, V2: 153

000771

Waste management
Discussion of implementation needs, V1: 97
Discussion of science and technology needs, V1: 95–96
Discussion of technology options, V1: 64–94
Technology rankings, V1: 98–127

Waste management configuration management system, char-230, V2: 10

Waste management, definitions of problems for
Hazardous-waste management, V1: 10–11
Mixed-waste management, V1: 11–13
Radioactive-waste management, V1: 7–10

Waste management regulations, V1: 155–216

Waste Minimization Evaluation System, wmin-100, V2: 146

Waste minimization regulations
DOE orders, V1: 204
Mixed waste, V1: 196
RCRA requirements, V1: 203
Recycling, V1: 204
Recycling refrigerants, V1: 204
Tennessee Hazardous Waste Reduction Act, V1: 204
Used oil, V1: 203

Waste mixtures (mixture rule, derived-from rule, contained-in policy, and mixed waste), V1: 164–166

Waste off-gases (adsorbable RAD constituents), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V2: 134
Physical treatment technologies
adsorption, wpro-202/203, V2: 134

Waste off-gases (entrained vapors/acids), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 126; V2: 134
Physical treatment technologies
adsorption, wpro-202/203, V1: 125; V2: 133
inorganic membrane separation, wpro-300, V1: 126
inorganic microporous filters, wpro-207, V2: 133

Waste off-gases (inorganic constituents), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 126; V2: 129
scrubbers, wpro-211/212, V1: 123
Physical treatment technologies
adsorption, wpro-202/203, V1: 123, 125; V2: 129
cyclone separation, wpro-302, V2: 129
filtration, wpro-201, V1: 123, 126; V2: 129
high-gradient magnetic separation, wpro-204, V1: 123, 126; V2: 129
inorganic membrane separation, wpro-300, V1: 123, 126; V2: 129
Thermal treatment technologies
low-temperature separation, wpro-220, V1: 124, 127

Waste off-gases (NO_x criteria pollutant), waste management alternatives for
Chemical treatment technologies
$DeNO_x$ processes, wpro-307, V1: 123, 126; V2: 132
Thermal treatment technologies
incineration, wpro-108, V1: 124, 127; V2: 133
molten salt oxidation, wpro-113, V1: 127; V2: 133

Waste off-gases (nonadsorbable RAD constituents), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V2: 125
Physical treatment technologies
filtration, wpro-201, V2: 125
fugitive atmospheric discharge, wpro-306, V2: 134
inorganic membrane separation, wpro-300, V2: 125

Waste off-gases (orphan gas cyliners), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 124, 126
Physical treatment technologies
recharacterize and dispose of/reuse, wpro-130, V1: 123
recycle/reuse, wpro-130, V1: 125
scrubbers, wpro-301, V2: 126

Waste off-gases (particulate constituents), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 123, 125; V2: 128
Physical treatment technologies
adsorption, wpro-202/203, V1: 123, 125; V2: 127
cyclone separation, wpro-302, V1: 123, 126; V2: 128
filtration, wpro-201, V1: 123, 125, 126; V2: 128
high-gradient magnetic separation, wpro-204, V1: 123, 126; V2: 128
inorganic membrane separation, wpro-300, V1: 123, 125, 126; V2: 127
scrubbers, wpro-301, V1: 123, 125, 126; V2: 128
Thermal treatment technologies
molten salt oxidation, wpro-113, V1: 127; V2: 128

Waste off-gases (radioactive constituents), waste management alternatives for
Chemical treatment technologies
Bucky ball chemistry, wpro-101, V1: 125; V2: 130
leaching and stripping, wpro-213, V1: 125; V2: 130
Physical treatment technologies
adsorption, wpro-202/203, V1: 125; V2: 130
filtration, wpro-201, V1: 125; V2: 130
inorganic membrane separation, wpro-300, V1: 125
scrubbers, wpro-301, V1: 125; V2: 130

Waste off-gases (semivolatile organic constituents), waste management alternatives for
Chemical treatment technologies
catalytic destruction, wpro-109, V2: 126
leaching and stripping, wpro-213, V1: 124; V2: 126
ozonation photolysis, wpro-214, V1: 124; V2: 126
Physical treatment technologies
adsorption, wpro-202/203, V1: 123; V2: 126
inorganic membrane separation, wpro-300, V1: 123; V2: 126
low-temperature separation, wpro-220, V1: 124; V2: 125
scrubbers, wpro-301, V1: 123, 126; V2: 126
Thermal treatment technologies
electron beam destruction, wpro-304, V1: 124; V2: 127
flameless thermal oxidizers, wpro-305, V1: 124; V2: 127
incineration, wpro-108, V1: 124; V2: 127
molten salt oxidation, wpro-113, V2: 127

Waste off-gases (SO_x criteria pollutant), waste management alternatives for
Chemical treatment technologies
flue gas desulfurization process, wpro-308, V1: 124, 126; V2: 132
Thermal treatment technologies
incineration, wpro-108, V1: 124, 127; V2: 132
molten salt oxidation, wpro-113, V1: 127; V2: 132

Waste off-gases (unknown characteristics), waste management alternatives for
Chemical treatment technologies
scrubbers, wpro-211/212, V2: 131
Physical treatment technologies
recharacterization and disposal, wpro-303, V2: 131
recycle/reuse, wpro-303, V2: 131

Waste off-gases (VOC constituents), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 124, 125; V2: 124
ozonation photolysis, wpro-214, V1: 124; V2: 124
Physical treatment technologies
adsorption, wpro-202/203, V1: 123, 125; V2: 124
filtration, wpro-201, V1: 125
inorganic membrane separation, wpro-300, V1: 123, 125; V2: 124
low-temperature separation, wpro-220, V1: 124; V2: 124
scrubbers, wpro-301, V1: 123, 125; V2: 124
Thermal treatment technologies
Bucky ball chemistry, wpro-101, V1: 125
catalytic destruction, wpro-109, V1: 123; V2: 125
electron beam destruction, wpro-304, V1: 124; V2: 125
flameless thermal oxidizers, wpro-305, V1: 124; V2: 125
incineration, wpro-108, V1: 124; V2: 125
molten salt oxidation, wpro-113, V2: 125

Waste processing sludges, mixed waste contaminated (RAD, PCBs, organics, inorganics), waste management alternatives for
Biological treatment technologies
biodegradation, wpro-117, V2: 44
Chemical treatment technologies
leaching and stripping, wpro-213, V2: 42
solvent extraction, wpro-211/212, V2: 42
supercritical fluid extraction, wpro-118, V1: 100; V2: 42
Thermal treatment technologies
chem char process, wpro-114, V2: 43
incineration, wpro-108, V1: 100; V2: 43
microwave treatment, wpro-115, V2: 43
molten glass combustor, wpro-116, V2: 44
plasma arc furnace, wpro-107, V2: 44
thermal desorption, wpro-106, V2: 43
wet air oxidation, wpro-215, V2: 43
Waste stabilization technologies
encapsulation, V1: 109; V2: 42

Waste processing sludges, RAD contamination only, waste management alternatives for
Biological treatment technologies
biosorption, wpro-226, V2: 64
Chemical treatment technologies
leaching and stripping, wpro-213, V2: 63
solvent extraction, wpro-211/212, V2: 62
Thermal treatment technologies
incineration, wpro-108, V2: 63
microwave treatment, wpro-115, V2: 63
molten glass combustor, wpro-116, V2: 63
plasma arc furnace, wpro-107, V2: 64
Waste stabilization technologies
encapsulation, V2: 62

Waste processing sludges, TRU contamination only, waste management alternatives for
Biological treatment technologies
biosorption, wpro-226, V2: 82
Chemical treatment technologies
leaching and stripping, wpro-213, V2: 81
solvent extraction, wpro-211/212, V2: 81

000773

Waste processing sludges, TRU contamination only, waste management alternatives for *(continued)*
Thermal treatment technologies
evaporation, wpro-223, V2: 82
incineration, wpro-108, V2: 81
microwave treatment, wpro-115, V2: 81
molten glass combustor, wpro-116, V2: 82
plasma arc furnace, wpro-107, V2: 82
Waste stabilization technologies
encapsulation, V2: 80

Waste processing sludges, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Biological treatment technologies
biodegradation, wpro-117, V2: 143
Physical treatment technologies
recycle/reuse, wpro-130, V2: 142
shallow land burial, wpro-132, V2: 142
Thermal treatment technologies
incineration, wpro-108, V1: 106; V2: 143
microwave treatment, wpro-115, V2: 143
thermal desorption, wpro-106, V2: 142

Waste processing solid residuals, mixed waste contaminated (RAD, organics, inorganics), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 99; V2: 44
solvent extraction, wpro-211/212, V1: 100; V2: 45
supercritical fluid extraction, wpro-118, V1: 100; V2: 44
transmutation, wpro-219, V1: 102; V2: 45
Thermal treatment technologies
chem char process, wpro-114, V1: 100; V2: 46
incineration, wpro-108, V1: 100; V2: 45
microwave treatment, wpro-115, V1: 100; V2: 46
molten glass combustor, wpro-116, V1: 100; V2: 47
molten salt oxidation, wpro-113, V1: 101; V2: 46
plasma arc furnace, wpro-107, V1: 101; V2: 47
thermal desorption, wpro-106, V1: 101; V2: 46
wet air oxidation, wpro-215, V1: 102; V2: 46
Waste stabilization technologies
encapsulation, V1: 99; V2: 44

Waste processing solid residuals, RAD contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 64
transmutation, wpro-219, V1: 105; V2: 64
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 65
microwave treatment, wpro-115, V1: 103; V2: 65
molten glass combustor, wpro-116, V1: 104; V2: 65
plasma arc furnace, wpro-107, V1: 104; V2: 65
Waste stabilization technologies
encapsulation, V1: 102; V2: 64

Waste processing solid residuals, TRU contamination only, waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 103; V2: 83
transmutation, wpro-219, V1: 105; V2: 83
Physical treatment technologies
package to meet WIPP WAC, wpro-128, V1: 105; V2: 83
Thermal treatment technologies
incineration, wpro-108, V1: 103; V2: 83
microwave treatment, wpro-115, V1: 103; V2: 83
molten glass combustor, wpro-116, V1: 104; V2: 84
plasma arc furnace, wpro-107, V1: 104; V2: 84
Waste stabilization technologies
encapsulation, V1: 102; V2: 83

Waste processing solid residuals, uncontaminated (no RAD or RCRA hazardous waste contamination), waste management alternatives for
Chemical treatment technologies
leaching and stripping, wpro-213, V1: 108; V2: 144
Physical treatment technologies
landfill disposal, wpro-131, V1: 106; V2: 143
Thermal treatment technologies
incineration, wpro-108, V1: 106; V2: 144
thermal desorption, wpro-106, V2: 144
Waste stabilization technologies
encapsulation, V2: 143

Wastes excluded from Subtitle C, V1: 164

Waste surveillance and inspection, robotics and automation alternatives for
Controls—algorithms
combined mobility/manipulation, roba-34, V1: 140, 146; V2: 159
control modes, roba-27, V1: 139, 146; V2: 158
emergency shutdown, roba-37, V1: 140, 146; V2: 160
manipulation (Cartesian control), roba-31, V1: 140, 146; V2: 159
manipulation (joint control), roba-30, V1: 139, 146; V2: 159
manipulation (redundancy control), roba-33, V1: 140, 146; V2: 159
manipulation (special purpose control), roba-31, V1: 140, 146; V2: 159
safety (collision avoidance), roba-35, V1: 140, 146; V2: 159

safety (load/rate limiting), roba-35, V1: 140, 146; V2: 159
vehicle/mobility driving, roba-28, V1: 139, 146; V2: 159
vehicle/mobility navigation, roba-29, V1: 139, 146; V2: 159
Controls—human/machine interface
console (data handling methods), roba-39, V1: 140, 146; V2: 160
console (fixed/mobile/suitcase), roba-38, V1: 140, 146; V2: 160
operator interface (command input), roba-40, V1: 140, 146; V2: 160
operator interface (operator assistance), roba-41, V1: 140, 146; V2: 160
operator interface (status/alert system), roba-42, V1: 140, 146; V2: 160
Mechanical—end-of-arm tooling technologies
end-effector changeout mechanisms, roba-24, V1: 139, 145; V2: 158
end effectors/alternatives, roba-23, V1: 139, 145; V2: 158
force limiting/compliant mechanisms, roba-26, V1: 139, 146; V2: 158
general gripper/tool interface, roba-25, V1: 139, 146; V2: 158
Mechanical—manipulation technologies
compact high-capacity manipulators, roba-19, V1: 139, 145; V2: 158
dexterous manipulators, roba-16, V1: 139, 145; V2: 157
Mechanical—mechanism technologies
precise programmable motions, roba-20, V1: 139, 145; V2: 158
stabilization/support mechanisms or booms, roba-22, V1: 139, 145; V2: 158
tool caddies, roba-21, V1: 139, 145; V2: 158
Mechanical—mobility technologies
data/signal transmission, roba-13, V1: 139, 145; V2: 157
failure recovery systems for mobile platforms, roba-11, V1: 139, 145; V2: 157
long-arm deployed robotic platforms, roba-9, V2: 157
mounted robotic platform, roba-8, V1: 139, 145; V2: 157
power sources for mobile platforms, roba-10, V1: 139, 145; V2: 157
transportation systems for mobile platforms, roba-12, V1: 139, 145; V2: 157
wheeled/tracked vehicle, roba-1, V1: 139, 145; V2: 157
Other technologies
characterization sensor integration, roba-58, V1: 141, 147; V2: 162
field hardening, roba-53, V1: 140, 147; V2: 161
information management for sample handling, roba-56, V1: 141, 147; V2: 162
integrated automated analytical laboratory, roba-55, V1: 140, 147; V2: 162
radiation hardening, roba-54, V1: 140, 147; V2: 161
sample collection, roba-57, V1: 141, 147; V2: 162
sample preparation, roba-59, V1: 141, 147; V2: 162
Sensors—control
force/torque sensors, roba-50, V1: 140, 147; V2: 161
position/velocity sensors, roba-48, V1: 140, 147; V2: 161
proximity probes as control sensors, roba-51, V1: 140, 147; V2: 161
tooling sensors, roba-52, V1: 140, 147; V2: 161
Sensors—perception
force/torque sensors, roba-46, V1: 140, 146; V2: 161
proximity probes, roba-45, V1: 140, 146; V2: 161
range finders, roba-44, V1: 140, 146; V2: 160
visual/aural systems, roba-43, V1: 140, 146; V2: 160

Wavelength dispersive X-ray spectroscopy, char-36, V1: 49; V2: 14

Wet air oxidation, wpro-215, V1: 102, 110, 116, 117, 120, 122; V2: 43, 46, 97, 101, 120

Wheeled/tracked vehicle, roba-1, V1: 139, 145; V2: 145, 157

— X —

X-ray fluorescence for in situ monitoring of toxic heavy metals, char-219 and char-6, V1: 49; V2: 14

— Y —

Y-12 Plant Industrial Landfill, wdis-101, V2: 151

000775

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VOLUME 2

TECHNOLOGY LOGIC DIAGRAM

PART A
Decontamination and Decommissioning

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000778

Contents

Acknowledgments v

Foreword vii

Explanation and Understanding Key ix

Characterization 1
- General Problems
  - Sampling Design 3
  - Sample Collection 3
  - Sample Preparation 4
  - Detection/Measurement—Field Methods 5
  - Detection/Measurement—Laboratory Methods 6
  - Data Analysis/Management 7
- Radioactive Elements 10
- Inorganics 12
- Organics 14
- Physical 17
- Oils and Purex Chemicals 18
- Polychlorinated Biphenols 19

Dismantlement 21
- Massive Containment 23
- Reactor Pools 23
- Buried Tanks 25
- Structural-Only Concrete 26
- Steel Containment Structures (Highly Contaminated) 28
- Structural Steel 30
- Asbestos 32
- Major Equipment Removal 32
- Entombment 36
- Needed Enabling Technologies 40

Decontamination 45
- Concrete 47
- Painted Concrete 56
- Stainless Steel, Structural Steel, Cu and Al Pipe 61
- Concrete Block and Tiled Concrete (Tile Removed) 72
- Tiled Concrete (Tile Decontaminated In Situ) 82
- Building Materials (Wood, Sheetrock, Tar and Felt Roofing) 85
- Piping (Steel, INOR, Al, and Cu) 87
- Stainless Steel Tank 97
- Zincalloy, Steel, and Al with Activation Products 105
- Asphalt Pavement 107

Robotics and Automation 113
- Mechanical—Mobility 115
- Mechanical—Manipulation 116
- Mechanical—Mechanisms 116
- Mechanical—End-of-Arm-Tooling 117
- Controls Algorithms 117
- Controls—Human/Machine Interface 118
- Sensors—Perception 119
- Sensors—Controls 119
- Other Technologies 120

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Foreword

The *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) was developed to provide a decision-support tool that relates environmental restoration (ER) and waste management (WM) problems at Oak Ridge National Laboratory (ORNL) to potential technologies that can remediate these problems. The TLD uses information from the *Strategic Roadmap for the Oak Ridge Reservation* and a previous Hanford TLD.

The TLD identifies the research, development, demonstration, testing, and evaluation needed to develop these technologies to a state that allows technology transfer and application to decontamination and decommissioning (D&D), remedial action (RA), and WM activities. It is essential that follow-on engineering studies be conducted to build on the output of this project. These studies will begin by selecting the most promising technologies identified in the TLD and finding an optimum mix of technologies that will provide a socially acceptable balance between cost and risk.

The TLD consists of three fundamentally separate volumes: Vol. 1 (*Technology Evaluation*), Vol. 2 (*Technology Logic Diagram*) and Vol. 3 (*Technology Evaluation Data Sheets*). Part A of Vols. 1. and 2 focuses on D&D. Part B of Vols. 1 and 2 focuses on the RA of contaminated facilities. Part C of Vols. 1 and 2 focuses on WM. Each part of Vol. 1 contains an overview of the TLD, an explanation of the program-specific responsibilities, a review of identified technologies, and the rankings of remedial technologies. Volume 2 (Pts. A, B, and C) contains the logic linkages among EM goals, environmental problems, and the various technologies that have the potential to solve these problems. Volume 3 (Pts. A, B, and C) contains the TLD data sheets.

Decontamination and decommissioning is the focus of Vol. 2, Pt. A, which has been divided into the four necessary subelements of D&D: characterization, dismantlement, decontamination, and robotics and automation. Each of these sections address general ORNL problems, which are then broken down by problem area/constituents and linked to potential D&D technologies. The diagrams also contain summary information about a technology's status, its science and technology needs, and its implementation needs. The diagram structure is explained in detail in the Explanation and Understanding Key that follows.

The TLD *Index*, a stand-alone volume, facilitates information searches on specific technologies. The *Index* actually comprises three separate indexes, one for each of the corresponding parts (A, B, and C) of Vols. 1 and 2. Information can be searched by specific ORNL problem, problem area/constituents, or technology name.

The technology evaluations contained in these volumes are based on the best information available during compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. L. Fellows, Editor, *Oak Ridge National Laboratory Technology Logic Diagram,* Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

Explanation and Understanding Key for the Technology Logic Diagram

The logic elements described in the "Technical Approach" section of Chap.1 of the Executive Summary serve as column headings in this diagram.

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems

Describes the problem areas identified that are the responsibility of the ORNL EM organizations (D&D, RA, and WM). These problems may be at sites other than ORNL. These descriptions come from the current "official" lists from each of these areas.

Problem Areas/Constituents

Addresses a subelement-specific list of problems, all of which are traceable directly to the ORNL problems. For example, the diagram for decontamination defines the problems/constituents in terms of (hazardous) contaminants and the substrate on which the contaminants reside. In contrast, the dismantlement diagram defines the problems/constituents in terms of massive concrete, structural steel, metal equipment, etc. In both examples, the problem/constituent is the dominating technical factor in selection of technologies to remediate the problems.

Reference Requirements

Refers to the Regulatory Compliance Chapter in the applicable Vol. 1 for D&D, RA, or WM. Requirements can only be determined after consideration of detailed site-, waste-, and technology-specific characteristics. Any pertinent milestones associated with remediation of the problem are listed.

Disposition indicates the (proposed) disposition or end state of the ORNL facility or land that is, or contains, the problem.

Subelements

Specifies the different components that must be addressed to solve the EM problem. For example, D&D activities are associated with characterization, decontamination, dismantlement, disassembly, materials disposition, robotics/automation, and regulatory compliance. The comparable subelements for RA are characterization, containment/isolation, treatment, retrieval, materials disposition, robotics/automation, and regulatory compliance. The subelements for WM are waste retrieval; characterization; processing; stabilization; minimization; packaging, handling, and transportation (PH&T); and disposal.

Alternatives

Provides the general or generic technology approaches to problem remediation.

Technologies

Provides a specific technology that may reasonably be applied to remediate the problem. **Technology Evaluation Data Sheet (TEDS) Codes**, located after the technology names in this column, refer to TEDSs in Vol. 3. The TEDS address each technology in more detail. Each TEDS contains a single, unique logic path from the Diagrams.

Rankings appear after the TEDS code for each technology. The technologies are ranked according to the following criteria:

- Overall assessment of usefulness (E—essential, H—high, M—medium, L—low)
- Ranking of the site problem (1–5 from lowest significance to highest)
- Time required to bring the technology to commercial or mature state at the site—expressed in years.
- Cost for bringing the technology from its present state to large-scale commercial use (millions [$M] or thousands [$K] of dollars).
- Projected unit processing cost for mature technology ($ per ft^3 or other unit or N for no estimate).

An example of a ranking follows: H-5-5 ($3.5M;N). This technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of $3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

Status

Provides information on the status of the preceding technology.

- **In Use**—problem is in the process of being remediated with this technology.
- **Accepted**—accepted by industry and/or the problem owner. The demonstrated technology exists for use at ORNL.
- **Demonstration**—technology is available but is not demonstrated and/or accepted for the problem at ORNL.
- **Predemonstration**—technology is under laboratory-, bench-, or pilot-scale testing.
- **Evolving Technology**—technology status is at a conceptual or preconceptual stage.
  - **Conceptual**—a scientific or knowledge basis for the technology exists.
  - **Preconceptual**—only a partial scientific or knowledge basis of the technology exists.

The following areas further define the applicability of a technology to the problem:

- **Efficacy**—the effectiveness of the technology in remediating the problem. Normally, quantitative measures are given for the technology's performance in standard practice, such as decontamination, estimating the final dpm/cm^2 of surface contamination; dismantlement, the time to cut a 24-in. pipe; and characterization, the analysis time and lower detection limit.
- **Waste**—the potential output from the technology. This describes the nature and volume of both the waste and the potentially useful materials (recyclable) suitable for materials disposition evaluation.

Science/Technology Needs

Lists needs in Science and Technology where support should be applied to develop an "immature" technology to a field-deployable state.

Science needs are related to the fundamental understanding of the scientific phenomena that form the basis for the technology. These needs are typically for laboratory or bench-scale experiments, and, when possible, experiments addressing specific areas of uncertainty are suggested.

Technology development (TD) conversion of a scientifically understood phenomenon into an operating system (technology) that can be applied to, and can remediate an EM problem.

Technology improvement needs relate to improvements that make a current technology more economical to apply, safer, and more effective or efficient. The demonstration of a technology on a site-specific problem is classified as a technology improvement need.

If scientific needs are specified, it should be understood that the needs of scientific technology development or improvement are necessary to implement newly developed scientific understanding. Likewise, testing a TD opportunity implies that technology improvements are also likely to be needed.

Past and currently funded Technical Task Plans (TTP) were correlated with the technologies. If a match was found, **"TTP Match"** appears in this column. The TTP number and technology number matches can be found in the TTP tables of Vol. 1, Pt. A, Pt. B, and Pt. C.

Implementation Needs

Covers many of the areas of concern for technology transfer activities. Specialized needs for both development of a technology and deployment of a mature technology are identified.

These needs were evaluated in the areas of (1) resources (financial or personnel); (2) hardware (process equipment, development equipment, and computers); (3) software (models, procedures, computer programs); (4) facilities (labs, shops, and buildings); and (5) education (training classes or degreed personnel). Only extraordinary needs are highlighted (i.e., those needs that would require long lead time or unusual procurements such as line items for facility construction).

Technology Integration identifies the technologies which can be integrated to produce a safer, better or cheaper remediation system.

The **cost** of applying the technology and the payback cost potential has been estimated. There are many reasons for payback, such as reducing the waste volume compared to a reference process, the sale of useable products, and the reduction of labor compared to a reference technology.

Characterization for Decontamination and Decommissioning

The Characterization section is comprehensive [illegible] generally inclusive [illegible] of ORNL Problems to which most of the [illegible] and of smaller [illegible] for the other ORNL problems where a [illegible] in addition to those offered in the general section. The former section is divided into [illegible] under the alternatives column. These [illegible] subsections, and sampling design, sample [illegible] sample preparation, [illegible] field methods, detection [illegible] data analysis [illegible] following these general subsections are listings under the [illegible] of radioactive elements, inorganics, organics, physical, and pathogens. [illegible] into field methods [illegible] methods according to their primary deployment.

Characterization for Decontamination and Decommissioning

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**All Problems Including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3035 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	General	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Sampling Design				
					M	Sequential Sampling Plans CHAR-252-OL *Ranking:** *M-3-5 ($.1M;$.5Kam*)*	**Accepted** **TTP Match**	Experimental Site Data **Available at X-10.**	Initial Planning Time
					E	Sampling Program Configuration Management System CHAR-228-OL *Ranking:** *E-5-1 ($.5M;$50Kam*)*	**Accepted** A range of application software to assist with configuration management is available both commercially and in the public domain. **TTP Match**	Enhancements to existing products may be required to provide the level of support needed for a large sampling program. **Available at X-10.**	Separate configuration management systems should be considered for each of (a) Characterization Sampling Program, (b) Remedial Action, (c) Waste Management, and (d) Decontamination and Decommissioning instead of setting up one large all-encompassing system.
					H	Optimization of Sampling Designs CHAR-71-OL *Ranking:** *H-5-.5 ($.1M;N)*	**Demonstration**	Literary searches for finding useful sampling designs from investigations in other fields. New statistical methods for sampling design. **Available at all sites.**	**Development Costs:** $100K
					Sample Collection				
					M	Ultrasonic Extraction CHAR-20-OL *Ranking:** *M-4-1 ($.2M;$400/sample)*	**Predemonstration,** technology not yet demonstrated. **TTP Match**	Testing needs to be performed to establish the enhancement of material retrieval from porous media using various solvents, acids, and bases.	**Hardware cost:** $2-5K; **Development Costs:** $200K. Inverse heads need to be designed for sampling from the floors and other horizontal (top-side) applications.
					M	In Situ Solvent Extraction CHAR-62-OL *Ranking:** *M-4-2 ($.4M;N)*	**Evolving Technology** (conceptual) **TTP Match**	Model studies are needed to develop the technique.	**Development Costs:** $400K
					E	Sampling and Mixing Methods CHAR-81-OL *Ranking:** *E-5-1 ($.2M;N)*	**Accepted** **TTP Match**	Need to optimize methods for collection of representative samples and to mix samples into a homogeneous state.	Requires statistical sampling design and proper laboratory blenders, mixers, and other equipment. **Development Costs:** $250K
						Membranes for Sample Collection and Concentration CHAR-55-OL *Ranking:** *No Ranking.*	**Accepted** Membranes are predominantly permeable to selected components in mixtures allowing separation for accumulation or to facilitate analysis/detection. **TTP Match**	System development or adaptation for specific applications; validation.	Sample collection systems for Site-specific applications.
					H	Punch Cores CHAR-82-OL *Ranking:** *H-5-1 ($.3M;N)*	**Demonstration**	None	Need to acquire and setup methods and equipment for coring sample matrices important at ORNL. **Development Costs:** $300K
					H	Metallographic Sectioning and Preparation CHAR-67-OL *Ranking:** *H-4-0 ($0M;<$500/sample)*	**Accepted**	Procedure development for specific applications are needed; then protocols for standardized preparation should be developed. **Available at X-10, K-25.**	None
					H	Multi-angle Drilling for Depth Profiling of Contaminants CHAR-64-OL *Ranking:** *H-4-1 ($.2M;N)*	**Demonstration**	Model studies need to be performed. **Available at K-25.**	**Development cost:** $200K

** See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.*

Characterization for Decontamination and Decommissioning

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D)	**All Problems Including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3035 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	General	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Sample Collection	Sampling Interface System for Surface Contamination by Organics CHAR-271-OL *Ranking:** *H-4-3 ($.775M;N)*	**Conceptual** **TTP Match**	Development of rapid heating interface and software for rapid contaminant identification by direct sampling ion trap mass spectrometry.	**Development cost:** of $775K over 3 years.
					H	Flashlamp Heating to Release or Desorb Surface and Subsurface Contaminants CHAR-87-OL *Ranking:** *H-4-2 ($.5M;N)*	**Predemonstration**	Depth profiling and surface area sampled must be determined for each material. Means of sampling the plume must be developed for each analyte.	To be determined for specific applications.
					H	Laser Ablation for Sample Collection CHAR-86-OL *Ranking:** *H-4-2 ($.5M;N)*	**Predemonstration** **TTP Match**	The technology for laser ablation is just now becoming available, and a program would be needed to develop the technique for practicing application of the analysis.	Same as Science/Technology needs.
					Sample Preparation				
					H	Radioactive Sample Preparation CHAR-205-OL *Ranking:** *H-4-1 ($.1M;N)*	**Demonstration**, current work shows that methods can be adapted to meet these needs. **TTP Match**	Adaptation of EPA and other methods, and development of new technologies for the safe and efficient preparation of radioactive samples for analysis. **Available at X-10.**	**Development cost:** $500K each of 2 years; personnel and facilities are available.
					H	Supercritical Fluid Extraction of Organics CHAR-208-OL *Ranking:** *H-4-1 ($.33M;$100/sample)*	**Predemonstration**, technology requires final development. **TTP Match**	Extraction conditions need to be optimized for the specific target analytes and matrices at the ORNL site. **Available at X-10.**	**Hardware cost:** $30K; **Development cost:** $300K
					H	Adaptation of the EPA Toxicity C haracteristic Leaching Process for Use with Radioactive Samples CHAR-209-OL *Ranking:**	**Predemonstration**, some work has been conducted, but full adaptation and testing remain to be done. **TTP Match**	The leaching equipment and protocol must be adapted to glove box and hot cell operations. **Available at X-10.**	**Development cost:** $450K. Equipment must be modified and tested under containment and shielding.
• Remedial Action (RA)—Soils, Ground Water and Surface Water					M	Supercritical Fluid Extraction of Inorganics CHAR-201-OL *Ranking:** *M-3-2 ($.2M;N)*	**Predemonstration** Supercritical Fluid Extraction of Inorganics, extraction of metal ions from liquid and solid material by supercritical carbon dioxide and chelators. **TTP Match**	Need to determine optimum extraction conditions, including chelators. **Available at X-10.**	**Equipment cost:** $30K; **Development cost:** $400K over 2 years.
					H	Microwave Digestion CHAR-19-OL *Ranking:** *H-5-1 ($.2M;$100/sample)*	**Accepted** **Demonstration** **TTP Match**	This technology shows much promise in reducing the amount of waste produced in analyzing samples as well as increasing the quality of the data obtained. **Available at X-10.**	Protocols are needed to optimize the digestion of environmental samples in preparation for subsequent analytical techniques.
• Waste Management (WM)					H	High Pressure Ashing for Sample Preparation CHAR-203-OL *Ranking:** *H-4-1 ($.1M;N)*	**Demonstration** Commercially available, but not mature.	High Pressure Ashing (HPA) is useful for the dissolution of organics and other difficult to dissolve materials. Commercially available but lacks sufficient validation to meet QA requirements. Some special sample types may be at the development stage. **Available at X-10.**	Some equipment/personnel currently available at ORNL to develop new procedures, but needs to be expanded to meet the increased work load. Estimated cost $60-120K/year for 2 years.

** See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.*

Characterization for Decontamination and Decommissioning

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**All Problems Including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3035 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulseleeder Pumps Pavement over 55-gal. Drum	General	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Detection/Measurment - Field	Fiber Optic Chemical Sensors CHAR-25-OL *Ranking:** *H-5-1 ($1M;$10/sample)*	**Accepted; Demonstration.** Remote detection using a variety of methods including optical absorption, Raman scattering and luminesce spectroscopy. The fiber optic is used to deliver or return light to or from the sample. This technology allows remote sensing in hazardous environments.	A combination of waveguides and spectroscopic techniques are needed that have been matched not only for each other but also for specific monitoring scenarios.	Waveguides are needed that can withstand the harsh chemical environment that may be present in some of the sampling locations.
						Ion Mobility Mass Spectrometry (IMMS) CHAR-264-OL *Ranking:** *M-5-2 ($1M;$50/sample)*	**Predemonstration.** Provides a means for the rapid separation and identification of complex mixtures based on the mobility of ions in an electric field at atmospheric	Software control of high-speed data acquisition, interpretation and instrument control. **Available at X-10.**	**Hardware costs:** $30K; software development additional.
						Immunoassay Detection CHAR-23-OL *Ranking:** *H-5-3 ($1M;$50/sample)*	**Accepted** Immunoassay detectors are used to determine environmentally important analytes. The technique is very selective and sensitive extremely easy to use.	This is a mature and emerging technology. Kits are designed to perform in specialized waste streams. DOE has calibrated PCB kit in the Analytical Field Screening Program.	Automated sampling and reading systems for quick on-line testing of groundwater and waste stream contamination.
						Portable Raman Spectrometer CHAR-84-OL *Ranking:** *M-5-2 ($1M;$10/sample)*	**Demonstration of field capabilities at ORNL.** Raman spectra provide finger print identification of chemical species. No direct contact with the sample is necessary. Often interfaced with fiber optics for remote sensing in inaccessible areas. **TTP Match**	Need portable equipment (laser,etc.) for in-situ use. Develop methods which exploit surface enhancement and resonance excitation for vastly improved sensitivity.	Equipment available at ORNL. Not assembled yet for specific applications.
						Optical Absorption Spectroscopy (OAS) CHAR-27-OL *Ranking:** *H-5-1 ($.6M;$50/sample)*	**Accepted Demonstration** Measures the transmission of UV, visible, and near IR to determine the concentration of chemical species in gases, liquids, or solids. OAS can be applied to the analysis of any species which absorbs electromagnetic radiation is the region of excitation, UV through IR. **TTP Match**	Mature, field-portable technology available in IR, UV. **Available at all sites.**	It can be implemented for site-specific needs.
						Air Monitoring CHAR-59-OL *Ranking:** *H-5-0 ($.25M;$500/sample)*	**Accepted** Encompasses several methods of monitoring particulate loading and characteristics during remedial action and decontamination and decommissioning activities. Collected samples can be analyzed for may different	This is a mature sampling technology with EPA protocols. **Available at all sites.**	This is a mature technology.
						Infrared Spectroscopy (Wavelength Dispersion) CHAR-18-OL *Ranking:** *M-5-1 ($.5M;$100/sample)*	**Accepted** This method includes: Long path (LP-FTIR); diffuse reflectance (DRIFT); and attenuated total reflectance (ATR) for determination of compounds found in the air, water, or on surfaces. **TTP Match**	No units currently exist on-site. Several vendors are marketing equipment. Software development would enhance site-specific applications. **Available at all sites.**	Centralized mounting areas with robotically controlled unit would allow multiple site areas to be monitored with one unit.
						Personnel Monitoring CHAR-52-OL *Ranking:** *H-5-1 ($.2M;N)*	**Demonstration**	Model studies are needed to correlate exposure and quantitative analysis from various human factors. **Available at all sites.**	We need a detailed monitoring program for personnel protection.

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Characterization for Decontamination and Decommissioning

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					M	Portable Luminescence Detection CHAR-92-OL *Ranking:** *M-5-1 ($.5M;$10/sample)*	**Predemonstration** The detection of organic and inorganic status chemicals using fluorescence, phosphorescence, and chemiluminescence. **TTP**	The technology is mature, but may not provide absolute identification of compounds in complex mixtures. **Available at all sites.**	Hardware is available at ORNL. Specific techniques need development and procedures written.
					M	Electrochemical Methods CHAR-10-OL *Ranking:** *M-4-2 ($.5M;$100/sample)*	**Accepted** Oxidizable or reducible species, excited by a voltage or current function in an electrical circuit, yield quantitative and qualitative information about species of interest. Selective and sensitive sampling is possible in many situations. **TTP Match**	Adaptation and protocols for model studies to be performed on complex systems are needed.	**Hardware cost:** $50K-$250K; **Development cost:** are $250K.
					Detection/Measurment - Lab				
					H	Contamination Control—Analytical Equipment CHAR-204-OL *Ranking:** *H-5-2 ($.5M;N)*	Commercially available for some systems, but usually must be done on a case-by-case basis due to facility limitations and different containment requirements. **TTP Match**	Contamination control for analytical equipment/instrumentation frequently requires extensive instrument modification to contain the equipment in radiochemical hoods, gloves boxes, or hot cells. **Available at X-10.**	Some equipment/personnel currently available at ORNL but needs to be expanded to meet the expected increase in work load. Implementation includes engineering design, fabrication of containment/shielding, and modification of facility. Typical cost for containment of an ICP in a glove box was approximately $150K several years ago; this did not include the cost of the instrument.Requires special expertise, but must be done for higher levels of radioactivity.
					M	Fourier Transform Infrared Spectroscopy (FT-IR) CHAR-8-OL *Ranking:** *M-4-1 ($.2M;$100–500/sample)*	**Accepted** **TTP Match**	Data base for rapid materials identification and model studies of materials interaction is needed. **Available at all sites.**	**Hardware cost:** $25K-$500K; **Development cost:** <$200K
					H	Isotopic Dilution Mass Spectrometry (ID-MS) CHAR-48-OL *Ranking:** *H-4-0 ($0M;$100–1000/sample)*	**Accepted**	Models studies are needed to enable quick analysis. **Available at X-10.**	Equipment, as well as the model studies mentioned above, is needed.
					M	Nuclear Magnetic Resonance (NMR) CHAR-11-OL *Ranking:** *M-4-0 ($0M;$200–500/sample)*	**Accepted, available on-site** **TTP Match**	None, available on-site. **Available at X-10.**	**Hardware cost:** $200K-$2M; **Development cost:** $200K-$500K.
					H	Secondary Ion Mass Spectroscopy (SIMS) CHAR-3-OL *Ranking:** *H-4-0 ($0M;$50–400/sample)*	**Accepted**	This is a mature technology. Model studies are needed to calibrate for depth-profiling studies. **Available at all sites.**	Instrumentation and personnel exist at the three plants.

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Characterization for Decontamination and Decommissioning

L-775 1

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
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					H	Laser Ionization Mass Spectrometry (LIMS, LAMMA, LIMMA) CHAR-4-OL *Ranking:** *M-4-0 ($0M;$100/sample)*	**Accepted** **TTP Match**	This is a mature technology. Model studies are needed to optimize results interpretation.	Prototype instrumentation and research instrumentation exists. More equipment would be required. The necessary personnel are available.
					M	Fourier Transform Infrared Spectroscopy (FTIR) CHAR-8-OL *Ranking:** *H-5-0 ($.1M;$50–200/sample)*	**Accepted, available on-site** **TTP Match**	Model studies and application design. **Available at all sites.**	**Hardware cost:** <$200K; **Development cost:** <$100K.
					H	Electrochemical Methods CHAR-10-OL *Ranking:** *M-4-1 ($.25M;>$100/sample)*	**Accepted** Oxidizable or reducible species, excited by a voltage or current function in an electrical circuit, yield quantitative and qualitative information about species of interest. Selective and sensitive sampling is possible in many situations. **TTP Match**	Adaptation and protocols for model studies to be performed on complex systems are needed.	**Hardware cost:** $50K-$250K; **Development cost:** are $250K.
					M				
				Data Analysis/Management		Project Information Access Services (Needed Enabling Technologies) DISM-151-OL *Ranking:** *No Ranking.*	**Demonstration**, an integrated project information access and management system is sufficiently different from current types of electronic information access support with DOE facilities as to warrant requiring a demonstration before deciding to proceed with implementation.	Technology to implement such a system is commercially available.	Computer networks, especially Ethernet (cable, fiber), need to be extended throughout the laboratory and other Energy Systems facilities.
					M	Network Architecture with Integrated Workstations CHAR-221-OL *Ranking:** *M-4-1 ($.25M;>$100/sample)*	**Demonstration** Commercial engineering workstations provide the capabilities to support this technology.	The greatest obstacle to use of this technology is the current legacy of older operating systems (DOS, MacOS) not designed to support integration of desktop applications with each other and with network services. **Available at X-10.**	This technology is best introduced in the context of a commitment to use open system standards for all new computer acquisitions.
						Client/Server Access to Standards and Regulatory Guidelines (Needed Enabling Technologies) DISM-153-OL *Ranking:** *No Ranking.*	**Demonstration**	Technology development needs are greatest in developing or acquiring a good, common user interface to support integration of the component technologies.	
					E	Data Access Services DISM-154-OL *Ranking:** *E-5-1 ($.5M;$200Kam)*	**Demonstration** The particular network and communications configurations needed to support restoration activities may not exist, so would have to set up and their successful operation demonstrated.	Some software will be available commercially; some will have to be developed locally.	Requirements and specifications for such services must be identified and documented to serve as a common reference so that data can be accessed using a single set of services regardless of the type of computer at each node on the

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Characterization for Decontamination and Decommissioning

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						Automated Scanning and Conversion of Engineering Drawings (Needed Enabling Technologies) DISM-155-OL *Ranking:** *No Ranking.*	**Demonstration** The basic technology is well established. Whether the current state of the art can adequately process the large number of drawings needed for reference and how effectively this technology can be integrated with other aspects of automated support needs to be demonstrated.	Improvements are needed in the speed and accuracy of converting scanned images to graphical representations that will meet the needs (e.g., ability to change scale to show more detail) of the environmental restoration program.	Considerable human intervention may be required to handle large drawings or drawings that cannot easily be laid flat on a scanning bed.
						Hazard Analysis Expert System CHAR-233-OL *Ranking:** *E-5-2 ($.5M;$150Kam)*	**Demonstration** Expert systems have been very effective tools for some applications; success or failure depends critically on how well the problem domain has been analyzed and how thoroughly the knowledge base has been specified.	Availability of and access to specification and design tools for developing the knowledge base and structure of the rules are the biggest needs.	Implementation strategy and problem analysis process used are the most important elements of developing a successful hazard analysis expert system.
						Application of Approximate Reasoning to Data Analysis/Evaluation CHAR-234-OL *Ranking:** *E-5-2 ($.5M;$150Kam)*	**Demonstration** Effective and successful use of this technology depends on availability of experienced and qualified technical people.	Development is needed of tools (e.g., a range of graphical models designed to assist in visualizing relationships) to assist with conceptual analysis or to examine consequences of choosing a logical strategy (e.g., automated theorem provers) in the analysis of problems.	Powerful computing capabilities exist for applying approximate reasoning techniques but are not widely used. Education and training in the use of this technology will be needed.
						Simulated Walkthrough Facility for Robotics Task Sequence Analysis (Needed Enabling Technologies) DISM-171-OL *Ranking:** *E-5-1 ($.3: $60K)*	**Demonstration** The IGRIP applications software running on a Silicon Graphics workstation is capable of identifying situations in which collisions will occur. It can also use human factors and ergonomics data to indicate which tasks requiring human assistance are or are not possible or safe for a human operator to	Development of support reference databases (e.g., human factors, ergonomics) to increase the effectiveness of this technology is an area of need.	The greatest need is to acquire the site-specific data, organize, assemble, and store it for rapid retrieval across computer networks. Integration of this technology with other networked resources will also be required at each site.
						Computer-based Training Systems (Needed Enabling Technologies) DISM-191-OL *Ranking:** *E-6-1($.3M) $100K*	**Demonstration** Application software is available that permits rapid development of courses using many media (visual, audio), including support for a variety of testing strategies.	Further development is needed in the area of authoring support.	A well-defined course development life cycle does not yet exist. Currently used software engineering development life cycle methods should work well.
						Computer-aided Task Analysis and Procedure Preparation (Needed Enabling Technologies) DISM-172-OL *Ranking:** *E-5-1 ($.5M: $150Kam)*	**Demonstration** This technology is used extensively in planning by various federal agencies, most notably the Department of Defense in military operations planning.	More natural language analysis tools are needed to assist with analysis of information used for planning, much of which is provided in text form.	Knowledge base development will require the largest effort, followed by development of expert systems and decision aids needed to make effective use of the information in the knowledge bases.

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Characterization for Decontamination and Decommissioning

L-7751

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						E Hypertext Information Systems (Needed Enabling Technologies) DISM-158-OL *Ranking:* E-5-1 ($.3M: $150Kam)*	**Demonstration** A range of products exists to support development of hypertext information systems having many capabilities such as mechanisms for linking related items, for starting execution and controlling other applications, and for navigating documents for faster access to information.	Authoring and design tools are needed.	Hypertext information systems must be designed with great care to avoid problems with maintenance (e.g., modifying or replacing blocks of text from which or to which many links have been made to selected text strings within the block).
						H Spatial Sample and Data Analysis Plans CHAR-253-OL *Ranking:* H-3-.5 ($.1M;$.5Kam)*	**Accepted TTP Match**	Personnel and computer time, access to survey data **Available at X-10.**	Time and data
						M Statistical Methods for the Analysis of Large Data Sets CHAR-251-OL *Ranking:* M-3-3 ($.5M;$.5Kam)*	**Conceptual**	To allow for the survey of many areas, statistical methods to take advantage of new parallel processors may need to be developed. **Available at X-10.**	Possible large-scale computer needs and software development time.
						E Quality Control for Measurement Processes CHAR-250-OL *Ranking:* E-4-.25 ($.05M;$.5Kam)*	**Accepted TTP Match**	Data from standards evaluations **Available at X-10.**	Access to quality standard measurements
						H Analysis of Censored Data CHAR-249-OL *Ranking:* H-4-.25 ($.05Kam)*	**Demonstration**, some work is available in the literature. The application likely will have to be expanded to meet current needs.	Computer work station with access to appropriate data bases. **Available at X-10.**	Access to appropriate data bases, computer time, mathematical development time, and programming time.
						L Criticality Indices (CI) CHAR-44-OL *Ranking:* L-2-1 ($.25M;N)*	**Accepted**	The program must be implemented to specifically address the D&D technologies to be implemented and suggest the modifications that are needed for low- versus how-enrichment materials.	Same as Science/Technology needs.
						M Modeling of Volatile Organic Compounds Migration in Porous Materials CHAR-53-OL *Ranking:* M-4-1 ($.2M;N)*	**Demonstration TTP Match**	Models need to be developed that are applicable to site-specific scenarios.	Software and hardware are needed to implement the modeling systems.
						M Task-scheduling Aids CHAR-241-OL *Ranking:* M-4-1 (0.5M;N)*	**Demonstration** Several component technologies must be integrated to provide the level of support needed for the highly regulated environment in which restoration activities will be conducted.	A combination of automated analysis tools (e.g., automated reasoning, theorem provers) and a conceptual framework for representing regulatory requirements needs to be developed that can identify possible logical conflicts that arise in scheduling tasks on jobs for which many requirements must be met.	Validation of data used for generating schedules will require much more attention in cases in which many regulations and requirements must be met.

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					E	3-D CAD Database of Buildings and Structures (Needed Enabling Technologies) DISM-156-OL *Ranking:** *E-5-2 ($2M: $300Kam)*	**Accepted** The basic technology is in wide use. A variety of commercial products is available for use on systems ranging from desktop computers to large mainframes.	Integration of this technology with the other supporting technologies that must work together with it to provide the high level of automation needed to assure proper compliance with environmental legislation governing restoration activities will be the main technology need.	Identification of all possible uses (e.g., "training" robots, visual "walkthroughs", tags for tracking activities) of this technology and development of database requirements to support them are very important foundations for effective use of this technology.
					M	Fractals Uesd to Select Models for Material Transport in Porous Media CHAR-225-OL *Ranking:** *M-2-2 ($.5M;$20Kam)*	**Evolving** One of the early application areas of the mathematical concepts of fractals and fractal geometry has been to flow in porous media.	Application of fractal concepts to problems of flows in porous media is useful in classifying existing models according to what is appropriate to use for a particular situation. **Available at X-10.**	Fractal concepts may be applied to analysis of data or to output from porous flow model calculations as criteria incorporated into existing software.
• Remedial Action (RA)—Soils, Ground Water and Surface Water		Radioactive Elements	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Field Methods	Proportional Counter for Alpha and Beta Activity CHAR-108-OL *Ranking:** *H-5-0 ($.1M;$100/sample)*	**Accepted**	This is a well-established technology. Some minor development may be needed to distinguish Technetium activity from Uranium. Probes for measuring vertical or overhead items are needed.	Normal
					M	Passive Monitors for Weak Beta Radionuclides CHAR-102-OL *Ranking:** *M-4-2 ($.6M;$20/sample)*	**Predemonstration** The thermally stimulated exoelectron (TSEE) technique is the weakly penetrating radiation analog to thermoluminescence. The exposed TSEE dosimeter is heated to liberate low-energy electrons from a thin surface layer. The thin exoactive layer is especially sensitive to low-energy, beta radiations such as those from H-3, C-14, or Tc-99.	A thorough evaluation of this technology is needed for differentiating Tc-99 from other radionuclides in mixed-surface contaminations. Pairs of detectors, one with a beta absorber on its surface, will be needed to discriminate weak beta from more penetrating radiations.	A commercial TSEE reader is available at ORNL. Different types of ceramic exoelectron materials should be tested to select the most suitable type for H-3, Tc-99, and other applications. Approximately $100K will be needed for development.
					M	Thermoluminescence Dosimeter Array for Spatial Characterization of Surface Alpha Contamination CHAR-103-OL *Ranking:** *M-4-3 ($.6M;$20/sample)*	**Demonstration** A flexible sheet containing a fine grid of miniature thermoluminescence dosimeter elements that have a preferential sensitivity to alpha rays. Exposed sheets are scanned with a laser beam to heat the individual chips and produce a readable thermoluminescence that is converted into a two-dimensional map.	It will need to be adapted to specific D&D needs. Size and shape of detector sheets need tailoring to specific geometrics. Discriminating ability in mixed radiation fields needs further definition. Technique is well-established but investigation of potentially confounding factors is needed. Such factors include moisture, oil, and radon.	**Development cost:** ~$200K.
• Waste Management (WM)					M	Long-Range Alpha Detector (LRAD) CHAR-65-OL *Ranking:** *M-4-1 ($.4M;$100/sample)*	**Demonstration** It is a screening device for detecting alpha radioactivity on surfaces or personnel and in soil or waste. It measures ionized air drawn from a container holding a contaminated object, irrespective of shape. **TTP Match**	Overall cost-$10K/device; after commercialization price should decrease.	Adaptation for site-specific applications. Field testing is needed (~$300K).

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Characterization for Decontamination and Decommissioning

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives		Technologies	Status	Science/Technology Needs	Implementation Needs
All Problems including various subparts of the following facilities: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3035 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	Radioactive Elements	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Field Methods	M	Bubble Dosimeters for Neutron Flux CHAR-216-OL *Ranking:** *M-4-1 ($.2M;$15/sample)*	**Accepted** These dosimeters are an integral part of a field neutron dosimetry system for use where neutron sources and shielding are not well known. They are capable of measuring neutron dose equivalent in low level fields and of providing simple spectral information.	The technique is well established in measuring neutron flux around personnel. It must be evaluated in potential confounding effects in less benign environments.	~$200K is needed to develop acoustic coupler for applications requiring real-time measurement of neutron dose rate and for development of a less expensive, automated bubble counter for reliable processing of passive detector results.
					H	Tritium/Beta/Gamma Floor Scanner CHAR-105-OL *Ranking:** *H-4-0 ($OM;N)*	**Predemonstration** A surface monitor is commercially available that utilizes, interchangeably, a tritium windowless proportional counter and a xenon-filled beta/gamma proportional counter.	None	Technology is currently available.
					H	Portable Gamma-Ray Scintillometers CHAR-263-OL *Ranking:** *H-4-0 ($0M;$100/sample)*	In either single-channel or multichannel format, they are available commercially. The instrument consists of a NaI crystal, photomultiplier tube, portable battery-operated power supply, pulse height analyzer, and readout. **TTP Match**	Robotic technology needed for remote control applications.	The technology is commercially available. Specialized detector holders may need to be developed for particular applications.
					M	Advanced Radiation Monitors CHAR-269-OL *Ranking:** *M-4-2 ($.4M;$50/sample)*	**Predemonstration** **TTP Match**	Development of additional probes is needed. **Available at X-10.**	Ca. $400K development costs over 2 years.
					H	Electret Passive Surface Alpha Monitor CHAR-95-OL *Ranking:** *H-4-1 ($.3M;$15/sample)*	**Demonstration** It is a device that performs as a passive ion chamber when placed on a contaminated surface; positive ions produced by alpha particles are drawn to a negatively charged Teflon electret screwed into the roof of the chamber. Sensitivity is sufficient to quantify alpha contamination after a few hours of exposure even at the most stringent DOE release limit of 100 dmp/100cm2.	The effects of potential confounding factors (e.g., dust, moisture, oils) need to be evaluated and ameliorated.	The limits of alpha monitoring in mixed radiation fields needs to be defined. Algorithms for multidevice deployment should be developed and tested to give a high confidence level of not missing contamination on large area surfaces. Development of needed protocols will require 1-2 years of effort.
					H	Alpha Track Etch Detectors for Surface Alpha Contamination CHAR-96-OL *Ranking:** *H-4-1 ($.4M;$10/sample)*	These are Alpha-sensitive plastics that can be cut to a size appropriate for specific applications, e.g., to fit inside pipes or in narrow crevices. After exposure, the plastic is developed chemically to visualize damage tracks produced by alpha emitting contamination.	Technique is well-established (i.e., commercially available) for measuring alpha activity in indoor air. Potentially confounding factors in surface or soil applications include: inhomogeneously sized particles, moisture, oils, and radon in soil.	Plastic monitors of differing sizes and flexibilities need to be tailored and fabricated for specific tasks to be identified in pilot testing on-site. Deployment of detectors in large numbers will require establishment of on-site chemical etching and track reading capabilities.
				Laboratory Methods	H	Neutron Activation CHAR-107-OL *Ranking:** *H-4-1 ($.2M;$300/sample)*	**Demonstration** **TTP Match**	Development is needed for containers that are larger than 55-gal drums. Separate calibration standards are needed for each matrix.	Normal

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Characterization for Decontamination and Decommissioning

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives		Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	**All Problems including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	Radioactive Elements	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Laboratory Methods	H	Sodium Iodide-Germanium Gamma Spectroscopy CHAR-106-OL *Ranking:** *H-4-0 ($OM;N)*	**Accepted** **TTP Match**	Correction factor methodology needs to be published.	None
						H	Upgrade of Radioanalytical Procedures CHAR-202-OL *Ranking:** *H-4-2 ($1M;N)*	**Development** Upgrade of Radioanalytical Procedures, general upgrade and modernization of radiochemical separation technology. **TTP Match**	Considerable new technology is available but lacks sufficient validation to meet QA requirements. Other areas are at the basic development stage. **Available at X-10.**	Some instrumentation/personnel currently exist at ORNL to develop new procedures but needs to be expanded to meet the increased work load. Estimated cost $600K/year
EM Problems • Facility Decontamination and Decommissioning (D&D)						H	Proportional Counter for Activity CHAR-108-OL *Ranking:** *H-5-0 ($.1M;$100/sample)*	**Accepted**	This is a well-established technology. Some minor development may be needed to distinguish Technetium activity from uranium. Probes for measuring vertical or overhead items are needed.	Normal
						H	Photo Electron Rejecting Alpha Liquid Scintillation (PERALS) CHAR-97-OL *Ranking:** *H-4-0 ($0M;N)*	A very sensitive (pCi/g) technique for measuring alpha-emitting isotopes in soil, water, and airborne dust. **TTP Match**	Cost effective, timely analysis of select alpha emitting radionuclides in large numbers of samples is needed to verify nonviolation of cleanup standards. **Available at X-10, Y-12.**	A PERALS laboratory is already set up at the ORNL DOR/SAR facility. It can be adapted for rapid "on-line" monitoring of both airborne and loose contamination.
						H	Neutron Activation Analysis CHAR-266-OL *Ranking:** *H-4-1 ($.2M;$300/sample)*	**Accepted, mature technology** **TTP Match**	Mature technology, startup studies to be done to evaluate possible interferences. **Available at X-10.**	Instrumentation and personnel currently exist at ORNL but needs to be expanded to meet the expected work load. Estimated cost of upgrade/expansion $250K
• Remedial Action (RA)—Soils, Ground Water and Surface Water						H	Gamma-Ray Spectrometry CHAR-268-OL *Ranking:** *H-5-0 ($.1M;$100/sample)*	**Mature technology.** **TTP Match**	Commercially available and mature. **Available at X-10.**	Some equipment/personnel currently available at ORNL but needs to be expanded to meet the expected increased work load. Detector costs range from $10K to $50K
						H	Liquid Scintillation Counting CHAR-267-OL *Ranking:** *H-5-0 ($.1M;$100/sample)*	**Mature technology.** **TTP Match**	Commercially available and mature. **Available at X-10.**	Some equipment/personnel currently available at ORNL but needs to be expanded to meet the expected increased work load. Instrument costs range from $[illegible]
						M	Radiographic Imaging CHAR-40-OL *Ranking:** *M-4-1 (N;N)*	**Accepted**	Scattering and attenuation factors that the host matrix exhibits on the radiograph need to be better understood.	A laboratory desktop radiographic imager would greatly facilitate the use of this technology.
		Inorganics			Field Methods	M	Atomic Emission Spectroscopy CHAR-76-OL *Ranking:** *M-4-1 ($.2M;N)*	**Accepted** **TTP Match**	The technology is well-developed and applicable as is.	Technology is available at K-25 Site.
• Waste Management (WM)										

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Characterization for Decontamination and Decommissioning

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	All Problems Including various subparts of the following facilities: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	Inorganics	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Field Methods				
EM Problems • Facility Decontamination and Decommissioning (D&D)					H	X-Ray Fluorescence for In Situ Monitoring of Toxic Heavy Metals CHAR-219-OL CHAR-6-OL *Ranking:** *H-5-1 ($.2M;$25/sample)*	**Accepted** Can be use for in situ monitoring of toxic heavy metals in paints, on surfaces, and in soils. Portable XRF units are commercially available and have been widely used for screening painted surfaces for lead contamination. **TTP Match**	Mature technology.	Substrate effects need to be studied. The lower limit of detection for some metals on surfaces needs to be measured (~$200K).
					H	Laser Ablation; Inductively Coupled Plasma; Atomic Emission Spectroscopy CHAR-111-OL *Ranking:** *H-5-3 ($1M;N)*	**Demonstration** **TTP Match**	Improvement of the robotic process for site-specific conditions (e.g., floor, wall, ceiling) is needed.	Normal
					Laboratory Methods				
					H	Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) CHAR-78-OL *Ranking:** *H-4-2 ($1M;$200/sample)*	**Demonstration** - available, but not fully developed.	It is applicable as is for multielement analysis of aqueous solutions. Development is progress to use the technology for surface analysis using laser ablation techniques, and for low specific activity, long-lived	It is now available at the X-10 Site. $400K development costs to extend to long-lived, low specific activity radionuclides.
					H	Inductively Coupled Plasma Spectroscopy (ICP) CHAR-77-OL *Ranking:** *H-4-0 ($.1M;$200/sample)*	**Accepted** **TTP Match**	It is applicable as is. This is a well-developed technology.	It is available at ORNL.
					H	Atomic Emission Spectroscopy (AE) CHAR-76-OL *Ranking:** *H-4-0 ($.1M;$200/sample)*	**Accepted** **TTP Match**	The technology is well-developed and applicable as is.	Technology is available at the K-25 Site.
					H	Ion Chromatography (IC) CHAR-50-OL *Ranking:** *H-4-0 ($.1M;$100/sample)*	**Accepted** **TTP Match**	A detector system that is optimized for the expected waste streams that will be generated needs to be determined.	We have systems available for process control of D&D efforts.
					M	Electron Diffraction (ED, SAED, LEED) CHAR-37-OL *Ranking:** *M-4-0 ($0M;$100/sample)*	**Accepted** **TTP Match**	None **Available at all sites.**	None
						Wavelength Dispersive X-Ray Spectroscopy (WDS, WDX) CHAR-36-OL *Ranking:** *No Ranking.*	**Accepted**	None **Available at all sites.**	None
					M	Energy Dispersive X-Ray Spectroscopy (EDS, EDX, EDAX) CHAR-35-OL *Ranking:** *M-4-0 ($0M;$100/sample)*	**Accepted** **TTP Match**	None **Available at all sites.**	None
• Remedial Action (RA)—Soils, Ground Water and Surface Water									
• Waste Management (WM)									

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Characterization for Decontamination and Decommissioning

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	All Problems Including various subparts of the following facilities: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulseleeder Pumps Pavement over 55-gal. Drum	Inorganics	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Laboratory Methods	Transmission Electron Microscopy (TEM) CHAR-34-OL M *Ranking:* M-4-0 ($0M;$100/sample)*	Accepted TTP Match	This is a mature technology. **Available at all sites.**	This is a mature technology.
EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)						Scanning Electron Microscopy (SEM) CHAR-33-OL M *Ranking:* M-4-0 ($0M;$100/sample)*	Accepted TTP Match	This is a mature technology. **Available at all sites.**	This is a mature technology.
						Particle-Induced X-Ray Emission (PIXIE) CHAR-17-OL M *Ranking:* M-4-0 ($0M;$100/sample)*	Accepted	This is not a mature technology; photon source is under development. **Available at K-25.**	The instrumentation is available on-site. Analysis is available at outside laboratories. Sampling scenarios could be designed to identify and use the
						Cold Vapor (Mercury) Analysis CHAR-24-OL H *Ranking:* H-4-0 ($0M;$100/sample)*	Accepted This technique is based on the atomic absorption spectroscopy of mercury and very sensitive and highly selective.	This is a mature technology which needs to be part of a mobile laboratory.	This is a mature technology which needs to be part of a mobile laboratory.
						Neutron Activation Analysis CHAR-266-OL H *Ranking:* H-4-1 ($.2M;$200/sample)*	Accepted, mature technology TTP Match	Mature technology, startup studies to be done to evaluate possible interferences. **Available at X-10.**	Instrumentation and personnel currently exist at ORNL but needs to be expanded to meet the expected work load. Estimated cost of upgrade and expansion $250K.
						Powder X-Ray Diffraction CHAR-31-OL M *Ranking:* M-4-0 ($0M;>$100/sample)*	Accepted	This is a mature technology. **Available at all sites.**	None
						Electron Spectroscopy for Chemical Analysis (ESCA) CHAR-1-OL M *Ranking:* M-4-0 ($0M;$200–600/sample)*	Accepted	Model studies are needed to identify binding energies for standard compounds of Tc and U for suspected matrices. **Available at all sites.**	Instrumentation and personnel currently exist at K-25.
						Auger Electron Spectroscopy (AES) CHAR-2-OL M *Ranking:* M-4-0 ($0M;$300–800/sample)*	Accepted TTP Match	Mature, model studies are needed to probe the host/contaminant effects for accurate depth profiling. **Available at X-10, Y-12, K-25.**	Instrumentation and personnel exist within the three plants.
						Glow Discharge Ionization Mass Spectroscopy CHAR-56-OL H *Ranking:* H-4-1 ($.5M;N)*	Accepted (laboratory) Predemonstration (field) TTP Match	Need to determine relative sensitivity factors, and use of DC and of glow discharges. **Available at X-10.**	**Hardware cost:** $200K **Development cost:** $500K
		Organics	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements	Characterization	Field Methods	Fluorescence Diagnosis of Contaminated Surfaces CHAR-110-OL M *Ranking:* M-3-2 ($1M;$10/sample)*	Predemonstration TTP Match	A modicum of fluorescence spectroscopy work will be required for some contaminants to fill in the gaps of published fluorescence data.	The required equipment such as a laser (light source), optics, detectors, personal computers (for data acquisition), and interfaces must be purchased.
						Infrared Absorption (Laser-Based Source) CHAR-85-OL M *Ranking:* M-4-2 ($.5M;N)*	Accepted (for commercial units) Evolving technology (for laser-based) TTP Match	Laser source would enhance sensitivity, but cost and size would increase appreciably,	Inexpensive commercial units can be purchased, detection limits ppm. Laser-based systems need to be developed. ($500K)

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Characterization for Decontamination and Decommissioning

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**All Problems Including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	Organics	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Field Methods	Portable Gas Chromatograph/Electron Capture Detection for Analyzing PCBs in Soil/Dust CHAR-100-OL *Ranking:** *H-4-0 ($.25M;$50/sample)*	**Accepted** **TTP Match**	Standard procedures need to be written. **Available at Y-12.**	We need to order GC/ECD devices (~$15K each).
						Portable Volatile Organic Compound Detectors CHAR-5-OL *Ranking:** *H-5-0 ($.25M;$10/sample)*	**Accepted.** Has been successfully used at ORNL. A valuable, quick, and yet inexpensive method to screen for the contamination of soils based on flame ionization or photoionization of sampled air. Useful at a variety of sites including leaking underground tanks pits in spillage. **TTP Match**	This is a mature technology. **Available at X-10, Y-12.**	For quick screening and surveying, instruments are available commercially. Interfacing the instruments with an ion mobility mass spectrometer would allow detection of individual compounds (~$30K).
						Direct Sampling Ion Trap Mass Spectrometry (DSITMS) CHAR-90-OL *Ranking:** *H-5-2 ($.2M;$50/sample)*	**Predemonstration,** method development needed. **TTP Match**	Methods need to be developed for specific applications. **Available at X-10.**	**Hardware cost:** $100K; personnel are needed for development, training, and implementation costs, $200K.
						Gas Chromatography in the Field CHAR-262-OL *Ranking:** *H-5-0 ($.25M;$50/sample)* *H-3-0 ($.25M;$50/sample)*	**Accepted.** Using flame ionization, electron capture, thermal conductivity, photoionization, flame photometric, or thermionic detectors with gas chromatography can determine a variety of environmentally important analytes.	Technology needs are minimal. While improvements can be made, in general, the technology is ready to use. **Available at all sites.**	A variety of gas chromatography equipment exists already at ORNL and may be useful for many needs. Various groups at ORNL have large sample handling capabilities.
						Synchronous Fluorescence Screening for Polycyclic Aromatic Hydrocarbons CHAR-101-OL *Ranking:** *M-4-1 ($.2M;<$50/sample)*	**Demonstration, technology available; Predemonstration.** When light of a specific wavelength is directed onto a sample, certain organic compounds (such as PAHs) absorb and re-emit that light (fluoresce) at a higher wavelength. In this technique, exciting and fluorescing wavelengths are scanned synchronously. Analytes can be differentiated because they absorb and fluoresce at different wavelengths. **TTP Match**	Technology needs to be validated in the EPA program. Numerous situations at X-10 have involved used oils and lubricants. **Available at X-10.**	**Hardware cost:** $25K; **Development cost:** $200K.
					Laboratory Methods	Analytical Methods for Chelators and Decontamination Agents CHAR-206-OL *Ranking:** *M-3-1* *($.25M;$500–1000/sample)*	**Demonstration,** an existing method shows the technology is promising, but further development is needed. **TTP Match**	Adapt current methods to the specific constituents and sample matrices at the ORNL site, conduct method performance validation, and prepare an analytical protocol.	**Development cost:** $250K.

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Characterization for Decontamination and Decommissioning

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• Clean-Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**All Problems Including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	Organics	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Laboratory Methods	M — Capillary Zone Electrophoresis CHAR-207-OL *Ranking:* M-3-1 ($.25M;$300/sample)*	**Demonstration**, the technology is gaining widespread acceptance in biomedical applications, and appears useful for RA/WM applications.	Adaptation and validation for the specific target compounds and sample matrices at the ORNL site. **Available at X-10.**	**Hardware cost:** $30K-$60K; **Development cost:** $250K.
						H — On-line Supercritical Fluid Extraction-Multidetector Gas Chromatography (SPE-GC) CHAR-115-OL *Ranking:* H-5-1 ($.25M;$300/sample)*	**Predemonstration**, technology requires final development and demonstration. **TTP Match**	The technology requires optimization for the most efficient extraction and chromatography of both total petroleum hydrocarbons and PCBs in a single operation.	**Capital cost:** $60K; **Development cost:** $250K.
						M — Gas Chromatography-Fourier Transform Infrared Spectroscopy (GC-FTIR) CHAR-66-OL *Ranking:* M-4-2 ($.5M;$400/sample)*	**Demonstration**, technology is available	Specific methods for targeted analytes and general methods for unknown identification need to be developed. **Available at X-10.**	**Hardware cost:** $200K; **Development cost:** $400K. One instrument is available at ORNL.
						M — Liquid Chromatography—Mass Spectroscopy (LC-MS) CHAR-89-OL *Ranking:* M-4-1 ($.3M;$500/sample)*	**Demonstration**, not yet available on-site for service work. **TTP Match**	Case-by-case development and demonstration for specific applications is needed. **Available at X-10, Y-12.**	**Hardware cost:** $200K; **Development cost:** $300K.
						E — Gas Chromatography—Mass Spectroscopy (GC-MS) CHAR-88-OL *Ranking:* E-5-0 ($0M;$200–800/sample)*	**Accepted**, available on-site **TTP Match**	Technology is applicable as is. Benefit would be derived from faster chromatography to shorten analysis time. **Available at all sites.**	Technology is available at ORNL.
						H — Synchronous Fluorescence Screening for Polycyclic Aromatic Hydrocarbons (PAHs) CHAR-101-OL *Ranking:* H-5-1 ($.2M;$10/sample)*	**Demonstration**, technology available. When light of a specific wavelength is directed onto a sample, certain organic compounds (such as PAHs) absorb and re-emit that light (fluoresce) at a higher wavelength. In this technique, exciting and fluorescing wavelengths are scanned synchronously. Analytes can be differentiated because they absorb and fluoresce at different wavelengths.	Technology needs to be validated in the EPA program. Numerous situations at X-10 have involved used oils and lubricants. **Available at X-10.**	**Hardware cost:** $25K; **Development cost:** $200K.
						H — Gas Chromatography CHAR-94-OL *Ranking:* H-5-0 ($0M;$300/sample)*	**Accepted**, technology available on-site. **TTP Match**	Technology needs are minimal. While improvements can be made, in general, the technology is ready to use.	A variety of gas chromatography equipment exists already at ORNL.
						E — Laser Ablation Organic Mass Spectrometry CHAR-93-OL *Ranking:* E-5-1 ($.3M;< $500/sample)*	**Predemonstration**, technology under development. **TTP Match**	Development of a sampling methodology (perhaps using a wipe of the surface) and test it on target compounds. **Available at X-10.**	**Hardware cost:** $120K; **Development cost:** $300K.
						E — Surface Enhanced Raman Scattering (SERS) CHAR-265-OL *Ranking:* E-4-1 ($.15M;N)*	**Evolving.** **TTP Match**	System development and validation for specific needs. **Available at X-10.**	**Hardware cost:** $10K-$250K. **Development cost:** ~$150K.

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Characterization for Decontamination and Decommissioning

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	**All Problems including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3035 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	Physical	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Field Methods	Instrument Response Models for Remote Sensing CHAR-246-OL *Ranking:** *E-5-2 ($0.6M;$200Kam)*	**Accepted** Instrument response models have been used for many years to evaluate satellite sensor, control, and communication systems.	Information necessary for developing models of the instrument subsystems and measurement processes must be provided.	Instrument response models are usually represented in software that executes on a computer, so implementation needs would be those of software developed for engineering and scientific applications.
EM Problems • Facility Decontamination and Decommissioning (D&D)					E	Fiber-Optic Systems for Measuring Multiple Physical Variables CHAR-248-OL *Ranking:** *E-5-3 ($1M;$.25/sample event)*	**Pre-demonstration** Proof-of-principle of this technology can be demonstrated in devices suitable for use in underground waste storage tanks. **TTP Match**	A range of applications can be developed using this technology. **Available at X-10.**	This technology should lend itself well to economies of scale in the manufacture of rugged, replaceable devices that should require low (or no) maintenance.
					Laboratory Methods	Particle Size Analysis CHAR-26-OL *Ranking:** *M-4-0 ($0M;$1000/sample)*	**Accepted**	None, this is a mature technology. **Available at all sites.**	In situ devices need to be implemented for more aggressive IH-HP protection of personnel and to ensure the control (spread) of radioactive contamination.
					M	Optical Microscopy CHAR-32-OL *Ranking:** *M-4-0 ($0M;$100–800/sample)*	**Accepted**	A particle atlas of site-specific materials is needed to allow rapid identification. **Available at all sites.**	A centralized image collection system is needed to establish a site-specific database.
					M	Magnetic Resonance Imaging CHAR-58-OL *Ranking:** *M-4-0 ($.2M;N)*	**Accepted** **TTP Match**	Model studies are needed for waste forms and various equipment parts.	Instrumentation is needed.
					M	Holographic Imaging CHAR-46-OL *Ranking:** *M-4-0 (N;N)*	**Accepted**	This is a mature technology.	A holographic imaging laboratory wit field-portable units is needed to allow holographic imaging of permanently-mounted
• Remedial Action (RA)—Soils, Ground Water and Surface Water					M	Inorganic Cementitious Matrix Composites Model CHAR-39-OL *Ranking:** *M-4-0 (N;N)*	**Demonstration** **TTP Match**	Characterization of variations in the cement for the various structures of interest is needed; and matrix/contaminant interaction studies need to be performed.	
					M	Nondestructive Testing for Concrete CHAR-38-OL *Ranking:** *M-4-0 ($0M;$100/sample)*	**Demonstration**	Testing protocols for evaluating and characterizing large concrete structures are needed.	A testing plan for site buildings and a field testing kit for site-wide deployment are needed.
• Waste Management (WM)					H	Modeling of Heterogenous Materials—Sampling CHAR-61-OL *Ranking:** *H-4-0 ($.3M;N)*	**Evolving technology** (conceptual) **TTP Match**	An experimental design, models need to be established. A study needs to be performed.	

** See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.*

Characterization for Decontamination and Decommissioning

EM Goals	ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**All Problems Including various subparts of the following facilities:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum	Physical	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Laboratory Methods	Radiation-Induced Segregation Model (RIS) CHAR-42-OL *Ranking:** *H-4-2 ($.5M;N)*	**Demonstration**	Models need to be used to determine if, in reactor equipment, the high radiation fields and temperature combinations allow for an enhancement of defect sites, which may cause variability in decontamination or dismantlement.	Same as Science/Technology needs.
	•Painted sheet metal floor of coolant salt cell, Bldg. 9203-1. •3,000-gallon stainless steel tank, Bldg. 9203-1. •Fission Products Development Laboratory Inactive Cells, Bldg. 3019.	Oils and Purex Chemicals	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Field Methods	Infrared Absorption (Laser Based Source) CHAR-85-OL *Ranking:** *M-3-2 ($.5M;N)*	**Accepted** (for commercial units) **Evolving technology** (for laser-based) **TTP Match**	Laser source would enhance sensitivity, but cost and size would increase appreciably,	Inexpensive commercial units can be purchased, detection limits ppm-ppt. Laser-based systems need to be developed.
						Portable Volatile Organic Compound Detectors CHAR-5-OL *Ranking:** *H-3-0 ($.25M;$10/sample)*	A valuable, quick, and yet inexpensive method to screen for the contamination of soils based on flame ionization or photoionization of sampled air. Useful at a variety of sites including leaking underground tanks pits in spillage. **TTP Match**	This is a mature technology. For quick screening and surveying, instruments are available commercially. Interfacing the instruments with an ion mobility mass spectrometer would allow detection of individual compounds (~$30K).	
						Direct Sampling Ion Trap Mass Spectrometry (DSITMS) CHAR-90-OL *Ranking:** *H-3-2 ($1M;$50/sample)*	**Predemonstration**, method development needed. **TTP Match**	Methods need to be developed for specific applications. **Available at X-10.**	**Hardware cost:** $100K; personnel are needed for development, training, and implementation costs, $200K.
						Sampling Interface System for Surface Contamination by Organics CHAR-271-OL *Ranking:** *H-4-3 ($.775M;N)*	**Conceptual** **TTP Match**	Development of rapid heating interface and software for rapid contaminant identification by direct sampling ion trap mass spectrometry.	**Development cost:** of $775K over 3 years.
						Fiber-Optic Chemical Sensors CHAR-25-OL *Ranking:** *H-3-1 ($1M;$10/sample)*	**Demonstration** **TTP Match**	A combination of waveguides and spectroscopic techniques that have been matched not only for each other but also for specific monitoring scenarios are needed.	Waveguides that can withstand the harsh chemical environment that may be present in some of the sampling locations are needed.
						Infrared Spectroscopy (Wavelength Dispersion) CHAR-18-OL *Ranking:** *M-3-1 ($.5M;$100/sample)*	**Accepted** **TTP Match**	No units currently exist on-site. Several vendors are marketing equipment. Software development would enhance site-specific applications. **Available at all sites.**	Centralized mounting areas with robotically controlled unit would allow multiple site areas to be monitored with one unit.
						Gas Chromatography—Mass Spectrometry (GC-MS) CHAR-88-OL *Ranking:** *E-3-0 ($0M;$200–800/sample)*	**Accepted**, available on-site **TTP Match**	Technology is applicable as is. Benefit would be derived from faster chromatography to shorten analysis time.	Technology is available at ORNL.

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Characterization for Decontamination and Decommissioning

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problem	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
•Painted sheet metal floor of coolant salt cell, Bldg. 9203-1. •3,000-gallon stainless steel tank, Bldg. 9203-1. •Fission Products Development Laboratory Inactive Cells, Bldg. 3019.	Oils and Purex Chemicals	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Laboratory Methods	On-line Supercritical Fluid Extraction—Multidetector Gas Chromatography (SFE-GC) CHAR-115-OL *Ranking:* H-3-1 ($.25M;$300/sample)*	**Predemonstration,** technology requires final development and demonstration. **TTP Match**	The technology requires optimization for the most efficient extraction and chromatography of both total petroleum hydrocarbons and PCBs in a single operation.	**Capital cost:** $60K; **Development cost:** $250K.
					Laser Ablation Organic Mass Spectrometry CHAR-93-OL *Ranking:* H-3-1 ($.3M;<$500/sample)*	**Predemonstration,** technology under development. **TTP Match**	Development of a sampling methodology (perhaps using a wipe of the surface) and test it on target compounds. **Available at X-10.**	**Hardware cost:** $120K; **Development cost:** $300K.
					Analytical Methods for Chelators and Decontamination Agents CHAR-206-OL *Ranking:* H-3-1 ($.25M;$500–1000/sample)*	**Demonstration,** an existing method shows the technology is promising,m but further development is needed. **TTP Match**	Adapt current methods to the specific constituents and sample matrices at the ORNL site, conduct method performance validation, and prepare an analytical protocol.	**Development cost:** $250K.
Asbestos Pipe Insulation, Building 9201-3	PCBs	Refer to Vol. 1, Pt. C, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Field Methods	Portable Gas Chromatograph /Electron Capture Detection for Analyzing PCBs CHAR-100-OL *Ranking:* H-3-0 ($.25M;$50/sample)*	**Accepted** **TTP Match**	**Available at Y-12.**	We need to order GC/ECD devices (~$15K each).
					PCB Immunoassay Kit CHAR-99-OL *Ranking:* H-3-0 ($.25M;$80/sample)*	**Accepted**	None **Available at X-10, K-25.**	The technology is ready to apply and should be used for routine analyses.
					Direct Sampling Ion Trap Mass Spectrometry (DSITMS) CHAR-90-OL *Ranking:* H-3-2 ($.2M;$50/sample)*	**Predemonstration,** method development needed. **TTP Match**	Methods need to be developed for specific applications. **Available at X-10.**	**Hardware cost:** $100K; personnel are needed for development, training, and implementation costs, $200K.
					Sampling Interface System for Surface Contamination by Organics CHAR-271-OL *Ranking:* No Ranking*	**Conceptual** **TTP Match**	Development of rapid heating interface and software for rapid contaminant identification by direct sampling ion trap mass spectrometry.	**Development cost:** of $775K over 3 years.
				Laboratory Methods	Gas Chromatography CHAR-94-OL *Ranking:* H-3-0 ($0M;$300/sample)*	**Accepted,** technology available on-site. **TTP Match**	Technology needs are minimal. While improvements can be made, in general, the technology is ready to use.	A variety of gas chromatography equipment exists already at ORNL and may be useful for many needs.
					On-line Supercritical Fluid Extraction—Multidetector Gas Chromatography (SFE-GC) CHAR-115-OL *Ranking:* H-3-1 ($.25M;$300/sample)*	**Predemonstration,** technology requires final development and demonstration. **TTP Match**	The technology requires optimization for the most efficient extraction and chromatography of both total petroleum hydrocarbons and PCBs in a single operation.	**Capital cost:** $60K; **Development cost:** $250K.

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Dismantlement for Decomtamination and Decommissioning

The Dismantlement section is written to address the X-10 Site problems specific to dismantlement: massive concrete, structural steel, asbestos materials, major dismantlement (removal of equipment), disassembly of equipment, and the need for other "enabling technologies." Basic to this approach is the assumption that dismantlement will not, in general, depend upon the type of contamination as long as containment and worker protection are provided. Each section will explain the relationship of the subject to the dismantlement problem list. Dismantlement has been assumed to follow a sequence similar to the current ongoing D&D efforts elsewhere.

There are some basic assumptions for dismantlement including: (1) equipment exteriors will have been decontaminated as much as practical, (2) remaining, or vestigial, contamination will have been located and characterized before dismantlement is initiated, (3) the products of dismantlement will be sorted materials in forms suitable for disposal as recyclable scrap or waste or for disposition to complete decontamination, and (4) recycle of materials will be desirable and or required.

Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Massive Containment	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting **H**	High-Pressure Abrasive Water Jet (Massive Containment) DISM-11-OL *Ranking:** H-5-5 ($5.5M;$10/ft2)	**Status:** Demonstration - Technology is a DOE sponsored development. Has not been demonstrated at X-10. **Efficacy:** High; robotics useful in high radiation areas. **Waste:** Contaminated water slurry. Amount would be minimal.	**Technology Improvement Needs:** 1: Need to develop a high efficiency fluid recovery system. 2: Need to address contaminated cracks in concrete.	**Unusual Needs:** Determine level of robotics technology available. **Development Costs:** $5.5M **Capital Costs:** $1M **Operating Costs:** $700/yd^3
EM Problems • Facility Decontamination and Decommissioning (D&D)					**M**	Diamond Wire Cutting (Massive Containment) DISM-12-OL *Ranking:** *M-5-5 ($3.5M;$100/ft^2)*	**Status:** Demonstration - Has not been demonstrated at X-10. **Efficacy:** High; industry accepted standard. **Waste:** Contaminated water slurry. Amount would be minimal.	**Technology Improvement Needs:** 1: Method of cutting large rebar must be developed. 2: High efficiency fluid recovery system must me developed.	**Unusual Needs:** Determine robotics technology available. **Development Costs:** $1.5M **Capital Costs:** $1M **Operating Costs:** $1200/yd^3
					Demolition **M**	Microwave Demolition (Massive Containment) DISM-16-OL *Ranking:** *M-5-9 ($5M;$6/ft^2)*	**Status:** Pre-demonstration - In final stage of development. **Efficacy:** Medium - will remove moderate amounts of material. **Waste:** No additional waste will be generated as a result of utilizing this technology.	**Technology Improvement Needs:** 1: Final phase of development. **Available in Private Sector.**	**Unusual Needs:** Need to develop a demonstration program. Need to develop track system. **Development Costs:** $5M **Capital Costs:** $2M **Operating Costs:** $17/ft^3
• Remedial Action (RA)—Soils, Ground Water and Surface Water		Reactor Pools	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting **M**	High-Pressure Abrasive Water Jet (Reactor Pools) DISM-21-OL *Ranking:** *M-4-7 ($5.5M;$15/ft^2)*	**Status:** Demonstration-Technology is a DOE sponsored development. Has not been demonstrated at X-10. **Efficacy:** High; robotics useful in high radiation areas. **Waste:** Contaminated water slurry. Amount would be minimal.	**Technology Improvement Needs:** 1: Need to develop a high efficiency fluid recover system. 2: Need to address contaminated cracks in concrete.	**Unusual Needs:** Determine level of robotics technology available. **Development Costs:** $5.5M **Capital Costs:** $1M **Operating Costs:** $700/yd^3

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Reactor Pools	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	Diamond Wire Cutting (Reactor Pools) DISM-22-OL *Ranking:* not ranked*	**Status:** Demonstration - has not been demonstrated at X-10. **Efficacy:** High; industry accepted standard. **Waste:** Contaminated water slurry. Amount would be minimal.	**Technology Improvement Needs:** 1: Method of cutting large rebar must be developed. 2: High efficiency fluid recovery system must be developed.	**Unusual Needs:** Determine robotics technology available. **Development Costs:** $3.5M **Capital Costs:** $1M **Operating Costs:** $1200/yd^3
						Explosive Cutting (Reactor Pools) DISM-23-OL *Ranking:* not ranked*	**Status:** Demonstration - not demonstrated at X-10. **Efficacy:** Low; not well suited for these types of structures. **Waste:** Contaminated water slurry used to hold down dust possible.	**Technology Improvement Needs:** 1: Crane system to remove large sections of concrete. 2: Remote method of cutting rebar in large amounts of debris is needed.	**Unusual Needs:** Need to witness an actual site being demolished. **Development Costs:** $2.5M **Capital Costs:** $0.75M **Operating Costs:** $400/yd^3
					Demolition	Demolition Compounds (Reactor Pools) DISM-25-OL M *Ranking:* M-4-6 ($4M;$90/ft^3)*	**Status:** Demonstration - has not been demonstrated at X-10 **Efficacy:** Medium; can be used on lightly reinforced concrete only. **Waste:** No additional waste will be generated as a result of the use of this technology.	**Technology Improvement Needs:** 1: Demonstration is required using a lightly reinforced building. 2: Hole geometry needs to be determined.	**Unusual Needs:** Method of cutting rebar must be developed. **Development Costs:** $40M **Capital Costs:** $0.5M **Operating Costs:** $900/yd^3
						Conventional Demolition (Reactor Pools) DISM-26-OL *Ranking:* No Ranking*	**Status:** Demonstration - has not been demonstrated at X-10 **Efficacy:** High; industry accepted standard. **Waste:** No additional waste will be generated as a result of utilizing this technology.	**Technology Improvement Needs:** 1: Vacuum system to handle dust must be created. 2: Crusher to down size concrete sections must be developed.	**Unusual Needs:** Need to determine level of robotic technology available. **Development Costs:** $4.5M **Capital Costs:** $0.5M **Operating Costs:** $400/ft^2

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Dismantlement for Decontamination and Decommissioning

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Various Facilities Including: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Reactor Pools	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Demolition	Microwave Demolition (Reactor Pools) DISM-28-OL M *Ranking:** *M-4-10 ($7M;$60/ft²)*	**Status:** Pre-demonstration - In final stage of development. **Efficacy:** Medium - will remove moderate amounts of material. **Waste:** No additional waste will be generated as a result of utilizing this technology.	**Technology Improvement Needs:** 1: Final phase of development.	**Unusual Needs:** Need to develop a demonstration program. Need to develop track system. **Development Costs:** $5M **Capital Costs:** $2M **Operating Costs:** TBD
	Buried Tanks	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	High-Pressure Abrasive Water Jet (Buried Tanks) DISM-31-OL H *Ranking:** *H-4-7 ($5.5M;$80/ft³)*	**Status:** Demonstration - Technology is a DOE sponsored development. Has not been demonstrated at X-10. **Efficacy:** High; robotics useful in high radiation areas. **Waste:** Contaminated water slurry. Amount would be minimal.	**Technology Improvement Needs:** 1: Need to develop a high efficiency fluid recovery system. 2: Need to address contaminated cracks in concrete.	**Unusual Needs:** Determine level of robotics technology available. **Development Costs:** $5.5M **Capital Costs:** $1.5M **Operating Costs:** $700/yd³
					Diamond Wire Cutting (Buried Tanks) DISM-32-OL *Ranking:** *not ranked*	**Status:** Demonstration - has not been demonstrated at X-10. **Efficacy:** High; industry-accepted standard. **Waste:** Contaminated water slurry. Amount would be minimal.	**Technology Improvement Needs:** 1: Method of cutting large rebar must be developed. 2: High efficiency fluid recovery system must be developed.	**Unusual Needs:** Determine robotics technology available. **Development Costs:** $3.5M **Capital Costs:** $1.5M **Operating Costs:** $1200/yd³
					Explosive Cutting (Buried Tanks) DISM-33-OL M *Ranking:** *M-4-7 ($2.5M;$60/ft³)*	**Status:** Demonstration - not demonstrated at X-10. **Efficacy:** Low; not well suited for these types of structures. **Waste:** Contaminated water slurry used to hold down dust possible.	**Technology Improvement Needs:** 1: Crane system to remove large sections of concrete. 2: Remote method of cutting rebar in large amounts of debris is needed.	**Unusual Needs:** Need to witness an actual site being demolished. **Development Costs:** $2.5M **Capital Costs:** $1M **Operating Costs:** $400/yd²
				Demolition	Demolition Compounds (Buried Tanks) DISM-35-OL M *Ranking:** *M-4-8 ($4M;$90/ft³)*	**Status:** Demonstration- has not been demonstrated at X-10. **Efficacy:** Medium; can be used on lightly reinforced concrete only. **Waste:** No additional waste will be generated as a result of the use of this technology.	**Technology Improvement Needs:** 1: Demonstration is required using a lightly reinforced building. 2: Hole geometry needs to be determined.	**Unusual Needs:** Method of cutting rebar must be developed. **Development Costs:** $4M **Capital Costs:** $0.75M **Operating Costs:** $900/yd³

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Buried Tanks	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Demolition	Conventional Demolition (Buried Tanks) DISM-36-OL *Ranking:** *not ranked*	**Status:** Demonstration - has not been demonstrated at X-10. **Efficacy:** High; industry accepted standard. **Waste:** No additional waste will be generated as a result of utilizing this technology.	**Technology Improvement Needs:** 1: Vacuum system to handle dust must be created. 2: Crusher to down size concrete sections must be developed.	**Unusual Needs:** Need to determine level of robotic technology available. **Development Needs:** $4.5M **Capital Costs:** $0.75M **Operating Costs:** $400/m^2
						Microwave Demolition (Buried Tanks) DISM-38-OL *Ranking:** *not ranked*	**Status:** Pre-demonstration - In final stages of development. **Efficacy:** Medium; will remove moderate amounts of material. **Waste:** No additional waste will be generated as a result of utilizing this technology.	**Technology Improvement Needs:** 1: Final phase of development.	**Unusual Needs:** Need to develop a demonstration program. Need to develop track system. **Development Needs:** $5M **Capital Costs:** $3.0M **Operating Costs:** TBD
• Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)		Structural-only-Concrete	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	M High-Pressure Abrasive Water Jet (Structural-Only Concrete) DISM-41-OL *Ranking:** *M-2-1 ($2M;$10/ft^3)*	**Status:** Demonstration - Technology is a DOE sponsored development. Has not been demonstrated at X-10. **Efficacy:** High; industry accepted standard. **Waste:** None.	**Technology Improvement Needs:** 1: Need to develop a high efficiency fluid recovery system	**Unusual Needs:** None **Development Costs:** $1M **Capital Costs:** $0.5M **Operating Costs:** $500/yd^3
						H Diamond Wire Cutting (Structural-Only Concrete) DISM-42-OL *Ranking:** *H-2-0.5 ($1.5M;$10/ft^3)*	**Status:** Demonstration - has not been demonstrated at X-10. **Efficacy:** High; industry accepted standard. **Waste:** None.	**Technology Improvement Needs:** 1: Method of cutting large rebar must be developed. 2: High efficiency fluid recovery system must be developed.	**Unusual Needs:** Determine robotics technology available. **Development Costs:** $1.5M **Capital Costs:** $0.5M **Operating Costs:** $800/yd^3

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Various Facilities Including: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Structural-only Concrete	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Demolition	H Conventional—Jack Hammer, Headache Ball, etc. (Structural-Only Concrete) DISM-44-OL *Ranking:** *H-2-0 ($0M;$20/ft³)*	**Status:** Demonstration - has not been demonstrated at X-10. **Efficacy:** High: industry accepted standard. **Waste:** None.	**Technology Improvement Needs:** 1: Vacuum system to handle dust must be created. 2: Crusher to down size concrete sections must be developed.	**Unusual Needs:** Need to determine level of robotic technology available. **Development Costs:** $1.5M **Capital Costs:** $0.4M **Operating Costs:** 200/ft²
						Explosive Cutting (Structural-Only Concrete) DISM-45-OL *Ranking:** *not ranked*	**Status:** Demonstration - not demonstrated at X-10. **Efficacy:** High; industry accepted standard. **Waste:** None.	**Technology Improvement Needs:** 1: Crane system to remove large sections of concrete. 2: Remote method of cutting rebar in large amounts of debris is needed.	**Unusual Needs:** Need to witness an actual site being demolished. **Development Costs:** $1.5M **Capital Costs:** $0.5M **Operating Costs:** $200/yd³
						M Demolition Compounds (Structural-Only Concrete) DISM-46-OL *Ranking:** *M-2-2 ($1.5M;$25/ft³)*	**Status:** Demonstration - has not been demonstrated at X-10. **Efficacy:** Medium; can be used on lightly reinforced concrete only. **Waste:** No additional waste will be generated as a result of the use of this technology.	**Technology Improvement Needs:** 1: Demonstration is required using a lightly reinforced building. 2: Hole geometry needs to be determined.	**Unusual Needs:** Method of cutting rebar must be developed. **Development Costs:** $1.5M **Capital Costs:** $0.4M **Operating Costs:** $500/yd²
						Microwave Demolition (Structural-Only Concrete) DISM-47-OL *Ranking:** *not ranked*	**Status:** Pre-demonstration - in final stage of development. **Efficacy:** Medium - will remove moderate amounts of material. **Waste:** No additional waste will be generated as a result of utilizing this technology.	**Technology Improvement Needs:** 1: Final phase of development.	**Unusual Needs:** Need to develop a demonstration program. Need to develop a track system. **Development Costs:** $5M **Capital Costs:** $1.5M **Operating Costs:** TBD
						H Grappler (Structural-Only Concrete) DISM-48-OL *Ranking:** *H-2-1 ($1M;$8/ft³)*	**Status:** Demonstration - not demonstrated at X-10 **Efficacy:** High - relatively inexpensive technology. **Waste:** No additional waste would be generated as a result of the use of this technology.	**Technology Improvement Needs:** 1: None	**Unusual Needs:** Need to verify applicability to X-10 structures. **Development Costs:** $2M-$2.5M **Capital Costs:** $2.0M **Operating Costs:** $100/yd³

** See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.*

Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Steel Containment Structures (Highly Contaminated)	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	**H** Laser Cutting (Steel Structures, Highly Contaminated) DISM-51-OL *Ranking:** *H-4-6 ($2.5M;$1000/cut)*	**Predemonstration** **Efficacy:** High; can cut any known material. Contamination could be alloyed to the process material. **Waste:** N/A; no waste generated by the process. Equipment will be decontaminated after use.	**Science Development:** The appropriate power level for the laser A fiber-optic delivery system **Technology Improvement:** A remote controlled manipulator	Personnel Training **Development Cost:** $2M - $2.5M **Capital Cost:** $3M/system **Operating Costs:** $1000/cut of 6 in. in diameter steel pipe
						H Abrasive Water Jet (Steel Structures, Highly Contaminated) DISM-53-OL *Ranking:** *H-4-3 ($750K;$100/h)*	**Demonstration** **Efficacy:** High; can cut any known material, steel up to 9 in. thick. Does not alloy contaminants to the process material. **Waste:** 2 lb/min of garnet is used. 1.5 gal/min of liquid waste is generated. The water can be recycled, therefore, reducing waste. Decontamination of manipulator.	**Science Development:** Recyclable abrasives A recovery system for the abrasives and water **Technology Improvement:** A remote controlled manipulator Longer lasting nozzles, hoses and intensifier pumps	Personnel Training **Development Cost:** $750K **Capital Cost:** $850K/system **Operating Costs:** $100/hour of cutting
						Cryogenic Liquid Cutting (Steel Structures, Highly Contaminated) DISM-55-OL *Ranking:** *not ranked*	**Evolving technology** **Efficacy:** High; can cut any known material. Does not alloy contaminants to the process material. Effective on hazardous materials having a low vaporization temperature. **Waste:** N/A; Decontamination of manipulator.	**Science Development:** Cryogenic liquid cutting **Technology Improvement:** A remote controlled manipulator Long lasting nozzles and hoses	Personnel Training **Development Cost:** $10M **Capital Cost:** $3.5M/system **Operating Costs:** $2000/cut
						M Plasma Arc Cutting (Steel Structures, Highly Contaminated) DISM-56-OL *Ranking:** *M-4-4 ($1M;$1300/cut)*	**Demonstration** **Efficacy:** Medium; can cut only conductive materials. Alloys contaminants to the process material. **Waste:** Water at 1/2 gal/hr is used to cool the nozzle. Nozzles. Particulate generation occurs at 4-6 lb/hr. Decontamination of manipulator.	**Science Development:** Computer aided process **Technology Improvement:** A remote controlled manipulator Longer lasting nozzles	Personnel Training **Development Cost:** $1M **Capital Cost:** $450K/system **Operating Costs:** $1300/cut

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Steel Containment Structures (Highly Contaminated)	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting E E	Oxygen Cutting (Steel Structures, Highly Contaminated) DISM-57-OL *Ranking:** *E-4-2 ($200K;$100/cut)*	**Accepted** **Efficacy:** High; cuts mostly ferrous metals. Alloys contaminants to the process material. **Waste:** N/A; Decontamination of manipulator.	**Technology Improvement:** A remote controlled manipulator to view the cutting and to manipulate the nozzle Remote control of the amount of oxygen and fuel gases being consumed **Available at all sites.**	Normal implementation needs. **Development Cost:** $200K **Capital Cost:** $300K/system **Operating Costs:** $100/cut
						Plasma Arc Saw (Steel Structures, Highly Contaminated) DISM-58-OL *Ranking:** *not ranked*	**Demonstration** **Efficacy:** Low; can cut any type of steel. Can cut geometrically complicated components. Alloys contaminants to the process material. **Waste:** Dust and aerosol from the process. The saw blade. Decontamination of manipulator.	**Science Development:** Computer aided process **Technology Improvement:** A remote controlled manipulator Different sizes of saw blades that are interchangeable	Personnel Training **Development Cost:** $1M - $1.5M **Capital Cost:** $1.2M - $1.4M/system **Operating Costs:** $1100/cut
						Thermal Arc Water Jet (Steel Structures, Highly Contaminated) DISM-59-OL *Ranking:** *not ranked*	**Demonstration** **Efficacy:** Low; can cut any type of steel. Can cut geometrically complicated components. Alloys contaminants to the process material. **Waste:** Dust and aerosol from the process. The water used to wash the material from the kerf. Decontamination of manipulator.	**Science Development:** Computer aided process **Technology Improvement:** A remote controlled manipulator	Personnel Training **Development Cost:** $1M - $1.5M **Capital Cost:** $1M - $1.2M/system **Operating Costs:** $1000/cut
						Conventional Disassembly (Steel Structures, Highly Contaminated) DISM-60-OL *Ranking:** *E-4-2 ($800K;$75/bolt & $600/cut)*	**Accepted** **Efficacy:** High; can cut or dismantle any material or component. Cutting is independent of geometry. Does not alloy contaminants to the process material. **Waste:** Saw blades. Decontamination of manipulator and associated equipment.	**Science Development:** The capability to capture the contaminants exiting the kerf **Technology Improvement:** A remote controlled manipulator **Available at all sites.**	Personnel Training **Development Cost:** $600K - $800K **Capital Cost:** $900K/system **Operating Costs:** $75/bolt & $600/cut

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Steel Containment Structures (Highly Contaminated)	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	**E** Grappler Mobile Shearing (Steel Structures, Highly Contaminated) DISM-61-OL *Ranking:** *E-4-1.5 ($250K;$250/cut)*	**Demonstrated** **Efficacy:** High; can shear and maneuver most any material or component. Cutting is independent of geometry. Does not alloy contaminants to the process material. **Waste:** N/A; Decontamination of manipulator and associated equipment.	**Technology Improvement:** A remote controlled manipulator	Personnel Training **Development Cost:** $250K **Capital Cost:** $400K/system **Operating Costs:** $250/cut
						H Explosive Cutting (Steel Structures, Highly Contaminated) DISM-62-OL *Ranking:** *H-4-3 ($1.3M;$12000/cut)*	**Demonstrated** **Efficacy:** High; can cut any known material in normal surroundings or under water. Used where other mechanical cutting methods are impractical. **Waste:** N/A; Decontamination of manipulator.	**Science Development:** A method of buttering the shock wave and its noise A method to contain the contamination that explodes of the material **Technology Improvement:** A remote controlled manipulator that will place the charges	Personnel Training **Development Cost:** $1.3M **Capital Cost:** $600K/system **Operating Costs:** $12,000/cut
		Structural Steel	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	**H** Laser Cutting (Structural Steel, Mild Contaminants) DISM-71-OL *Ranking:** *H-2-4 ($2.5M;$900/cut)*	**Predemonstration** **Efficacy:** High; can cut any known material. Contamination will be alloyed to the process material. **Waste:** N/A; no waste generated by the process. Equipment will be decontaminated after use.	**Science Development:** The appropriate power level for the laser A fiber-optic delivery system	Personnel Training **Development Cost:** $2M - $2.5M **Capital Cost:** $1.5M/system **Operating Costs:** $900/cut of 6 in. in diameter steel pipe
• Remedial Action (RA)—Soils, Ground Water and Surface Water						**H** Abrasive Water Jet (Structural Steel, Mild Contaminants) DISM-72-OL *Ranking:** *H-2-2 ($250K;$100/h)*	**Demonstration** **Efficacy:** High; can cut any known material, steel up to 9 in. thick. Does not alloy contaminants to the process material. **Waste:** 2 lb/min of garnet is used. 1.5 gal/min of liquid waste is generated. The water can be recycled, therefore, reducing waste. Decontamination of manipulator.	**Science Development:** Recyclable abrasives A recovery system for the abrasives and water **Technology Improvement:** Longer lasting nozzles, hoses and intensifier pumps **Available in Private Sector.**	Personnel Training **Development Cost:** $250K **Capital Cost:** $700K/system **Operating Costs:** $100/hour of cutting
• Waste Management (WM)									

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Various Facilities Including: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Structural Steel	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	Plasma Arc Cutting (Structural Steel, Mild Contaminants) DISM-74-OL M *Ranking:** *M-2-4 ($250K;$600/cut)*	**Demonstration** **Efficacy:** Medium; can cut only conductive materials. Alloys contaminants to the process material. **Waste:** Water at 1/2 gal/hr is used to cool the nozzle. Particulate generation occurs at 4-6 lb/hr. Decontamination of manipulator.	None **Available at Y-12.**	Normal implementation needs. **Development Cost:** $250K **Capital Cost:** $50K/system **Operating Costs:** $600/cut
						Oxygen Cutting (Structural Steel, Mild Contaminants) DISM-75-OL E *Ranking:** *E-2-N/A ($N/A;$150/cut)*	**Accepted** **Efficacy:** High; cuts mostly ferrous metals. Alloys contaminants to the process material. **Waste:** N/A; Decontamination of manipulator.	None **Available at all sites and Private Sector.**	Normal implementation needs. **Development Cost:** N/A **Capital Cost:** $3000/system **Operating Costs:** $150/cut
						Thermite Lance (Structural Steel, Mild Contaminants) DISM-79-OL *Ranking:** *not ranked*	**Predemonstrated** **Efficacy:** Medium; can cut steel in normal surroundings or under water. **Waste:** N/A; Decontamination of manipulator.	**Science Development:** A method to contain the contamination **Available in Private Sector.**	Personnel Training **Development Cost:** $75K **Capital Cost:** $1000/system **Operating Costs:** $150/cut
					Demolition	Conventional Disassembly (Structural Steel, Mild Contaminants) DISM-76-OL E *Ranking:** *E-2-1 ($200K;$10/bolt & $300/cut)*	**Accepted** **Efficacy:** High; can cut or dismantle any material or component. Cutting is independent of geometry. Does not alloy contaminants to the process material. **Waste:** Airborne contaminents. Decontamination of manipulator and associated equipment.	**Science Development:** The capability to capture the contaminants exiting the kerf	Personnel Training **Development Cost:** $200K **Capital Cost:** $100K/system **Operating Costs:** $10/bolt & $300/cut
						Grappler Mobile Shearing (Structural Steel, Mild Contaminants) DISM-77-OL E *Ranking:** *E-2-1 ($N/A;$150/cut)*	**Demonstrated** **Efficacy:** High; can shear and maneuver most any material or component. Cutting is independent of geometry. Does not alloy contaminants to the process material. **Waste:** N/A; Decontamination of manipulator and associated equipment.	None **Available in Private Sector.**	Normal implementation needs. **Development Cost:** N/A **Capital Cost:** $400K/system **Operating Costs:** $150/cut
						Explosive Cutting (Structural Steel, Mild Contaminants) DISM-78-OL *Ranking:** *not ranked*	**Demonstrated** **Efficacy:** High; can cut any known material in normal surroundings or under water. Used where other mechanical cutting methods are impractical. **Waste:** N/A; Decontamination of manipulator.	**Science Development:** A method of buffering the shock wave and its noise A method to contain the contamination that explodes of the material **Available in Private Sector.**	Personnel Training **Development Cost:** $200K **Capital Cost:** $175K/system **Operating Costs:** $10,000/cut

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Various Facilities Including: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Asbestos	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Stripping	Conventional (Asbestos) DISM-81-OL *Ranking:** *not ranked*	**Available** **Efficacy:** low; very labor intensive **Waste:** protective clothing and plastic bags. Very large volume	None required **Available in Private Sector.**	**Unusual needs:** none required **Development Costs:** none required **Capital Costs:** none required **Operating Costs:** $20.00 sq/ft
EM Problems • Facility Decontamination and Decommissioning (D&D)						Conventional/Automated with Vacuum System (Asbestos) DISM-82-OL *Ranking:** *H-3-6 ($200K;$30/ft^3)*	**Available** **Efficacy:** medium, industry accepted **Waste:** Plastic bags and protective clothing. Amounts would decrease by 70% over conventional method.	None required **Available at Y-12.**	**Unusual needs:** none required **Development Costs:** $200k **Capital Costs:** $100k **Operating Costs:** $2.00 sq/ft
						CO_2 Blasting (Asbestos) DISM-83-OL *Ranking:** *M-3-7 ($3.5M;$60/ft^3)*	**Demonstration**—has not been demonstrated at X-10 **Efficacy:** high; industry accepted **Waste:** plastic bags. Amount would be minimal compared to conventional method.	Pipe hangers close to walls Pipes close to walls	**Unusual needs:** determine robotics Available **Development Costs:** $3.5m **Capital Costs:** $1.2m **Operating Costs:** $.20 sq/ft
						Glassification (Asbestos) DISM-86-OL *Ranking:** *not ranked*	**Demonstration**—has not been demonstrated at X-10 **Efficacy:** high, huge cost savings in disposal **Waste:** very minimal	Study to determine size capacity for disposal System to process material into workable size	**Unusual needs:** determine available robotics implementations **Development Costs:** $3.4m **Capital Costs:** $1.2m **Operating Costs:** $.35 sq/ft
					Cutting	Laser Cutting (Asbestos) DISM-84-OL *Ranking:** *H-3-3 ($3.5M;$50/ft^3)*	**Development** **Efficacy:** high; potentially useful in cutting other hazardous materials such as PCBs, volatile organic compounds, etc. **Waste:** disposal bags. Waste would be minimal	Confirmation of negligible dispersement Confirmation of cut cauterization	**Unusual needs:** determine beam containment, laser safety, and optics protection from flaming **Development Costs:** $3.5m **Capital Costs:** $1.5m **Operating Costs:** $.25 sq/ft
• Remedial Action (RA)—Soils, Ground Water and Surface Water		Major Equipment Removal	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement		Abrasive Water Jet (Asbestos) DISM-85-OL *Ranking:** *M-3-6 ($3.5M;$50/ft^3)*	**Demonstration**—has not been demonstrated at X-10 **Efficacy:** medium; industry accepted **Waste:** contaminated water slurry. Could be substantial without recovery system.	High efficiency water recovery and recycle system must be developed. Improvement of wear on nozzles, hoses, and pumps when abrasives are used	**Unusual needs:** determine robotics technology Available **Development Costs:** $3.5m **Capital Costs:** $1.1m **Operating Costs:** $1.25 sq/ft
					Demolition	Thermite Cutting (Major Equipment Removal) DISM-88-OL *Ranking:** *not ranked*	**Status: Pre-Demonstration** **Efficacy:** Low. Messy operation, may cause alloying of contaminates with metals, gross cutting tool **Waste:** Metals alloyed with radioactive contaminates	**Technology Improvement:** None **Science Development:** None	Incorporate remote operations capability **Development Costs:** $500K **Capital Costs:** $10K not incl. remote manipulation provisions **Operating Costs:** $10/m^3 of waste generated
• Waste Management (WM)									

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Major Equipment Removal	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Demolition	Oxyacetylene (Major Equipment Removal) DISM-89-OL *Ranking:** *not ranked*	**Status:** Accepted **Efficacy:** Medium. Commonly used in normal environments, could be easily adapted to remote operations, limited material cutting capability **Waste:** Metals alloyed with contaminates possible	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability. **Development Costs:** $500K **Capital Costs:** $10K not incl. remote manipulation provisions **Operating Costs:** $5/ft^3 of waste generated
					Cutting	Mechanical Saws (Major Equipment Removal) DISM-90-OL *Ranking:** *M-5-1 ($250K;$40/ft^3)*	**Status:** Accepted **Efficacy:** High. Commonly used in normal environments, could be easily adapted to remote operations, slow process **Waste:** None	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $250K **Capital Costs:** $10K not incl. remote manipulation provisions **Operating Costs:** $20/ft^3 of waste generated
					M	Laser Cutting (Major Equipment Removal) DISM-91-OL *Ranking:** *not ranked*	**Status:** Predemonstration **Efficacy:** Low. Commonly used in normal environments, probably expensive to adapt to remote operations **Waste:** Metals alloyed with contaminates possible	**Technology Improvement:** Waveguide improvements - fiberoptics **Science Development:** None	Incorporate remote operations capability **Development Costs:** $3-5M **Capital Costs:** $200K not incl. remote manipulation provisions **Operating Costs:** $50/ft^3 of waste generated
					H	Plasma Arc Cutting (Major Equipment Removal) DISM-92-OL *Ranking:** *H-5-4 ($2–3.5M;$50/ft^3)*	**Status:** Demonstration **Efficacy:** High. Commonly used in normal environments, readily adaptable to remote operations **Waste:** Metals alloyed with contaminates possible	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability. **Development Costs:** $2-3.5M **Capital Costs:** $200K not incl. remote manipulation provisions **Operating Costs:** $50/ft^3 of waste generated
					H	High-PressureWater Jet (Major Equipment Removal) DISM-93-OL *Ranking:** *H-5-4 ($2–4M;$40/ft^3)*	**Status:** Accepted **Efficacy:** Low. Commonly used in normal environments, readily adaptable to remote operations **Waste:** Liquids (water) containing suspended particulate	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $2-4M **Capital Costs:** $200K not incl. remote manipulation provisions **Operating Costs:** $40/ft^3 of waste generated

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Various Facilities Including: Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Major Equipment Removal	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	Diamond Wire Cutting (Major Equipment Removal) DISM-94-OL *Ranking:** *not ranked*	**Status:** Demonstration **Efficacy:** Medium, Commonly used in normal environments, readily adaptable to remote operations **Waste:** Liquids (water) containing suspended particulate	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $2-3M **Capital Costs:** $150K not incl. remote manipulation provisions **Operating Costs:** $40/ft^3 of waste generated
EM Problems • Facility Decontamination and Decommissioning (D&D)					H	Advanced Laser Cutting (Major Equipment Removal) DISM-95-OL *Ranking:** *H-5-5 ($2.5–4M;$50/ft^3)*	**Status:** Predemonstration **Efficacy:** Low, Under development for use in normal environments, probably expensive to adapt to remote operations **Waste:** Metals alloyed with contaminates possible	**Technology Improvement:** Scaling laser system to required levels **Science Development:** None	Incorporate remote operations capability **Development Costs:** $2-3M **Capital Costs:** $250K not incl. remote manipulation provisions **Operating Costs:** $50/ft^3 of waste generated
						Explosive Cutting (Major Equipment Removal) DISM-96-OL *Ranking:** *not ranked*	**Status:** Demonstration **Efficacy:** Low, Difficult to contain, not recommendad for contaminated materials **Waste:** None	**Technology Improvement:** A means of beffering the associated shock wave. **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $TBD **Capital Costs:** <$100K not incl remote manipulation provisions **Operating Costs:** $TBD/ft^3 of waste generated
• Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)						High-Pressure Abrasive Water Jet (Major Equipment Removal) DISM-97-OL *Ranking:** *not ranked*	**Status:** Demonstration **Efficacy:** High, Commonly used in normal environments, readily adaptable to remote operations **Waste:** Liquids (water) containing suspended particulate	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $2-3M **Capital Costs:** $200K not incl. remote manipulation provisions **Operating Costs:** $40/ft^3 of waste generated

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Dismantlement for Decontamination and Decommissioning

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Major Equipment Removal	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Cutting	Plasma Arc Saw Cutting (Major Equipment Removal) DISM-98-OL *Ranking:** *not ranked*	**Status:** Demonstration **Efficacy:** Low, Commonly used in normal environments, readily adaptable to remote operations **Waste:** Metals alloyed with contaminates possible	**Technology Improvement:** Saw design for material thicknesses>100mm will require development **Science Development:** None	Incorporate remote operations capability **Development Costs:** $3-4M **Capital Costs:** $250K not incl. remote manipulation provisions **Operating Costs:** $50/ft^3 of waste generated
						Thermal Arc Water Jet Cutting (Major Equipment Removal) DISM-99-OL *Ranking:** *not ranked*	**Status:** Demonstration **Efficacy:** Low, Primarily and under water tool, may be difficult to adapt for out of water operation **Waste:** Metals alloyed with contaminates possible	**Technology Improvement:** None **Science Development:** None	Incorporate remote operations capability **Development Costs:** $2-3M **Capital Costs:** $1M not incl. remote manipulation provisions **Operating Costs:** $40/ft^3 of waste generated
					H	Advanced Automatic Fixtures, Bug-O, etc. (Major Equipment Removal) DISM-100-OL *Ranking:** *H-5-3 ($1.5–2.5M;$30/ft^3)*	**Status:** Accepted **Efficacy:** High, Commonly used in normal environments, readily adaptable to remote operations **Waste:** None	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $1-2M **Capital Costs:** $200M not incl. remote manipulation provisions **Operating Costs:** $30/ft^3 of waste generated
						Liquified Cryogenic Gas Cutting (Major Equipment Removal) DISM-101-OL *Ranking:**	**Status:** Evolving Technology **Efficacy:** Low, Currently not ready for use. **Waste:** None	**Technology Improvement:** Significant development effort required. **Science Development:**	Incorporate remote operations capability **Development Costs:** $2-3M **Capital Costs:** ~$10M not incl. remote manipulation provisions **Operating Costs:** $60/ft^3 of waste generated

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Dismantlement for Decontamination and Decommissioning

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Major Equipment Removal	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Conventional	Conventional Disassembly (Major Equipment Removal) DISM-102-OL *Ranking:** *not ranked*	**Status:** Accepted **Efficacy:** High, proven methods for remote environments, slow **Waste:** None	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $0.5-1M **Capital Costs:** $250 not incl. remote manipulation provisions **Operating Costs:** $40/ft^3 of waste generated
EM Problems • Facility Decontamination and Decommissioning (D&D)					Automated Conventional	Grabbler/Gross Shearing and Lifting (Major Equipment Removal) DISM-103-OL *Ranking:** *not ranked*	**Status:** Demonstration **Efficacy:** Medium, Commonly used in normal environments, readily adaptable to remote operations **Waste:** None	**Technology Improvement:** None **Science Development:** None **Available at all sites.**	Incorporate remote operations capability **Development Costs:** $1-2M **Capital Costs:** $250K not incl. remote manipulation provisions **Operating Costs:** $30/ft^3 of waste generated
• Remedial Action (RA)—Soils, Ground Water and Surface Water		Entombment	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Entombment	Thermoset Polymer/Thermal Plastic Stabilization (Entombment) DISM-109-OL *Ranking:** *not ranked*	**Demonstration.** **Efficacy:** Very useful particularly as compared to specialty grouts. Widely used at other sites. Leachability index of 11-12. Eliminates voids. **Waste Produced:** None unless excess promoter remains.	Evaluation prior to use to insure compatibility with the waste being stabilized.	Develop process methodology to insure, homogeneous mixing, maximum cost benefit, and elimination of excess promoter. Staff training. Solidification and transfer system needed. **Overall Cost:** $11/ft^3
						Ground Water Diversion (Entombment) DISM-110-OL *Ranking:** *not ranked*	**Accepted.** This technology's use is based on the need to divert groundwater away from the entombed area. **Waste:** Low **Efficacy:** High (French Drains)	None	Commercially available French drains are presumed to be adequate if designed properly. The cost of this technology is low, and the amount of waste generated is also low. Prototype testing of groundwater diversion techniques at the DOE X-10 Site will be required before acceptance by site D&D officials.
• Waste Management (WM)									

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Entombment	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Entombment	Temporary Entombment/Clay Fill (Entombment) DISM-111-OL *Ranking:** *not ranked*	**Demonstration.** This technology has been used at other sites and is proposed for the X-10 graphite reactor transfer trench for the purpose of temporary entombment. Efficacy considered high. The biggest limitation of this technology is leaching of contaminants because hydrologic isolation beneath the basement level is not addressed and hydrologic isolation. **Waste Produced:** Process itself - none. Decommissioning a filled site could result in increased waste. **Overall Cost:** $0.3M - $2M per 10^5 ft^3. **Efficacy:** Medium	Definition of hydrologic isolation needs and moistruizing of clay to prevent drying and cracking need to be assessed.	Prototype testing at the DOE X-10 Site will be required prior to acceptance by site D&D officials.
• Remedial Action (RA)—Soils, Ground Water and Surface Water					H	Capping—Above Ground Environmental Barrier (Entombment) DISM-112-OL *Ranking:** *H-4-3 ($0.5M;$3/ft^3)*	**Accepted.** Used in both the public, commercial and government sectors. Capping technology has been demonstrated at other sites for the purpose of long-term protection of burial sites. In-situ grouting of low-level burial trenches has taken place at ORNL. Y-12 plant site has capped waste with asphalt matrixed over polyurethane sheets. **Efficacy:** of this technology is considered moderate. The biggest limitation of this technology is long-term stability and hydraulic isolation. Because this approach requires additional excavation, it is considered to be high in cost. **Waste:** Low.	In order to ensure stable isolation of contaminated structures, application-specific hydraulic isolation caps must be developed. These barriers must include embedded sensors (discussed in another data sheet) to ensure structural and hydraulic isolation is maintained.	**Overall Cost:** $5K-13K for 10,000 ft^2 (dependent on liner thickness requirement).
• Waste Management (WM)					H	Encasement—Subsurface waste storage with void reduction (Entombment) DISM-113-OL *Ranking:** *H-4-3 ($0.5M;$10/ft^3)*	**Evolving - Conceptual.** Entombment of material and structures using existing structures should be a cost effective approach. Approach uses combination of existing accepted technologies. **Waste Produced:** None **Overall Cost:** Dependent on site and regulatory requirements. **Efficacy:** High	Little or no development. Integration of hydraulic isolation, solidification, senior technology, etc. needed.	Develop integration plan and demonstrate on small scale.

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Entombment	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Entombment H	Permenent Entombment (Entombment) DISM-114-OL *Ranking:** *H-4-3 ($1M;$15/m³)*	**Conceptual.** Utilizes numerous existing technologies to achieve a potentially cost effective means for dealing with low level waste and underground structures. **Waste Produced:** No additional waste from the entombment process. **Efficacy:** High. While concept is conceptual, it's implementation relies on the integration of accepted or demonstrated technologies. The commercial sector uses geosynthetic, high-density polyethylene liner and cap systems to environmentally safeguard sanitary landfills, leach pads, tailings dams, and the impounding of municipal incineration end products.	Application specific demonstration of capping, hydrologic isolation, sensors, etc. are needed.	Prototype testing of embedded sensors and engineering lining and cap barriers in a filled excavation application will be required prior to acceptance by site D&D officials. **Overall Cost:** To be determined by the site requirements and type of waste.
					H	Engineered Storage—for very "hot" items, future disposal (Entombment) DISM-115-OL *Ranking:** *H-4-8 ($7M;$400/m³)*	**Demonstrated** for similar situation in Weapons Facilities. **Waste:** Waste can be significantly reduced **Efficacy:** Certain to work; will require significant engineering and standards generation.	No new science and/or technology is needed.	Engineering of a prototype and licensing required to demonstrate process and lay ground work for other sizes and levels of radiation. **Development Cost:** Approximately $6-9 million to get to the first usable and licensed cask. **Capital Cost:** Total facility D&D of a site such as the MSRE at ORNL would require $20-30 million for all long term storage/shipping containers for high radiation level items. This may be off-set by a significant reduction in construction cost for roofed warehouses or other less durable concepts for interim storage. **Operating Cost:** Projected cost would be in the range of $400/cu-ft of stored equipment components.
						Hydraulic Isolation (Entombment) DISM-116-OL *Ranking:**	**Demonstration** Approaches vary with corresponding state of demonstrated usefulness. Isolation with high velocity jet grouting has been used at the White Oak Creek Enboynet, ORNL. Waste Produce4d- Overall Cost -$2M - $3M for 4DPE text. Efficacy- Medium to high: dependantion the process in question.	Development and evaluations of great formulations. Demonstration of capabilities of other approaches are needed.	Tasting and demonstration of applicable technologies, so that selecting can be based on use requirements.

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Entombment	Refer to Vol. 1, Pt. A Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Entombment	Rubblization via Crushing and/or Shredding (Entombment) DISM-117-OL *Ranking:** *Not Ranked*	**Demonstration.** Commercial products available which should meet requirements but neither detailed assessment or on site demonstration performed as yet. **Waste Produced:** Little to none. **Efficacy:** High. Greatly reduces the waste volume by reducing voids and permits easier incorporation.	Higher-torque, more durable shredders would be useful. Less labor intense systems are also needed.	Develop specifications, utilization plans, and user training. **Overall Cost:** $50K to $100K for large metal and cover.
					H	Sensors for Monitoring Entombment Integrity (Entombment) DISM-118-OL *Ranking:** *H-4-3 ($0.8M;$1K/sensor)*	**Predemonstration.** Use of integrated sensors in entombed structures and/or in capping etc. will provide information on integrity and stability. **Waste Produced:** None **Efficacy:** High	Development of application specific sensors, deployment approaches, and testing for survivability (and senior projected life) are needed.	**Implementation Needs:** Develop requirements for sensors and deployment. **Overall Cost:** $100K to $500K fully instrumented site.
						Modular Entombment—with provisions for future removal (Entombment) DISM-119-OL *Ranking:** *not ranked*	**Demonstration.** Use of preforms of metal or plastic to cost large blocks of material for temporary storage in entombed structures provides a cost effective means of dealing with waste. **Waste Produced:** Increases volume of waste b the percent of stabilizing material (grout, plastics, etc) added. **Efficacy:** High	Develop mixing requirements and test preforms for use with casting materials. Also assess cast block size for optimization of handling, storage, and relocation.	Develop application requirements, training needs, and handling requirements. **Overall Cost:** $25/gallon (polymerization material) (See DISM-109-OL *Ranking:**
						Concrete-Based Solidification/Stabilization DISM-120-OL *Ranking:** *not ranked*	**Accepted.** Currently has been used at K-25 Site as well as at other DOE sites. Use has surfaced several problems which would need to be dealt with if technology is elected. (Note that potentially increased waste volume if the entombed area is ever retrieved). **Efficacy:** High	Develop better understanding of needs for assuring validation of solidification and stabilization of the composite.	Mixing methodologies to avoid hot spots, installation of material to insure bonding and curing and pouring needs must be dealt with in implementation planning. **Overall cost:** $2.5 to $38/ft^3 depending on site requirements.

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						Zoning for Containment—Three Zones (Needed Enabling Technologies) DISM-141-OL *Ranking:** *Not Ranked*	**Accepted** Containment to prevent spread of exposed contamination to less contaminated areas has been demonstrated to be an effective cost reduction tool. At the Mound Laboratory facility a technique involving 3-Zones, "Cold, Buffer, and Hot" is being used to isolate contamination. Temporary containment has been shown to prevent increasing contamination in the surrounding building when removing gloveboxes. This technology will be necessary during dismantlement. It will allow an estimated 80 - 90% of the materials to be removed to be treated as low level waste. Commercial suppliers are available.	Lighter weight materials such as honeycomb construction may make panels easier to handle and cheaper. Inflatable panels may be applicable.	Panels need to be engineered to allow reuse of panels in the next dismantlement zone. Design for enhanced fire protection design. Flammable materials would be prohibited. Cost savings would result from reduction of disposal cost for 80 -90% of the material in the diffusion facilities. Low level waste can be disposed at $20/cu-ft. Material exceeding the limits for low level cost approximately $100/cu-ft to dispose. Assuming all building materials can be disposed as low level waste the savings would be $1-2 Billion for the older buildings.
						Point-and-Direct Tooling Positioning (Needed Enabling Technologies) DISM-142-OL *Ranking:** *Not Ranked*	**Evolving/Conceptual** Pre-proof of principle stage. **Efficacy:** Reduced contact of worker with materials, low cost, easily adapted to multiple uses. **Waste:** None	Develop prototype and demonstrate efficacy. Cost to develop ~$500K.	Overall cost - minimal (believed less than $50K per unit). Field test prototype system. Test cost $500K. Implementation cost per unit - $50K.
					H	Computer-Based D&D Information Retrieval (Needed Enabling Technologies) DISM-143-OL *Ranking:** *H-3-3 ($3.5M;$50/ft^3)*	**Demonstration** Status exists with FDDI networks being the primary nominee for this purpose. An FDDI network exists within Energy Systems and is being evaluated through the mathematics and physics group and C&TD. The application of this technology initially only requires customizing to meet the exact distribution requirements of the D&D program. **Waste:** None. **Efficacy:** High	Specific programs, technology development needs, and technology improvement needs.	Cost of proof of principle, amount of resources, equipment, hardware, software, facility, and educational needs. Reference requirements that are needed to deploy the technology successfully. **Cost:** Low.

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						Laser Triangular Mapping of Facilities (Needed Enabling Technologies) DISM-146-OL *Ranking:** *Not Ranked*	**Pre-demonstration** Laser scanning and distance mapping have been applied in many different disciplines. Actual integration into a computer 3-D database for remote manipulation is probably in the pre-development stages by commercial enterprises.	Specific detailed software that integrates the 3-D mapping to an existing database for use in robotic or remote manipulation applications will be required. Manipulation of the database and adjustment/calibration of the sensors in a real-time hand mode of operation will be necessary to achieve success of this program	1. A development effort between Energy Systems and commercial systems developers will be required. 2. A resource of programmers, workstation computers, lasers, I&C coordinators, commercial firms, and best efforts contracts will be required to demonstrate this technology. 3. After a 1-2 year development effort with individuals skilled in robotics, mechanical design, electronics design, software design, and optics and optical mapping/ a sufficient expertise should be available to initiate a design and procurement specification for procurement of multiple units to accomplish the optimum methods of D&D utilizing either/or remote or robotic methods.
						Video Mapping (Needed Enabling Technologies) DISM-147-OL *Ranking:** *Not Ranked*	**Demonstration** Video images can be an effective means of establishing configuration layouts for planning and executing work. Digitizing video (photographic) images for establishing baseline layouts and for computer-automated comparison of different positions with a baseline to characterize and establish equipment differences would facilitate planning and work direction. Comparison of multiple digitized images to highlight differences and conversion of images to line drawings is a well-established, demonstrated set of technologies.	Technology development needs include the assembly of an imaging/computer system, software development, procedure development, and personnel training.	Resource requirements and development needs are as follows: 1. Imaging, computer, and related hardware (approx. $40K-60K). 2. System integration and development (approx. $300K-400K). 3. Development personnel: image technologist, software specialist, project manager. 4. System functional testing. 5. 9 to 15 months development. Deployment Requirements: 1. Procedure development and documentation ($30K to 50K). 2. User training ($10K - 20K). 3. System replication cost (if more than one system) ($60K - 80K).

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Dismantlement for Decontamination and Decommissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	**Various Facilities Including:** Bldg. 3028 Bldg. 3028E Bldg. 3029 Bldg. 3030 Bldg. 3031 Bldg. 3032 Bldg. 3033 Bldg. 3036 Bldg. 3038 Bldg. 3517 Bldg. 7500 Bldg. 9219-1 MSRE, Bldg. 9201-3 Bldg. 9419-1 Process Piping and Tankage Drain Lines Pulsefeeder Pumps Pavement over 55-gal. Drum ORR Biological Shield HRT Structure ORR Hot Cell Liners Membrane Between HRT Concrete	Needed Enabling Technologies	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Dismantlement	Needed Enabling Technologies	**E** Project Information Access Services (Needed Enabling Technologies) DISM-151-OL *Ranking:** *E-2-1 ($N/A;$150/cut)*	**Demonstration** The technology needs to be demonstrated because of the degree of integration of different host computers required to support effective information access across wide area networks.	Technology to implement such a system is commercially available and is found typically in financial services companies and some large corporations. **Available at X-10.**	Computer networks, especially Ethernet (cable, fiber), need to be extended throughout the X-10 Site to provide a basic foundation for information access and file transfers.
EM Problems • Facility Decontamination and Decommissioning (D&D)						Network Architecture with Integrated Workstations (Needed Enabling Technologies) DISM-152-OL *Ranking:** *Not Ranked*	**Demonstration** **Efficacy:** Reduced time and cost to obtain or transfer information. **Waste: N/A**	None **Available at X-10.**	Software acquisition; user training.
						E Client/Server Access to Standards and Regulatory Guidelines (Needed Enabling Technologies) DISM-153-OL *Ranking:** *E-2-N/A ($N/A;$150/cut)*	**Demonstration** Component technologies are well-established, commercially available, and affordable. They have not yet been integrated for use in a client/server environment.	A product is needed that provides network access to the databases on CD-ROM using the TCP/IP communications protocols between client and server. **Available at X-10.**	Automated, on-line access to basic reference documents is essential to reducing costs and increasing reliability of operations in a highly regulated work environment.
						Data Access Services (Needed Enabling Technologies) DISM-154-OL *Ranking:** *Not Ranked*	**Demonstration** The particular network and communications configurations needed to support restoration activities may not exist, so would have to set up and their successful operation demonstrated.	Some software will be available commercially; some will have to be developed locally.	Requirements and specifications for such services must be identified and documented to serve as a common reference so that data can be accessed using a single set of services regardless of the type of computer at each node on the network.
• Remedial Action (RA)—Soils, Ground Water and Surface Water						**E** Automated Scanning and Conversion of Engineering Drawings (Needed Enabling Technologies) DISM-155-OL *Ranking:** *E-2-1 ($200K;$10/bolt & $300/cut)*	**Demonstration** The basic technology is well established. Whether the current state of the art can adequately process the large number of drawings needed for reference and how effectively this technology can be integrated with other aspects of automated support needs to be demonstrated.	Improvements are needed in the speed and accuracy of converting scanned images to graphical representations that will meet the needs (e.g., ability to change scale to show more detail) of the environmental restoration program. **Available at Y-12.**	Considerable human intervention may be required to handle large drawings or drawings that cannot easily be laid flat on a scanning bed.
						M 3-D CAD Data Base of Buildings and Structures (Needed Enabling Technologies) DISM-156-OL *Ranking:** *M-2-4 ($250K;$600/cut)*	**Accepted** The basic technology is in wide use. A variety of commercial products is available for use on systems ranging from desktop computers to large mainframes.	Integration of this technology with the other supporting technologies that must work together with it to provide the high level of automation needed to assure proper compliance with environmental legislation governing restoration activities will be the main technology need.	Identification of all possible uses (e.g., "training" robots, visual "walkthroughs", tags for tracking activities) of this technology and development of database requirements to support them are very important foundations for effective use of this technology.
• Waste Management (WM)						Client/Server Architecture for Data Base Access (Needed Enabling Technologies) DISM-157-OL *Ranking:** *Not Ranked*	**Demonstration** The effectiveness and appropriateness of a particular architecture design to meet the requirements of the restoration activities needs to be demonstrated.	This technology will benefit most from improvements in network technology (higher transmission speeds, improved transmission protocols and data access services) needed to support it.	Effectiveness depends strongly on the definition, design and implementation of the data dictionaries, data directories and data models that are the essential foundation for use of this technology.

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Dismantlement for Decontamination and Decommissioning

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EM Problems • Facility Decontamination and Decommissioning (D&D)					H	Electronic Catalog Descriptions and Source Locations of Site Historical Data (Needed Enabling Technologies) DISM-159-OL *Ranking:** *H-2-4 ($2.5M;$900/cut)*	**Accepted** Standard database products can be used to create and maintain the inventory database.	Methods will be needed to evaluate and sort historical records according to their likely usefulness.	Initial implementation efforts must focus on locating the collections of records and documents of historical value.
					H	Computer Aided Task Analysis and Procedure Preparation (Needed Enabling Technologies) DISM-172-OL *Ranking:** *H-3-6 ($200K;$30/ft^3)*	**Demonstration** This technology is used extensively in planning by various federal agencies, most notably the Department of Defense in military operations planning.	More natural language analysis tools are needed to assist with analysis of information used for planning, much of which is provided in text form. **Available at X-10.**	Knowledge base development will require the largest effort, followed by development of expert systems and decision aids needed to make effective use of the information in the knowledge bases.
						Generalized Object-Oriented Simulation Software (Needed Enabling Technologies) DISM-173-OL *Ranking:** *Not Ranked*	**Demonstration** The simulation environment is being used currently in ongoing studies associated with several different nuclear reactor design concepts. Modules would have to be written to model other types of systems.	Improvements are needed most in graphical display support systems. **Available at X-10.**	Successful deployment depends on availability of applications programmers who understand object-oriented design and programming principles and have experience applying this understanding to models of physical systems.
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Automated Engineering System Life Cycle Planning (Needed Enabling Technologies) DISM-174-OL *Ranking:** *Not Ranked*	**Accepted** A variety of commercial products developed to assist with managing large software development processes can be adapted for effective use in other engineering disciplines.	Improvements are needed to provide new types of support in order to satisfy regulatory requirements.	The usual life cycle planning methods must be modified to accommodate requirements of applicable environmental legislation which imposes constraints and requires additional elements to augment common practice.
						Automated System Reliability and Safety Analysis (Needed Enabling Technologies) DISM-175-OL *Ranking:** *Not Ranked*	**Accepted/Demonstration** Tools for some types of analysis are in common use in engineering development environments for things like software, aircraft, communications satellites, and medical diagnostic equipment.	Few automated analysis tools exist since much of the effort for these analysis requires checking for consistency, correctness, completeness, tolerance of designs to various kinds of system failures, and unintended function.	Detailed knowledge of the system being analyzed (its behavior and attributes), its intended use, operation, and constraints that apply is essential to being able to automate any such analysis.
						Geographic Information System for DOE Sites (Needed Enabling Technologies) DISM-181-OL *Ranking:** *Not Ranked*	**Accepted** Most information, data, and computer system components for a basic geographic information system (GIS) for each DOE site already exists but must be integrated to meet the needs of the environmental restoration program.	Existing technology must be enhanced by adding a tagging mechanism to permit the system to be used for tracking activities and to link information in databases associated with a physical location to appropriate map and drawing displays on desktop computers. **Available at X-10.**	A large initial effort may be required to scan and digitize diagrams and drawings for electronic storage and quick retrieval or transfer across networks.

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Dismantlement for Decontamination and Decommissioning

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EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

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Decontamination

The Decontamination [illegible] concepts and [illegible] for removing various contaminants from facilities [illegible] different [illegible] because of the large number of combinations of contaminants and substrate [illegible] was necessary to limit the size of the diagram. This was accomplished by [illegible] areas into different groups that had common treatment technologies.

Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	H Ultrahigh-Pressure Water DCON-35-OL *Ranking:** *H-5-1 (1.7; $1/ft²)*	**Accepted** Technology has been used by industry. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Unless a recycle system is developed, waste would be 3-5 gal water/ft² concrete cleaned that contains ~0.01 ft³ concrete residue, plus the contaminants removed.	**Technology Improvement:** To minimize waste generation, a system is needed to treat the water so that it can be recycled. **Technology Improvement:** Automation, especially for walls and ceilings.	A water treatment system is needed to minimize liquid wastes from this technology. **Development Cost:** $1.3M **Capital Cost:** ~$500K **Operating Cost:** ~$1/ft²
	Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241							
	Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters							
	Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
	Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241							
	Bldg. 3036 Floor	Concrete Cs-137, Sr-90				H Shot Blasting DCON-36-OL *Ranking:** *H-3-0 (<0.1; $1/ft2)*	**Accepted** Commercial iron shot blasters are in use at the K-25 site. **Efficacy:** They are generally effective but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants plus 0.05lb spent shot per ft² of concrete decontaminated.	**Technology Improvement:** Automation, especially for walls and ceilings.	Normal implementation needs. **Development Cost:** None **Capital Cost:** ~$50K **Operating Cost:** ~$1/ft²
	Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation							
	Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
	Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt							
	Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
	Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				H Scabblers/Scarifiers DCON-37-OL *Ranking:** *H-4-2 (0.5; $5/ft2)*	**Accepted** Mechanical scabblers are used for concrete decontamination at the K-25 Site and elsewhere. **Efficacy:** They are generally effective, but leave some hot spots. Waste is ~0.01 ft³ removed substrate (1/16" cut) containing removed contaminants per ft² of substrate decontaminated	**Technology Improvement:** Automation, especially for walls and ceilings.	Normal implementation needs. **Development Cost:** None **Capital Cost:** ~$500K (largest size) **Operating Cost:** ~ $5/ft²
	Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				H Grit Blasting DCON-38-OL *Ranking:** *H-4-0 (<0.1; $5/ft2)*	**Accepted** Has been used successfully for many applications in the nuclear industry. **Efficacy:** Technology is generally effective. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants per ft² of concrete decontaminated plus spent grit.	**Technology Improvement:** automation, especially for walls and ceilings.	Normal implementation needs. **Development Cost:** None **Capital Cost:** ~$500K (largest size) **Operating Cost:** $~5/ft²
	Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				H Centrifuge Cryogenic CO_2 Pellet Blasting DCON-39-OL *Ranking:** *H-5-2 (1.0; <$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Technology Improvement:** 1) Demonstration of an on-line, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen-depletion precautions. **Development Cost:** <$1M **Capital Cost:** $100K **Operating Cost:** <$1/ft²
	Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products							

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Ice Blasting DCON-40-OL H *Ranking:** *H-5-1 (<1.0; $1/ft2)*	**Demonstration** **Efficacy:** Efficacy of commercial system for this application needs demonstration. **Waste:** Waste would be about 14 to 18 gallons per hour waste water containing removed contaminants.	**Development:** Demonstration of efficacy of commercial system. **Technology Improvement:** Automation/robotics, especially for walls, corners, etc.	A water treatment system is needed to minimize liquid wastes from this technology. **Development Cost:** $250K **Capital Cost:** $100K-$1M **Operating Cost:** <$1/ft²
EM Problems • Facility Decontamination and Decommissioning (D&D)	Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241				Supercritical CO_2 Blasting DCON-41-OL H *Ranking:** *H-5-1 (O.75+; >$1/ft2)*	**Predemonstration** **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed concrete and contaminants contained in a cyclone and a HEPA filter.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminants. Demonstrate efficacy for contaminants of interest.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen depletion precautions. **Development Cost:** $250K-1M **Capital Cost:** ~$500K **Operating Cost:** $1+/ft²
	Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters				Plastic Pellet Blasting DCON-42-OL M *Ranking:** *M-4-0 (<0.1; $1/ft2)*	**Accepted** Plastic pellet blasting is a widely used alternate to sand blasting for applications in which it is desired to impart minimal damage to the substrate. **Efficacy:** Technology should remove smearable, but not fixed contamination, from concrete. **Waste:** Waste would be spent plastic pellets plus removed contamination.	**Technology Improvement:** Develop and demonstrate system for processing waste. **Technology Improvement:** Minimize blast media erosion to minimize waste; automation/robotics, especially for walls, etc.; improve containment of waste and removed contaminants.	A system for processing waste to an acceptable form is needed. **Development Cost:** Improvements $5.5M+ **Capital Cost:** ~$50K **Operating Cost:** $0.20 - $2.15/ft
	Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
	Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241							
	Bldg. 3036 Floor	Concrete Cs-137, Sr-90							
	Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation							
	Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
	Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt							
	Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
	Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				Hand Grinding, Honing, Scraping DCON-43-OL H *Ranking:** *H-2-0 (<<0.1; $1/ft2)*	**Accepted** **Efficacy:** Grinding with hand-held power grinders has been successfully used for small-scale decontamination. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	None **Available at X-10, K-25.**	A collection system for the vaporized deposits would be needed to implement this technology. **Development Costs:** None **Capital Cost:** $150 ($5K with vacuum system and $50-500K with remote operation) **Operating Cost:** ~$1/ft²
	Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				Automated Grinding DCON-44-OL H *Ranking:** *H-2-1 (~ $1; N)*	**Conceptual** Grinding has been successfully used for small scale decontamination. This grinding was done with hand-held power grinders Remotely operated grinding equipment is available, but no references to its use for decontamination have been found. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** The applicability of this technology to items with rad contamination should be demonstrated.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** $600K **Capital cost:** $250K
	Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
• Remedial Action (RA)—Soils, Ground Water and Surface Water	Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products							
• Waste Management (WM)									

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						Explosive DCON-48-OL L *Ranking:** *L-2-5 (4; $50/ft2)*	**Demonstration** Blasting has been used to decontaminate nuclear reactor shielding. Demonstration will be needed for other applications. Safety concerns need to be resolved; care must be taken to contain the dust and to prevent structural damage to the building being decontaminated and the surrounding structures. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** Improvements in the methods of applying explosives and in the uniformity of the detonation are needed. The explosion will generate toxic organic vapors. The technology to control toxic vapors formed by the explosion must be developed and demonstrated.	A certified blasting technician will be needed. **Capital cost:** $50K **Operating cost:** $50/ft² **Development cost:** $1-4M
					Thermal Surface Removal Methods	Microwave Scabbling DCON-71-OL H *Ranking:** *H-3-2 (2.5+; >$1/ft2)*	**Predemonstration** In FY 1991 ORNL demonstrated reliable removal of noncontaminated concrete surfaces using a stationary microwave device. A mobile device is under development. **Efficacy:** Since microwave scrabbling removes the contaminated concrete surface, the decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** The waste generated is concrete rubble with particle diameters lying primarily in the range of 1 to 10 mm plus the contaminants. For a removal depth of 10 mm, 0.03 ft³ of concrete rubble is generated per ft² of concrete decontaminated.	**Development:** The development and testing of a mobile prototype microwave concrete removal machine needs to be completed.	Normal implementation needs. **Development Cost:** $2.5M **Capital Cost:** ~$250K **Operating Cost:** >$1/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Thermal Surface Removal Methods	Plasma Torch DCON-72-OL H *Ranking:** *H-4-1 (= $1/ft2)*	**Evolving Technology Conceptual** Plasma torches exist commercially to weld and cut materials that have very high melting temperatures or require an inert atmosphere. **Efficacy:** Its efficacy in removing various organic contaminants or to spall off layers of contaminated concrete has not been investigated. **Waste:** Wastes would consist of materials used to trap reaction products from the decomposition of organics and spalled concrete with contaminants.	**Science:** Laboratory tests are needed to evaluate the efficacy of vaporizing or decomposing organics, determine the decomposition reaction by-products, and suitable for trapping materials. Laboratory tests of thermal stress-induced spalling of concrete are also needed. Computer modeling of plasma-surface interactions and heat transfer in concrete are needed. **Development:** Plasma torches having geometries and conditions suitable for decontamination need to be developed along with suitable collection and gas treatment systems. **Available at Y-12.**	A collection system for the vaporized contaminants would be needed to implement this technology. **Development Costs:** ~$500K **Capital costs:** ~$100K **Operating costs:** $0.01-$1.00/ft²
EM Problems • Facility Decontamination and Decommissioning (D&D)	Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241				Laser Heating DCON-73-OL M *Ranking:** *M-4-4 (3; $1/ft2)*	**Demonstration** Currently being used to remove organic coatings from metal surfaces. **Efficacy:** Current prototype systems are capable of removing 2-mil-thick coatings at the rate of 100 ft²/hr. Effectiveness on contaminants and substrates of interest is uncertain. **Waste:** Waste will be prefilters and HEPA filters filled with contaminants.	**Development:** Current prototype needs to be evaluated for possible use on contaminated areas. Systems with different operational parameters (e.g., wavelength, pulse durations) should be evaluated as well.	A collection system for the vaporized contaminants would be needed to implement this technology. **Development Costs:** $2M+ **Capital Cost:** $500K-$1M+/machine **Operating Cost:** ~$1/ft²
	Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192				Laser Etching and Ablation DCON-74-OL M *Ranking:** *M-4-4 (3.5; >$1/ft2)*	**Predemonstration** Several research groups at university and government laboratories have used the technology to remove radiological and organic contaminants from various surfaces. **Efficacy:** The technique is slow to remove large deposits. **Waste:** Wastes would be removed contaminants, some substrate material, and HEPA filters from the filtration system.	**Development:** Existing lasers, delivery systems, and filtration systems need to be integrated into a prototype system for demonstration.	A collection system for the vaporized contaminants would be needed to implement this technology. **Development Costs:** $2M+ **Capital Cost:** $0.5-1M/machine **Operating Cost:** >$1/ft²
	Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters				Flashlamp Cleaning DCON-77-OL H *Ranking:** *H-3-3 (2.5; ~$1/ft2)*	**Predemonstration** Flashlamp systems are being used to remove organic contamination from metals, precious metals, and fragile substrates. Hanford-Westinghouse Laboratory is conducting tests of xenon flashlamp systems for removing radiological contamination from surfaces inside metal storage vessels. **Efficacy:** Technology is likely to be effective for surface contamination. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	**Development:** Commercially available flashlamp systems need to be evaluated for radiological contamination	A collection system for the vaporized contaminants would be needed to implement this technology. **Development Cost:** ~$2.5 M **Capital Cost:** $50-100K/machine **Operating Cost:** ~1.00/ft²
	Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
	Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241							
	Bldg. 3036 Floor	Concrete Cs-137, Sr-90							
	Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation							
	Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
	Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt							
	Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
	Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
• Remedial Action (RA)—Soils, Ground Water and Surface Water	Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products							
• Waste Management (WM)									

* *See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.*

Decontamination

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Compressed-Air Cryogenic CO_2 Pellet Blasting DCON-51-OL H *Ranking:** *H-4-1 (0.7; >$1/ft2)*	**Demonstration** This technology is commercially available. It has been used at nuclear reactor sites to decontaminate hand tools and some equipment. **Efficacy:** The efficacy of this technology for removing the listed contaminants from concrete has not been demonstrated and is doubtful. **Waste:** Wastes would be HEPA filters filled with the removed contaminants.	**Development:** Evaluate technology that has recently been demonstrated in Department of Defense programs regarding automation and improvements in pellet delivery.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants. **Development Costs:** about $0.50M **Capital Cost:** About $200,000 **Operating Cost:** >$1/ft²
Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241				High-Pressure Water DCON-52-OL M *Ranking:** *M-3-1 (1.3; <$1/ft²)*	**Accepted** High pressure water blasting has been used very successfully to decontaminate various large and complex surfaces at nuclear power plants. **Efficacy:** Technique is expected to be effective with a DF of about 50 for loosely adhering contamination on concrete. DFs will be higher if chemical cleaning agents are also used. Technique is expected to be ineffective for fixed contamination on concrete. **Waste:** Waste is 4 to >100 gpm of contaminated waste water.	**Technology Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. **Technology Improvement:** Remote operation will necessitate the adaptation of the high pressure water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development Cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital Cost:** $50K-$75K (about $250K with remote operation) **Operating Cost:** <$1.00/ft²
Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192				Superheated Water DCON-53-OL M *Ranking:** *M-4-1 (1.4; <$1/ft²)*	**Accepted** Technology is available and has been used by industry. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has soaked into the concrete. On finished concrete, technology may drive contaminants deeper into substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	**Technology Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. **Technology Improvement:** Remote operation will necessitate the adaptation of the superheated water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development Cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital Cost:** About $175K (about $250K with remote operation) **Operating Cost:** <$1.00/ft²
Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters				Water Flushing DCON-54-OL M *Ranking:** *M-4-1 (1.3; <$1/ft2)*	**Accepted** Flushing with hot water is often used following scrubbing, especially on floors. **Efficacy:** The technique is not effective on fixed insoluble contamination. On finished concrete, technology may drive contaminants deeper into substrate. **Waste:** The waste generated is the contaminated water from the flushing operation.	**Technology Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the hot water cleaning operation.	A water treatment system is needed to minimize liquid wastes from this technology. **Development Cost:** About $1.2M **Capital Cost:** <$5K **Operating Cost:** <$1/ft²
Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241							
Bldg. 3036 Floor	Concrete Cs-137, Sr-90							
Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation							
Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt							
Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products							

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning Methods	Steam Cleaning DCON-55-OL M *Ranking:** *M-4-1 (1.3; ~$1/ft2)*	**Accepted** The technique has proven useful, especially on complex shapes and large surfaces. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has soaked into the concrete. On finished concrete, technology may drive contaminants deeper into substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	**Technology Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Remote operation will necessitate the adaptation of the steam and vacuum collection systems to robotic system control.	A wastewater treatment / recycle system will be needed to use this technology. **Development Cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital Cost:** $50K-$75K (about $250K with remote operation) **Operating Cost:** ~ $1.00/ft²
	Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241							
	Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters							
	Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
	Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241				Hand Brushing Used to Remove Surface Contamination DCON-56-OL H *Ranking:** *H-2-0 (0; $1/ft2)*	**Accepted** Brushing is a common decontamination technique. **Efficacy:** Brushing is effective for loose contamination only. **Waste:** Waste consists of removed contamination plus other loose debris.	None **Available at K-25.**	Normal implementation needs. **Capital cost:** negligible **Operating cost:** $1.00/ft² **Development cost:** none
	Bldg. 3036 Floor	Concrete Cs-137, Sr-90							
	Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation							
	Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
	Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt				Automated Brushing DCON-57-OL M *Ranking:** *M-3-2 (1; $300/ft)*	**Demonstration** This technology has been used at Rocky Flats to remove plutonium contamination from the inside of pipes. **Efficacy:** Tests would be needed to demonstrate its effectiveness for other contaminants on other substrates. **Waste:** Waste would be removed contamination plus any other loose debris.	**Development:** Tests to demonstrate that this technology is effective for the problems at ORNL.	Vacuum collection system Development costs-$200K-1M **Capital cost:** $250K(remotely operated system) **Operating cost:** $300/linear foot of pipe
	Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
	Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				Sponge Blasting DCON-58-OL M *Ranking:** *M-3-1 (1.3; $2/ft2)*	**Accepted** Although the technology is relatively new, it is currently being used by at least two sites including a nuclear power plant. **Efficacy:** Extensive data on decontamination factors are not available. With the aggressive sponges, which are impregnated with abrasives, this technology may be effective for the listed contaminants and substrates. **Waste:** Wastes consist of about 0.01 ft³ of blasting media and removed contaminants per ft² of area decontaminated plus any liquid cleaning agents that may have been added.	**Technology Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the sponge blasting operation.	A wastewater treatment / recycle system will be needed to use this technology. **Development Cost:** About $1.2M **Capital Cost:** Sponge blasting system: About $20K (with sifter system) **Operating Cost:** About $2/ft²
	Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
• Remedial Action (RA)—Soils, Ground Water and Surface Water	Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products				Solvent Washing to Remove Radiological Contamination DCON-61-OL M *Ranking:** *M-3-2 (1; N)*	**Conceptual** Plutonium contaminated items at Richland, WA were rinsed with Freon. The vendor who supplied the equipment for Richland ten years ago no longer sells it. **Efficacy:** This technique is mainly applicable to smearable contamination. **Waste:** Waste would be spent solvent containing removed contaminants.	**Science:** Solvents that are less damaging to the environment need to be identified and demonstrated. **Available in Private Sector.**	Vapor collection system **Capital Cost:** $300K (1980 dollars) **Development Cost:** <$1M to identify and demonstrate the replacement solvent. **Operating Cost:** An average of 7.5 minutes per item was required when decontaminating small items.
• Waste Management (WM)									

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EM Problems: • Facility Decontamination and Decommissioning (D&D)

Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Strippable Coatings DCON-63-OL M *Ranking:** *M-3-0 (<0.1; >$1/ft²)*	**Accepted** Technology has been used for decontamination applications involving hazardous and radioactive contaminants. **Efficacy:** Decontamination factors of one to several hundred can be expected with two applications. **Waste:** Waste is a solid polymer (volume = 1 mm x surface area decontaminated) containing the removed contaminants.	**Technology Improvement:** Develop coatings with lower material costs and greater ease of application.	Normal implementation needs. **Capital cost:** Negligible **Operating cost:** $1-$1.40/ft²
	Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241							
	Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters							
	Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
	Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241				Vacuum (Low Pressure) DCON-7-OL M *Ranking:** *M-4-0 (<0.1; $1/ft²)*	**Accepted** Vacuum cleaners have long been used to clean up loose contamination at the gaseous diffusion plants. **Efficacy:** Since little of the listed contaminants are expected to be in loose form, this technique is not expected to be effective in cleaning concrete floors at ORNL. **Waste:** The waste is a HEPA filter filled with the contaminants and other materials that are removed by the vacuum.	None	Normal implementation needs. **Capital Cost:** <$10K **Operating cost:** >$1/ft²
	Bldg. 3036 Floor	Concrete Cs-137, Sr-90							
	Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation							
	Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
	Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt							
	Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
	Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products			Chemical Surface Cleaning Methods	Chemical Foams DCON-8-OL M *Ranking:** *M-4-1 (3; $.50-2/ft²)*	**Demonstration** Widely used throughout the nuclear industry. Foam is used as a carrier of chemical decontamination agents, not as the agent itself. It is sprayed onto component walls or the component is filled with the foam. It can be wiped, rinsed, or vacuumed off. **Efficacy:** Decontamination effectiveness was 63-92% with DF = 2.7 to 12.5 inside a hot cell in one study. **Waste:** Small amount of contaminated sulfonated detergents, synthetic wetting agents, coupling agents, rinse water, and drying cloth.	**Development:** Scale-up/development of the process to a size appropriate for ORNL use. The technology itself is inexpensive, but development and scale-up will probably require support. **Technology Improvement:** Full control over the mean bubble dimensions and the volume swell factor are needed, indicating that some basic research will be necessary.	Normal implementation needs. **Development cost:** $1M-$4M; **Capital cost:** $50K **Operating cost:** $0.50-$2/ft²
	Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				Fluoboric Acid Treatment DCON-11-OL M *Ranking:** *M-4-2 (2; N)*	**Demonstration** Technology was designed specifically for D&D. **Efficacy:** Unrestricted use of materials should be possible after decontamination, due to high decontamination factor (DF). Fluoboric (or fluosilicic) acid can scabble and clean cement and brickwork. If contaminated to a depth of only a few mm, concrete flooring and structures can be returned to unrestricted use.	**Development:** Although the method has seen application at Chernobyl with good results, development work is needed to test applicability at ORNL.	Fluoboric acid exhibits low vapor pressure and requires only standard precautions for acid or base work. The plant can be manufactured in modular form and installed in existing buildings. Hardware (equipment): Fabrication of all key plant parts from polypropylene or from Halar-coated metal. **Capital Cost:** in 1990 to set up a plant for decontaminating 5 tons/day of steel cost $774K, excluding development, planning, and buildings. **Operating cost:** Relatively low; this is a very simple process.
	Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products							

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning Methods	Biological Surface Cleaning DCON-3-OL L *Ranking:** *L-2-3(1.0M;~$1/ft²)*	**Evolving Technology / Pre-conceptual** The knowledge base exists for biological treatments of various contaminants; however, there is not a data base for application of the technology for surface decontamination. **Efficacy:** This technology is quite likely to be successful for oil and PCBs. It could be successful for radionuclides of interest, but these contaminants would remain in the bacterial sludge. **Waste:** The waste generated would be the contaminated layer of microbes removed from the treated surface.	**Science:** Literature study and bench-scale tests of microbes on radionuclides of interest. **Development:** Develop methods for applying a layer of microbes, supplying needed nutrients, and removing the microbe layer from the decontaminated item. **Available at X-10, K-25.**	Facilities for cultivating the bacteria and disposing of the bacterial sludge would be needed. **Development Cost:** $300K-$600K **Capital Cost:** ~$200K **Operating Cost:** $0.10-$3.00+/ft²
	Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241							
	Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters							
	Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
	Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241							
	Bldg. 3036 Floor	Concrete Cs-137, Sr-90							
EM Problems • Facility Decontamination and Decommissioning (D&D)	Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation				Detergent Treatments DCON-13-OL M *Ranking:** *M-4-0 (0; >$1/ft2)*	**Accepted** Surface smearable decontamination with caustic chemicals (soap and water) is accepted technology and is used extensively at ORNL. The caustic hand-scrubbing process was applied to cleaning small items. **Efficacy:** Soaps, carbonates, etc., will remove smearable, but not fixed contamination. **Waste:** Waste would be spent detergent solution containing removed contaminants (normally treated by neutralization and precipitation).	None for removal of smearable contamination with carbonates, soaps, etc. **Available at X-10, K-25.**	This is an established process that could be implemented at ORNL with no major changes. **Capital Cost:** <$10K Operating costs: >$1/ft
	Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
	Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt							
	Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
	Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
	Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products				Electromigration DCON-20-OL M *Ranking:** *M-3-3.5 (1.2; N)*	**Predemonstration** Limited testing on a small scale. **Efficacy:** Initial data indicate 90+% removal of U & Tc from concrete. Applicable, in principle, to actinides & chromate. Removal of oil & PCBs possible, in principle, but not demonstrated. **Waste:** Wastes would be electrolytes containing removed contaminants and scrap cell components.	**Development:** Additional small-scale "proof of the principle" tests are needed followed by larger scale field demonstration. A treatment system that would permit recycle of the electrolyte is needed.	Normal implementation needs. **Development Cost:** $1M **Capital Cost:** ~$200K **Operating Cost:** ~$5/ft²
	Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
• Remedial Action (RA)—Soils, Ground Water and Surface Water	Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products							
• Waste Management (WM)									

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Decontamination

EM Goals

- Clean Up Legacy Waste
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EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
Oak Ridge Reactor Biological Shield	Concrete Fission Products, Corrosion Products	Refer to Vol. 1, PL A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning Methods M	Chelation Treatment DCON-21-OL *Ranking:** *M-4-2 (1.5; <$1/ft2)*	**Demonstration** The technology has been employed at various facility operations and nuclear power plant sites. **Efficacy:** Excellent DFs, achieving acceptable decontamination levels resulting in unconditional release. Easy to apply in-situ as agent acts at neutral pH and are non-hazardous, non-fuming, have no gas evolution and are biodegradable. **Waste:** Simple waste minimizing treatment and disposal as a non-RCRA waste. Minimizes waste through oxidative destruction of chelate agent, partitioning of organics (including PCBs) and concentration of radionuclides precipitated out in the flocculent sludge which can be further de-watered.	**Development:** Validation of updated chelating agents is needed and is currently underway at ORNL to confirm total efficacy and economic advantage.	Application equipment for in-situ decontamination. Support personnel and equipment to sample, analyze, develop appropriate concentrations, ensure oxidation of organics and/or complete partitioning will be necessary. Spray booth or dipping tank facilities with heating capabilities desirable on-site or accessible by decontamination facility. **Operating Cost:** <$1/ft²
Bldg. 3028 Hot Cell Interiors	Concrete Fission Products, Cm-244, Pm-147, Am-241							
Bldg. 3029 Hot Cell Interiors	Concrete Cs-137, Sr-90, Co-60, Ir-192							
Bldg. 3030 Hot Cell Interiors	Concrete 43 Beta/Gamma Emitters							
Bldg. 3031 Hot Cell Interiors	Concrete Gd-153, Am-241							
Bldg. 3032 Hot Cell Interiors	Concrete P-32, Am-241							
Bldg. 3036 Floor	Concrete Cs-137, Sr-90							
Homogeneous Reactor Test Structure	High-Density Concrete Fission Products, Corrosion Products, Induced Radiation							
Bldg. 3517 Hot Cell Interiors	Concrete C-137, Sr-90, Co-60							
Bldg. 9419-1 floor, 1st Floor Molten Salt Cells	Concrete U, Th, Molten Salt							
Bldg. 3038 Cell Interiors	Concrete Sr-90, Cs-137, Co-60, I-129							
Graphite Reactor Biological Shields	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Graphite Reactor Canal	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Graphite Reactor Ductwork	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Graphite Reactor Stack	Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
Slab Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products, Activation Products							

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	ORR Hot Cell Interiors, Floors, Cell Faces	Painted Concrete Fission Products, TRU	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Ultrahigh-Pressure Water DCON-35-OL H *Ranking:** *H-5-1 (1.7; $1/ft2)*	**Accepted** Technology has been used by industry. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Unless a recycle system is developed, waste would be 3-5 gal water/ft² concrete cleaned that contains ~0.01 ft³ concrete residue, plus the contaminants removed.	**Technology Improvement:** To minimize waste generation, a system is needed to treat the water so that it can be recycled. **Technology Improvement:** Automation, especially for walls and ceilings.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** $1.3M **Capital cost:** ~$500K **Operating Cost:** ~$1/ft²
EM Problems • Facility Decontamination and Decommissioning (D&D)	Bldg. 3028 Hot Cell Interiors, Floors, Cell Faces	Painted Concrete Fission Products, Cm-147, Pm-241,Am				Shot Blasting DCON-36-OL H *Ranking:** *H-3-0 (<0.1; ~$1/ft2)*	**Accepted** Commercial iron shot blasters are in use at the K-25 site. **Efficacy:** They are generally effective but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants plus 0.05lb spent shot per ft² of concrete decontaminated.	**Technology Improvement:** Automation, especially for walls and ceilings.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$50K **Operating Cost:** ~$1/ft²
	Bldg. 3029 Cell Faces	Painted Concrete Cs-137, Sr-90, Co-60, Ir-192				Scabblers/Scarifiers DCON-37-OL H *Ranking:** *H-4-2 (0.5; $5/ft2)*	**Accepted** Mechanical scabblers are used for concrete decontamination at the K-25 Site and elsewhere. **Efficacy:** They are generally effective, but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed substrate (1/16" cut) containing removed contaminants per ft² of substrate decontaminated.	**Technology Improvement:** Automation, especially for walls and ceilings.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$500K **Operating Cost:** < $5/ft² (More than shot blasting)
	Bldg. 3030 Floors and Cell Faces	Painted Concrete 43 Beta, Gamma Emitters				Grit Blasting DCON-38-OL H *Ranking:** *H-4-0 (<0.1 $5/ft2)*	**Accepted** Has been used successfully for many applications in the nuclear industry. **Efficacy:** Technology is generally effective. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants per ft² of concrete decontaminated plus spent grit.	**Technology Improvement:** automation, especially for walls and ceilings.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$50K **Operating Cost:** $~5/ft²
	Bldg. 3031 Floors and Cell Faces	Painted Concrete Gd-153, Am-241				Centrifuge Cryogenic CO_2 Pellet Blasting DCON-39-OL H *Ranking:** *H-5-2 (1.0; <$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Technology Improvement:** 1) Demonstration of an on-line, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen-depletion precautions. **Development cost:** <$1M **Capital cost:** $100K **Operating Cost:** <$1/ft²
	Bldg. 3032 Floors and Cell Faces	Painted Concrete P-32, Am-241							
	Bldg. 3033 Cell Faces	Painted Concrete H-3, Kr-85							
	Bldg. 3036 Floors	Painted Concrete Cs-137, Sr-90							
	Bldg. 3517 High Bay Floors & Cell Faces	Painted Concrete Cs-137, Sr-90, Co-60							
	Bldg. 9201-3 Coolant Salt Cell	Painted Concrete U. Th, Coolant Salt							
	Bldg. 9201-3 Molten Salt Cell	Painted Concrete U, Th, Molten Salt							
	Bldg. 3038 Cell Floor & Surfaces	Painted Concrete Sr-90, Cs-137, Co-60, I-129							
	Bldg. 3505 Floors and Cell Faces	Painted Concrete Fission Products, TRU							
	Bldg. 3506 Hot Cell Interiors	Painted Concrete Fission Products							
	Bldg. 3515 Floors and Cell Faces	Painted Concrete Fission Products							
	Bldg. 3047 Floors and Cell Faces	Painted Concrete Cs, Sr, Co, Cm, Eu, Am, Pu							
	Bldg. 7852 Floors and Cell Faces	Painted Concrete Fission Products, Corrosion Products, Cs, Sr, TRU, Co, Cm, Eu, Am, Pu							
• Remedial Action (RA)—Soils, Ground Water and Surface Water	Bldg. 3019 Hot Cell Interiors, Floors, and Cell Faces	Painted Concrete U-233, Pu-239, Fission Products							
	Graphite Reactor Biological Shield Exterior	Painted Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products							
• Waste Management (WM)									

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean-Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	ORR Hot Cell Interiors, Floors, Cell Faces Bldg. 3028 Hot Cell Interiors, Floors, Cell Faces Bldg. 3029 Cell Faces Bldg. 3030 Floors and Cell Faces Bldg. 3031 Floors and Cell Faces Bldg. 3032 Floors and Cell Faces Bldg. 3033 Cell Faces Bldg. 3036 Floors Bldg. 3517 High Bay Floors & Cell Faces Bldg. 9201-3 Coolant Salt Cell Bldg. 9201-3 Molten Salt Cell Bldg. 3038 Cell Floor & Surfaces Bldg. 3505 Floors and Cell Faces Bldg. 3506 Hot Cell Interiors Bldg. 3515 Floors and Cell Faces Bldg. 3047 Floors and Cell Faces Bldg. 7852 Floors and Cell Faces Bldg. 3019 Hot Cell Interiors, Floors, and Cell Faces Graphite Reactor Biological Shield Exterior	Painted Concrete Fission Products, TRU Painted Concrete Fission Products, Cm-147, Pm-241,Am Painted Concrete Cs-137, Sr-90, Co-60, Ir-192 Painted Concrete 43 Beta, Gamma Emitters Painted Concrete Gd-153, Am-241 Painted Concrete P-32, Am-241 Painted Concrete H-3, Kr-85 Painted Concrete Cs-137, Sr-90 Painted Concrete Cs-137, Sr-90, Co-60 Painted Concrete U. Th, Coolant Salt Painted Concrete U, Th, Molten Salt Painted Concrete Sr-90, Cs-137, Co-60, I-129 Painted Concrete Fission Products, TRU Painted Concrete Fission Products Painted Concrete Fission Products Painted Concrete Cs, Sr, Co, Cm, Eu, Am, Pu Painted Concrete Fission Products, Corrosion Products, Cs, Sr, TRU, Co, Cm, Eu, Am, Pu Painted Concrete U-233, Pu-239, Fission Products Painted Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Ice Blasting DCON-40-OL H *Ranking:** *H-5-1 (<1.0; $1/ft2)*	**Demonstration** **Efficacy:** Efficacy of commercial system for this application needs demonstration. **Waste:** Waste would be about 14 to 18 gallons per hour waste water containing removed contaminants.	**Development:** Demonstration of efficacy of commercial system. **Technology Improvement:** Automation/robotics, especially for walls, corners, etc.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** $250K **Capital cost:** $100K-$1M **Operating Cost:** $1/ft²
						Supercritical CO_2 Blasting DCON-41-OL H *Ranking:** *H-5-1 (O.75+; >$1/ft2)*	**Predemonstration** **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed concrete and contaminants contained in a cyclone and a HEPA filter.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminants. Demonstrate efficacy for contaminants of interest.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen depletion precautions. **Development cost:** $250K-1M **Capital cost:** ~$500K **Operating Cost:** $1+/ft²
						Plastic Pellet Blasting DCON-42-OL M *Ranking:** *M-4-0 (<0.1; ~$1/ft2)*	**Accepted** Plastic pellet blasting is a widely used alternate to sand blasting for applications in which it is desired to impart minimal damage to the substrate. **Efficacy:** Technology should remove smearable, but not fixed contamination, from concrete. May have trouble removing paint to reach contamination underneath. **Waste:** Waste would be spent plastic pellets plus removed contamination.	**Technology Improvement:** Develop and demonstrate system for processing waste. **Technology Improvement:** Minimize blast media erosion to minimize waste; automation/robotics, especially for walls, etc.; improve containment of waste and removed contaminants.	A system for processing waste to an acceptable form is needed. **Development Cost (Improvements):** $5.5M+ **Capital cost:** ~$50K **Operating Cost:** $0.20 - $2.15/ft
						Hand Grinding, Honing, Scraping DCON-43-OL H *Ranking:** *H-2-0 (<0.1; ~$1/ft2)*	**Accepted** **Efficacy:** Grinding with hand-held power grinders has been successfully used for small-scale decontamination. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	None **Available at X-10, K-25.**	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** None **Capital cost:** $150 ($5K with vacuum system and $50-500K with remote operation) **Operating Cost:** ~$1/ft²
						Automated Grinding DCON-44-OL H *Ranking:** *H-2-1 ($1; N)*	**Conceptual** Grinding has been successfully used for small scale decontamination. This grinding was done with hand-held power grinders Remotely operated grinding equipment is available, but no references to its use for decontamination have been found. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** The applicability of this technology to items with rad contamination should be demonstrated.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** $600K **Capital cost:** $250K-500K

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	ORR Hot Cell Interiors, Floors, Cell Faces Bldg. 3028 Hot Cell Interiors, Floors, Cell Faces Bldg. 3029 Cell Faces Bldg. 3030 Floors and Cell Faces Bldg. 3031 Floors and Cell Faces Bldg. 3032 Floors and Cell Faces Bldg. 3033 Cell Faces Bldg. 3036 Floors Bldg. 3517 High Bay Floors & Cell Faces Bldg. 9201-3 Coolant Salt Cell Bldg. 9201-3 Molten Salt Cell Bldg. 3038 Cell Floor & Surfaces Bldg. 3505 Floors and Cell Faces Bldg. 3506 Hot Cell Interiors Bldg. 3515 Floors and Cell Faces Bldg. 3047 Floors and Cell Faces Bldg. 7852 Floors and Cell Faces Bldg. 3019 Hot Cell Interiors, Floors, and Cell Faces Graphite Reactor Biological Shield Exterior	Painted Concrete Fission Products, TRU Painted Concrete Fission Products, Cm-147, Pm-241,Am Painted Concrete Cs-137, Sr-90, Co-60, Ir-192 Painted Concrete 43 Beta, Gamma Emitters Painted Concrete Gd-153, Am-241 Painted Concrete P-32, Am-241 Painted Concrete H-3, Kr-85 Painted Concrete Cs-137, Sr-90 Painted Concrete Cs-137, Sr-90, Co-60 Painted Concrete U. Th, Coolant Salt Painted Concrete U, Th, Molten Salt Painted Concrete Sr-90, Cs-137, Co-60, I-129 Painted Concrete Fission Products, TRU Painted Concrete Fission Products Painted Concrete Fission Products Painted Concrete Cs, Sr, Co, Cm, Eu, Am, Pu Painted Concrete Fission Products, Corrosion Products, Cs, Sr, TRU, Co, Cm, Eu, Am, Pu Painted Concrete U-233, Pu-239, Fission Products Painted Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods M	Concrete Milling DCON-47-OL *Ranking:** *M-1-2 (<1; $0.75/ft2)*	**Accepted** The equipment is commercially available, but no reference to its use for decontamination has been found. This technology is suited for horizontal surfaces only. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Technology Improvement:** The technology to operate this equipment remotely needs to be developed and demonstrated.	A collection system for the contaminated dust would be needed to implement this technology. **Development cost:** None **Capital cost:** $400K **Operating Cost:** $0.75/ft²
						Explosive DCON-48-OL *Ranking:** *L-2-5 (4; $50/ft2)*	**Demonstration** Blasting has been used to decontaminate nuclear reactor shielding. Demonstration will be needed for other applications. Safety concerns need to be resolved; care must be taken to contain the dust and to prevent structural damage to the building being decontaminated and the surrounding structures. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** Improvements in the methods of applying explosives and in the uniformity of the detonation are needed. The explosion will generate toxic organic vapors. The technology to control toxic vapors formed by the explosion must be developed and demonstrated.	A certified blasting technician will be needed. **Capital cost:** $50K **Operating Cost:** $50/ft² **Development cost:** $1-4M
					Thermal Surface Removal Methods H	Microwave Scabbling DCON-71-OL *Ranking:** *H-3-2 (2.5+; >$1/ft2)*	**Predemonstration** In FY 1991 ORNL demonstrated reliable removal of noncontaminated concrete surfaces using a stationary microwave device. A mobile device is under development. **Efficacy:** Since microwave scrabbling removes the contaminated concrete surface, the decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** The waste generated is concrete rubble with particle diameters lying primarily in the range of 1 to 10 mm plus the contaminants. For a removal depth of 10 mm, 0.03 ft³ of concrete rubble is generated per ft² of concrete decontaminated.	**Development:** The development and testing of a mobile prototype microwave concrete removal machine needs to be completed.	Normal implementation needs. **Development cost:** $2.5M **Capital cost:** ~$250K **Operating Cost:** >$1/ft²

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	ORR Hot Cell Interiors, Floors, Cell Faces Bldg. 3028 Hot Cell Interiors, Floors, Cell Faces Bldg. 3029 Cell Faces Bldg. 3030 Floors and Cell Faces Bldg. 3031 Floors and Cell Faces Bldg. 3032 Floors and Cell Faces Bldg. 3033 Cell Faces Bldg. 3036 Floors Bldg. 3517 High Bay Floors & Cell Faces Bldg. 9201-3 Coolant Salt Cell Bldg. 9201-3 Molten Salt Cell Bldg. 3038 Cell Floor & Surfaces Bldg. 3505 Floors and Cell Faces Bldg. 3506 Hot Cell Interiors Bldg. 3515 Floors and Cell Faces Bldg. 3047 Floors and Cell Faces Bldg. 7852 Floors and Cell Faces Bldg. 3019 Hot Cell Interiors, Floors, and Cell Faces Graphite Reactor Biological Shield Exterior	Painted Concrete Fission Products, TRU Painted Concrete Fission Products, Cm-147, Pm-241,Am Painted Concrete Cs-137, Sr-90, Co-60, Ir-192 Painted Concrete 43 Beta, Gamma Emitters Painted Concrete Gd-153, Am-241 Painted Concrete P-32, Am-241 Painted Concrete H-3, Kr-85 Painted Concrete Cs-137, Sr-90 Painted Concrete Cs-137, Sr-90, Co-60 Painted Concrete U. Th, Coolant Salt Painted Concrete U, Th, Molten Salt Painted Concrete Sr-90, Cs-137, Co-60, I-129 Painted Concrete Fission Products, TRU Painted Concrete Fission Products Painted Concrete Fission Products Painted Concrete Cs, Sr, Co, Cm, Eu, Am, Pu Painted Concrete Fission Products, Corrosion Products, Cs, Sr, TRU, Co, Cm, Eu, Am, Pu Painted Concrete U-233, Pu-239, Fission Products Painted Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Thermal Surface Removal Methods	Plasma Torch DCON-72-OL H *Ranking:** *H-4-1 (0.5; $1/ft2)*	**Evolving Technology** **Conceptual** Plasma torches exist commercially to weld and cut materials that have very high melting temperatures or require an inert atmosphere. **Efficacy:** Its efficacy in removing various organic contaminants or to spall off layers of contaminated concrete has not been investigated. **Waste:** Wastes would consist of materials used to trap reaction products from the decomposition of organics and spalled concrete with contaminants.	**Science:** Laboratory tests are needed to evaluate the efficacy of vaporizing or decomposing organics, determine the decomposition reaction by-products, and suitable for trapping materials. Laboratory tests of thermal stress-induced spalling of concrete are also needed. Computer modeling of plasma-surface interactions and heat transfer in concrete are needed. **Development:** Plasma torches having geometries and conditions suitable for decontamination need to be developed along with suitable collection and gas treatment systems. **Available at Y-12.**	A collection system for the vaporized materials would be needed to implement this technology. **Development cost:** ~$500K **Capital Costs:** ~$100K **Operating Costs:** $1.00/ft²
EM Problems • Facility Decontamination and Decommissioning (D&D)						Laser Heating DCON-73-OL M *Ranking:** *M-4-4 (3; $1/ft2)*	**Demonstration** Currently being used to remove organic coatings from metal surfaces. **Efficacy:** Current prototype systems are capable of removing 2-mil-thick coatings at the rate of 100 ft²/hr. Effectiveness on contaminants and substrates of interest is uncertain. **Waste:** Waste will be prefilters and HEPA filters filled with contaminants.	**Development:** Current prototype needs to be evaluated for possible use on contaminated areas. Systems with different operational parameters (e.g., wavelength, pulse durations) should be evaluated as well.	A collection system for the vaporized contaminants would be needed to implement this technology. **Development cost:** $2M+ **Capital cost:** $500K-$1M+/machine **Operating Cost:** ~$1/ft²
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Laser Etching and Ablation DCON-74-OL M *Ranking:** *M-4-4 (3.5; >$1/ft2)*	**Predemonstration** Several research groups at university and government laboratories have used the technology to remove radiological and organic contaminants from various surfaces. **Efficacy:** The technique is slow to remove large deposits. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	**Development:** Existing lasers, delivery systems, and filtration systems need to be integrated into a prototype system for demonstration.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** $2M+ **Capital cost:** $0.5-1M/machine **Operating Cost:** >$1/ft²
• Waste Management (WM)						Flashlamp Cleaning DCON-77-OL H *Ranking:** *H-3-3 (2.5; $1/ft2)*	**Predemonstration** Flashlamp systems are being used to remove organic contamination from metals, precious metals, and fragile substrates. Hanford-Westinghouse Laboratory is conducting tests of xenon flashlamp systems for removing radiological contamination from surfaces inside metal storage vessels. **Efficacy:** Technology is likely to be effective for surface contamination. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	**Development:** Commercially available flashlamp systems need to be evaluated for deposit removal.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** ~$2.5 M **Capital cost:** $50-100K/machine **Operating Cost:** ~1.00/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	ORR Hot Cell Interiors, Floors, Cell Faces Bldg. 3028 Hot Cell Interiors, Floors, Cell Faces Bldg. 3029 Cell Faces Bldg. 3030 Floors and Cell Faces Bldg. 3031 Floors and Cell Faces Bldg. 3032 Floors and Cell Faces Bldg. 3033 Cell Faces Bldg. 3036 Floors Bldg. 3517 High Bay Floors & Cell Faces Bldg. 9201-3 Coolant Salt Cell Bldg. 9201-3 Molten Salt Cell Bldg. 3038 Cell Floor & Surfaces Bldg. 3505 Floors and Cell Faces Bldg. 3506 Hot Cell Interiors Bldg. 3515 Floors and Cell Faces Bldg. 3047 Floors and Cell Faces Bldg. 7852 Floors and Cell Faces Bldg. 3019 Hot Cell Interiors, Floors, and Cell Faces Graphite Reactor Biological Shield Exterior	Painted Concrete Fission Products, TRU Painted Concrete Fission Products, Cm-147, Pm-241,Am Painted Concrete Cs-137, Sr-90, Co-60, Ir-192 Painted Concrete 43 Beta, Gamma Emitters Painted Concrete Gd-153, Am-241 Painted Concrete P-32, Am-241 Painted Concrete H-3, Kr-85 Painted Concrete Cs-137, Sr-90 Painted Concrete Cs-137, Sr-90, Co-60 Painted Concrete U. Th, Coolant Salt Painted Concrete U, Th, Molten Salt Painted Concrete Sr-90, Cs-137, Co-60, I-129 Painted Concrete Fission Products, TRU Painted Concrete Fission Products Painted Concrete Fission Products Painted Concrete Cs, Sr, Co, Cm, Eu, Am, Pu Painted Concrete Fission Products, Corrosion Products, Cs, Sr, TRU, Co, Cm, Eu, Am, Pu Painted Concrete U-233, Pu-239, Fission Products Painted Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods H	Compressed-Air Cryogenic CO_2 Pellet Blasing DCON-51-OL *Ranking:** *H-4-1 (0.7; >$1/ft2)*	**Demonstration** This technology is commercially available. It has been used at nuclear reactor sites to decontaminate hand tools and some equipment. **Efficacy:** The efficacy of this technology for removing the listed contaminants from concrete has not been demonstrated and is doubtful. **Waste:** Wastes would be HEPA filters filled with the removed contaminants.	**Development:** Evaluate technology that has recently been demonstrated in Department of Defense programs regarding automation and improvements in pellet delivery.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants plus oxygen depletion precautions. **Development cost:** about $0.50M **Capital cost:** About $200,000 **Operating Cost:** >$1/ft²
• Facility Decontamination and Decommissioning (D&D)					Chemical Surface Cleaning Methods H	Fluoboric Acid Treatment DCON-11-OL *Ranking:** *H-4-2 (2; N)*	**Demonstration** Technology was designed specifically for D&D. **Efficacy:** Unrestricted use of materials should be possible after decontamination, due to high decontamination factor (DF). Fluoboric (or fluosilicic) acid can scabble and clean cement and brickwork. If contaminated to a depth of only a few mm, concrete flooring and structures can be returned to unrestricted use.	**Development:** Although the method has seen application at Chernobyl with good results, development work is needed to test applicability at ORNL.	Fluoboric acid exhibits low vapor pressure and requires only standard precautions for acid or base work The plant can be manufactured in modular form and installed in existing buildings.Hardware (equipment): Fabrication of all key plant parts from polypropylene or from Halar-coated metal. **Capital cost:** $774K (1990 plant cost for decontaminating 5 tons/day of steel, excluding development, planning, and buildings.) **Operating Cost:** Relatively low; this is a very simple process.
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Chelation Treatment DCON-21-OL *Ranking:** *M-4-2 (1.5; <$1/ft2)*	**Demonstration** The technology has been employed at various facility operations and nuclear power plant sites. **Efficacy:** Excellent DFs achieving acceptable decontamination levels resulting in unconditional release. Easy to apply in-situ as agent acts at neutral pH and are non-hazardous, non-fuming, have no gas evolution and are biodegradable. **Waste:** Simple waste minimizing treatment and disposal as a non-RCRA waste. Minimizes waste through oxidative destruction of chelate agent, partictioning of organics (including PCBs) and concentration of radionuclides precipitated out in the flocculent sludge which can be further de-watered.	**Development:** Validation of updated chelating agents is needed and is currently underway at ORNL to confirm total efficacy and economic advantage.	Application equipment for in-situ decontamination. Support personnel and equipment to sample, analyze, develop appropriate concentrations, ensure oxidation of organics and/or complete partitioning will be necessary. Spray booth or dipping tank facilities with heating capabilities desirable on-site or accessible by decontamination facility. **Operating Cost:** <$1/ft²
• Waste Management (WM)									

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	ORR Hot Cell Liners Bldg. 3028 Hot Cell Liners Bldg. 3029 Hot Cell Liners Bldg. 3030 Hot Cell Liners Bldg. 3031 Hot Cell Liners Bldg. 3032 Hot Cell Liners Bldg. 3033 Process Piping Membrane Between HRT Concrete Bldg. 3029, Cell 2 Wall Bldg. 7500 High Bay Area MSRE Exterior Siding ORR Building Siding Bldg. 3028E Charging Area Bldg. 3029 Exterior Walls Bldg. 3030 Siding/Interior Walls Bldg. 3031 Siding/Interior Walls Bldg. 3032 Siding/Interior Walls Bldg. 3033 Siding/Interior Walls Bldg. 3036 Siding/Interior Walls MSRE Bldg. Structure ORR Steel Bldg. Structure Bldg. 3028E Steel Structure Bldg. 3029 Structure Bldg. 3030 Steel Bldg. Structure Bldg. 3517 Hot Cell Liners Bldg. 3038 Glove Boxes Bldg. 3038 Glove Boxes & Cell Interior Bldg. 3517 Interior/Exterior Walls Bldg. 9201-3:3 Walls & Upper Floors Molten Salt Cells Bldg. 9201-3 Walls & Roof Coolant Salt Cells Bldg. 3031 Structure Bldg. 3032 Structure Bldg. 9419-1 Handrail MSRE Piping ORR Primary Coolant Piping Instrument & Air Lines in Coolant Salt Cell, Bldg. 9201-3 HRT Process Piping MSRE Off-Gas System ORR Demineralizer Piping (Outside Pool) Graphite Reactor Process Piping	Stainless Steel Fission Products, Corrosion Products Stainless Steel Fission Products, Cm-147, Pm-241, Am Stainless Steel Cs-137, Sr-90, Co-60, Ir-192 Stainless Steel 43 Beta, Gamma Emitters Stainless Steel Gd-153, Am-241 Stainless Steel P-32, Am-241 Stainless Steel H-3, Kr-85 Steel Plate Fission Products, Corrosion Products Steel Plate Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Fission Products Sheet Steel Fission Products, TRU Sheet Steel Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel 43 Beta, Gamma Emitters Sheet Steel Gd-153, Am-241 Sheet Steel P-32, Am-241 Sheet Steel H-3, Kr-85 Sheet Steel Cs-137, Sr-90 Structural Steel Cs, Sr, TRU, Co-60 Structural Steel Fission Products Structural Steel Fission Products, TRU Structural Steel Cs-137, Sr-90, Co-60, Ir-92 Structural Steel 43 Beta, Gamma Emitters Stainless Steel Cs-137, Sr-90, Co-60 Stainless Steel Pu-238, Am-241, Cm-244 Stainless Steel Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I Stainless Steel Cs-137, Sr-90, Co-60 Sheet Steel U, Th, Molten Salt Sheet Steel U, Th, Coolant Salt Structural Steel Gd-153, Am-241 Structural Steel P-32, Am-241 Painted Steel Pipe Exterior U, Th, Molten Salt INOR-8 Pipe Exterior U, Be, LiF, ThF_4 Al Piping Exterior Fission Products, Corrosion Products Cu Tubing Exterior U, Th, H-3, Molten Salt Stainless Steel Pipe Exterior Uranyl Sulfate, Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, C-14, Fe-55, Cs-137, Pu, Sr-90, Co-60	Refer to the Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Ultrahigh-Pressure Water DCON-35-OL H *Ranking:** *H-5-1 (1.7M;$1/ft2)*	**Accepted** Technology has been used by industry. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused into the metal. **Waste:** Unless a recycle system is developed, waste would be 3-5 gal water/ft² cleaned that contains ~0.01 ft³ metal residue, plus the contaminants removed.	**Improvement:** To minimize waste generation, a system is needed to treat the water so that it can be recycled. **Improvement:** Automation, especially for walls and ceilings.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** $1.3M **Capital cost:** ~$500K **Operating cost:** ~$1/ft²
EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)						Shot Blasting DCON-36-OL H *Ranking:** *H-3-0 (<0.1M;$1/ft2)*	**Accepted** Commercial iron shot blasters are in use at the K-25 site. **Efficacy:** They are generally effective but leave some hot spots. **Waste:** Waste would be spent shot, abraded substrate, and removed contaminants in filters and HEPA filters.	**Improvement:** Automation, especially for walls and ceilings.	A collecitor system with adequate filtration **Development cost:** None **Capital cost:** ~$50K **Operating cost:** ~$1/ft²
						Grit Blasting DCON-38-OL H *Ranking:** *H-4-0 (<0.1$5/ft2)*	**Accepted** Has been used successfully for many applications in the nuclear industry. **Efficacy:** Technology is generally effective. **Waste:** Waste would be spent grit, abraded substrated, and removed contaminants in filters and HEPA filters.	**Improvement:** automation, especially for walls and ceilings. Better vacuum system demonstration.	A collecitor system with adequate filtration **Development cost:** None **Capital cost:** ~$50K **Operating cost:** $~5/ft²
						Centrifuge Cryogenic CO_2 Pellet Blasting DCON-39-OL H *Ranking:** *H-5-2 (1.0M;<$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently, as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Improvement:** 1) Demonstration of an on live, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen-depletion precautions. **Development cost:** <$1M **Capital cost:** $100K **Operating cost:** <$1/ft²
						Ice Blasting DCON-40-OL H *Ranking:** *H-5-1 (<1.0M;$1/ft2)*	**Demonstration** **Efficacy:** Efficacy of commercial system for this application needs demonstration. **Waste:** Waste would be about 14 to 18 gallons per hour waste water containing removed contaminants.	**Development:** **Demonstration** of efficacy of commercial system. **Improvement:** Automation/robotics, especially for walls, corners, etc.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** $250K **Capital cost:** $100K-$1M **Operating cost:** <$1/ft²

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	ORR Hot Cell Liners Bldg. 3028 Hot Cell Liners Bldg. 3029 Hot Cell Liners Bldg. 3030 Hot Cell Liners Bldg. 3031 Hot Cell Liners Bldg. 3032 Hot Cell Liners Bldg. 3033 Process Piping Membrane Between HRT Concrete Bldg. 3029, Cell 2 Wall Bldg. 7500 High Bay Area MSRE Exterior Siding ORR Building Siding Bldg. 3028E Charging Area Bldg. 3029 Exterior Walls Bldg. 3030 Siding/Interior Walls Bldg. 3031 Siding/Interior Walls Bldg. 3032 Siding/Interior Walls Bldg. 3033 Siding/Interior Walls Bldg. 3036 Siding/Interior Walls MSRE Bldg. Structure ORR Steel Bldg. Structure Bldg. 3028E Steel Structure Bldg. 3029 Structure Bldg. 3030 Steel Bldg. Structure Bldg. 3517 Hot Cell Liners Bldg. 3038 Glove Boxes Bldg. 3038 Glove Boxes & Cell Interior Bldg. 3517 Interior/Exterior Walls Bldg. 9201-3:3 Walls & Upper Floors Molten Salt Cells Bldg. 9201-3 Walls & Roof Coolant Salt Cells Bldg. 3031 Structure Bldg. 3032 Structure Bldg. 9419-1 Handrail MSRE Piping ORR Primary Coolant Piping Instrument & Air Lines in Coolant Salt Cell, Bldg. 9201-3 HRT Process Piping MSRE Off-Gas System ORR Demineralizer Piping (Outside Pool) Graphite Reactor Process Piping	Stainless Steel Fission Products, Corrosion Products Stainless Steel Fission Products, Cm-147, Pm-241, Am Stainless Steel Cs-137, Sr-90, Co-60, Ir-192 Stainless Steel 43 Beta, Gamma Emitters Stainless Steel Gd-153, Am-241 Stainless Steel P-32, Am-241 Stainless Steel H-3, Kr-85 Steel Plate Fission Products, Corrosion Products Steel Plate Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Fission Products Sheet Steel Fission Products, TRU Sheet Steel Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel 43 Beta, Gamma Emitters Sheet Steel Gd-153, Am-241 Sheet Steel P-32, Am-241 Sheet Steel H-3, Kr-85 Sheet Steel Cs-137, Sr-90 Structural Steel Cs, Sr, TRU, Co-60 Structural Steel Fission Products Structural Steel Fission Products, TRU Structural Steel Cs-137, Sr-90, Co-60, Ir-92 Structural Steel 43 Beta, Gamma Emitters Stainless Steel Cs-137, Sr-90, Co-60 Stainless Steel Pu-238, Am-241, Cm-244 Stainless Steel Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I Stainless Steel Cs-137, Sr-90, Co-60 Sheet Steel U, Th, Molten Salt Sheet Steel U, Th, Coolant Salt Structural Steel Gd-153, Am-241 Structural Steel P-32, Am-241 Painted Steel Pipe Exterior U, Th, Molten Salt INOR-8 Pipe Exterior U, Be, LiF, ThF$_4$ Al Piping Exterior Fission Products, Corrosion Products Cu Tubing Exterior U, Th, H-3, Molten Salt Stainless Steel Pipe Exterior Uranyl Sulfate, Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, C-14, Fe-55, Cs-137, Pu, Sr-90, Co-60	Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	**H** Supercritical CO_2 Blasting DCON-41-OL *Ranking:** *H-5-1 (O.75+M;>$1/ft2)*	**Predemonstration** **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed concrete and contaminants contained in a cyclone and a HEPA filter.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminants. Demonstrate efficacy for contaminants of interest.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen depletion precautions. **Development cost:** $250K-1M **Capital cost:** ~$500K **Operating cost:** ~$2/ft²
						M Plastic Pellet Blasting DCON-42-OL *Ranking:** *M-4-0 (<0.1M;$1/ft2)*	**Accepted** Plastic pellet blasting is a widely used alternate to sand blasting for applications in which it is desired to impart minimal damage to the substrate. **Efficacy:** Technology should remove smearable, but not fixed contamination. **Waste:** Waste would be spent plastic pellets plus removed contamination.	**Improvement:** Develop and demonstrate system for processing waste. **Improvement:** Minimize blast media erosion to minimize waste; automation/robotics, especially for walls, etc.; improve containment of waste and removed contaminants.	A system for processing waste to an acceptable form is needed. **Development cost:** (Improvements) $5.5M+ **Capital cost:** ~$50K **Operating cost:** $0.20 - $2.15/ft
						H Hand Grinding, Honing, Scraping DCON-43-OL *Ranking:** *H-2-0 (<<0.1M;$1/ft2)*	**Accepted** **Efficacy:** Grinding with hand-held power grinders has been successfully used for small-scale decontamination. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	None **Available at X-10, K-25.**	A collection system for the vaporized contaminants would be needed to implement this technology. **Development cost:** None **Capital cost:** $150 ($5K with vacuum system and $50-500K with remote operation) **Operating cost:** ~$1/ft²
• Remedial Action (RA)—Soils, Ground Water and Surface Water						**H** Automated Grinding DCON-44-OL *Ranking:** *H-2-1 ($1M;$1M;N)*	**Conceptual** Grinding has been successfully used for small scale decontamination. This grinding was done with hand-held power grinders. Remotely operated grinding equipment is available, but no references to its use for decontamination have been found. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the metal. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	Development: The applicability of this technology to items with rad contamination should be demonstrated.	A collection system for the vaporized contaminants would be needed to implement this technology. **Development cost:** $600K **Capital cost:** $250-500K
						M Metal Milling DCON-45-OL *Ranking:** *M-2-1 ($0.15M;$17.50/ft2)*	**Accepted** **Efficacy:** Milling has been used to decontaminate metal items. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	Improvement: The technology to operate this equipment remotely needs to be developed and demonstrated. **Available at K-25.**	The contaminated equipment must be removed and disassembled before this technology can be used. **Capital cost:**~$150K **Operating cost:**~17.50/ft2 **Development cost:**$3M for remote operation.
• Waste Management (WM)									

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	ORR Hot Cell Liners Bldg. 3028 Hot Cell Liners Bldg. 3029 Hot Cell Liners Bldg. 3030 Hot Cell Liners Bldg. 3031 Hot Cell Liners Bldg. 3032 Hot Cell Liners Bldg. 3033 Process Piping Membrane Between HRT Concrete Bldg. 3029, Cell 2 Wall Bldg. 7500 High Bay Area MSRE Exterior Siding ORR Building Siding Bldg. 3028E Charging Area Bldg. 3029 Exterior Walls Bldg. 3030 Siding/Interior Walls Bldg. 3031 Siding/Interior Walls Bldg. 3032 Siding/Interior Walls Bldg. 3033 Siding/Interior Walls Bldg. 3036 Siding/Interior Walls MSRE Bldg. Structure ORR Steel Bldg. Structure Bldg. 3028E Steel Structure Bldg. 3029 Structure Bldg. 3030 Steel Bldg. Structure Bldg. 3517 Hot Cell Liners Bldg. 3038 Glove Boxes Bldg. 3038 Glove Boxes & Cell Interior Bldg. 3517 Interior/Exterior Walls Bldg. 9201-3:3 Walls & Upper Floors Molten Salt Cells Bldg. 9201-3 Walls & Roof Coolant Salt Cells Bldg. 3031 Structure Bldg. 3032 Structure Bldg. 9419-1 Handrail MSRE Piping ORR Primary Coolant Piping Instrument & Air Lines in Coolant Salt Cell, Bldg. 9201-3 HRT Process Piping MSRE Off-Gas System ORR Demineralizer Piping (Outside Pool) Graphite Reactor Process Piping	Stainless Steel Fission Products, Corrosion Products Stainless Steel Fission Products, Cm-147, Pm-241, Am Stainless Steel Cs-137, Sr-90, Co-60, Ir-192 Stainless Steel 43 Beta, Gamma Emitters Stainless Steel Gd-153, Am-241 Stainless Steel P-32, Am-241 Stainless Steel H-3, Kr-85 Steel Plate Fission Products, Corrosion Products Steel Plate Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Fission Products Sheet Steel Fission Products, TRU Sheet Steel Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel 43 Beta, Gamma Emitters Sheet Steel Gd-153, Am-241 Sheet Steel P-32, Am-241 Sheet Steel H-3, Kr-85 Sheet Steel Cs-137, Sr-90 Structural Steel Cs, Sr, TRU, Co-60 Structural Steel Fission Products Structural Steel Fission Products, TRU Structural Steel Cs-137, Sr-90, Co-60, Ir-92 Structural Steel 43 Beta, Gamma Emitters Stainless Steel Cs-137, Sr-90, Co-60 Stainless Steel Pu-238, Am-241, Cm-244 Stainless Steel Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I Stainless Steel Cs-137, Sr-90, Co-60 Sheet Steel U, Th, Molten Salt Sheet Steel U, Th, Coolant Salt Structural Steel Gd-153, Am-241 Structural Steel P-32, Am-241 Painted Steel Pipe Exterior U, Th, Molten Salt INOR-8 Pipe Exterior U, Be, LiF, TiF_3 Al Piping Exterior Fission Products, Corrosion Products Cu Tubing Exterior U, Th, H-3, Molten Salt Stainless Steel Pipe Exterior Uranyl Sulfate, Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, C-14, Fe-55, Cs-137, Pu, Sr-90, Co-60	**Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.**	Decontamination	Thermal Surface Removal Methods	Plasma Torch DCON-72-OL H *Ranking:** *H-4-1 (0.5M;$1/ft2)*	**Evolving Technology** **Conceptual** Plasma torches exist commercially to weld and cut materials that have very high melting temperatures or require an inert atmosphere. **Efficacy:** Its efficacy in removing various organic contaminants or to remove layers of contaminated metal has not been investigated. **Waste:** Wastes would consist of materials used to trap reaction products from the decomposition of organics, vaporized substrate, and removed contaminants.	**Science:** Laboratory tests are needed to evaluate the efficacy of vaporizing or decomposing organics, determine the decomposition reaction by-products, and suitable trapping materials. Computer modeling of plasma-surface interactions and heat transfer are needed. **Development:** Plasma torches having geometries and conditions suitable for decontamination need to be developed along with suitable collection and gas treatment systems. **Available at Y-12.**	A collection system for the vaporized deposits would be needed to implement this technology. Development costs: ~$500K Capital costs: ~$100K Operating costs: $0.01-$1.00/ft²
						Laser Heating DCON-73-OL M *Ranking:** *M-4-4 (3M;$1/ft2)*	**Demonstration** Currently being used to remove organic coatings from metal surfaces. **Efficacy:** Current prototype systems are capable of removing 2-mil-thick coatings at the rate of 100 ft²/hr. Effectiveness on contaminants and substrates of interest is uncertain. **Waste:** Waste will be prefilters and HEPA filters filled with contaminants.	**Development:** Current prototype needs to be evaluated for possible use on contaminated areas. Systems with different operational parameters (e.g., wavelength, pulse durations) should be evaluated as well.	A collection system for the vaporized deposits would be needed to implement this technology. An electric power supply would be needed. **Development cost:** $2M+ **Capital cost:** $500k-$1M+/machine **Operating cost:** ~$1/ft²
						Laser Etching and Ablation DCON-74-OL M *Ranking:** *M-4-4 (3.5M;>$1/ft2)*	**Predemonstration** Several research groups at university and government laboratories have used the technology to remove radiological and organic contaminants from various surfaces. **Efficacy:** The technique is slow to remove large deposits. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	**Development:** Existing lasers, delivery systems, and filtration systems need to be integrated into a prototype system for demonstration.	A collection system for the vaporized deposits would be needed to implement this technology. Development costs: $2M+ **Capital cost:** $0.5-1M/machine **Operating cost:** >$1/ft²
						Plasma Surface Cleaning DCON-75-OL H *Ranking:** *H-4-2 (1.0M;>$1/ft2)*	**Predemonstration** Plasma surface cleaning by glow discharges are commonly and effectively utilized for clearing high bonding energy contaminants from surfaces of metals prior to the operation of fusion devices. **Efficacy:** Technology is expected to be effective for removing deposits from listed substrates, but whether the plasma can follow the irregular shapes involved is uncertain. **Waste:** Wastes would be the vaporized deposits plus filters and HEPA filters from the collection system.	**Science:** Data on cleaning rates for contaminants and substrates of interest are needed. Development - The capability of plasma generation and cleaning on complex internal surfaces of contaminated equipment with large surface areas needs to be established. **Available at Y-12.**	A collection system with appropriate filters for the vaporized deposits would be needed to use this technology. An electric power supply would be needed. **Development cost:** About $2M+ **Capital cost:** $0.5-1M /machine **Operating cost:** > $1/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	ORR Hot Cell Liners Bldg. 3028 Hot Cell Liners Bldg. 3029 Hot Cell Liners Bldg. 3030 Hot Cell Liners Bldg. 3031 Hot Cell Liners Bldg. 3032 Hot Cell Liners Bldg. 3033 Process Piping Membrane Between HRT Concrete Bldg. 3029, Cell 2 Wall Bldg. 7500 High Bay Area MSRE Exterior Siding ORR Building Siding Bldg. 3028E Charging Area Bldg. 3029 Exterior Walls Bldg. 3030 Siding/Interior Walls Bldg. 3031 Siding/Interior Walls Bldg. 3032 Siding/Interior Walls Bldg. 3033 Siding/Interior Walls Bldg. 3036 Siding/Interior Walls MSRE Bldg. Structure ORR Steel Bldg. Structure Bldg. 3028E Steel Structure Bldg. 3029 Structure Bldg. 3030 Steel Bldg. Structure Bldg. 3517 Hot Cell Liners Bldg. 3038 Glove Boxes Bldg. 3038 Glove Boxes & Cell Interior Bldg. 3517 Interior/Exterior Walls Bldg. 9201-3:3 Walls & Upper Floors Molten Salt Cells Bldg. 9201-3 Walls & Roof Coolant Salt Cells Bldg. 3031 Structure Bldg. 3032 Structure Bldg. 9419-1 Handrail MSRE Piping ORR Primary Coolant Piping Instrument & Air Lines in Coolant Salt Cell, Bldg. 9201-3 HRT Process Piping MSRE Off-Gas System ORR Demineralizer Piping (Outside Pool) Graphite Reactor Process Piping	Stainless Steel Fission Products, Corrosion Products Stainless Steel Fission Products, Cm-147, Pm-241, Am Stainless Steel Cs-137, Sr-90, Co-60, Ir-192 Stainless Steel 43 Beta, Gamma Emitters Stainless Steel Gd-153, Am-241 Stainless Steel P-32, Am-241 Stainless Steel H-3, Kr-85 Steel Plate Fission Products, Corrosion Products Steel Plate Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Fission Products Sheet Steel Fission Products, TRU Sheet Steel Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel 43 Beta, Gamma Emitters Sheet Steel Gd-153, Am-241 Sheet Steel P-32, Am-241 Sheet Steel H-3, Kr-85 Sheet Steel Cs-137, Sr-90 Structural Steel Cs, Sr, TRU, Co-60 Structural Steel Fission Products Structural Steel Fission Products, TRU Structural Steel Cs-137, Sr-90, Co-60, Ir-92 Structural Steel 43 Beta, Gamma Emitters Stainless Steel Cs-137, Sr-90, Co-60 Stainless Steel Pu-238, Am-241, Cm-244 Stainless Steel Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I Stainless Steel Cs-137, Sr-90, Co-60 Sheet Steel U, Th, Molten Salt Sheet Steel U, Th, Coolant Salt Structural Steel Gd-153, Am-241 Structural Steel P-32, Am-241 Painted Steel Pipe Exterior U, Th, Molten Salt INOR-8 Pipe Exterior U, Be, LiF, ThF_4 Al Piping Exterior Fission Products, Corrosion Products Cu Tubing Exterior U, Th, H-3, Molten Salt Stainless Steel Pipe Exterior Uranyl Sulfate, Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, C-14, Fe-55, Cs-137, Pu, Sr-90, Co-60	Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Thermal Surface Removal Methods	Flashlamp Cleaning DCON-77-OL *Ranking:** **Predemonstration** Flashlamp systems are being used to remove organic contamination from metals, precious metals, and fragile substrates. Hanford-Westinghouse Laboratory is conducting tests of xenon flashlamp systems for removing radiological contamination from surfaces inside metal storage vessels. **Efficacy:** Technology is likely to be effective for surface contamination. **Waste:** Wastes would be removed contaminants some substrate material, and HEPA filters from the filtration system.	Development: Commercially available flashlamp systems need to be evaluated for deposit removal.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** ~$2.5 M **Capital cost:** $50-100K/machine **Operating cost:** ~1.00/ft²
					Surface Cleaning Methods H	Compressed-Air Cryogenic CO_2 Pellet Blasing DCON-51-OL *Ranking:** *H-4-1 (0.7M;>$1/ft2)*	**Demonstration** This technology is commercially available. It has been used at nuclear reactor sites to decontaminate hand tools and some equipment. **Efficacy:** The efficacy of this technology for removing the listed contaminants from concrete has not been demonstrated and is doubtful. **Waste:** Wastes would be HEPA filters filled with the removed contaminants.	Development: Evaluate technology that has recently been demonstrated in Department of Defense programs regarding automation and improvements in pellet delivery.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants plus oxygen depletion precautions. Development Costs: about $0.50M **Capital cost:** About $200,000 **Operating cost:** >$1/ft²
					M	High-Pressure Water DCON-52-OL *Ranking:** *M-3-1 (1.3M;<$1/ft2)*	**Accepted** High pressure water blasting has been used very successfully to decontaminate various large and complex surfaces at nuclear power plants. **Efficacy:** Technique is expected to be effective with a DF of about 50 for loosely adhering contamination on concrete. DFs will be higher if chemical cleaning agents are also used. Technique is expected to be ineffective for fixed contamination. **Waste:** Waste is 4 to >100 gpm of contaminated waste water.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Improvement - Remote operation will necessitate the adaptation of the high pressure water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** $50K-$75K (about $250K with remote operation) **Operating cost:** <$1.00/ft²
					M	Superheated Water DCON-53-OL *Ranking:** *M-4-1 (1.4M;$1/ft2)*	**Accepted** Technology is available and has been used by industry. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has penetrated into the substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Improvement - Remote operation will necessitate the adaptation of the superheated water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** About $175K (about $250K with remote operation) **Operating cost:** ~$1.00/ft²

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						Steam Cleaning DCON-55-OL M *Ranking:** *M-4-1 (1.3M;$1/ft2)*	**Accepted** The technique has proven useful, especially on complex shapes and large surfaces. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has penetrated into the metal. On finished concrete, technology may drive contaminants deeper into substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	Improvement - To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Remote operation will necessitate the adaptation of the steam and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** $50K-$75K (about $250K with remote operation) **Operating cost:** $0.03-$1.00/ft^2
						Hand Brushing Used to Remove Surface Contamination DCON-56-OL H *Ranking:** *H-2-0 (0M;$1/ft2)*	**Accepted** Brushing is a common decontamination technique. **Efficacy:** Brushing is effective for loose contamination only. **Waste:** Waste consists of removed contamination plus other loose debris.	None **Available at K-25.**	Vacuum collection system. **Capital cost:**negligible **Operating cost:**$1.00/ft^2 **Development cost:**none
						Automated Brushing DCON-57-OL M *Ranking:** *M-3-2 (1M;$300/ft)*	**Demonstration** This technology has been used at Rocky Flats to remove plutonium contamination from the inside of pipes. **Efficacy:** Tests would be needed to demonstrate its effectiveness for other contaminants on other substrates. **Waste:** Waste would be removed contamination plus any other loose debris.	**Development:** Tests to demonstrate that this technology is effective for the problems at ORNL.	Vacuum collection system. Development costs:$200K-1M **Capital cost:**$250K(remotely operated system) **Operating cost:**$300/linear foot of pipe
						Sponge Blasting DCON-58-OL M *Ranking:** *M-3-1 (1.3M;$2/ft2)*	**Accepted** Although the technology is relatively new, it is currently being used by at least two sites including a nuclear power plant. **Efficacy:** Extensive data on decontamination factors are not available. With the aggressive sponges, which are impregnated with abrasives, this technology may be effective for the listed contaminants and substrates. **Waste:** Wastes consist of about 0.01 ft^3 of blasting media and removed contaminants per ft^2 of area decontaminated plus any liquid cleaning agents that may have been added.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the sponge blasting operation.	A wastewater treatment / recycle system will be needed to use this technology. **Development cost:** About $1.2M **Capital cost:** Sponge blasting system: About $20K (with sifter system) **Operating cost:** About $2/ft^2

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Sr, Cs, Co, I Stainless Steel Cs-137, Sr-90, Co-60 Sheet Steel U, Th, Molten Salt Sheet Steel U, Th, Coolant Salt Structural Steel Gd-153, Am-241 Structural Steel P-32, Am-241 Painted Steel Pipe Exterior U, Th, Molten Salt INOR-8 Pipe Exterior U, Be, LiF, ThF_4 Al Piping Exterior Fission Products, Corrosion Products Cu Tubing Exterior U, Th, H-3, Molten Salt Stainless Steel Pipe Exterior Uranyl Sulfate, Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, C-14, Fe-55, Cs-137, Pu, Sr-90, Co-60	Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Solvent Washing to Remove Radiological Contamination DCON-61-OL *Ranking:** H Solvent Washing to Remove Organics DCON-62-OL *Ranking:** *H-2-2 (?M;N)* M Strippable Coatings DCON-63-OL *Ranking:** *M-3-0 (<0.1M;>$1/ft2)* M Vacuum (Low Pressure) DCON-64-OL *Ranking:** *M-4-0 (<0.1M;$1/ft2)*	**Conceptual** Plutonium contaminated items at Richland, WA were rinsed with Freon. The vendor who supplied the equipment for Richland ten years ago no longer sells it. **Efficacy:** This technique is mainly applicable to smearable contamination. **Waste:** Waste would be spent solvent containing removed contaminants. **Conceptual** Solvent degreasing was used successfully, but its use was stopped to avoid exposing the workers and the environment to the hazardous solvents. This equipment is produced by a number of manufacturers and its use for removing organic surface contamination is common in a variety of industries. **Efficacy:** The technique is effective for most organics. **Waste:** Waste would be spent solvent containing removed contamination. **Accepted** Technology has been used for decontamination applications involving hazardous and radioactive contaminants. **Efficacy:** Decontamination factors of one to several hundred can be expected with two applications. **Waste:** Waste is a solid polymer (volume = 1 mm x surface area decontaminated) containing the removed contaminants. **Accepted** Vacuum cleaners have long been used to clean up loose contamination. **Efficacy:** Since little of the listed contaminants are expected to be in loose form, this technique is not expected bo be effective. **Waste:** the waste is a HEPA filter filled with the contaminants and otherr materials that are removed by the vacuum.	**Science:** Solvents that are less damaging to the environment need to be identified and demonstrated. **Available in Private Sector.** **Science:** Solvents that are less damaging to the environment need to be identified and demonstrated. **Improvement:** Develop coatings with lower material costs and greater ease of application. **None**	Vapor collection system **Capital cost:** $300K (1980 dollars) **Development cost:** <$1M to identify and demonstrate the replacement solvent. **Operating cost:** an average of 7.5 minutes per item was required when decontaminating small items. **Capital cost:** $400K (1992 dollars) for a 4,000-lb capacity unit. **Labor cost:** One operator for one hour to load, clean, and unload 4,000 lb of metal. Normal implementation needs. **Capital cost:** Negligible **Operating cost:** $1-$1.40/ft² Normal implementation needs. **Capital cost:** <$10K **Operating cost:** >$1/ft²

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EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)					Metal Refining Methods H	Smelt Purification DCON-31-OL *Ranking:** *H-3-3 (100M;$1/lb)*	**Demonstration** Smelt purification of radioactive metals has been performed by a large number of investigators on a lab-scale and by some investigators on a large-scale. The metals include mild steel, stainless steel, nickel, copper, monel, aluminum, and others. **Efficacy:** Metal purification has been demonstrated except for aluminum. U is removed to 0.01-4ppm. Tc is not removed. **Waste:** Waste are slags, scrubber solutions, chemical trap materials, and HEPA filters.	**Development:** Attempt to demonstrate fluxing agent for removing radionuclides of interest. If possible, demonstrate removal of radionuclides of interest on a larger scale.	Scientific Ecology Group (SEG) personnel estimate the costs of metal smelting at roughly $0.93/lb of metal in 1992 dollars, depending on the type metal and configuration of the metal. Kellogg et al. estimated that the capital and operating costs of smelting the 90,000 tons of DOE scrap metal presently on hand at K-25 could be recovered through sale of the metal if a *de minimis* were established. The quantity of metals at ORNL is probably not sufficient to be cost effective unless added to this. The technology development needs will require further lab and pilot-scale evaluation. The development costs are roughly estimated at $3M - $5M.
						Electrorefining DCON-32-OL *Ranking:**	**Predemonstration** Electrorefining is a well-established commercial technology. However, this technology cannot be considered mature concerning its use for decontaminating radioactive metal because this application is much less established. **Efficacy:** Technology is likely to be effective for the listed contaminants and substrates. **Waste:** Waste would be solid mixed waste from assumed treatment of electrolyte solutions for recycle.	**Development:** Demonstrate (1) separation for radionuclides and substrates of interest and (2) recycle electrolyte solutions.	An electrorefining plant would also require a smelting and anode forming facility to form the impure metal into anodes of proper configuration. The capital costs altogether are estimated at $200M. The cost of an operating facility with a 10 million-pound/year capacity is estimated at $2M capital and $6/lb operating costs, which exceed the present value of virtually any metal because commercial companies operate on a much larger scale. Development costs are estimated at $3M. To allow sale of the purified metal, either a *de minimis* level must be established in the USA or permission must be obtained to sell the metal in Europe where a *de minimis* level exists.

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Structure Bldg. 3517 Hot Cell Liners Bldg. 3038 Glove Boxes Bldg. 3038 Glove Boxes & Cell Interior Bldg. 3517 Interior/Exterior Walls Bldg. 9201-3:3 Walls & Upper Floors Molten Salt Cells Bldg. 9201-3 Walls & Roof Coolant Salt Cells Bldg. 3031 Structure Bldg. 3032 Structure Bldg. 9419-1 Handrail MSRE Piping ORR Primary Coolant Piping Instrument & Air Lines in Coolant Salt Cell, Bldg. 9201-3 HRT Process Piping MSRE Off-Gas System ORR Demineralizer Piping (Outside Pool) Graphite Reactor Process Piping	Stainless Steel Fission Products, Corrosion Products Stainless Steel Fission Products, Cm-147, Pm-241, Am Stainless Steel Cs-137, Sr-90, Co-60, Ir-192 Stainless Steel 43 Beta, Gamma Emitters Stainless Steel Gd-153, Am-241 Stainless Steel P-32, Am-241 Stainless Steel H-3, Kr-85 Steel Plate Fission Products, Corrosion Products Steel Plate Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Fission Products Sheet Steel Fission Products, TRU Sheet Steel Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel 43 Beta, Gamma Emitters Sheet Steel Gd-153, Am-241 Sheet Steel P-32, Am-241 Sheet Steel H-3, Kr-85 Sheet Steel Cs-137, Sr-90 Structural Steel Cs, Sr, TRU, Co-60 Structural Steel Fission Products Structural Steel Fission Products, TRU Structural Steel Cs-137, Sr-90, Co-60, Ir-92 Structural Steel 43 Beta, Gamma Emitters Stainless Steel Cs-137, Sr-90, Co-60 Stainless Steel Pu-238, Am-241, Cm-244 Stainless Steel Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I Stainless Steel Cs-137, Sr-90, Co-60 Sheet Steel U, Th, Molten Salt Sheet Steel U, Th, Coolant Salt Structural Steel Gd-153, Am-241 Structural Steel P-32, Am-241 Painted Steel Pipe Exterior U, Th, Molten Salt INOR-8 Pipe Exterior U, Be, LiF, ThF_4 Al Piping Exterior Fission Products, Corrosion Products Cu Tubing Exterior U, Th, H-3, Molten Salt Stainless Steel Pipe Exterior Uranyl Sulfate, Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, C-14, Fe-55, Cs-137, Pu, Sr-90, Co-60	Refer to the Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Metal Refining Methods M	Leach/Electrowinning DCON-34-OL *Ranking:** *M-2-5 (200M;$3.80/lb)*	**Predemonstration** Leach/Electrowinning is a well-established commercial method for producing nickel from nickel ore, but is not used commercially to refine impure nickel metal. **Efficacy:** Scientific Ecology Group, Inc. (SEG), has purified nickel to <1 Bq/g of Tc on a small scale. The Tc must be removed from the electrolytic solutions by ion exchange or some other method. The method has not been evaluated for treatment of metals other than nickel. At ORNL, nickel was not used extensively. **Waste:** Recycle of electrolytic solutions will result in a solid mixed waste bearing the contaminants and traces of the purified metal amounting to roughly 2% by weight of the metal purified.	**Development:** Pilot-scale testing of this method is needed with special attention to the leaching process, decontamination efficiency, and recycle of the electrolytic solutions. The development work by SEG may satisfy some of this requirement.	A leach/electrowinning plant would require a size-reduction facility, a leaching facility, and a tankhouse for the electrolytic cells. The costs of an operating facility with a 10-million-pound-per-year capacity are estimated by INCO at $200M capital and $3.80/lb operating costs. The operating costs exceed the present value of most all metals because commercial nickel companies operate on a much larger scale. The development costs are estimated by INCO at $440K if the work were done at their facilities. To allow sale of the resulting purified metal, either a *de minimis* must be established for the USA or permission must be obtained to sell the metal in Europe where a *de minimis* standard exists.
						Chemical Surface Cleaning Methods M	Chemical Foams DCON-8-OL *Ranking:** *M-4-1 (3M;$0.50-$2/ft2)*	**Demonstration** Widely used throughout the nuclear industry. Foam is used as a carrier of chemical decontamination agents, not as the agent itself. It can be sprayed on and wiped, rinsed, or vacuumed off. **Efficacy:** Effectiveness for listed contaminants and substrates has not been demonstrated. **Waste:** Small amount of contaminated sulfonated detergents, synthetic wetting agents, coupling agents, rinse water, and drying cloth.	**Development:** Scale-up/development of the process to a size appropriate for ORNL use. The technology itself is inexpensive, but development and scale-up will probably require support. **Improvement:** Full control over the mean bubble dimensions and the volume swell factor are needed, indicating that some basic research will be necessary.	These estimated costs are: **Development cost:** $1M-$4M; **Capital cost:** $50K Operating cost: $0.50-$2/ft²
							Chemical Gels DCON-9-OL *Ranking:** *M-4-2 (3M;N)*	**Demonstration** The use of chemical gels is most suited to in situ decontamination of large surfaces. Gel is used as a carrier of chemical decontamination agents, not as the agent itself. It is sprayed on component walls; allowed to work; and then scrubbed, wiped, rinsed, or peeled off. Steps include scraping and vacuuming of solid waste material, preliminary hot water rinsing, and gel spraying throughout the cell. **Efficacy:** Expected to be effective only for smearable contamination. **Waste:** Wastes would be carboxymethylcellulose gelling agent, aluminum nitrate chelating agent, wash water, acidic chemical agent (possibly nitric-hydrofluoric-oxalic acid), and the removed contaminants. Wastes are reportedly 4-5 times less compared to chemical solutions.	**Development:** Complex gel formulation with a number of compounds may be required, depending on the objectives. Laboratory optimization will be necessary, with any change in variables.	Normal implementation needs: **Development cost:** $1M-$4M **Capital cost:** <$50K **Operating cost:** $0.50-$2.00/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	ORR Hot Cell Liners Bldg. 3028 Hot Cell Liners Bldg. 3029 Hot Cell Liners Bldg. 3030 Hot Cell Liners Bldg. 3031 Hot Cell Liners Bldg. 3032 Hot Cell Liners Bldg. 3033 Process Piping Membrane Between HRT Concrete Bldg. 3029, Cell 2 Wall Bldg. 7500 High Bay Area MSRE Exterior Siding ORR Building Siding Bldg. 3028E Charging Area Bldg. 3029 Exterior Walls Bldg. 3030 Siding/Interior Walls Bldg. 3031 Siding/Interior Walls Bldg. 3032 Siding/Interior Walls Bldg. 3033 Siding/Interior Walls Bldg. 3036 Siding/Interior Walls MSRE Bldg. Structure ORR Steel Bldg. Structure Bldg. 3028E Steel Structure Bldg. 3029 Structure Bldg. 3030 Steel Bldg. Structure Bldg. 3517 Hot Cell Liners Bldg. 3038 Glove Boxes Bldg. 3038 Glove Boxes & Cell Interior Bldg. 3517 Interior/Exterior Walls Bldg. 9201-3:3 Walls & Upper Floors Molten Salt Cells Bldg. 9201-3 Walls & Roof Coolant Salt Cells Bldg. 3031 Structure Bldg. 3032 Structure Bldg. 9419-1 Handrail MSRE Piping ORR Primary Coolant Piping Instrument & Air Lines in Coolant Salt Cell, Bldg. 9201-3 HRT Process Piping MSRE Off-Gas System ORR Demineralizer Piping (Outside Pool) Graphite Reactor Process Piping	Stainless Steel Fission Products, Corrosion Products Stainless Steel Fission Products, Cm-147, Pm-241, Am Stainless Steel Cs-137, Sr-90, Co-60, Ir-192 Stainless Steel 43 Beta, Gamma Emitters Stainless Steel Gd-153, Am-241 Stainless Steel P-32, Am-241 Stainless Steel H-3, Kr-85 Steel Plate Fission Products, Corrosion Products Steel Plate Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Cs, Sr, TRU, Co-60 Sheet Steel Fission Products Sheet Steel Fission Products, TRU Sheet Steel Cs-137, Sr-90, Co-60, Ir-192 Sheet Steel 43 Beta, Gamma Emitters Sheet Steel Gd-153, Am-241 Sheet Steel P-32, Am-241 Sheet Steel H-3, Kr-85 Sheet Steel Cs-137, Sr-90 Structural Steel Cs, Sr, TRU, Co-60 Structural Steel Fission Products Structural Steel Fission Products, TRU Structural Steel Cs-137, Sr-90, Co-60, Ir-92 Structural Steel 43 Beta, Gamma Emitters Stainless Steel Cs-137, Sr-90, Co-60 Stainless Steel Pu-238, Am-241, Cm-244 Stainless Steel Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I Stainless Steel Cs-137, Sr-90, Co-60 Sheet Steel U, Th, Molten Salt Sheet Steel U, Th, Coolant Salt Structural Steel Gd-153, Am-241 Structural Steel P-32, Am-241 Painted Steel Pipe Exterior U, Th, Molten Salt INOR-8 Pipe Exterior U, Be, LiF, TiF_3 Al Piping Exterior Fission Products, Corrosion Products Cu Tubing Exterior U, Th, H-3, Molten Salt Stainless Steel Pipe Exterior Uranyl Sulfate, Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, Corrosion Products Stainless Steel Pipe Exterior Fission Products, C-14, Fe-55, Cs-137, Pu, Sr-90, Co-60	Refer to the Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning Methods	Organic Acid Treatments DCON-10-OL *Ranking:** *H-4-2 (2M;N)*	**Demonstration** The technology is currently in use by BNFL at Capenhurst gaseous diffusion plant. BNFL uses citric and sulfuric acids in sequence for removal of U and Tc, respectively, from metal surfaces (mostly wrought aluminum). **Efficacy:** DF of 300 for U alpha and 40 for Tc beta are reported (11.1 Bq/g alpha, 0.04 Bq/g beta). Has not been demonstrated to remove other radionuclides. **Waste:** Wastes include citric and sulfuric acids containing uranium and other metal ions and ion exchange media containing the metals. Uranium is difficult to precipitate.	**Development:** Pilot plant development for waste treatments (ion exchange columns) to verify that we can meet our standards and regulations. More fundamental studies are needed in secondary waste disposal.	Purchase of technology, regulatory compliance for pilot-scale decontamination, and waste treatment demonstrations. BNFL's expertise may reduce the amount of original research, etc. necessary to begin implementation. Cost $400K-$1M. No present ORNL facility could be adapted for citric acid cleaning, but decontamination with BNFL's citric acid process should pose no undue difficulties. It may well be less costly to implement than the more familiar nitric acid process would be due to the relative nontoxicity and ease of treating secondary waste stream. **Development cost:** $400K-$1M (rough estimate) **Capital cost:** $4M-$10M if new equipment is required **Operating cost:** $300/Mg (BNFL estimate)
						Fluoboric Acid Treatment DCON-11-OL *Ranking:** *H-4-2 (2M;N)*	**Demonstration** Technology was designed specifically for D&D. **Efficacy:** Attacks nearly every metal surface and metallic oxide. Removes oxide and contaminated outer layer in controllable, uniform and efficient manner. High decontamination factor (DF); however, high corrosion.	**Development:** Although the method has seen application at Chernobyl with good results, development work is needed to test applicability at ORNL.	Fluoboric acid exhibits low vapor pressure and requires only standard precautions for acid or base work. The plant can be manufactured in modular form and installed in existing buildings. Hardware (equipment): Fabrication of all key plant parts from polypropylene or from Halar-coated metal. Capital cost in 1990 to set up a plant for decontaminating 5 tons/day of steel was $774K, excluding development, planning, and buildings. Operating cost will be relatively low; this is a very simple process.
						Inorganic Acid Treatments DCON-12-OL *Ranking:** *M-3-0 (4M;N)*	**Accepted** Nitric acid decontamination has been the preferred method at ORNL for cleaning items in various facility operations since the 1940s. In addition, the technique has been widely used at K-25 and Portsmouth. **Efficacy:** DFs are in the 100 range. **Waste:** Wastes consist of large quantities of corrosive wastes containing the removed contaminants and require treatment and disposal as mixed waste.	**Improvements:** Adaptation of modifications to system (i.e., scrubbers, filters, treatment for nitrates and heavy metals) In order to meet regulatory requirements. Possible development of HNO_3/HF decontamination methods, with or without ultrasonic agitation. Continuing research and development, waste treatment, and volume reduction. Possible research and development in control of base metal dissolution. **Available at X-10, K-25.**	Nitrate treatment facility either on site or accessible to decontamination facility. Operating costs may be relatively high. Nitric acid decontamination was used extensively at most DOE plants, but data is not available regarding costs. Currently, Portsmouth plant is developing a data base to track costs, but it will not contain historical data. **Development cost:** (improvements) $400K-1M (rough estimate) **Capital cost:** <$4M-$10M (rough estimate)

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Decontamination

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						REDOX Treatments DCON-14-OL M *Ranking:** *M-4-1 (3M;<$1/ft2)*	**Demonstration** REDOX treatments have been demonstrated for nuclear power plant decontamination, but not for the contaminants of interest. **Efficacy:** DFs of 10-100 can be expected based on experience in nuclear power plants. **Waste:** With recycle, waste is spent ion exchange media containing removed contaminants. With neutralization and evaporation, waste is a solid mixed waste containing the removed contaminants and chemicals from the REDOX reagents.	**Development:** All REDOX techniques will require demonstration to determine their usefulness to decontamination of ORNL operations and applicability to various contaminant films.	A system for treating the REDOX reagents to permit recycling these reagents will be needed to use this technology. **Development costs:** $1M to bring a REDOX decontamination development through bench-scale and demonstration phases. **Capital cost:** >$1M **Operating cost:** <$1/ft
						Biological DCON-3-OL L *Ranking:** *L-2-Unknown*	**Evolving Technology / Pre-conceptual** The knowledge base exists for biological treatments of various contaminants; however, there is not a data base for application of the technology for surface decontamination. **Efficacy:** This technology is quite likely to be successful for oil and PCBs. It could be successful for other radionuclides, but these contaminants would remain in the bacterial sludge. **Waste:** The waste generated would be the contaminated layer of microbes removed from the treated surface.	**Science:** Literature study and bench-scale tests of microbes on contaminants of interest. Development - Develop methods for applying a layer of microbes, supplying needed nutrients, and removing the microbe layer from the decontaminated item.	Facilities for cultivating the bacteria and disposing of the bacterial sludge would be needed. **Development cost:** $300K-$600K **Capital cost:** ~$200K **Operating cost:** ~$1/ft²

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

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Decontamination

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					H Catalytic Extraction Process DCON-6-OL *Ranking:** *H-5-4 (20M;$1/lb)*	**Predemonstration** Has not been used to process scrap bearing radioactivity. However, the method is virtually the same as smelt purification when applied to metals. **Efficacy:** High reduction of U is expected. Removal effectiveness on fission products, etc., is not known. **Waste:** Wastes would be slag containing contaminants plus contaminants in scrubber solution or chemical trapping materials.	**Science:** Evaluate effectiveness on fission products, etc. **Development:** Demonstrate effectiveness of removal of fission products, etc.	"Off the shelf" induction or arc furnace. **Development cost:** $3M - $5M **Capital cost:** ~$16 million **Operating cost:** $1/lb.

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Decontamination

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		MSRE Bldg. Interior/Exterior Walls	Concrete Block Fission Products, Corrosion Products							
		ORR Bldg. Interior/Exterior Walls	Concrete Block Fission Products							
		Bldg. 3028 Interior/Exterior Walls	Concrete Block Fission Products, TRU							
		Bldg. 3029 Interior/Exterior Walls	Concrete Block Cs-137, Sr-90, Co-60, Ir-192							
		Bldg. 3031 Stacked Shielding	Concrete Block Gd-153, Am-241							
		Bldg. 3032 Interior/Exterior Walls	Concrete Block P-32, Am-241				Shot Blasting DCON-36-OL H *Ranking:** *H-3-0 (<0.1M;$1/ft2)*	**Accepted** Commercial iron shot blasters are in use at the K-25 site. **Efficacy:** They are generally effective but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants plus 0.05lb spent shot per ft² of concrete decontaminated.	**Improvement:** Automation, especially for walls and ceilings.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$50K **Operating cost:** ~$1/ft²
		Bldg. 3036 Interior Walls	Concrete Block Cs-137, Sr-90							
		Bldg. 3038 Interior Walls	Concrete Block Sr-90, Cs-137, Co-60, I-129							
		Bldg. 3517 Interior/Exterior Walls	Concrete Block Cs-137, Sr-90, Co-60							
		Bldg. 7500 Floors	Tiled Concrete• Cs, Sr, TRU, Co-60				Scabblers/Scarifiers DCON-37-OL H *Ranking:** *H-4-2 (0.5M;$5/ft2)*	**Accepted** Mechanical scabblers are used for concrete decontamination at the K-25 Site and elsewhere. **Efficacy:** They are generally effective, but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed substrate (1/16" cut) containing removed contaminants per ft² of substrate decontaminated.	**Improvement:** Automation, especially for walls and ceilings.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$500K **Operating cost:** ~$5/ft²
		MSRE Bldg. Floors	Tiled Concrete• Fission Products, Corrosion Products							
		ORR Bldg. Floors	Tiled Concrete• Fission Products							
		Bldg. 3028 Floors	Tiled Concrete• Fission Products, TRU							
		Bldg. 3029 Floors	Tiled Concrete• Cs-137, Sr-90, Co-60, Ir-192							
		Bldg. 3030 Floors	Tiled Concrete• 43 Beta, Gamma Emitters							
		Bldg. 3031 Floors	Tiled Concrete• Gd-153, Am-241							
		Bldg. 3032 Floors	Tiled Concrete• P-32, Am-241							
		Bldg. 3033 Floors	Tiled Concrete• H-3, Kr-85				Grit Blasting DCON-38-OL H *Ranking:** *H-4-0 (<0.1$5/ft2)*	**Accepted** Has been used successfully for many applications in the nuclear industry. **Efficacy:** Technology is generally effective. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants per ft² of concrete decontaminated plus spent grit.	**Improvement:** automation, especially for walls and ceilings.	Normal implementation needs. **Development cost:** none **Capital cost:** ~$50K **Operating cost:** $~5/ft²
		Bldg. 3036 Floors	Tiled Concrete• Cs-137, Sr-90							
	• Remedial Action (RA)—Soils, Groundwater and Surface Water	Bldg. 3517 Floors	Tiled Concrete• Cs-137, Sr-90, Co-60							
		Bldg. 9201-3 Molten Salt Cells, Floor	Tiled Concrete• U, Th, Molten Salt							
		Bldg. 9201-3 Coolant Salt Cell, Floor	Tiled Concrete• U, Th, Coolant Salt							
		Bldg. 3038 Floors	Tiled Concrete• Sr-90, Cs-137, Co-60, I-129				Centrifuge Cryogenic CO_2 Pellet Blasting DCON-39-OL H *Ranking:** *H-5-2 (1.0M;<$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Improvement:** 1) Demonstration of an on-line, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants plus oxygen-depletion precautions. **Development cost:** <$1M **Capital cost:** $100K **Operating cost:** <$1/ft²
	• Waste Management (WM)									

•Assumes tile has been removed

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Groundwater and Surface Water • Waste Management (WM)	Bldg. 7500 Interior/Exterior Walls MSRE Bldg. Interior/Exterior Walls ORR Bldg. Interior/Exterior Walls Bldg. 3028 Interior/Exterior Walls Bldg. 3029 Interior/Exterior Walls Bldg. 3031 Stacked Shielding Bldg. 3032 Interior/Exterior Walls Bldg. 3036 Interior Walls Bldg. 3038 Interior Walls Bldg. 3517 Interior/Exterior Walls Bldg. 7500 Floors MSRE Bldg. Floors ORR Bldg. Floors Bldg. 3028 Floors Bldg. 3029 Floors Bldg. 3030 Floors Bldg. 3031 Floors Bldg. 3032 Floors Bldg. 3033 Floors Bldg. 3036 Floors Bldg. 3517 Floors Bldg. 9201-3 Molten Salt Cells, Floor Bldg. 9201-3 Coolant Salt Cell, Floor Bldg. 3038 Floors	Concrete Block Cs, Sr, TRU, Co-60 Concrete Block Fission Products, Corrosion Products Concrete Block Fission Products Concrete Block Fission Products, TRU Concrete Block Cs-137, Sr-90, Co-60, Ir-192 Concrete Block Gd-153, Am-241 Concrete Block P-32, Am-241 Concrete Block Cs-137, Sr-90 Concrete Block Sr-90, Cs-137, Co-60, I-129 Concrete Block Cs-137, Sr-90, Co-60 Tiled Concrete* Cs, Sr, TRU, Co-60 Tiled Concrete* Fission Products, Corrosion Products Tiled Concrete* Fission Products Tiled Concrete* Fission Products, TRU Tiled Concrete* Cs-137, Sr-90, Co-60, Ir-192 Tiled Concrete* 43 Beta, Gamma Emitters Tiled Concrete* Gd-153, Am-241 Tiled Concrete* P-32, Am-241 Tiled Concrete* H-3, Kr-85 Tiled Concrete* Cs-137, Sr-90 Tiled Concrete* Cs-137, Sr-90, Co-60 Tiled Concrete* U, Th, Molten Salt Tiled Concrete* U, Th, Coolant Salt Tiled Concrete* Sr-90, Cs-137, Co-60, I-129	Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Ice Blasting DCON-40-OL H *Ranking:** *H-5-1 (<1.0M;$1/ft2)*	**Demonstration** **Efficacy:** Efficacy of commercial system for this application needs demonstration. **Waste:** Waste would be about 14 to 18 gallons per hour waste water containing removed contaminants.	**Development:** Demonstration of efficacy of commercial system. **Improvement:** Automation/robotics, especially for walls, corners, etc.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** $250K **Capital cost:** $100K-$1M **Operating cost:** <$1/ft²
						Supercritical CO_2 Blasting DCON-41-OL H *Ranking:** *H-5-1 (O.75+M;>$1/ft2)*	**Predemonstration** **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed concrete and contaminants contained in a cyclone and a HEPA filter.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminants. Demonstrate efficacy for contaminants of interest.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen depletion precautions. **Development cost:** $250K-1M **Capital cost:** ~$500K **Operating cost:** $1+/ft²
						Plastic Pellet Blasting DCON-42-OL M *Ranking:** *M-4-0 (<0.1M;$1/ft2)*	**Accepted** Plastic pellet blasting is a widely used alternate to sand blasting for applications in which it is desired to impart minimal damage to the substrate. **Efficacy:** Technology should remove smearable, but not fixed contamination, from concrete. **Waste:** Waste would be spent plastic pellets plus removed contamination.	**Improvement:** Develop and demonstrate system for processing waste. **Improvement:** Minimize blast media erosion to minimize waste; automation/robotics, especially for walls, etc.; improve containment of waste and removed contaminants.	A system for processing waste to an acceptable form is needed. Improvements: **Development cost:** (Improvements) $5.5M+ **Capital cost:** ~$50K **Operating cost:** $0.20 - $2.15/ft
						Hand Grinding, Honing, Scraping DCON-43-OL H *Ranking:** *H-2-0 (<<0.1M;$1/ft2)*	**Accepted** **Efficacy:** Grinding with hand-held power grinders has been successfully used for small-scale decontamination. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	None **Available at X-10, K-25.**	A collection system for the vaporized contaminants would be needed to implement this technology. Development costs: None **Capital cost:** $150 ($5K with vacuum system and $50-500K with remote operation) **Operating cost:** ~$1/ft²
						Automated Grinding DCON-44-OL H *Ranking:** *H-2-1 ($1M;$1M;N)*	**Conceptual** Grinding has been successfully used for small scale decontamination. This grinding was done with hand-held power grinders Remotely operated grinding equipment is available, but no references to its use for decontamination have been found. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	Development: The applicability of this technology to items with rad contamination should be demonstrated.	A collection system for the vaporized contaminants would be needed to implement this technology. **Development cost:**$600K **Capital cost:**$250-500K

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Groundwater and Surface Water • Waste Management (WM)	Bldg. 7500 Interior/Exterior Walls MSRE Bldg. Interior/Exterior Walls ORR Bldg. Interior/Exterior Walls Bldg. 3028 Interior/Exterior Walls Bldg. 3029 Interior/Exterior Walls Bldg. 3031 Stacked Shielding Bldg. 3032 Interior/Exterior Walls Bldg. 3036 Interior Walls Bldg. 3038 Interior Walls Bldg. 3517 Interior/Exterior Walls Bldg. 7500 Floors MSRE Bldg. Floors ORR Bldg. Floors Bldg. 3028 Floors Bldg. 3029 Floors Bldg. 3030 Floors Bldg. 3031 Floors Bldg. 3032 Floors Bldg. 3033 Floors Bldg. 3036 Floors Bldg. 3517 Floors Bldg. 9201-3 Molten Salt Cells, Floor Bldg. 9201-3 Coolant Salt Cell, Floor Bldg. 3038 Floors	Concrete Block Cs, Sr, TRU, Co-60 Concrete Block Fission Products, Corrosion Products Concrete Block Fission Products Concrete Block Fission Products, TRU Concrete Block Cs-137, Sr-90, Co-60, Ir-192 Concrete Block Gd-153, Am-241 Concrete Block P-32, Am-241 Concrete Block Cs-137, Sr-90 Concrete Block Sr-90, Cs-137, Co-60, I-129 Concrete Block Cs-137, Sr-90, Co-60 Tiled Concrete* Cs, Sr, TRU, Co-60 Tiled Concrete* Fission Products, Corrosion Products Tiled Concrete* Fission Products Tiled Concrete* Fission Products, TRU Tiled Concrete* Cs-137, Sr-90, Co-60, Ir-192 Tiled Concrete* 43 Beta, Gamma Emitters Tiled Concrete* Gd-153, Am-241 Tiled Concrete* P-32, Am-241 Tiled Concrete* H-3, Kr-85 Tiled Concrete* Cs-137, Sr-90 Tiled Concrete* Cs-137, Sr-90, Co-60 Tiled Concrete* U, Th, Molten Salt Tiled Concrete* U, Th, Coolant Salt Tiled Concrete* Sr-90, Cs-137, Co-60, I-129	Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods **M**	Concrete Milling DCON-47-OL *Ranking:** *M-1-2 (<1M;$0.75/ft2)*	**Accepted** The equipment is commercially available, but no reference to its use for decontamination has been found. This technology is suited for horizontal surfaces only. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	Improvement: The technology to operate this equipment remotely needs to be developed and demonstrated.	A collection system for the contaminated dust that is generated would be needed to implement this technology. **Development cost:** None **Capital cost:** $400K **Operating cost:** $0.75/ft²
						Explosive DCON-48-OL *Ranking:** *L-2-5 (4M;$50/ft2)*	**Demonstration** Blasting has been used to decontaminate nuclear reactor shielding. Demonstration will be needed for other applications. Safety concerns need to be resolved; care must be taken to contain the dust and to prevent structural damage to the building being decontaminated and the surrounding structures. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** Improvements in the methods of applying explosives and in the uniformity of the detonation are needed. The explosion will generate toxic organic vapors. The technology to control toxic vapors formed by the explosion must be developed and demonstrated.	A certified blasting technician will be needed. **Capital cost:**$50K **Operating cost:**$50/ft² **Development cost:**$1-4M
					Thermal Surface Removal Methods **H**	Microwace Scabbling DCON-71-OL *Ranking:** *H-3-2 (2.5+M;>$1/ft2)*	**Predemonstration** In FY 1991 ORNL demonstrated reliable removal of noncontaminated concrete surfaces using a stationary microwave device. A mobile device is under development. **Efficacy:** Since microwave scrabbling removes the contaminated concrete surface, the decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** The waste generated is concrete rubble with particle diameters lying primarily in the range of 1 to 10 mm plus the contaminants. For a removal depth of 10 mm, 0.03 ft³ of concrete rubble is generated per ft² of concrete decontaminated.	**Development:** The development and testing of a mobile prototype microwave concrete removal machine needs to be completed.	Normal implementation needs. **Development cost:** $2.5M **Capital cost:** ~$250K **Operating cost:** >$1/ft²

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Decontamination

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Groundwater and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
Bldg. 7500 Interior/Exterior Walls MSRE Bldg. Interior/Exterior Walls ORR Bldg. Interior/Exterior Walls Bldg. 3028 Interior/Exterior Walls Bldg. 3029 Interior/Exterior Walls Bldg. 3031 Stacked Shielding Bldg. 3032 Interior/Exterior Walls Bldg. 3036 Interior Walls Bldg. 3038 Interior Walls Bldg. 3517 Interior/Exterior Walls Bldg. 7500 Floors MSRE Bldg. Floors ORR Bldg. Floors Bldg. 3028 Floors Bldg. 3029 Floors Bldg. 3030 Floors Bldg. 3031 Floors Bldg. 3032 Floors Bldg. 3033 Floors Bldg. 3036 Floors Bldg. 3517 Floors Bldg. 9201-3 Molten Salt Cells, Floor Bldg. 9201-3 Coolant Salt Cell, Floor Bldg. 3038 Floors	Concrete Block Cs, Sr, TRU, Co-60 Concrete Block Fission Products, Corrosion Products Concrete Block Fission Products Concrete Block Fission Products, TRU Concrete Block Cs-137, Sr-90, Co-60, Ir-192 Concrete Block Gd-153, Am-241 Concrete Block P-32, Am-241 Concrete Block Cs-137, Sr-90 Concrete Block Sr-90, Cs-137, Co-60, I-129 Concrete Block Cs-137, Sr-90, Co-60 Tiled Concrete* Cs, Sr, TRU, Co-60 Tiled Concrete* Fission Products, Corrosion Products Tiled Concrete* Fission Products Tiled Concrete* Fission Products, TRU Tiled Concrete* Cs-137, Sr-90, Co-60, Ir-192 Tiled Concrete* 43 Beta, Gamma Emitters Tiled Concrete* Gd-153, Am-241 Tiled Concrete* P-32, Am-241 Tiled Concrete* H-3, Kr-85 Tiled Concrete* Cs-137, Sr-90 Tiled Concrete* Cs-137, Sr-90, Co-60 Tiled Concrete* U, Th, Molten Salt Tiled Concrete* U, Th, Coolant Salt Tiled Concrete* Sr-90, Cs-137, Co-60, I-129	Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Thermal Surface Removal Methods	Plasma Torch DCON-72-OL *Ranking:** *H-4-1 (0.5M;$1/ft2)*	**Evolving Technology** **Conceptual** Plasma torches exist commercially to weld and cut materials that have very high melting temperatures or require an inert atmosphere. **Efficacy:** Its efficacy in removing various organic contaminants or to spall off layers of contaminated concrete has not been investigated. **Waste:** Wastes would consist of materials used to trap reaction products from the decomposition of organics and spalled concrete with contaminants.	**Science:** Laboratory tests are needed to evaluate the efficacy of vaporizing or decomposing organics, determine the decomposition reaction by-products, and suitable for trapping materials. Laboratory tests of thermal stress-induced spalling of concrete are also needed. Computer modeling of plasma-surface interactions and heat transfer in concrete are needed. **Development:** Plasma torches having geometries and conditions suitable for decontamination need to be developed along with suitable collection and gas treatment systems. **Available at Y-12.**	A collection system for the vaporized deposits would be needed to implement this technology. Development costs: ~$500K Capital costs: ~$100K Operating costs: $0.01-$1.00/ft² (170K/hr.)
					Laser Heating DCON-73-OL *Ranking:** *M-4-4 (3M;$1/ft2)*	**Demonstration** Currently being used to remove organic coatings from metal surfaces. **Efficacy:** Current prototype systems are capable of removing 2-mil-thick coatings at the rate of 100 ft²/hr. Effectiveness on contaminants and substrates of interest is uncertain. **Waste:** Waste will be prefilters and HEPA filters filled with contaminants.	Development: Current prototype needs to be evaluated for possible use on contaminated areas. Systems with different operational parameters (e.g., wavelength, pulse durations) should be evaluated as well.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost: $2M+** **Capital cost: $500K-$1M+/machine** **Operating cost: ~$1/ft²**
					Laser Etching and Ablation DCON-74-OL *Ranking:** *M-4-4 (3.5M;>$1/ft2)*	**Predemonstration** Several research groups at university and government laboratories have used the technology to remove radiological and organic contaminants from various surfaces. **Efficacy:** The technique is slow to remove large deposits. **Waste:** Wastes would be removed contamination, some substrate material, and HEPA filters from the filtration system.	Development: Existing lasers, delivery systems, and filtration systems need to be integrated into a prototype system for demonstration.	A collection system for the vaporized deposits would be needed to implement this technology. Development costs: $2M+ **Capital cost: $0.5-1M/machine** **Operating cost: >$1/ft²**
					Flashlamp Cleaning DCON-77-OL *Ranking:** *H-3-3 (2.5M;$1/ft2)*	**Predemonstration** Flashlamp systems are being used to remove organic contamination from metals, precious metals, and fragile substrates. Hanford-Westinghouse Laboratory is conducting tests of xenon flashlamp systems for removing radiological contamination from surfaces inside metal storage vessels. **Efficacy:** Technology is likely to be effective for surface contamination. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	Development: Commercially available flashlamp systems need to be evaluated for decontamination.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost: ~$2.5 M** **Capital cost: $50-100K/machine** **Operating cost: ~1.00/ft²**

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Groundwater and Surface Water • Waste Management (WM)	Bldg. 7500 Interior/Exterior Walls MSRE Bldg. Interior/Exterior Walls ORR Bldg. Interior/Exterior Walls Bldg. 3028 Interior/Exterior Walls Bldg. 3029 Interior/Exterior Walls Bldg. 3031 Stacked Shielding Bldg. 3032 Interior/Exterior Walls Bldg. 3036 Interior Walls Bldg. 3038 Interior Walls Bldg. 3517 Interior/Exterior Walls Bldg. 7500 Floors MSRE Bldg. Floors ORR Bldg. Floors Bldg. 3028 Floors Bldg. 3029 Floors Bldg. 3030 Floors Bldg. 3031 Floors Bldg. 3032 Floors Bldg. 3033 Floors Bldg. 3036 Floors Bldg. 3517 Floors Bldg. 9201-3 Molten Salt Cells, Floor Bldg. 9201-3 Coolant Salt Cell, Floor Bldg. 3038 Floors	Concrete Block Cs, Sr, TRU, Co-60 Concrete Block Fission Products, Corrosion Products Concrete Block Fission Products Concrete Block Fission Products, TRU Concrete Block Cs-137, Sr-90, Co-60, Ir-192 Concrete Block Gd-153, Am-241 Concrete Block P-32, Am-241 Concrete Block Cs-137, Sr-90 Concrete Block Sr-90, Cs-137, Co-60, I-129 Concrete Block Cs-137, Sr-90, Co-60 Tiled Concrete* Cs, Sr, TRU, Co-60 Tiled Concrete* Fission Products, Corrosion Products Tiled Concrete* Fission Products Tiled Concrete* Fission Products, TRU Tiled Concrete* Cs-137, Sr-90, Co-60, Ir-192 Tiled Concrete* 43 Beta, Gamma Emitters Tiled Concrete* Gd-153, Am-241 Tiled Concrete* P-32, Am-241 Tiled Concrete* H-3, Kr-85 Tiled Concrete* Cs-137, Sr-90 Tiled Concrete* Cs-137, Sr-90, Co-60 Tiled Concrete* U, Th, Molten Salt Tiled Concrete* U, Th, Coolant Salt Tiled Concrete* Sr-90, Cs-137, Co-60, I-129	Refer to the Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Compressed-Air Cryogenic CO_2 Pellet Blasing DCON-51-OL H *Ranking:** *H-4-1 (0.7M;>$1/ft2)*	**Demonstration** This technology is commercially available. It has been used at nuclear reactor sites to decontaminate hand tools and some equipment. **Efficacy:** The efficacy of this technology for removing the listed contaminants from concrete has not been demonstrated and is doubtful. **Waste:** Wastes would be HEPA filters filled with the removed contaminants.	Development: Evaluate technology that has recently been demonstrated in Department of Defense programs regarding automation and improvements in pellet delivery.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants plus oxygen depletion precautions. **Development cost:** about $0.50M **Capital cost:** About $200,000 **Operating cost:** >$1/ft²
						High-Pressure Water DCON-52-OL M *Ranking:** *M-3-1 (1.3M;<$1/ft2)*	**Accepted** High pressure water blasting has been used very successfully to decontaminate various large and complex surfaces at nuclear power plants. **Efficacy:** Technique is expected to be effective with a DF of about 50 for loosely adhering contamination on concrete. DFs will be higher if chemical cleaning agents are also used. Technique is expected to be ineffective for fixed contamination on concrete. **Waste:** Waste is 4 to >100 gpm of contaminated waste water.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Improvement - Remote operation will necessitate the adaptation of the high pressure water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** $50K-$75K (about $250K with remote operation) **Operating cost:** <$1.00/ft²
						Superheated Water DCON-53-OL M *Ranking:** *M-4-1 (1.4M;$1/ft2)*	**Accepted** Technology is available and has been used by industry. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has soaked into the concrete. On finished concrete, technology may drive contaminants deeper into substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Improvement - Remote operation will necessitate the adaptation of the superheated water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** About $175K (about $250K with remote operation) **Operating cost:** ~$1.00/ft²
						Water Flushing DCON-54-OL M *Ranking:** *M-4-1 (1.3M;<$1/ft2)*	**Accepted** Flushing with hot water is often used following scrubbing, especially on floors. **Efficacy:** The technique is not effective on fixed insoluble contamination. On finished concrete, technology may drive contaminants deeper into substrate. **Waste:** The waste generated is the contaminated water from the flushing operation.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the hot water cleaning operation.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** About $1.2M **Capital cost:** <$5K **Operating cost:** <$1/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Groundwater and Surface Water • Waste Management (WM)	Bldg. 7500 Interior/Exterior Walls MSRE Bldg. Interior/Exterior Walls ORR Bldg. Interior/Exterior Walls Bldg. 3028 Interior/Exterior Walls Bldg. 3029 Interior/Exterior Walls Bldg. 3031 Stacked Shielding Bldg. 3032 Interior/Exterior Walls Bldg. 3036 Interior Walls Bldg. 3038 Interior Walls Bldg. 3517 Interior/Exterior Walls Bldg. 7500 Floors MSRE Bldg. Floors ORR Bldg. Floors Bldg. 3028 Floors Bldg. 3029 Floors Bldg. 3030 Floors Bldg. 3031 Floors Bldg. 3032 Floors Bldg. 3033 Floors Bldg. 3036 Floors Bldg. 3517 Floors Bldg. 9201-3 Molten Salt Cells, Floor Bldg. 9201-3 Coolant Salt Cell, Floor Bldg. 3038 Floors	Concrete Block Cs, Sr, TRU, Co-60 Concrete Block Fission Products, Corrosion Products Concrete Block Fission Products Concrete Block Fission Products, TRU Concrete Block Cs-137, Sr-90, Co-60, Ir-192 Concrete Block Gd-153, Am-241 Concrete Block P-32, Am-241 Concrete Block Cs-137, Sr-90 Concrete Block Sr-90, Cs-137, Co-60, I-129 Concrete Block Cs-137, Sr-90, Co-60 Tiled Concrete• Cs, Sr, TRU, Co-60 Tiled Concrete• Fission Products, Corrosion Products Tiled Concrete• Fission Products Tiled Concrete• Fission Products, TRU Tiled Concrete• Cs-137, Sr-90, Co-60, Ir-192 Tiled Concrete• 43 Beta, Gamma Emitters Tiled Concrete• Gd-153, Am-241 Tiled Concrete• P-32, Am-241 Tiled Concrete• H-3, Kr-85 Tiled Concrete• Cs-137, Sr-90 Tiled Concrete• Cs-137, Sr-90, Co-60 Tiled Concrete• U, Th, Molten Salt Tiled Concrete• U, Th, Coolant Salt Tiled Concrete• Sr-90, Cs-137, Co-60, I-129	Refer to the Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning Methods	Steam Cleaning DCON-55-OL M *Ranking:** *M-4-1 (1.3M;$1/ft2)*	**Accepted** The technique has proven useful, especially on complex shapes and large surfaces. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has soaked into the concrete. On finished concrete, technology may drive contaminants deeper into substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Remote operation will necessitate the adaptation of the steam and vacuum collection systems to robotic system control.	Normal implementation needs. **Development cost:** (Improvements) Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** $50K-$75K (about $250K with remote operation) **Operating cost:** $0.03-$1.00/ft²
						Hand Brushing Used to Remove Surface Contamination DCON-56-OL H *Ranking:** *H-2-0 (0M;$1/ft2)*	**Accepted** Brushing is a common decontamination technique. **Efficacy:** Brushing is effective for loose contamination only. **Waste:** Waste consists of removed contamination plus other loose debris.	None **Available at K-25.**	Normal implementation needs. **Capital cost:**negligible **Operating cost:**$1.00/ft² **Development cost:**none
						Automated Brushing DCON-57-OL M *Ranking:** *M-3-2 (1M;$300/ft)*	**Demonstration** This technology has been used at Rocky Flats to remove plutonium contamination from the inside of pipes. **Efficacy:** Tests would be needed to demonstrate its effectiveness for other contaminants on other substrates. **Waste:** Waste would be removed contamination plus any other loose debris.	**Development:** Tests to demonstrate that this technology is effective for the problems at ORNL.	Vacuum Ccollection system Development costs-$200K-1M **Capital cost:**$250K(remotely operated system) **Operating cost:**$300/linear foot of pipe
						Sponge Blasting DCON-58-OL M *Ranking:** *M-3-1 (1.3M;$2/ft2)*	**Accepted** Although the technology is relatively new, it is currently being used by at least two sites including a nuclear power plant. **Efficacy:** Extensive data on decontamination factors are not available. With the aggressive sponges, which are impregnated with abrasives, this technology may be effective for the listed contaminants and substrates. **Waste:** Wastes consist of about 0.01 ft³ of blasting media and removed contaminants per ft² of area decontaminated plus any liquid cleaning agents that may have been added.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the sponge blasting operation.	A wastewater treatment / recycle system will be needed to use this technology. **Development cost:** About $1.2M **Capital cost:** Sponge blasting system: About $20K (with sifter system) **Operating cost:** About $2/ft²
						Solvent Washing to Remove Radiological Contamination DCON-61-OL M *Ranking:** *M-3-2 (1M;N)*	**Conceptual** Plutonium contaminated items at Richland, WA were rinsed with Freon. The vendor who supplied the equipment for Richland ten years ago no longer sells it. **Efficacy:** This technique is mainly applicable to smearable contamination. **Waste:** Waste would be spent solvent containing removed contaminants.	**Science:** Solvents that are less damaging to the environment need to be identified and demonstrated. **Available at all sites.**	Vapor collection system Capital cost $300K (1980 dollars) Development cost <$1M to identify and demonstrate the replacement solvent. Operating cost—an average of 7.5 minutes per item was required when decontaminating small items.

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Bldg. 7500 Interior/Exterior Walls	Concrete Block Cs, Sr, TRU, Co-60	Refer to the Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Strippable Coatings DCON-63-OL M *Ranking:** *M-3-0 (<0.1M;>$1/ft2)*	**Accepted** Technology has been used for decontamination applications involving hazardous and radioactive contaminants. **Efficacy:** Decontamination factors of one to several hundred can be expected with two applications. **Waste:** Waste is a solid polymer (volume = 1 mm x surface area decontaminated) containing the removed contaminants.	**Improvement:** Develop coatings with lower material costs and greater ease of application.	Normal implementation needs. **Capital cost:** Negligible **Operating cost:** $1-$1.40/ft²
	MSRE Bldg. Interior/Exterior Walls	Concrete Block Fission Products, Corrosion Products							
	ORR Bldg. Interior/Exterior Walls	Concrete Block Fission Products							
	Bldg. 3028 Interior/Exterior Walls	Concrete Block Fission Products, TRU							
	Bldg. 3029 Interior/Exterior Walls	Concrete Block Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3031 Stacked Shielding	Concrete Block Gd-153, Am-241							
	Bldg. 3032 Interior/Exterior Walls	Concrete Block P-32, Am-241				Vacuum (Low Pressure) DCON-7-OL L *Ranking:** *L-1-2 (2M;N)*	**Accepted** Vacuum cleaners have long been used to clean up loose contamination at the gaseous diffusion plants. **Efficacy:** Since little of the listed contaminants are expected to be in loose form, this technique is not expected to be effective in cleaning concrete floors at ORNL. **Waste:** The waste is a HEPA filter filled with the contaminants and other materials that are removed by the vacuum.	None	Normal implementation needs. **Capital cost:** <$10K **Operating cost:** >$1/ft²
EM Problems • Facility Decontamination and Decommissioning (D&D)	Bldg. 3036 Interior Walls	Concrete Block Cs-137, Sr-90							
	Bldg. 3038 Interior Walls	Concrete Block Sr-90, Cs-137, Co-60, I-129							
	Bldg. 3517 Interior/Exterior Walls	Concrete Block Cs-137, Sr-90, Co-60							
	Bldg. 7500 Floors	Tiled Concrete• Cs, Sr, TRU, Co-60			Chemical Surface Cleaning Methods	Chemical Foams DCON-8-OL M *Ranking:** *M-4-1 (3M;$0.50-$2/ft2)*	**Demonstration** Widely used throughout the nuclear industry. Foam is used as a carrier of chemical decontamination agents, not as the agent itself. It is sprayed on to component walls or the component is filled with the foam. It can be wiped, rinsed, or vacuumed off. **Efficacy:** Decontamination effectiveness was 63-92% with DF = 2.7 to 12.5 inside a hot cell in one study. **Waste:** Small amount of contaminated sulfonated detergents, synthetic wetting agents, coupling agents, rinse water, and drying cloth.	**Development:** Scale-up/development of the process to a size appropriate for ORNL use. The technology itself is inexpensive, but development and scale-up will probably require support. **Improvement:** Full control over the mean bubble dimensions and the volume swell factor are needed, indicating that some basic research will be necessary.	These estimated costs are **Development cost:** $1M-$4M; **Capital cost:** $50K **Operating cost:** $0.50-$2/ft²
	MSRE Bldg. Floors	Tiled Concrete• Fission Products, Corrosion Products							
	ORR Bldg. Floors	Tiled Concrete• Fission Products							
	Bldg. 3028 Floors	Tiled Concrete• Fission Products, TRU							
	Bldg. 3029 Floors	Tiled Concrete• Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3030 Floors	Tiled Concrete• 43 Beta, Gamma Emitters							
	Bldg. 3031 Floors	Tiled Concrete• Gd-153, Am-241							
	Bldg. 3032 Floors	Tiled Concrete• P-32, Am-241							
	Bldg. 3033 Floors	Tiled Concrete• H-3, Kr-85							
• Remedial Action (RA)—Soils, Groundwater and Surface Water	Bldg. 3036 Floors	Tiled Concrete• Cs-137, Sr-90							
	Bldg. 3517 Floors	Tiled Concrete• Cs-137, Sr-90, Co-60							
	Bldg. 9201-3 Molten Salt Cells, Floor	Tiled Concrete• U, Th, Molten Salt				Fluoboric Acid Treatment DCON-11-OL H *Ranking:** *H-4-2 (2M;N)*	**Demonstration** Technology was designed specifically for D&D. **Efficacy:** Unrestricted use of materials should be possible after decontaminatio, due to high decontamination factor (DF). Fluoboric (or fluosilicic) acid can scabble and clean cement and brickwork. If contaminated to a depth of only a few mm, concrete flooring and structures can be returned to unrestricted use.	**Development:** Although the method has seen application at Chernobyl with good results, development work is needed to test applicability at ORNL.	Fluoboric acid exhibits low vapor pressure and requires only standard precautions for acid or base work. The plant can be manufactured in modular form and installed in existing buildings. **Hardware (equipment):** Fabrication of all key plant parts from polypropylene or from Halar-coated metal. **Capital cost:** in 1990 to set up a plant for decontaminating 5 tons/day of steel was $774K, excluding development, planning, and buildings. **Operating cost:** Relatively low; this is a very simple process.
	Bldg. 9201-3 Coolant Salt Cell, Floor	Tiled Concrete• U, Th, Coolant Salt							
• Waste Management (WM)	Bldg. 3038 Floors	Tiled Concrete• Sr-90, Cs-137, Co-60, I-129							

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						M Detergent Treatments DCON-13-OL *Ranking:** *M-4-0 (0M;>$1/ft2)*	**Accepted** Surface smearable decontamination with caustic chemicals (soap and water) is accepted technology and is used extensively at ORNL. The caustic hand-scrubbing process was applied to cleaning small items. **Efficacy:** Soaps, carbonates, etc., will remove smearable, but not fixed contamination. **Waste:** Waste would be spent detergent solution containing removed contaminants (normally treated by neutralization and precipitation).	None for removal of smearable contamination with carbonates, soaps, etc. **Available at X-10, K-25.**	This is an established process that could be implemented at ORNL with no major changes. **Capital cost:** <$10K **Operating cost:** >$1/ft
						M Chelation Treatment DCON-21-OL *Ranking:** *M-4-2 (1.5M;<$1/ft2)*	**Demonstration** The technology has been employed at various facility operations and nuclear power plant sites. **Efficacy:** Excellent DFs achieving acceptable decontamination levels resulting in unconditional release. Easy to apply in-situ as agent acts at neutral pH and are non-hazardous, non-fuming, have no gas evolution and are biodegradable. **Waste:** Simple waste minimizing treatment and disposal as a non-RCRA waste. Minimizes waste through oxidative destruction of chelate agent, partitioning of organics (including PCBs) and concentration of radionuclides precipitated out in the flocculent sludge which can be further de-watered.	**Development:** Validation of updated chelating agents is needed and is currently underway at ORNL to confirm total efficacy and economic advantage.	Application equipment for in-situ decontamination. Support personnel and equipment to sample, analyze, develop appropriate concentrations, ensure oxidation of organics and/or complete partitioning will be necessary. Spray booth or dipping tank facilities with heating capabilities desirable on-site or accessible by decontamination facility. **Operating Cost:** <$1/ft²

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					Bulk Decontamination Methods M	Solvent Extraction DCON-1-OL *Ranking:** *M-2-? (<2M;N)*	Solvent extraction is a mature technical field but specific extractants have not been identified for all radionuclides, PCB extraction from concrete etc. **Efficacy:** An attractive solvent, triethylamine, has been evaluated for organic extraction from sludge and found to be a very effective solvent and one for which industrial processing equipment is available commercially. Has been demonstrated remotely but not for waste materials. **Waste:** Solvent containing removed contaminants.	**Development:** Survey and tests of specific extractants applicable to PCB-contaminated concrete, transite and metal are needed. A portable "spot" remover can be developed or adapted from commercial devices. Applicability of rotary contractor, solvent recycle and, if appropriate because of solvent selection, an off-gas treatment system.	Development cost - $1750K assuming availability of lab scale and pilot-scale extraction units from ORNL, and industrial participation in demo. Development (pilot-scale) equipment may be used in production. **Operating Cost:** $5 to $50/lb.
					M	Incineration DCON-2-OL *Ranking:** *M-2-12 (30M;$10/lb)*	**Accepted** The incineration of contaminated combustible building materials is common in the nuclear industry **Waste:** Depends on the design of the incenerator and the ash content of the waste being burned. During a test, the K1435 incenerator generated 1.1 gallons of wastewater and 27 pounds of ash per 100 pounds of waste fed.	None **Available at K-25.**	**Capital cost:** $26M Operating cost :$10/lb About 8-10 years may be required for writing an environmental impact statement, holding public hearings, and obtaining the necessary permits-TSCA permit, RCRA permit, NESHAP permit, and Clean Air Act permit
					L	Biological DCON-3-OL *Ranking:** *L-2-Unknown*	**Preconceptual** **Efficacy:** unknown **Waste:** Unknown	**Development:** This technology would have to be developed and scaled-up.	**Development cost:** >$4M **Capital cost:** unknown **Operating Cost:** unknown
					L	Dry Heat (Bulk Roasting) DCON-4-OL *Ranking:** *L-1-1 (2M;N)*	**Evolving technology** The technology is available, but has not been demonstrated or accepted for decontamination at the X-10 Site. It is not known what the technology can do. **Waste:** Unknown	**Science:** The characteristics of the specific materials and their contaminants must be defined before a decontamination plan can be formulated. The characteristics of the specific contaminants must be matched to the decontaminating advantages of roasting. **Development:** After a sound technical basis is shown, the primary process could be optimized for worker safety and efficiency. Secondary waste logistics need to be defined.	Off-gas treatment is needed for this technology. **Overall Cost:** ~$10/lb is typical for this process.

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Bldg. 7500 Floors	Tiled Concrete[a] Cs, Sr, TRU, Co-60	Refer to the Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Ultrahigh-Pressure Water DCON-35-OL H *Ranking:** *H-5-1 (1.7M;$1/ft2)*	**Accepted** Technology has been used by industry. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Unless a recycle system is developed, waste would be 3-5 gal water/ft² concrete cleaned that contains ~0.01 ft³ concrete residue, plus the contaminants removed.	**Improvement:** To minimize waste generation, a system is needed to treat the water so that it can be recycled. **Improvement:** Automation.	A water treatment/recycle system is needed to minimize liquid wastes from this technology. **Development cost:** $1.3M **Capital cost:** ~$500K **Operating cost:** ~$1/ft²
	MSRE Bldg. Floors	Tiled Concrete[a] Fission Products, Corrosion Products				Shot Blasting DCON-36-OL H *Ranking:** *H-3-0 (<0.1M;$1/ft2)*	**Accepted** Commercial iron shot blasters are in use at the K-25 site. **Efficacy:** They are generally effective but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants plus 0.05lb spent shot per ft² of concrete decontaminated.	**Improvement:** Automation.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$50K **Operating cost:** ~$1/ft²
	ORR Bldg. Floors	Tiled Concrete[a] Fission Products				Scabblers/Scarifiers DCON-37-OL H *Ranking:** *H-4-2 (0.5M;$5/ft2)*	**Accepted** Mechanical scabblers are used for concrete decontamination at the K-25 Site and elsewhere. **Efficacy:** They are generally effective, but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed substrate (1/16" cut) containing removed contaminants per ft² of substrate decontaminated	**Improvement:** Automation.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$500K **Operating cost:** < $1/ft² (More than shot blasting)
	Bldg. 3028 Floors	Tiled Concrete[a] Fission Products, TRU				Grit Blasting DCON-38-OL H *Ranking:** *H-4-0 (<0.1$5/ft2)*	**Accepted** Has been used successfully for many applications in the nuclear industry. **Efficacy:** Technology is generally effective. **Waste:** Waste is ~0.01 ft³ removed concrete (1/16" cut) containing removed contaminants per ft² of concrete decontaminated plus spent grit.	**Improvement:** Automation.	A vacuum collection system with pre-filters and HEPA filters would be needed to use this technology. **Development cost:** None **Capital cost:** ~$500K **Operating cost:** $~2/ft²
	Bldg. 3029 Floors	Tiled Concrete[a] Cs-137, Sr-90, Co-60, Ir-192				Centrifuge Cryogenic CO_2 Pellet Blasting DCON-39-OL H *Ranking:** *H-5-2 (1.0M;<$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Improvement:** 1) Demonstration of an on-line, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen-depletion precaution. **Development cost:** <$1M **Capital cost:** $100K **Operating cost:** <$1/ft²
	Bldg. 3030 Floors	Tiled Concrete[a] 43 Beta, Gamma Emitters							
	Bldg. 3031 Floors	Tiled Concrete[a] Gd-153, Am-241							
	Bldg. 3032 Floors	Tiled Concrete[a] P-32, Am-241							
	Bldg. 3033 Floors	Tiled Concrete[a] H-3, Kr-85							
	Bldg. 3036 Floors	Tiled Concrete[a] Cs-137, Sr-90							
	Bldg. 3517 Floors	Tiled Concrete[a] Cs-137, Sr-90, Co-60							
	Bldg. 9201-3 Molten Salt Cells, Floor	Tiled Concrete[a] U, Th, Molten Salt							
	Bldg. 9201-3 Coolant Salt Cell, Floor	Tiled Concrete[a] U, Th, Coolant Salt							
	Bldg. 3038 Floors	Tiled Concrete[a] Sr-90, Cs-137, Co-60, I-129							
EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)									

[a]Asumes tile decontaminated in situ

* See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.

Decontamination

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
Bldg. 7500 Floors MSRE Bldg. Floors ORR Bldg. Floors Bldg. 3028 Floors Bldg. 3029 Floors Bldg. 3030 Floors Bldg. 3031 Floors Bldg. 3032 Floors Bldg. 3033 Floors Bldg. 3036 Floors Bldg. 3517 Floors Bldg. 9201-3 Molten Salt Cells, Floor Bldg. 9201-3 Coolant Salt Cell, Floor Bldg. 3038 Floors	Tiled Concrete[a] Cs, Sr, TRU, Co-60 Tiled Concrete[a] Fission Products, Corrosion Products Tiled Concrete[a] Fission Products Tiled Concrete[a] Fission Products, TRU Tiled Concrete[a] Cs-137, Sr-90, Co-60, Ir-192 Tiled Concrete[a] 43 Beta, Gamma Emitters Tiled Concrete[a] Gd-153, Am-241 Tiled Concrete[a] P-32, Am-241 Tiled Concrete[a] H-3, Kr-85 Tiled Concrete[a] Cs-137, Sr-90 Tiled Concrete[a] Cs-137, Sr-90, Co-60 Tiled Concrete[a] U, Th, Molten Salt Tiled Concrete[a] U, Th, Coolant Salt Tiled Concrete[a] Sr-90, Cs-137, Co-60, I-129	Refer to the Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Supercritical CO_2 DCON-41-OL *Ranking:** H Hand Grinding, Honing, Scraping DCON-43-OL *Ranking:** *H-2-0 (<<0.1M;$1/ft2)* H Automated Grinding DCON-44-OL *Ranking:** *H-2-1 ($1M;$1M;N)* M Concrete Milling DCON-47-OL *Ranking:** *M-1-2 (<1M;$0.75/ft2)*	**Predemonstration** This technology is being developed by as private company. **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed substrated and contaminats contained in a cyclone and a HEPA filter. **Accepted** **Efficacy:** Grinding with hand-held power grinders has been successfully used for small-scale decontamination. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters. **Conceptual** Grinding has been successfully used for small scale decontamination. This grinding was done with hand-held power grinders Remotely operated grinding equipment is available, but no references to its use for decontamination have been found. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters. **Conceptual** The equipment is commercially available, but no reference to its use for decontamination has been found. This technology is suited for horizontal surfaces only. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminats. Demonstrated efficicay for contaminants of interest. None **Available at X-10, K-25.** **Development:** The applicability of this technology to items with rad contamination should be demonstrated. **Improvement:** The technology to operate this equipment remotely needs to be developed and demonstrated.	Normal implementation needs plus oxygen depletion precautions. **Development cost:** $1 - 4M **Capital cost:** $500K -$1M **Operating cost:** $1+/sq. ft. A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** None **Capital cost:** $150 ($5K with vacuum system and $50-500K with remote operation) **Operating Cost:** ~$1/ft A collection system for the vaporized deposits would be needed to implement this technology. Development cost-$600K Capital cost-$250K A collection system for the vaporized deposits would be needed to implement this technology. Development cost-None Capital cost-$400K Operating cost-$1.50/ft

[a]Asumes tile decontaminated in situ

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Bldg. 7500 Floors MSRE Bldg. Floors ORR Bldg. Floors Bldg. 3028 Floors Bldg. 3029 Floors Bldg. 3030 Floors Bldg. 3031 Floors Bldg. 3032 Floors Bldg. 3033 Floors Bldg. 3036 Floors Bldg. 3517 Floors Bldg. 9201-3 Molten Salt Cells, Floor Bldg. 9201-3 Coolant Salt Cell, Floor Bldg. 3038 Floors	Tiled Concrete[a] Cs, Sr, TRU, Co-60 Tiled Concrete[a] Fission Products, Corrosion Products Tiled Concrete[a] Fission Products Tiled Concrete[a] Fission Products, TRU Tiled Concrete[a] Cs-137, Sr-90, Co-60, Ir-192 Tiled Concrete[a] 43 Beta, Gamma Emitters Tiled Concrete[a] Gd-153, Am-241 Tiled Concrete[a] P-32, Am-241 Tiled Concrete[a] H-3, Kr-85 Tiled Concrete[a] Cs-137, Sr-90 Tiled Concrete[a] Cs-137, Sr-90, Co-60 Tiled Concrete[a] U, Th, Molten Salt Tiled Concrete[a] U, Th, Coolant Salt Tiled Concrete[a] Sr-90, Cs-137, Co-60, I-129	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods L	Explosive DCON-48-OL *Ranking:** *L-2-5 (4M;$50/ft2)*	**Demonstration:** Blasting has been used to decontaminate nuclear reactor shielding. Demonstration will be needed for other applications. Safety concerns need to be resolved; care must be taken to contain the dust and to prevent structural damage to the building being decontaminated and the surrounding structures. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the concrete. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** Improvements in the methods of applying explosives and in the uniformity of the detonation are needed. The explosion will generate toxic organic vapors. The technology to control toxic vapors formed by the explosion must be developed and demonstrated.	A certified blasting technician will be needed. Capital cost-$50K Operating cost-$50/ft² Development cost-$1-4M

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Decontamination

EM Goals

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EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
Bldg. 7500 Interior Walls MSRE Bldg. Interior Walls ORR Bldg. Interior Walls Bldg. 3028 Interior Walls Bldg. 3029 Interior Walls Bldg. 3030 Interior Walls Bldg. 3031 Interior Walls Bldg. 3032 Interior Walls Bldg. 3036 Interior Walls Bldg. 3517 Interior Walls Bldg. 7500 Roof MSRE Bldg. Roof ORR Bldg. Roof Bldg. 3028 Roof Bldg. 3029 Roof Bldg. 3030 Roof Bldg. 3031 Roof Bldg. 3032 Roof Bldg. 3033 Roof Bldg. 3036 Roof Bldg. 3038 Roof Bldg. 3517 Roof Floor Under and Shield . 7500 Around Evaporator in Bldg	Wood/Sheetrock Cs, Sr, TRU, Co-60 Wood/Sheetrock Cs, Sr, TRU, Co-60 Wood/Sheetrock Fission Products Wood/Sheetrock Fission Products, TRU Wood/Sheetrock Cs-137, Sr-90, Co-60, Ir-192 Wood/Sheetrock 43 Beta, Gamma Emitters Wood/Sheetrock Gd-153, Am-241 Wood/Sheetrock P-32, Am-241 Wood/Sheetrock Cs-137, Sr-90 Wood/Sheetrock Cs-137, Sr-90, Co-60 Tar and Felt Roofing Cs, Sr, TRU, Co-60 Tar and Felt Roofing Cs, Sr, TRU, Co-60 Tar and Felt Roofing Fission Products Tar and Felt Roofing Fission Products, TRU Tar and Felt Roofing Cs-137, Sr-90, Co-60, Ir-192 Tar and Felt Roofing 43 Beta, Gamma Emitters Tar and Felt Roofing Gd-153, Am-241 Tar and Felt Roofing P-32, Am-241 Tar and Felt Roofing H-3, Kr-85 Tar and Felt Roofing Cs-137, Sr-90 Tar and Felt Roofing Sr-90, Cs-137, Co-60, I-129 Tar and Felt Roofing Cs-137, Sr-90, Co-60 Concrete Uranyl Sulfate, Fission Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Bulk Decontamination Methods	Solvent Extraction DCON-1-OL M *Ranking:** *M-2-? (<2M;N)*	**Demonstration** Solvent extraction is a mature technical field but specific extractants have not been identified for all radionuclides, PCB extraction from concrete etc. **Efficacy:** An attractive solvent, triethylamine, has been evaluated for organic extraction from sludge and found to be very effective solvent and one for which industrial processing equipment is available commercially. Has been demonstrated remotely but not for waste materials. **Waste:** Solvent containing removed contaminates.	**Development:** Survey and tests of specific extractants applicable to PCB-contaminated concrete, transite and metal are needed. A portable "spot" remover can be developed or adapted from commercial devices. Applicability of rotary contractor, solvent recycle and, if appropriate because of solvent selection, an off-gas treatment system.	**Development cost:** $750K assuming availability of lab scale and pilot-scale extraction units from ORNL, and industrial participation in demo. Development (pilot-scale) equipment may be used in production. **Operating cost:** $5 to $50/lb.
					Incineration DCON-2-OL M *Ranking:** *M-2-12 (30M;$10/lb)*	**Accepted** The incineration of contaminated combustible building materials is common in the nuclear industry **Waste:** Depends on the design of the incenerator and the ash content of the waste being burned. During a test, the K1435 incenerator generated 1.1 gallons of wastewater and 27 pounds of ash per 100 pounds of waste fed.	None **Available at K-25.**	**Capital cost:** $26M **Operating cost:** $10/lb About 8-10 years may be required for writing an environmental impact statement, holding public hearings, and obtaining the necessary permits-TSCA permit, RCRA permit, NESHAP permit, and Clean Air Act permit
					Dry Heat (Bulk Roasting) DCON-4-OL L *Ranking:** *L-1-1 (2M;N)*	**Evolving technology** The technology is available, but has not been demonstrated or accepted for decontamination at the X-10 Site. **Efficacy:** It is not known what the technology can do. **Waste:** Unknown	**Science:** The characteristics of the specific materials and their contaminants must be defined before a decontamination plan can be formulated. The characteristics of the specific contaminants must be matched to the decontaminating advantages of roasting. Development: After a sound technical basis is shown, the primary process could be optimized for worker safety and efficiency. Secondary waste logistics need to be defined.	Off-gas treatment is needed for this technology. **Overall Cost:** ~$10/lb is typical for this process.
					Chemical Leaching DCON-5-OL M *Ranking:** *M-3-2 (1M;<$1/ft2)*	**Predemonstration** Although chemical leaching is an accepted technique for some applications, bench scale tests are needed to determine which chemical would be effective. **Waste:** Waste would be original materials contaminated with chemical leachates plus chemical leachates containing removed contaminants or sludges, filter cakes, and ion exchange resin from recycle system containing removed contaminants.	**Science:** Bench scale tests are needed to determine which chemicals would be effective and what secondary waste treatment would be necessary to recycle chemicals.	Extensive chemical processing system for chemical leaching with a waste treatment system for treatment or recycle of spent chemical leaching solution. **Development cost:** Efficacy demo: $350K Waste treatment: $400K **Capital cost:** $2M Chemical leaching: $350K to $1000K Waste treatment: $1M **Operating cost:** <$1/ft^2 or $5-$50/lb

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Bldg. 7500 Interior Walls	Wood/Sheetrock Cs, Sr, TRU, Co-60	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Bulk Decontamination Methods H *Ranking:** *H-5-4 (20M;$1/lb)*	Catalytic Extraction Process DCON-6-OL	**Predemonstration** **Efficacy:** Has not been used for these materials or for scrap having radioactivity. **Waste:** Slag containing metallic contaminates plus contaminated scrubber solution or chemical trap materials.	**Science:** Lab evaluation effectiveness on the radionuclides of interest and on the materials of interest. **Development:** Demonstrate effectiveness for materials and contaminants of interest.	"Off-the-shelf" induction or arc furnace with off-gas treatment system. **Development cost:** $3M-$5M **Capital cost:** 1/2 of an incinerator of equal capacity - $16M **Operating cost:** 1/3 of an incinerator $2 - $3/lb
	MSRE Bldg. Interior Walls	Wood/Sheetrock Cs, Sr, TRU, Co-60							
	ORR Bldg. Interior Walls	Wood/Sheetrock Fission Products							
	Bldg. 3028 Interior Walls	Wood/Sheetrock Fission Products, TRU							
	Bldg. 3029 Interior Walls	Wood/Sheetrock Cs-137, Sr-90, Co-60, Ir-192				Vacuum (Low Pressure) DCON-7-OL L *Ranking:** *L-1-2 (2M;N)*	**Preconceptual** **Efficacy:** The basis for the technology does not currently exist. Proprietary vacuum process to remove Cr^{+6} from transite. Technique should work for volatile contaminates only. **Waste:** Caustic scrubber solution containing removed contaminates and other volatiles.	**Development:** The characteristics of the specific contaminants must be matched to the advantages of decontamination by volatilization under vacuum conditions.	Large blower systems are needed to draw a vacuum on the building, sprayer systems are needed to spray acid on the material. capital and operating cost are considered proprietary. Rough guesses follow. **Capitol cost:** $1 to $10M **Operating cost:** $2 to $8/ft²
	Bldg. 3030 Interior Walls	Wood/Sheetrock 43 Beta, Gamma Emitters							
	Bldg. 3031 Interior Walls	Wood/Sheetrock Gd-153, Am-241							
	Bldg. 3032 Interior Walls	Wood/Sheetrock P-32, Am-241							
	Bldg. 3036 Interior Walls	Wood/Sheetrock Cs-137, Sr-90							
EM Problems • Facility Decontamination and Decommissioning (D&D)	Bldg. 3517 Interior Walls	Wood/Sheetrock Cs-137, Sr-90, Co-60							
	Bldg. 7500 Roof	Tar and Felt Roofing Cs, Sr, TRU, Co-60			Chemical Surface Cleaning Methods M *Ranking:** *M-4-2 (1.5M;<$1/ft2)*	Chelation Treatment DCON-21-OL	**Demonstration** **Efficacy:** Excellent DFs. Easy to apply in-situ as agent acts at neutral pH and is non-hazardous, non-fuming, have no gas evolution and is biodegradable. The technology has been employed at various facility operations and nuclear power plant sites achieving acceptable decontamination levels resulting in unconditional release. **Waste:** Simple waste minimizing treatment and disposal as a non-RCRA waste. Minimizes waste through oxidative destruction of chelate agent, particioning of organics (including PCBs) and concentration of radionuclides precipitated out in the flocculent sludge which can be further de-watered.	**Development:** Validation of updated chelating agents is needed and is currently underway at ORNL to confirm total efficacy and economic advantage.	Application equipment for in-situ decontamination. Support personnel and equipment to sample, analyze, develop appropriate concentrations, ensure oxidation of organics and/or complete partitioning will be necessary. Spray booth or dipping tank facilities with heating capabilities desirable on-site or accessible by decontamination facility. **Operating cost:** <$1/ft²
	MSRE Bldg. Roof	Tar and Felt Roofing Cs, Sr, TRU, Co-60							
	ORR Bldg. Roof	Tar and Felt Roofing Fission Products							
	Bldg. 3028 Roof	Tar and Felt Roofing Fission Products, TRU							
	Bldg. 3029 Roof	Tar and Felt Roofing Cs-137, Sr-90, Co-60, Ir-192							
	Bldg. 3030 Roof	Tar and Felt Roofing 43 Beta, Gamma Emitters							
	Bldg. 3031 Roof	Tar and Felt Roofing Gd-153, Am-241							
	Bldg. 3032 Roof	Tar and Felt Roofing P-32, Am-241							
	Bldg. 3033 Roof	Tar and Felt Roofing H-3, Kr-85							
	Bldg. 3036 Roof	Tar and Felt Roofing Cs-137, Sr-90							
• Remedial Action (RA)—Soils, Ground Water and Surface Water	Bldg. 3038 Roof	Tar and Felt Roofing Sr-90, Cs-137, Co-60, I-129							
	Bldg. 3517 Roof	Tar and Felt Roofing Cs-137, Sr-90, Co-60							
	Floor Under and Shield 7500 Around Evaporator in Bldg	Concrete Uranyl Sulfate, Fission Products							
• Waste Management (WM)									

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	HRT Process Piping ORR Demineralizer Piping (Outside Pool) Bldg. 3517 Process Piping and Tankage MSRE Off-gas System Drain Lines from Molten Salt Cells, Bldg. 9201-3 Drain Lines from Coolant Salt Cell, Bldg. 9201-3 Drain Lines from Bldg. 9419-1 MSRE Reactor Piping ORR Primary Coolant Piping Instrument Air Lines and Air Lines in Coolant Salt Cell, Bldg. 9201-3 Pulse-feeder Pumps	Stainless Steel Pipe Interior UO2SO4, Fission Products, Corrosion Products Stainless Steel Pipe Interior Fission Products, Corrosion Products Stainless Steel Pipe Interior Cs-137, Sr-90 Steel Pipe Interior Steel Pipe Interior U, Th, Molten Salt Steel Pipe Interior U, Th, Coolant Salt Steel Pipe Interior U, Th, Molten Salt INOR Piping Interior U, Be, L, F, TiF3 Aluminum Piping Interior Fission Products, Corrosion Products Copper Tubing Interior U, Th, H-3, Molten Salt Metal Heavy Water	Refer to Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	H Ultrahigh-Pressure Water DCON-35-OL *Ranking:** *H-5-1 (1.7M;$1/ft2)*	**Accepted** Technology has been used by industry to decontaminate metal parts. **Efficacy:** Should work for listed contaminants and substrates. **Waste:** Unless a recycle system is developed, waste would be 3-5 gal water/ft² concrete cleaned containing contaminants removed plus, perhaps, some metal substrate.	**Improvement:** To minimize waste generation, a system is needed to treat the water so that it can be recycled. **Improvement:** Vacuum systems with nozzles designed to match commonly decontaminated parts are needed to minimize the spread of contamination.	Whenever necessary, prior removal and disassembly of contaminated equipment plus an enclosed glove box and/or room that is easily decontaminated on the inside is needed in which the Ultrahigh-pressure water (UHPW) system will be used. **Development cost:** $1.3M (Recycle system); $200K-$1M (Vacuum system for each nozzle design) **Capital cost:** >$500K (with vacuum system) Glove box: <$50K Work room: ~$250K **Operating cost:** ~$2/ft²
• Facility Decontamination and Decommissioning (D&D)						H Centrifuge Cryogenic CO_2 Pellet Blasting DCON-39-OL *Ranking:** *H-5-2 (1.0M;<$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Improvement:** 1) Demonstration of an on-line, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen-depletion precaution. **Development cost:** <$1M **Capital cost:** $100K **Operating cost:** <$1/ft²
• Remedial Action (RA)—Soils, Ground Water and Surface Water						H Ice Blasting DCON-40-OL *Ranking:** *H-5-1 (<1.0M;$1/ft2)*	**Demonstration** **Efficacy:** Efficacy of commercial system for this application needs demonstration. **Waste:** Waste would be about 14 to 18 gallons per hour waste water containing removed contaminants.	**Development:** Demonstration of efficacy of commercial system. **Improvement:** Automation/robotics.	Whenever necessary, prior removal and disassembly of contaminated equipment plus an enclosed glove box and/or room that is easily decontaminated in which the decontaminaiton will be accomplished are needed to use this technology. **Capital cost:** Evaporator for wastewater treatment: ~$60K Ice blasting system: ~$280K (Add about $240K for automatic control) Glove box: <$50K Work room: ~$250K **Operating cost:** ~$1/ft²
• Waste Management (WM)						H Supercritical CO_2 Blasting DCON-41-OL *Ranking:** *H-5-1 (O.75+M;>$1/ft2)*	**Predemonstration** **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed concrete and contaminants contained in a cyclone and a HEPA filter.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminants. Demonstrate efficacy for contaminants of interest.	Whenever necessary, prior removal and disassembly of contaminated equipment plus an enclosed glove box and/or room that is easily decontaminated in which the decontaminaiton will be accomplished plus oxygen depletion precautions are needed to use this technology. **Development cost:** $250K-1M **Capital cost:** Supercritical CO_2 SystemL $500-1M Glove box: <$50K Work room: ~$250K **Operating cost:** ~$2/ft²

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[a] Not applicable to aluminum pipe interior.

Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	HRT Process Piping ORR Demineralizer Piping (Outside Pool) Bldg. 3517 Process Piping and Tankage MSRE Off-gas System Drain Lines from Molten Salt Cells, Bldg. 9201-3 Drain Lines from Coolant Salt Cell, Bldg. 9201-3 Drain Lines from Bldg. 9419-1 MSRE Reactor Piping ORR Primary Coolant Piping Instrument Air Lines and Air Lines in Coolant Salt Cell, Bldg. 9201-3 Pulse-feeder Pumps	Stainless Steel Pipe Interior UO2SO4, Fission Products, Corrosion Products Stainless Steel Pipe Interior Fission Products, Corrosion Products Stainless Steel Pipe Interior Cs-137, Sr-90 Steel Pipe Interior Steel Pipe Interior U, Th, Molten Salt Steel Pipe Interior U, Th, Coolant Salt Steel Pipe Interior U, Th, Molten Salt INOR Piping Interior U, Be, L, F, TiF3 Aluminum Piping Interior Fission Products, Corrosion Products Copper Tubing Interior U, Th, H-3, Molten Salt Metal Heavy Water	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Plastic Pellet Blasting DCON-42-OL M *Ranking:** *M-4-0 (<0.1M;$1/ft2)*	**Accepted** Plastic pellet blasting is a widely used alternate to sand blasting for applications in which it is desired to impart minimal damage to the substrate. **Efficacy:** Technology is not likely to remove listed contaminants from listed substrates. **Waste:** Waste would be spent plastic pellets plus removed contamination.	**Improvement:** Develop and demonstrate system for processing waste. **Improvement:** Minimize blast media erosion to minimize waste; automation/robotics improve containment of waste and removed contaminants.	Whenever necessary, prior removal and disassembly of contaminated equipment plus an enclosed glove box and/or room that is easily decontaminated in which the decontaminaiton will be accomplished plus a system for processing wastes to an acceptable form are needed to use this technology. **Development cost:** $250K-1M **Capital cost:** Plastic pellet blasting system: ~$50K Glove box: <$50K Work room: ~$250K **Operating cost:** ~$0.75-2.25/ft³
• Facility Decontamination and Decommissioning (D&D)						Automated Grinding DCON-44-OL H *Ranking:** *H-2-1 ($1M;$1M;N)*	**Conceptual** Grinding has been successfully used for small scale decontamination. This grinding was done with hand-held power grinders Remotely operated grinding equipment is available, but no references to its use for decontamination have been found. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the metal. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	Development: The applicability of this technology to items with rad contamination should be demonstrated.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** $600K **Capital cost:** $250K
• Remedial Action (RA)—Soils, Ground Water and Surface Water					Thermal Surface Removal Methods	Laser Heating[a] DCON-73-OL M *Ranking:** *M-4-4 (3M;$1/ft2)*	**Demonstration** Currently being used to remove organic coatings from metal surfaces. **Efficacy:** Current prototype systems are capable of removing 2-mil-thick coatings at the rate of 100 ft²/hr. Effectiveness on contaminants and substrates of interest is uncertain. **Waste:** Waste will be prefilters and HEPA filters filled with contaminants.	Development: Current prototype needs to be evaluated for possible use on contaminated areas. Systems with different operational parameters (e.g., wavelength, pulse durations) should be evaluated as well.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** $2M+ **Capital cost:** $500k-$1M+/machine **Operating cost:** ~$1/ft²
• Waste Management (WM)						Laser Etching and Ablation[a] DCON-74-OL M *Ranking:** *M-4-4 (3.5M>$1/ft2)*	**Predemonstration** Several research groups at university and government laboratories have used the technology to remove radiological and organic contaminants from various surfaces. **Efficacy:** The technique is slow to remove large deposits. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	Development: Existing lasers, delivery systems, and filtration systems need to be integrated into a prototype system for demonstration.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** $2M+ **Capital cost:** $0.5-1M/machine **Operating cost:** >$1/ft²

EM Problems

[a] Not applicable to aluminum pipe interior.

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Decontamination

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives		Technologies	Status	Science/ Technology Needs	Implementation Needs
HRT Process Piping ORR Demineralizer Piping (Outside Pool) Bldg. 3517 Process Piping and Tankage MSRE Off-gas System Drain Lines from Molten Salt Cells, Bldg. 9201-3 Drain Lines from Coolant Salt Cell, Bldg. 9201-3 Drain Lines from Bldg. 9419-1 MSRE Reactor Piping ORR Primary Coolant Piping Instrument Air Lines and Air Lines in Coolant Salt Cell, Bldg. 9201-3 Pulse-feeder Pumps	Stainless Steel Pipe Interior UO2SO4, Fission Products, Corrosion Products Stainless Steel Pipe Interior Fission Products, Corrosion Products Stainless Steel Pipe Interior Cs-137, Sr-90 Steel Pipe Interior Steel Pipe Interior U, Th, Molten Salt Steel Pipe Interior U, Th, Coolant Salt Steel Pipe Interior U, Th, Molten Salt INOR Piping Interior U, Be, L, F, TiF3 Aluminum Piping Interior Fission Products, Corrosion Products Copper Tubing Interior U, Th, H-3, Molten Salt Metal Heavy Water	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Thermal Surface Removal Methods	H	Plasma Surface Cleaning[a] DCON-75-OL *Ranking:** *H-4-2 (1.0M;>$1/ft2)*	**Predemonstration** Plasma surface cleaning by glow discharges are commonly and effectively utilized for cleaning high bonding energy contaminants from surfaces of metals prior to the operation of fusion devices. **Efficacy:** Technology is expected to be effective for removing deposits from listed substrates, but whether the plasma can follow the irregular shapes involved is uncertain. **Waste:** Wastes would be the vaporized deposits plus filters and HEPA filters from the collection system.	**Science:** Data on cleaning rates for contaminants and substrates of interest are needed. Development - The capability of plasma generation and cleaning on complex internal surfaces of contaminated equipment with large surface areas needs to be established. **Available atY-12.**	A collection system with appropriate filters for the vaporized deposits would be needed to use this technology. An electric power supply would be needed. **Development cost:** About $1M+ **Capital cost:** $0.5-M/machine **Operating cost:** > $1/ft²
					M	Plasma Etching/Fluorination DCON-76-OL *Ranking:** *M-3-3 (5M;>$2/ft2)*	**Predemonstration** Plasma etching processes are used in material processing and microelectronic manufacturing. **Efficacy:** Extrapolating these plasma processes for vaporizing and recovering radionuclide deposits is considered feasible. Reactive plasma decontamination rates should be higher than unassisted gas-phase decontamination rates. **Waste:** Wastes would be the vaporized deposits plus filters and HEPA filters from the collection system.	**Science:** Data on cleaning rates for contaminants and substrates of interest are needed. **Development:** The capability of plasma etching on deposits in complex equipment with large surface areas needs to be established.	A collection system with appropriate filters for the vaporized deposits would be needed to use this technology. An electric power supply would be needed. **Development cost:** ~$5M **Capital cost:** ~$1M **Operating cost:** $0.70-$7.00/ft²
					H	Flashlamp Cleaning DCON-77-OL *Ranking:** *H-3-3 (2.5M;$1/ft2)*	**Predemonstration** Flashlamp systems are being used to remove organic contamination from metals, precious metals, and fragile substrates. Hanford-Westinghouse Laboratory is conducting tests of xenon flashlamp systems for removing radiological contamination from surfaces inside metal storage vessels. **Efficacy:** Technology is likely to be effective for surface contamination. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	**Development:** Commercially available flashlamp systems need to be evaluated for deposit removal.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** ~$2.5 M **Capital cost:** $50-100K/machine **Operating cost:** ~1.00/ft²

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	HRT Process Piping ORR Demineralizer Piping (Outside Pool) Bldg. 3517 Process Piping and Tankage MSRE Off-gas System Drain Lines from Molten Salt Cells, Bldg. 9201-3 Drain Lines from Coolant Salt Cell, Bldg. 9201-3 Drain Lines from Bldg. 9419-1 MSRE Reactor Piping ORR Primary Coolant Piping Instrument Air Lines and Air Lines in Coolant Salt Cell, Bldg. 9201-3 Pulse-feeder Pumps	Stainless Steel Pipe Interior UO2SO4, Fission Products, Corrosion Products Stainless Steel Pipe Interior Fission Products, Corrosion Products Stainless Steel Pipe Interior Cs-137, Sr-90 Steel Pipe Interior Steel Pipe Interior U, Th, Molten Salt Steel Pipe Interior U, Th, Coolant Salt Steel Pipe Interior U, Th, Molten Salt INOR Piping Interior U, Be, L, F, TiF3 Aluminum Piping Interior Fission Products, Corrosion Products Copper Tubing Interior U, Th, H-3, Molten Salt Metal Heavy Water	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Compressed-Air Cryogenic CO_2 Pellet Blasting DCON-51-OL H *Ranking:** *H-4-1 (0.7M;>$1/ft2)*	**Demonstration** This technology is commercially available. It has been used at nuclear reactor sites to decontaminate hand tools and some equipment. **Efficacy:** The efficacy of this technology for removing the listed contaminants from concrete has not been demonstrated and is doubtful. **Waste:** Wastes would be HEPA filters filled with the removed contaminants.	Development: Evaluate technology that has recently been demonstrated in Department of Defense programs regarding automation and improvements in pellet delivery.	Prior removal and disassembly of contaminated equipment and a glove box that is easily decontaminated in which the decontamination will be accomplished plus design and construction of a vacuum waste-handling system with filters and HEPA filters to handle the vaporized CO_2 containing the removed deposits are needed to use this technology. **Development cost:** $500K **Capital cost:** CO_2 System: ~$200K Glove box: <$50K **Operating cost:** $2-10/ft[a]
						Superheated Water DCON-53-OL M *Ranking:** *M-4-1 (1.4M;$1/ft2)*	**Accepted** Technology is available and has been used by industry. **Efficacy:** The removal of tightly bound or imbedded contaminants, such as the listed contaminants on the listed substrates is likely to be slight. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Improvement - Remote operation will necessitate the adaptation of the superheated water and vacuum collection systems to robotic system control.	Whenever necessary, prior removal and disassembly of contaminated equipment and a glove box that is easily decontaminated in which the decontamination will be accomplished plus design and construction of a water recycle system are needed to use this technology. **Development cost:** about $1.2M Superheated water system: ~$175K Glove box: <$50K Work room: ~$250K **Operating cost:** $0.05-$2/ft[a]
						Water Flushing DCON-54-OL M *Ranking:** *M-4-1 (1.3M;<$1/ft2)*	**Accepted** Flushing with hot water is often used following scrubbing, or before other chemical treatments. **Efficacy:** The technique is not effective on fixed insoluble contamination. **Waste:** The waste generated is the contaminated water from the flushing operation.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the hot water cleaning operation.	A water treatment system is needed to minimize liquid wastes from theis technology. **Development cost:** ~$1.2M **Capital cost:** <$5K **Operating cost:** <$1/ft[a]
						Steam Cleaning DCON-55-OL M *Ranking:** *M-4-1 (1.3M;$1/ft2)*	**Accepted** The technique has proven useful, especially on complex shapes and large surfaces. **Efficacy:** Technology is not expected to be effective for listed contaminants and substrates. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	Improvement - To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Remote operation will necessitate the adaptation of the steam and vacuum collection systems to robotic system control.	Whenever necessary, prior removal and disassembly of contaminated equipment and a glove box that is easily decontaminated in which the decontamination will be accomplished plus design and construction of a water recycle system are needed to use this technology. **Development cost:** about $1.2M Steam system: $50-75K Glove box: <$50K Work room: ~$250K **Operating cost:** $0.05-$2/ft[a]

[a] Not applicable to aluminum pipe interior.

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	HRT Process Piping ORR Demineralizer Piping (Outside Pool) Bldg. 3517 Process Piping and Tankage MSRE Off-gas System Drain Lines from Molten Salt Cells, Bldg. 9201-3 Drain Lines from Coolant Salt Cell, Bldg. 9201-3 Drain Lines from Bldg. 9419-1 MSRE Reactor Piping ORR Primary Coolant Piping Instrument Air Lines and Air Lines in Coolant Salt Cell, Bldg. 9201-3 Pulse-feeder Pumps	Stainless Steel Pipe Interior UO2SO4, Fission Products, Corrosion Products Stainless Steel Pipe Interior Fission Products, Corrosion Products Stainless Steel Pipe Interior Cs-137, Sr-90 Steel Pipe Interior Steel Pipe Interior U, Th, Molten Salt Steel Pipe Interior U, Th, Coolant Salt Steel Pipe Interior U, Th, Molten Salt INOR Piping Interior U, Be, L, F, TiF3 Aluminum Piping Interior Fission Products, Corrosion Products Copper Tubing Interior U, Th, H-3, Molten Salt Metal Heavy Water	Refer to Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Automated Brushing DCON-57-OL M *Ranking:** *M-3-2 (1M;$300/ft)*	**Demonstration** This technology has been used at Rocky Flats to remove plutonium contamination from the inside of pipes. **Efficacy:** Tests would be needed to demonstrate its effectiveness for other contaminants on other substrates. **Waste:** Waste would be removed contamination plus any other loose debris.	**Development:** Tests to demonstrate that this technology is effective for the problems at ORNL.	Vacuum Collection system **Development cost:** $200K-1M **Capital cost:** $250K(remotely operated system) **Operating cost:** $300/linear foot of pipe
						Dry Heat (Bulk Roasting) DCON-4-OL L *Ranking:** *L-1-1 (2M;N)*	**Evolving technology** The technology is available, but has not been demonstrated or accepted for decontamination at the X-10 Site. **Efficacy:** It is not known what the technology can do. **Waste:** Any removed contaminants and other volatiles in filters, scrubber, or condenser.	**Science:** The characteristics of the specific materials and their contaminants must be defined before a decontamination plan can be formulated. The characteristics of the specific contaminants must be matched to the decontaminating advantages of roasting. **Development:** After a sound technical basis is shown, the primary process could be optimized for worker safety and efficiency. Secondary waste logistics need to be defined.	Off-gas treatment is needed for this technology. **Overall cost:** ~$10/lb is typical for this process.
						Solvent Washing to Remove Radiological Contamination DCON-61-OL M *Ranking:** *M-3-2 (1M;N)*	**Conceptual** Plutonium contaminated items at Richland, WA were rinsed with Freon. The vendor who supplied the equipment for Richland ten years ago no longer sells it. **Efficacy:** This technique is mainly applicable to smearable contamination. **Waste:** Waste would be spent solvent containing removed contaminates.	**Science:** Solvents that are less damaging to the environment need to be identified and demonstrated. **Available in Private Sector.**	Vapor collection system **Development cost:** <$1M to identify and demonstrate the replacement solvent. **Capitol cost:** $300K (1980 dollars) **Operating cost:** an average of 7.5 minutes per item was required when decontaminating small items.
						Vacuum Cleaning DCON-64-OL M *Ranking:** *M-4-0 (<0.1M;$1/ft2)*	**Accepted** Vacuum cleaners have long been used to clean up loose contamination at the gaseous diffusion plants. **Efficacy:** Since little of the listed contaminates are expected to be in loose form, this technique is not expected to be effective in cleaning the listed contaminants from the listed substrates. **Waste:** The waste is a HEPA filter filled with the contaminates and other materials that are removed by the vacuum.	None	Normal Implementation needs. **Capitol Cost:** <$10K **Operating cost:** >$1/ft

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean-Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	HRT Process Piping ORR Demineralizer Piping (Outside Pool) Bldg. 3517 Process Piping and Tankage MSRE Off-gas System Drain Lines from Molten Salt Cells, Bldg. 9201-3 Drain Lines from Coolant Salt Cell, Bldg. 9201-3 Drain Lines from Bldg. 9419-1 MSRE Reactor Piping ORR Primary Coolant Piping Instrument Air Lines and Air Lines in Coolant Salt Cell, Bldg. 9201-3 Pulse-feeder Pumps	Stainless Steel Pipe Interior UO_2SO_4, Fission Products, Corrosion Products Stainless Steel Pipe Interior Fission Products, Corrosion Products Stainless Steel Pipe Interior Cs-137, Sr-90 Steel Pipe Interior Steel Pipe Interior U, Th, Molten Salt Steel Pipe Interior U, Th, Coolant Salt Steel Pipe Interior U, Th, Molten Salt INOR Piping Interior U, Be, L, F, TiF3 Aluminum Piping Interior Fission Products, Corrosion Products Copper Tubing Interior U, Th, H-3, Molten Salt Metal Heavy Water	Refer to Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods M	Ultrasonic Cleaning DCON-65-OL *Ranking:** *M-2-1 (0.1M;>$2/ft2)*	**Accepted** Ultrasonic cleaning has been used for many years in the private sector and in government installations for removing surface contamination from relatively small metal parts which can fit into an ultrasonic bath. **Efficacy:** Technology will work well for loosely bound surface deposits, but not for tightly bound materials. **Waste:** Wastes would be spent ultrasonic bath solutions containing any removed contaminants.	**Improvement:** Definition of acceptable cleaning liquids which (1) are not hazardous, (2) can be separated from the contaminants, and (3) can be reused to minimize secondary wastes. **Improvement:** More aggressive cleaning action.	Requires removal, disassembly, and size reduction of contaminated equipment. Development cost (Improvements): $1M **Capital cost:** $10K-$100K **Operating cost:** $2 - $10/ft^2 or more
					Melt Refining Methods H	Smelt Purification DCON-31-OL *Ranking:** *H-3-3 (100M;$1/lb)*	**Demonstration** Smelt purification of radioactive metals has been performed by a large number of investigators on a lab-scale and by some investigators on a large-scale. The metals include mild steel, stainless steel, nickel, copper, monel, aluminum, and others. **Efficacy:** Metal purification has been demonstrated. U is removed to 0.01-4ppm. Tc is not removed. **Waste:** Waste are slags, scrubber solutions, chemical trap materials, and HEPA filters.	**Development:** Attempt to demonstrate fluxing agent for removing radionuclides of interest. If possible, demonstrate removal of radionuclides of intereston a larger scale.	Scientific Ecology Group (SEG) personnel estimate the costs of metal smelting at roughly $0.93/lb of metal in 1992 dollars, depending on the type metal and configuration of the metal. Kellogg et al. estimated that the capital and operating costs of smelting the 90,000 tons of DOE scrap metal presently on hand at K-25 could be recovered through sale of the metal if a *de minimis* were established. The quantity of metals at ORNL is probably not sufficient to be cost effective unless added to this. The technology development needs will require further lab and pilot-scale evaluation. The development costs are roughly estimated by the investigator at $3M - $5M.
					Electrorefining M	Electrorefining DCON-32-OL *Ranking:** *M-2-5 (200M;$6/lb)*	**Predemonstration** Electrorefining is a well-established commercial technology. However, this technology cannot be considered mature concerning its use for decontaminating radioactive metal because this application is much less established. **Efficacy:** Tc plates out on the cathode. Technology is likely to be effective for the listed contaminants and substrates. **Waste:** Waste would be solid mixed waste from assumed treatment of electrolyte solutions for recycle.	**Development:** Demonstrate (1) separation of radionuclides and substrates of interest and (2) recycle electrolyte solutions.	An electrorefining plant used for recovery of nickel would also require a smelting and anode forming facility to form the impure nickel into anodes of proper configuration. The capital costs altogether are estimated at $200M. The cost of an operating facility with a 10 million-pound/year capacity is estimated at $2M capital and $6/lb operating costs, which exceed the present value of nickel ($3.60/lb) because commercial nickel companies operate on a much larger scale. Development costs are estimated at $3M. To allow sale of the purified nickel, either a *de minimis* level must be established in the USA or permission must be obtained to sell the metal in Europe where a *de minimis* level exists.

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Decontamination

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EM Problems • Facility Decontamination and Decommissioning (D&D)					Chemical Surface Cleaning M	Chemical Foams DCON-8-OL *Ranking:** *M-4-1 (3M;$0.50-$2/ft2)*	**Demonstration** Widely used throughout the nuclear industry. Foam is used as a carrier of chemical decontamination agents, not as the agent itself. It can be sprayed on and wiped, rinsed, or vacuumed off. **Efficacy:** Effectiveness for listed contaminants and substrates has not been demonstrated. **Waste:** Small amount of contaminated sulfonated detergents, synthetic wetting agents, coupling agents, rinse water, and drying cloth.	**Development:** Scale-up/development of the process to a size appropriate for ORNL use. The technology itself is inexpensive, but development and scale-up will probably require support. **Improvement:** Full control over the mean bubble dimensions and the volume swell factor are needed, indicating that some basic research will be necessary.	These estimated costs are: **Development cost:** $1M-$4M; **Capital cost:** $50K **Operating cost:** $0.50-$2/ft[a]
• Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)					Organic Acid Treatments H	Organic Acid Treatments DCON-10-OL *Ranking:** *H-4-2 (2M;N)*	**Demonstrated** The technology is currently in use by BNFL at Capenhurst gaseous diffusion plant. BNFL uses citric and sulfuric acids in sequence for removal of U and Tc, respectively, from metal surfaces (mostly wrought aluminum). **Efficacy:** DF of 300 for U alpha and 40 for Tc beta are reported (11.1 Bq/g alpha, 0.04 Bq/g beta). Has not been demonstrated to remove other radionuclides. **Waste:** Wastes include citric and sulfuric acids containing uranium and other metal ions and ion exchange media containing the metals. Uranium is difficult to precipitate.	**Development:** Pilot plant development for waste treatments (ion exchange columns) to verify that we can meet our standards and regulations. More fundamental studies are needed in secondary waste disposal.	Purchase of technology, regulatory compliance for pilot-scale decontamination, and waste treatment demonstrations. BNFL's expertise may reduce the amount of original research, etc. necessary to begin implementation. No present ORNL facility could be adapted for citric acid cleaning, but decontamination with BNFL's citric acid process should pose no undue difficulties. It may well be less costly to implement than the more familiar nitric acid process would be due to the relative nontoxicity and ease of treating secondary waste stream. **Development cost:** $400K-$1M (rough estimate) **Capital cost:** $4M-$10M if new equipment is required **Operating cost:** $300/Mg (BNFL estimate)

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	HRT Process Piping ORR Demineralizer Piping (Outside Pool) Bldg. 3517 Process Piping and Tankage MSRE Off-gas System Drain Lines from Molten Salt Cells, Bldg. 9201-3 Drain Lines from Coolant Salt Cell, Bldg. 9201-3 Drain Lines from Bldg. 9419-1 MSRE Reactor Piping ORR Primary Coolant Piping Instrument Air Lines and Air Lines in Coolant Salt Cell, Bldg. 9201-3 Pulse-feeder Pumps	Stainless Steel Pipe Interior UO2SO4, Fission Products, Corrosion Products Stainless Steel Pipe Interior Fission Products, Corrosion Products Stainless Steel Pipe Interior Cs-137, Sr-90 Steel Pipe Interior Steel Pipe Interior U, Th, Molten Salt Steel Pipe Interior U, Th, Coolant Salt Steel Pipe Interior U, Th, Molten Salt INOR Piping Interior U, Be, L, F, TiF3 Aluminum Piping Interior Fission Products, Corrosion Products Copper Tubing Interior U, Th, H-3, Molten Salt Metal Heavy Water	Refer to Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning	Fluoboric Acid Treatment DCON-11-OL H *Ranking:** *H-4-2 (2M;N)*	**Demonstration** Technology was designed specifically for D&D. **Efficacy:** Unrestricted use of materials should be possible after decontamination, due to high decontamination factor (DF).	**Development:** Although the method has seen application at Chernobyl with good results, development work is needed to test applicability at ORNL.	Fluoboric acid exhibits low vapor pressure and requires only standard precautions for acid or base work. The plant can be manufactured in modular form and installed in existing buildings.Hardware (equipment): Fabrication of all key plant parts from polypropylene or from Halar-coated metal. Capital cost in 1990 to set up a plant for decontaminating 5 tons/day of steel was DM 1.3 million ($774K), excluding development, planning, and buildings. Operating cost will be relatively low; this is a very simple process.
						Inorganic Acid Treatments DCON-12-OL M *Ranking:** *M-3-0 (4M;N)*	**Accepted** Nitric acid decontamination has been the preferred method at ORNL for cleaning items in various facility operations since the 1940s. In addition, the technique has been widely used at K-25 and Portsmouth. **Efficacy:** DFs are in the 100 range. **Waste:** Wastes consist of large quantities of corrosive wastes containing the removed contaminants and require treatment and disposal as mixed waste.	Improvements: Adaptation of modifications to system (i.e., scrubbers, filters, treatment for nitrates and heavy metals) In order to meet regulatory requirements. Possible development of HNO3/HF decontamination methods, with or without ultrasonic agitation. Continuing research and development, waste treatment, and volume reduction. Possible research and development in control of base metal dissolution. **Available at X-10, K-25.**	Nitrate treatment facility either on site or accessible to decontamination facility. Operating costs may be relatively high. Nitric acid decontamination was used extensively at most DOE plants, but data is not available regarding costs. Currently, Portsmouth plant is developing a data base to track costs, but it will not contain historical data. **Development cost:** (improvements): $400K-1M (rough estimate) **Capital cost:** <$4M-$10M (rough estimate)
						Detergent Treatment DCON-13-OL M *Ranking:** *M-4-0 (0M>$1/ft2)*	**Accepted** Surface smearable decontamination with caustic chemicals (soap and water) is accepted technology and is used extensively at ORNL. The caustic hand-scrubbing process was applied to cleaning small items. **Efficacy:** Since many of the listed contaminants are expected to be fixed, caustic scrubbing is expected to only partially decontaminate the contaminated surfaces. **Waste:** Wastes would consist of used caustic solution containing the removed contaminants.	None for removal of smearable contamination with carbonates, soaps, etc. **Available at X-10, K-25.**	This is an established process that could be implemented at ORNL with no major changes. **Capital cost:** <$10K **Operating costs:** >$1/ft

* Not applicable to aluminum pipe interior.

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Clean Up Legacy Waste Prevent Future Insult Develop Environmental Stewardship	Tank S.E. of Building 7500	Stainless Steel Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Ultrahigh-Pressure Water DCON–35–OL H *Ranking:** *H-5-1 (1.7M;$1/ft2)*	Accepted Technology has been used by industry. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused into the metal. **Waste:** Unless a recycle system is developed, waste would be 3-5 gal water/ft² metal cleaned that contains metal residue, plus the contaminants removed.	**Improvement:** To minimize waste generation, a system is needed to treat the water so that it can be recycled. **Improvement:** Automation.	A water treatment/recycle system is needed to minimize liquid wastes from this technology. **Development cost:** $1.3M **Capital cost:** ~$500K **Operating cost:** ~$1/ft²
EM Problems Facility Decontamination and Decommissioning (D&D)						Centrifuge Cryogenic CO_2 Pellet Blasting DCON–39–OL H *Ranking:** *H-5-2 (1.0M;<$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Improvement:** 1) Demonstration of an on line, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen-depletion precaution. **Development cost:** <$1M **Capital cost:** $100K **Operating cost:** <$1/ft²
emedial Action RA)—Soils, round Water nd Surface ater						Supercritical CO_2 Blasting DCON–41–OL H *Ranking:** *DCON-41-OL* *H-5-1 (O.75+M;>$1/ft2)*	**Predemonstration** **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed contaminants contained in a cyclone and a HEPA filter.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminants. Demonstrate efficacy for contaminants of interest.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen depletion precautions. **Development cost:** $250K-1M **Capital cost:** ~$500K **Operating Cost:** $1+/ft²
ste nagement M)						Plastic Pellet Blasting DCON–42–OL M *Ranking:** *M-4-0 (<0.1M;$1/ft2)*	**Accepted** Plastic pellet blasting is a widely used alternate to sand blasting for applications in which it is desired to impart minimal damage to the substrate. **Efficacy:** Technology should remove smearable, but not fixed contamination. **Waste:** Waste would be spent plastic pellets plus removed contamination.	**Improvement:** Develop and demonstrate system for processing waste. **Improvement:** Minimize blast media erosion to minimize waste; automation/robotics, especially for walls, etc.; improve containment of waste and removed contaminants.	A system for processing waste to an acceptable form is needed. Improvements: **Development cost:** $5.5M+ **Capital cost:** ~$50K **Operating Cost:** $0.20 - $2.15/ft

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EM Problems • Facility Decontamination and Decommissioning (D&D)					Thermal Surface Removal Methods	Laser Heating DCON–73–OL M *Ranking:** *M-4-4 (3M;$1/ft2)*	**Demonstration** Currently being used to remove organic coatings from metal surfaces. **Efficacy:** Current prototype systems are capable of removing 2-mil-thick coatings at the rate of 100 ft²/hr. Effectiveness on contaminants and substrates of interest is uncertain. **Waste:** Waste will be prefilters and HEPA filters filled with contaminants.	Development: Current prototype needs to be evaluated for possible use on contaminated areas. Systems with different operational parameters (e.g., wavelength, pulse durations) should be evaluated as well.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost: $2M+** **Capital cost: $500k-$1M+/machine** **Operating Cost: ~$1/ft²**
						Laser Etching and Ablation DCON–74–OL M *Ranking:** *M-4-4 (3.5M;>$1/ft2)*	**Predemonstration** Several research groups at university and government laboratories have used the technology to remove radiological and organic contaminants from various surfaces. **Efficacy:** The technique is slow to remove large deposits. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	Development: Existing lasers, delivery systems, and filtration systems need to be integrated into a prototype system for demonstration.	A collection system for the vaporized deposits would be needed to implement this technology. Development cost: $2M+ **Capital cost: $0.5-1M/machine** **Operating Cost: >$1/ft²**
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Compressed Air Cryogenic CO2 Pellet Blasing DCON–51–OL H *Ranking:** *H-4-1 (0.7M;>$1/ft2)*	**Demonstration** This technology is commercially available. It has been used at nuclear reactor sites to decontaminate hand tools and some equipment. **Efficacy:** The efficacy of this technology for removing the listed contaminants from concrete has not been demonstrated and is doubtful. **Waste:** Wastes would be HEPA filters filled with the removed contaminants.	Development: Evaluate technology that has recently been demonstrated in Department of Defense programs regarding automation and improvements in pellet delivery.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants. Development cost: about $0.50M **Capital cost:** About $200,000 **Operating Cost:** >$1/ft²
• Waste Management (WM)									

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EM Problems • Facility Decontamination and Decommissioning (D&D)						M Water Flushing DCON-54-OL *Ranking:** *M-4-1 (1.3M;<$1/ft2)*	**Accepted** Flushing with hot water is often used following scrubbing, especially on floors. **Efficacy:** The technique is not effective on fixed insoluble contamination. **Waste:** The waste generated is the contaminated water from the flushing operation.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the hot water cleaning operation.	A water treatment system is needed to minimize liquid wastes from this technology. **Development Cost:** About $1.2M **Capital cost:** <$5K **Operating Cost:** >$1/ft^2
						M Steam Cleaning DCON-55-OL *Ranking:** *M-4-1 (1.3M;$1/ft2)*	**Accepted** The technique has proven useful, especially on complex shapes and large surfaces. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has penetrated into the metal. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	Improvement - To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Remote operation will necessitate the adaptation of the steam and vacuum collection systems to robotic system control.	Normal implementation needs. **Development Cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** $50K-$75K (about $250K with remote operation) **Operating Cost:** >$1.00/ft^2
• Remedial Action (RA)—Soils, Ground Water and Surface Water						M Automated Brushing DCON-57-OL *Ranking:** *M-3-2 (1M;$300/ft)*	**Demonstration** This technology has been used at Rocky Flats to remove plutonium contamination from the inside of pipes. **Efficacy:** Tests would be needed to demonstrate its effectiveness for other contaminants on other substrates. **Waste:** Waste would be removed contamination plus any other loose debris.	**Development:** Tests to demonstrate that this technology is effective for the problems at ORNL.	Vacuum Collection system Development costs-$200K-1M **Capital cost:**$250K(remotely operated system) Operating cost-$300/linear foot of pipe
• Waste Management (WM)						L Dry Heat (Bulk Roasting) DCON-4-OL *Ranking:** *L-1-1 (2M;N)*	**Evolving technology** The technology is available, but has not been demonstrated or accepted for decontamination at the X-10 Site. **Efficacy:** It is not known what the technology can do. **Waste:** Any removed contaminants and other volatiles in filters, scrubbers, or condenser.	**Science:** The characteristics of the specific materials and their contaminants must be defined before a decontamination plan can be formulated. The characteristics of the specific contaminants must be matched to the decontaminating advantages of roasting. **Development:** After a sound technical basis is shown, the primary process could be optimized for worker safety and efficiency. Secondary waste logistics need to be defined.	Off-gas treatment is needed for this technology. **Overall costs:** ~$10/lb. is tyupical for this process.

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EM Problems • Facility Decontamination and Decommissioning (D&D)						Vacuum Cleaning DCON–64–OL M *Ranking:* *M-4-0 (<0.1M;$1/ft2)*	**Accepted** Vacuum cleaners have long been used to clean up loose contamination. **Efficacy:** Since little of the listed contaminates are expected to be in loose form, this technique is not expected to be effective. **Waste:** The waste is a HEPA filter filled with the contaminates and other materials that are removed by the vacuum.	None	Normal implementation needs. **Capitol Cost:** <$10K **Operating cost:** >$1/ft²
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Ultrasonic Cleaning DCON–65–OL M *Ranking:** *M-2-1 (0.1M;>$2/ft2)*	**Accepted** Ultrasonic cleaning has been used for many years in the private sector and in government installations for removing surface contamination from relatively small metal parts which can fit into an ultrasonic bath. **Efficacy:** Technology will work well for loosely bound surface deposits, but not for tightly bound materials. **Waste:** Wastes would be spent ultrasonic bath solutions containing any removed contaminants.	**Improvement:** Definition of acceptable cleaning liquids which (1) are not hazardous, (2) can be separated from the contaminants, and (3) can be reused to minimize secondary wastes. **Improvement:** More aggressive cleaning action.	Requires removal, disassembly, and size reduction of contaminated equipment. **Development cost:** (Improvements): $1M **Capital cost:** $10K-$100K **Operating Cost:** $2 - $10/ft² or more
• Waste Management (WM)					Melt Refining Methods	Smelt Purification DCON–31–OL H *Ranking:** *H-3-3 (100M;$1/lb)*	**Demonstration** Smelt purification of radioactive metals has been performed by a large number of investigators on a lab-scale and by some investigators on a large-scale. The metals include mild steel, stainless steel, nickel, copper, monel, aluminum, and others. **Efficacy:** Metal purification has been demonstrated. U is removed to 0.01-4ppm. Tc is not removed. **Waste:** Waste are slags, scrubber solutions, chemical trap materials, and HEPA filters.	**Development:** Attempts to demonstrate fluxing agent for removing radionuclides of interest. If possible, demonstrate removal of radionuclides of interest on a larger scale.	Scientific Ecology Group (SEG) personnel estimate the costs of metal smelting at roughly $0.93/lb of metal in 1992 dollars, depending on the type metal and configuration of the metal. Kellogg et al. estimated that the capital and operating costs of smelting the 90,000 tons of DOE scrap metal presently on hand at K-25 could be recovered through sale of the metal if a *de minimis* were established. The quantity of metals at ORNL is probably not sufficient to be cost effective unless added to this. The technology development needs will require further lab and pilot-scale evaluation. The development costs are roughly estimated by the investigator at $3M - $5M.

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Tank S.E. of Building 7500	Stainless Steel Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Melt Refining Methods	Electrorefining DCON–32–OL M *Ranking:** *M-2-5 (200M;$6/lb)*	**Predemonstration** Electrorefining is a well-established commercial technology. However, this technology cannot be considered mature concerning its use for decontaminating radioactive metal because this application is much less established. **Efficacy:** Tc plates out on the cathode. Technology is likely to be effective for the listed contaminants and substrates. **Waste:** Waste would be solid mixed waste from assumed treatment of electrolyte solutions for recycle.	**Development:** Demonstrate (1) separation of radionuclides and substrates of interest; and (2) recycle electrolyte solutions.	An electrorefining plant used for recovery of nickel would also require a smelting and anode forming facility to form the impure nickel into anodes of proper configuration. The capital costs altogether are estimated at $200M. The cost of an operating facility with a 10 million-pound/year capacity is estimated at $2M capital and $6/lb operating costs, which exceed the present value of nickel ($3.60/lb) because commercial nickel companies operate on a much larger scale. Development costs are estimated at $3M. To allow sale of the purified nickel, either a *de minimis* level must be established in the USA or permission must be obtained to sell the metal in Europe where a *de minimis* level exists.
						Leach/Electrowinning DCON–34–OL M *Ranking:** *M-2-5 (200M;$3.80/lb)*	**Predemonstration** Leach/Electrowinning is a well-established commercial method for producing nickel from nickel ore, but is not used commercially to refine impure nickel metal. **Efficacy:** Scientific Ecology Group, Inc. (SEG), has purified nickel to <1 Bq/g of Tc on a small scale. The Tc must be removed from the electrolytic solutions by ion exchange or some other method. The method has not been evaluated for treatment of metals other than nickel. At ORNL, nickel was not used extensively. **Waste:** Recycle of electrolytic solutions will result in a solid mixed waste bearing the contaminants and traces of the purified metal amounting to roughly 2% by weight of the metal purified.	**Development:** Pilot-scale testing of this method is needed with special attention to the leaching process, decontamination efficiency, and recycle of the electrolytic solutions. The development work by SEG may satisfy some of this requirement.	A leach/electrowinning plant would require a size-reduction facility, a leaching facility, and a tankhouse for the electrolytic cells. The costs of an operating facility with a 10-million-pound-per-year capacity are estimated by INCO at $200M capital and $3.80/lb operating costs. The operating costs exceed the present value of most all metals because commercial nickel companies operate on a much larger scale. The development costs are estimated by INCO at $440K if the work were done at their facilities. To allow sale of the resulting purified nickel, either a *de minimis* must be established for the USA or permission must be obtained to sell the metal in Europe where a de minimis standard exists.
EM Problems • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)					Chemical Surface Cleaning	Chemical Foams DCON–8–OL M *Ranking:** *M-4-1 (3M;$0.50–$2/ft2)*	**Demonstration** Widely used throughout the nuclear industry. Foam is used as a carrier of chemical decontamination agents, not as the agent itself. It can be sprayed on and wiped, rinsed, or vacuumed off. **Efficacy:** Effectiveness for listed contaminants has not been demonstrated. **Waste:** Small amount of contaminated sulfonated detergents, synthetic wetting agents, coupling agents, rinse water, and drying cloth.	**Development:** Scale-up/development of the process to a size appropriate for ORNL use. The technology itself is inexpensive, but development and scale-up will probably require support. **Improvement:** Full control over the mean bubble dimensions and the volume swell factor are needed, indicating that some basic research will be necessary.	Normal implementation needs. **Development Cost:** $1M-$4M **Capital cost:** $50K Operating cost: $0.50-$2/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Tank S.E. of Building 7500	Stainless Steel Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning	Organic Acid Treatments DCON–9–OL M *Ranking:** *M-4-2 (3M;N)*	ioned The technology is currently in use by BNFL at Capenhurst gaseous diffusion plant. BNFL uses citric and sulfuric acids in sequence for removal of U and Tc, respectively, from metal surfaces (mostly wrought aluminum). **Efficacy:** DF of 300 for U alpha and 40 for Tc beta are reported (11.1 Bq/g alpha, 0.04 Bq/g beta). Has not been demonstrated to remove other radionuclides. **Waste:** Wastes include citric and sulfuric acids containing uranium and other metal ions and ion exchange media containing the metals. Uranium is difficult to precipitate.	**Development:** Pilot plant development for waste treatments (ion exchange columns) to verify that we can meet our standards and regulations. More fundamental studies are needed in secondary waste disposal.	Purchase of technology, regulatory compliance for pilot scale decontamination, and waste treatment demonstrations. BNFL's expertise may reduce the amount of original research, etc. necessary to begin implementation. No present ORNL facility could be adapted for citric acid cleaning, but decontamination with BNFL's citric acid process should pose no undue difficulties. It may well be less costly to implement than the more familiar nitric acid process would be due to the relative nontoxicity and ease of treating secondary waste stream. **Development Cost:** $400K-$1M (rough estimate) **Capital cost:** $4M-$10M if new equipment is required. **Operating Cost:** $300/Mg (BNFL estimate)
EM Problems • Facility Decontamination and Decommissioning (D&D)						Fluoboric Acid Treatment DCON–11–OL H *Ranking:** *H-4-2 (2M;N)*	**Demonstration** Technology was designed specifically for D&D. Unrestricted use of materials should be possible after decontamination, due to high decontamination factor (DF).	**Development:** Although the method has seen application at Chernobyl with good results, development work is needed to test applicability at ORNL.	Fluoboric acid exhibits low vapor pressure and requires only standard precautions for acid or base work. The plant can be manufactured in modular form and installed in existing buildings. Hardware (equipment): Fabrication of key plant parts from polypropylene or from Halar coated metal. Capital cost in 1990 to set up a plant for decontaminating 5 tons/day steel was DM 1.3 million ($774K), excluding development, planning, and buildings. Operating cost will be relatively low; this is a very simple process.
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Inorganic Acid Treatments DCON–12–OL M *Ranking:** *M-3-0 (4M;N)*	**Accepted** Nitric acid decontamination has been the preferred method at ORNL for cleaning items in various facility operations since the 1940s. In addition, the technique has been widely used at K-25 and Portsmouth. **Efficacy:** DFs are in the 100 range. **Waste:** Wastes consist of large quantities of corrosive wastes containing the removed contaminants and require treatment and disposal as mixed waste.	Improvements: Adaptation of modifications to system (i.e., scrubbers, filters, treatment for nitrates and heavy metals) In order to meet regulatory requirements. Possible development of HNO3/HF decontamination methods, with or without ultrasonic agitation. Continuing research and development, waste treatment, and volume reduction. Possible research and development in control of base metal dissolution. **Available at X-10, K-25.**	Nitrate treatment facility either on site or accessible to decontamination facility. **Operating cost:** may be relatively high. Nitric acid decontamination was used extensively at most DOE plants, but data is not available regarding costs. Currently, Portsmouth plant is developing a data base to track costs; it will not contain historical data. **Development cost:** $ (improvements) $400K-$1M (rough estimate) **Capital cost:** <$4M-$10M (rough estimate)
• Waste Management (WM)									

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Tank S.E. of Building 7500	Stainless Steel Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning	Detergent Treatment DCON–13–OL M *Ranking:** *M-4-0 (0M;>$1/ft2)*	**Accepted** Surface smearable decontamination with caustic chemicals (soap and water) is accepted technology and is used extensively at ORNL. The caustic hand-scrubbing process was applied to cleaning small items. **Efficacy:** Since many of the listed contaminants are expected to be fixed, caustic scrubbing is expected to only partially decontaminate the contaminated surfaces. **Waste:** Wastes would consist of used caustic solution containing the removed contaminants.	None for removal of smearable contamination with carbonates, soaps, etc. **Available at X-10, K-25.**	This is an established process that could be implemented at ORNL with no major changes. **Capital cost: <$10K** **Operating costs: >$1/ft**
EM Problems • Facility Decontamination and Decommissioning (D&D)						REDOX Treatments DCON–14–OL M *Ranking:** *M-4-1 (3M;<$1/ft2)*	**Demonstration** REDOX treatments have been demonstrated for nuclear power plant decontamination, but not for the contaminants of interest. **Efficacy:** DFs of 10-100 can be expected based on experience in nuclear power plants. **Waste:** With recycle, waste is spent ion exchange media containing removed contaminants. With neutralization and evaporation, waste is a solid mixed waste containing the removed contaminants and chemicals	**Development:** All REDOX techniques will require demonstration to determine their usefulness to decontamination of ORNL operations and applicability to various contaminant films.	**Development cost: >$1M** **Capital cost: >$1M** **Operating Cost: <$1/ft²**
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Electropolishing DCON–15–OL M *Ranking:** *M-4-2 (3M;>$1/ft2)*	**Demonstration** Electropolishing is a surface removal technique and the amount of surface removed is proportional to factors such as current, time, and voltage. Electropolishing isessentially a "line of sight" process so cracks, crevices, areas out of sight of , or shadowed by, the electrode will not be decontaminated.Contaminated electrolyte must be removed for complete decontamination to be achieved. Electropolishing is difficult to apply to in-situ equipment.	**Development:** Primary and secondary waste treatment and solution recycle need to be developed. Cleanup principles (e.g., ion exchange and filtering) are well established, so that only design and demonstration are needed.	**Development Cost: ~$400K to $1M** **Operating Cost: >$1/ft² with additional capitol cost**
• Waste Management (WM)									

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Tank S.E. of Building 7500	Stainless Steel Fission Products, Corrosion Products	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning M	Chelation Treatment DCON–21–OL *Ranking:** *M-4-2 (1.5M;<$1/ft2)*	**Demonstration Efficacy:** Excellent DFs. Easy to apply in-situ as agent acts at neutral pH and is non-hazardous, non-fuming, has no gas evolution and is biodegradable. The technology has been employed at various facility operations and nuclear power plant sites achieving acceptable decontamination levels resulting in unconditional release. **Waste:** Simple waste minimizing treatment and disposal as a non-RCRA waste. Minimizes waste through oxidative destruction of chelate agent, partitioning of organics (including PCBs) and concentration of radionuclides precipitated out in the flocculent sludge which can be further de-watered.	**Development** Validation of updated chelating agents is needed and is currently underway at ORNL to confirm total efficacy and economic advantage.	Application equipment for in-situ decontamination. Support personnel and equipment to sample, analyze, develop appropriate concentrations, ensure oxidation of organics and/or complete partitioning will be necessary. Spray booth or dipping tank facilities with heating capabilities desirable on-site or accessible by decontamination facility. **Operating Cost:** <$1/ft²

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	HRT Reactor LITR Tank Internal Surfaces LITR Water Piping	Zincalloy UO_2SO_4, Fission Products, Corrosion Products, Activation Products Steel Corrosion Products, Fission Products, Activation Products Aluminum Piping Fission Products, Corrosion Products, Activation Products	Refer to Vol. 1, PLA, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Metal Refining Methods	Smelt Purification DCON–31–OL H *Ranking:** *H-3-3 (100M;$1/lb)*	**Demonstration** Smelt purification of radioactive metals has been performed by a large number of investigators on a lab-scale and by some investigators on a large-scale. The metals include mild steel, stainless steel, nickel, copper, monel, aluminum, and others. Metal purification has been demonstrated except for aluminum. **Efficacy:** Only activation products that are different chemical species from the bulk of the metal can be removed. **Waste:** Waste are slags, scrubber solutions, chemical trap materials, and HEPA filters.	**Development** Pilot-scale testing of this method is needed with special attention to decontamination efficiency for activation products.	Scientific Ecology Group (SEG) personnel estimate the costs of metal smelting at roughly $0.93/lb of metal in 1992 dollars, depending on the type metal and configuration of the metal. Kellogg et al. estimated that the capital and operating costs of smelting the 90,000 tons of DOE scrap metal presently on hand at K-25 could be recovered through sale of the metal if a *de minimis* were established. The quantity of metals at ORNL is probably not sufficient to be cost effective unless added to this. The technology development needs will require further lab and pilot-scale evaluation. The development costs are roughly estimated at $3M-$5M.
EM Problems • Facility Decontamination and Decommissioning (D&D)						Electrorefining DCON–32–OL M *Ranking:** *M-2-5 (200M;$6/lb)*	**Predemonstration** Electrorefining is a well-established commercial technology. However, this technology cannot be considered mature concerning its use for decontaminating radioactive metal because this application is much less established. **Efficacy:** Only activation products that are different chemical species from the bulk of the metal can be removed. **Waste:** Waste would be solid mixed waste from assumed treatment of electrolyte solutions for recycle.	**Development** Pilot-scale testing of this method is needed with special attention to decontamination efficiency for activation products, and recycle of the electrolytic solutions.	An electrorefining plant used for recovery of nickel would also require a smelting and anode forming facility to form the impure nickel into anodes of proper configuration. The capital costs are estimated at $200M. The cost of an operating facility with a 10 million-pound/year capacity is estimated at $2M capital and $6/lb operating costs, which exceed the present value of nickel ($3.60/lb) because commercial nickel companies operate on a much larger scale. Development costs are estimated at $3M. To allow sale of the purified nickel, either a *de minimis* level must be established in the USA or permission must be obtained to sell the metal in Europe where a *de minimis* level exists.
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Leach/Electrowinning DCON–34–OL M *Ranking:** *M-2-5 (200M;$3.80/lb)*	**Predemonstration** Leach/Electrowinning is a well-established commercial method for producing nickel from nickel ore, but is not used commercially to refine impure nickel metal. **Efficacy:** Scientific Ecology Group, Inc. (SEG), has purified nickel to <1 Bq/g of Tc on a small scale. The Tc must be removed from the electrolytic solutions by ion exchange or some other method. The method has not been evaluated for treatment of metals other than nickel. At ORNL, nickel was not used extensively. Only activation products that are different chemical species from the bulk of the metal can be removed. **Waste:** Recycle of electrolytic solutions will result in a solid mixed waste bearing the contaminants and traces of the purified metal amounting to roughly 2% by weight of the metal purified.	**Development:** Pilot-scale testing of this method is needed with special attention to the leaching process, decontamination efficiency. Pilot-scale testing of this method is needed with special attention to decontamination efficiency for activation products, and recycle of the electrolytic solutions. The development work by SEG may satisfy some of this requirement.	A leach/electrowinning plant would require a size-reduction facility, a leaching facility, and a tankhouse for the electrolytic cells. The costs of an operating facility with a 10-million-pound-per-year capacity are estimated by INCO at $200M capital and $3.80/lb operating costs. The operating costs exceed the present value of most all metals because commercial companies operate on a much larger scale. The development costs are estimated by INCO at $440K if the work were done at their facilities. To allow sale of the resulting purified metal, either a *de minimis* must be established for the USA or permission must be obtained to sell the metal in Europe where a *de minimis* standard exists.
• Waste Management (WM)									

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	HRT Reactor LITR Tank Internal Surfaces LITR Water Piping	Zincalloy UO^2SO^4, Fission Products, Corrosion Products, Activation Products Steel Corrosion Products, Fission Products, Activation Products Aluminum Piping Fission Products, Corrosion Products, Activation Products	Refer to Vol. 1, PLA, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Metal Refining Methods L	Transmutation DCON–78–OL *Ranking:** *L-1-10 (500,N)*	**Preconceptual Evolving Technology** Untried for decontamination purposes. Reactors and Strategic Defense Initiative particle accelerators are capable of producing the needed particle fluxes. **Efficacy:** Can remove only those isotopes with significantly larger cross-sections than the bulk material. **Waste:** Needs to be determined.	**Science:** Determine whether activation products have cross sections that allow transmutation without activating the bulk of the material. Work out separation schemes for transmuted materials and determine wastes. **Development:** Demonstrate feasibility of process and gather cost data.	High particle fluxes from an accelerator or a nuclear reactor are needed for this technology. **Development Cost:** $0.1-10M Capitol Cost:~ $500M **Operating Cost:** Prohibitively high

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Decontamination

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
Pavement Over 55-gal Drum, Bldg. 7500 Cells Other Contaminated Asphalt Pavement Surfaces	Asphalt Pavement Fission Products, Corrosion Products Asphalt Pavement Various Radionuclides	Refer to Vol. 1, Pt.A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	**H** Ultrahigh-Pressure Water DCON–35–OL *Ranking:** *H-5-1 (1.7M;$1/ft2)*	**Accepted** Technology has been used by industry. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the asphalt. **Waste:** Unless a recycle system is developed, waste would be 3-5 gal water/ft² cleaned that contains ~0.01 ft³ asphalt residue, plus the contaminants removed.	**Improvement:** To minimize waste generation, a system is needed to treat the water so that it can be recycled. **Improvement:** Automation.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** $1.3M **Capital cost:** ~$500K **Operating cost:** ~$1/ft²
					H Scabblers/Scarifiers DCON–37–OL *Ranking:** *H-4-2 (0.5M;$5/ft2)*	**Accepted** **Efficacy:** Mechanical scabblers are widely used. They are generally effective, but leave some hot spots. **Waste:** Waste is ~0.01 ft³ removed substrate (1/16" cut) containing removed contaminants per ft² of substrate decontaminated	**Improvement:** Automation.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$500K **Operating cost:** ~$1/ft² (More than shot blasting)
					H Grit Blasting DCON–38–OL *Ranking:** *H-4-0 (<0.1$5/ft2)*	**Accepted** Has been used successfully for many applications in the nuclear industry. **Efficacy:** Technology is generally effective. **Waste:** Waste is ~0.01 ft³ removed asphalt (1/16" cut) containing removed contaminants per ft² of asphalt decontaminated plus spent grit.	**Improvement:** Automation.	Normal implementation needs. **Development cost:** None **Capital cost:** ~$500K **Operating cost:** $~5/ft²
					H Centrifuge Cryogenic CO_2 Pellet Blasting DCON–39–OL *Ranking:** *H-5-2 (1.0M;<$1/ft2)*	**Demonstration** Centrifuge pellet acceleration has been demonstrated in the DOE fusion energy program, as a decontamination tool in the Y-12 facility waste minimization effort, and more recently as an aircraft depaint mechanism. **Efficacy:** Technology is likely to be successful with very high decontamination factors. **Waste:** The waste will be HEPA filters containing the combination of contaminants and substrate material.	**Development:** Demonstration of mobile system with high velocity pellets delivered at a sufficient rate and adequate collection of removed contaminants. **Improvement:** 1) Demonstration of an on-line, real time contaminant sensor which would minimize the decontamination effort and limit the waste stream; 2) automation	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen-depletion precautions. **Development cost:** <$1M **Capital cost:** $100K **Operating cost:** <$1/ft²
					H Ice Blasting DCON–40–OL *Ranking:** *H-5-1 (<1.0M;$1/ft2)*	**Demonstration** **Efficacy:** Efficacy of commercial system for this application needs demonstration. **Waste:** Waste would be about 14 to 18 gallons per hour waste water containing removed contaminants.	**Development:** Demonstration of efficacy of commercial system. **Improvement:** Automation/robotics.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** $200K **Capital cost:** $100K-$1M **Operating cost:** <$1/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Pavement Over 55-gal Drum, Bldg. 7500 Cells Other Contaminated Asphalt Pavement Surfaces	Asphalt Pavement Fission Products, Corrosion Products Asphalt Pavement Various Radionuclides	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods	Supercritical CO_2 Blasting DCON–41–OL H *Ranking:** *H-5-1 (O.75+M;>$1/ft2)*	**Predemonstration** **Efficacy:** Likely to be effective with nearly infinite decontamination factors. **Waste:** Waste would be removed concrete and contaminants contained in a cyclone and a HEPA filter.	**Development:** Investigate the effect of operating parameters on removal rates and removal and collection efficiencies for contaminants. Demonstrate efficacy for contaminants of interest.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants, plus oxygen depletion precautions. **Development cost:** $250K-1M **Capital cost:** ~$500K **Operating Cost:** $1+/ft²
						Plastic Pellet Blasting DCON–42–OL M *Ranking:** *M-4-0 (<0.1M;$1/ft2)*	**Accepted** Plastic pellet blasting is a widely used alternate to sand blasting for applications in which it is desired to impart minimal damage to the substrate. **Efficacy:** Technology should remove smearable, but not fixed contamination, from asphalt. **Waste:** Waste would be spent plastic pellets plus removed contamination.	**Improvement:** Develop and demonstrate system for processing waste. **Improvement:** Minimize blast media erosion to minimize waste; automation/robotics, especially for walls, etc.; improve containment of waste and removed contaminants.	A system for processing waste to an acceptable form is needed. Improvements: **Development cost:** $5.5M+ **Capital cost:** ~$50K **Operating Cost:** $0.20 - $2.15/ft
						Hand Grinding, Honing, Scraping DCON–43–OL H *Ranking:** *H-2-0 (<<0.1M;$1/ft2)*	**Accepted** **Efficacy:** Grinding with hand-held power grinders has been successfully used for small-scale decontamination. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	None **Available at X-10, K-25.**	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** None **Capital cost:** $150 ($5K with vacuum system and $50-500K with remote operation) **Operating cost:** ~$1/ft²
						Automated Grinding DCON–44–OL H *Ranking:** *H-2-1 ($1M;$1M;N)*	**Conceptual** Grinding has been successfully used for small scale decontamination. This grinding was done with hand-held power grinders Remotely operated grinding equipment is available, but no references to its use for decontamination have been found. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the asphalt. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	Development: The applicability of this technology to items with rad contamination should be demonstrated.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** $600K **Capital cost:** $250K
						Concrete Milling DCON–47–OL M *Ranking:** *M-1-2 (<1M;$0.75/ft2)*	**Accepted** The equipment is commercially available, but no reference to its use for decontamination has been found. This technology is suited for horizontal surfaces only. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the asphalt. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	Improvement: The technology to operate this equipment remotely needs to be developed and demonstrated.	A collection system for the vaporized deposits would be needed to implement this technology. **Development cost:** None **Capital cos:** $1.50/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D)	Pavement Over 55-gal Drum, Bldg. 7500 Cells Other Contaminated Asphalt Pavement Surfaces	Asphalt Pavement Fission Products, Corrosion Products Asphalt Pavement Various Radionuclides	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Mechanical Surface Removal Methods L	Explosive DCON–48–OL *Ranking:** *L-2-5 (4M;$50/ft2)*	**Demonstration** Blasting has been used to decontaminate nuclear reactor shielding. Demonstration will be needed for other applications. Safety concerns need to be resolved; care must be taken to contain the dust and to prevent structural damage to the building being decontaminated and the surrounding structures. **Efficacy:** The decontamination efficiency should be essentially 100% unless the contamination has diffused deep into the asphalt. **Waste:** Waste would be removed contaminants and substrate contained in filters and HEPA filters.	**Development:** Improvements in the methods of applying explosives and in the uniformity of the detonation are needed. The explosion will generate toxic organic vapors. The technology to control toxic vapors formed by the explosion must be developed and demonstrated.	A certified blasting technician will be needed. Capital cost-$50K Operating cost-$50/ft² Development cost-$1-4M
• Remedial Action (RA)—Soils, Ground Water and Surface Water					Thermal Surface Removal Methods M	Laser Etching and Ablation DCON–74–OL *Ranking:** *M-4-4 (3.5M;>$1/ft2)*	**Predemonstration** Several research groups at university and government laboratories have used the technology to remove radiological and organic contaminants from various surfaces. **Efficacy:** The technique is slow to remove large deposits. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	**Development:** Existing lasers, delivery systems, and filtration systems need to be integrated into a prototype system for demonstration.	A collection system for the vaporized contaminants would be needed to implement this technology. **Development cost:** $2M+ **Capital cost:** $0.5-1M/machine **Operating Cost:** >$1/ft²
• Waste Management (WM)					H	Flashlamp Cleaning DCON–77–OL *Ranking:** *H-3-3 (2.5M;$1/ft2)*	**Predemonstration** Flashlamp systems are being used to remove organic contamination from metals, precious metals, and fragile substrates. Hanford-Westinghouse Laboratory is conducting tests of xenon flashlamp systems for removing radiological contamination from surfaces inside metal storage vessels. **Efficacy:** Technology is likely to be effective for surface contamination. **Waste:** Wastes would be removed deposits, some substrate material, and HEPA filters from the filtration system.	Development: Commercially available flashlamp systems need to be evaluated for radiological decontamination.	A collection system for the vaporized contaminants would be needed to implement this technology. **Development cost:** ~$2.5 M **Capital cost:** $50-100K/machine **Operating Cost:** ~1.00/ft²
					H	Compressed Air Cryogenic CO2 Pellet Blasing DCON–51–OL *Ranking:** *H-4-1 (0.7M;>$1/ft2)*	**Demonstration** This technology is commercially available. It has been used at nuclear reactor sites to decontaminate hand tools and some equipment. **Efficacy:** The efficacy of this technology for removing the listed contaminants from asphalt has not been demonstrated and is doubtful. **Waste:** Wastes would be HEPA filters filled with the removed contaminants.	Development: Evaluate technology that has recently been demonstrated in Department of Defense programs regarding automation and improvements in pellet delivery.	Design and construction of a vacuum waste-handling system with HEPA filters to handle the vaporized CO_2 containing the removed contaminants. **Development cost:** about $0.50M **Capital cost:** About $200,000 **Operating Cost:** ~$1/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship ↓ **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Pavement Over 55-gal Drum, Bldg. 7500 Cells Other Contaminated Asphalt Pavement Surfaces	Asphalt Pavement Fission Products, Corrosion Products Asphalt Pavement Various Radionuclides	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Thermal Surface Removal Methods	High-Pressure Water DCON–52–OL M *Ranking:** *M-3-1 (1.3M;<$1/ft2)*	**Accepted** High pressure water blasting has been used very successfully to decontaminate various large and complex surfaces at nuclear power plants. **Efficacy:** Technique is expected to be effective with a DF of about 50 for loosely adhering contamination. DFs will be higher if chemical cleaning agents are also used. Technique is expected to be ineffective for fixed contamination on asphalt. **Waste:** Waste is 4 to >100 gpm of contaminated waste water.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Improvement - Remote operation will necessitate the adaptation of the high pressure water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** $50K-$75K (about $250K with remote operation) **Operating Cost:** <$1.00/ft^2
						Superheated Water DCON–53–OL M *Ranking:** *M-4-1 (1.4M;$1/ft2)*	**Accepted** Technology is available and has been used by industry. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has soaked into the asphalt. On finished asphalt, technology may drive contaminants deeper into substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Improvement - Remote operation will necessitate the adaptation of the superheated water and vacuum collection systems to robotic system control.	A water treatment system is needed to minimize waste. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** About $175K (about $250K with remote operation) **Operating Cost:** <$1.00/ft^2
						Water Flushing DCON–54–OL M *Ranking:** *M-4-1 (1.3M;<$1/ft2)*	**Accepted** Flushing with hot water is often used following scrubbing, especially on floors. **Efficacy:** The technique is not effective on fixed insoluble contamination. On finished asphalt, technology may drive contaminants deeper into substrate. **Waste:** The waste generated is the contaminated water from the flushing operation.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the water flushing operation.	A water treatment system is needed to minimize liquid wastes from this technology. **Development cost:** About $1.2M **Capital cost:** <$5K **Operating cost:** <$1/ft^2
						Steam Cleaning DCON–55–OL M *Ranking:** *M-4-1 (1.3M;$1/ft2)*	**Accepted** The technique has proven useful, especially on complex shapes and large surfaces. **Efficacy:** Technology should be effective except for fixed insoluble contamination or contamination that has soaked into the asphalt. On finished asphalt, technology may drive contaminants deeper into substrate. **Waste:** Waste will be 0.4 to 2.0 gpm wastewater containing removed contaminants.	Improvement - To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be reused. Remote operation will necessitate the adaptation of the steam and vacuum collection systems to robotic system control.	Normal implementation needs. **Development cost:** Water treatment system: About $1.2M Remote operation: $3-4M **Capital cost:** $50K-$75K (about $250K with remote operation) **Operating Cost:** <$1.00/ft^2
						Hand Brushing Used to Remove Surface Contamination DCON–56–OL H *Ranking:** *H-2-0 (0M;$1/ft2)*	**Accepted** Brushing is a common decontamination technique. **Efficacy:** Brushing is effective for loose contamination only. **Waste:** Waste consists of removed contamination plus other loose debris.	None **Available at K-25.**	Normal implementation needs. Capital cost-negligible Operating cost-$1.00/ft^2 Development cost-none

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Decontamination

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• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship	Pavement Over 55-gal Drum, Bldg. 7500 Cells Other Contaminated Asphalt Pavement Surfaces	Asphalt Pavement Fission Products, Corrosion Products Asphalt Pavement Various Radionuclides	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods	Automated Brushing DCON–57–OL M *Ranking:** *M-3-2 (1M;$300/ft)*	**Demonstration** This technology has been used at Rocky Flats to remove plutonium contamination from the inside of pipes. **Efficacy:** Tests would be needed to demonstrate its effectiveness for other contaminants on other substrates. **Waste:** Waste would be removed contamination plus any other loose debris.	**Development:** Tests to demonstrate that this technology is effective for the problems at ORNL.	Vacuum Collection system **Development cost:** $200K-1M **Capital cost:** $250K(remotely operated system) **Operating cost:** $300/linear foot of pipe
EM Problems • Facility Decontamination and Decommissioning (D&D)						Sponge Blasting DCON–58–OL M *Ranking:** *M-3-1 (1.3M;$2/ft2)*	**Accepted** Although the technology is relatively new, it is currently being used by at least two sites including a nuclear power plant. **Efficacy:** Extensive data on decontamination factors are not available. With the aggressive sponges, which are impregnated with abrasives, this technology may be effective for the listed contaminants and substrates. **Waste:** Wastes consist of about 0.01 ft³ of blasting media and removed contaminants per ft² of area decontaminated plus any liquid cleaning agents that may have been added.	**Improvement:** To minimize waste generation, a water treatment system is needed for decontamination of the wastewater so that the water can be recycled and reused in the sponge blasting operation.	A wastewater treatment / recycle system will be needed to use this technology. **Development cost:** About $1.2M **Capital cost:** Sponge blasting system: About $20K (with sifter system) **Operating Cost:** About $2/ft²
• Remedial Action (RA)—Soils, Ground Water and Surface Water						Solvent Washing to Remove Radiological Contamination DCON–61–OL M *Ranking:** *M-3-2 (1M;N)*	**Conceptual** Plutonium contaminated items at Richland, WA were rinsed with Freon. The vendor who supplied the equipment for Richland ten years ago no longer sells it. **Efficacy:** This technique is mainly applicable to smearable contamination. **Waste:** Waste would be spent solvent containing removed contaminates.	**Science:** Solvents that are less damaging to the environment need to be identified and demonstrated. **Available in Private Sector.**	Vapor collection system **Capital cost:** $300K (1980 dollars) **Development cost:** <$1M to identify and demonstrate the replacement solvent. **Operating cost:** an average of 7.5 minutes per item was required when decontaminating small items.
• Waste Management (WM)						Strippable Coatings DCON–63–OL M *Ranking:* *M-3-0 (<0.1M;>$1/ft2)*	**Accepted** Technology has been used for decontamination applications involving hazardous and radioactive contaminants. **Efficacy:** Decontamination factors of one to several hundred can be expected with two applications. **Waste:** Waste is a solid polymer (volume = 1 mm x surface area decontaminated) containing the removed contaminants.	**Improvement:** Develop coatings with lower material costs and greater ease of application.	Normal implementation needs. **Capital cost:** Negligible **Operating cost:** $1-$1.40/ft²

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Decontamination

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/ Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Pavement Over 55-gal Drum, Bldg. 7500 Cells Other Contaminated Asphalt Pavement Surfaces	Asphalt Pavement Fission Products, Corrosion Products Asphalt Pavement Various Radionuclides	Refer to Vol. 1, PLA, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Decontamination	Chemical Surface Cleaning Methods L	Vacuum Cleaning DCON–7–OL *Ranking:* *L-1-2 (2M;N)*	**Accepted** Vacuum cleaners have long been used to clean up loose contamination at the gaseous diffusion plants. **Efficacy:** Since little of the listed contaminates are expected to be in loose form, this technique is not expected to be effective in cleaning asphalt pavement at ORNL. **Waste:** The waste is a HEPA filter filled with the contaminates and other materials that are removed by the vacuum.	None	Normal implementation needs. **Capitol cost:** <$10K **Operating cost:** >$1/ft²
						Ultrasonic Cleaning DCON–65–OL *Ranking:**	**Accepted** Ultrasonic cleaning has been used for many years in the private sector and in government installations for removing surface contamination from relatively small metal parts which can fit into an ultrasonic bath. **Efficacy:** Technology will work well for loosely bound surface deposits, but not for tightly bound materials. **Waste:** Wastes would be spent ultrasonic bath solutions containing any removed contaminants.	**Improvement:** Definition of acceptable cleaning liquids which (1) are not hazardous, (2) can be separated from the contaminants, and (3) can be reused to minimize secondary wastes. **Improvement:** More aggressive cleaning action.	Requires removal, disassembly, and size reduction of contaminated asphalt. **Development cost (Improvements):** $1M **Capital cost:** $10K-$100K **Operating cost:** $2 - $10/ft² or more

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The identification of the tec [illegible] ning remedial action, and waste m [illegible] purp these technologies is to provide [illegible] decontamination, and dismantl [illegible] as these "other" decommissio [illegible] For example a robotic platform [illegible] dismantlement tools.

The robotics/ automation te [illegible] (2) Control, and (3) Sensors; with [illegible] were selected for this section o [illegible] the deployment of tools and senso [illegible] waste by reduction or eliminati [illegible] handling redundant tasks.

Robotics and Automation for Decontamination and Decomissioning

EM Goals

- Clean Up Legacy Waste
- Prevent Future Insult
- Develop Environmental Stewardship

EM Problems

- Facility Decontamination and Decommissioning (D&D)
- Remedial Action (RA)—Soils, Ground Water and Surface Water
- Waste Management (WM)

ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
Stabilized Hot Cells Abandoned Hot Cells Reactors and Support Facilities Storage Buildings	Robotics/automation (R/A) is a cross-cutting technology that provides support to characterization, decontamination, and dismantlement activities. Specifically support is provided for the following tasks. **I. Characterization** R/A provides methods of deploying sensors and instruments required for in-situ characterization, monitoring, and surveying as described by the Characterization Data Sheets contained in Vol. 3. R/A provides methods for deploying tools to collect and prepare samples for subsequent analysis in analytical laboratories. These technologies are described in ROBA-57 and -59-OL. R/A provides the technologies required for the automation of analytical laboratories as described in ROBA-55 and -56-OL. **II. Decontamination** Provides methods of deploying decontamination tools and/or performing tasks in areas sufficiently hazardous to preclude human access. Most of these high hazard areas will be encountered in hot cells or shut-down reactors. R/A will also be required for those tasks that generate secondary environmental hazards, e.g., grinding, carbon dioxide blasting, etc. **III. Dismantlement** Provides methods of deploying dismantlement tools and/or performing tasks in areas within buildings or structures that are sufficiently hazardous to preclude human access. Similar to the decontamination activities, most of these tasks will be in hot cell or shut-down reactors. **IV. Waste Retrieval** R/A provides the vehicles, mobile platforms, or excavation systems necessary to retrieve radiologically or chemically hazard wastes or soils from waste fields or impoundments. Mobile platforms suitable for these tasks are described in ROBA-1-OL. **V. Waste Sorting and Packaging** R/A provides the bridge-mounted robotic systems (ROBA-8-OL), the manipulation systems, (ROBA-16-OL), and the End-of-Arm Tooling (ROBA-23 through -26-OL) required for the sorting and repackaging of RH-TRU waste. **VI. Surveillance and Inspection** R/A provides the vehicles or mobile platforms (ROBA-1-OL) and sensors (ROBA-43 through -46-OL) required for the periodic surveillance and inspection of waste containers in above-ground storage areas.	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Robotics/Automation	Mechanical—Mobility	E Wheeled/Tracked Vehicle ROBA-I-OL *Ranking:* E-5-2 ($3M;N)*	**Accepted** **Efficacy:** An essential technology. High probability of being useful for reactors, support buildings, and storage areas. **Waste:** Possible emissions. Decontamination of system after use. **TTP Match**	Development: -Improved controls to allow more autonomy of operation. -Improved design for decontamination after use.	-Training of operators in advanced control stations. -Development Costs: $3.0M
				M Internal Duct/Pipe Crawler ROBA-5-OL *Ranking:* M-3-2 ($1M;N)*	**Predemonstration** **Efficacy:** High for straight runs of pipe without obstacles; low if obstacles are present. **Waste:** Decontamination of system after use. **TTP Match**	Development: -Miniaturization of sensors/tooling. -Ability to negotiate around obstructions. -Cable management system for tethered equipment.	-No unusual needs -Development Costs: $1.0M
				M External Duct/Pipe Crawlers ROBA-6-OL *Ranking:* M-3-4 ($5M;N)*	**Predemonstration** **Efficacy:** High if obstacles are not present; low if obstacles are present. **Waste:** Decontamination of system after use. **TTP Match**	Development: -Robotic compatibility of tooling. -Ability to negotiate around obstructions.	-No unusual needs -Development Costs: $5.0M
				M Specialized Robotic Deployment Platforms ROBA-7-OL *Ranking:* M-4-3 ($5M;N)*	**Demonstration** **Efficacy:** Low for most applications in D&D. Unique applications may require extensive development. **Waste:** Frequent decontamination with resulting waste fluids may be necessary. **TTP Match**	Development: -Specialized controls and sensors -Improved vision systems	- Cold test beds and operator training. -Development Costs: $5.0M
				M Bridge-Mounted Robotic Platforms ROBA-8-OL *Ranking:* M-2-1 ($5M;N)*	**Accepted** **Efficacy:** High, although number of applications may be limited. **Waste:** Minimal waste will be generated.	None	-Standardization -Development Costs: $1.0M
				M Long Arm Deployed Robotic Platforms ROBA-9-OL *Ranking:* M-4-3 ($5M;N)*	**Accepted** **Efficacy:** Medium. Accurate positioning may be a problem. Limited applications in D&D. **Waste:** Hydraulic fluid during operation. Decontamination fluids after use.	Development: -Flexible body control. -End-point sensing. -Collision avoidance. -Weight-to-payload ratio reduction.	-Cold test beds -Extensive operator training -Development Costs: $5.0M
				E Power Sources for Mobile Platforms ROBA-10-OL *Ranking:* E-5-1 ($0.5M;N)*	**Accepted** **Efficacy:** An essential technology. Accepted status means high efficacy. **Waste:** Batteries, and exhaust emissions.	Technology Improvement: - Energy storage capacity - Duty cycle availability - Current capacity/discharge rate - Emission control	- No unusual needs Development Costs: $1 to 4M
				E Failure Recovery Systems for Mobile Platforms ROBA-11-OL *Ranking:* E-5-1 ($0.5M;N)*	**Accepted** **Efficacy:** High. This is an essential technology that is well established. **Waste:** Little or no waste.	None	-No unusual needs -Development Costs: $0.5M

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Robotics and Automation for Decontamination and Decomissioning

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
• Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship **EM Problems** • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM)	Stabilized Hot Cells Abandoned Hot Cells Reactors & Support Facilities Storage Buildings	Robotics/automation (R/A) is a cross-cutting technology that provides support to characterization, decontamination, and dismantlement activities. Specifically support is provided for the following tasks. **I. Characterization** R/A provides methods of deploying sensors and instruments required for in-situ characterization, monitoring, and surveying as described by the Characterization Data Sheets contained in Vol. 3. R/A provides methods for deploying tools to collect and prepare samples for subsequent analysis in analytical laboratories. These technologies are described in ROBA-57 and -59-OL. R/A provides the technologies required for the automation of analytical laboratories as described in ROBA-55 and -56-OL. **II. Decontamination** Provides methods of deploying decontamination tools and/or performing tasks in areas sufficiently hazardous to preclude human access. Most of these high hazard areas will be encountered in hot cells or shut-down reactors. R/A will also be required for those tasks that generate secondary environmental hazards, e.g., grinding, carbon dioxide blasting, etc. **III. Dismantlement** Provides methods of deploying dismantlement tools and/or performing tasks in areas within buildings or structures that are sufficiently hazardous to preclude human access. Similar to the decontamination activities, most of these tasks will be in hot cell or shut-down reactors. **IV. Waste Retrieval** R/A provides the vehicles, mobile platforms, or excavation systems necessary to retrieve radiologically or chemically hazard wastes or soils from waste fields or impoundments. Mobile platforms suitable for these tasks are described in ROBA-1-OL. **V. Waste Sorting and Packaging** R/A provides the bridge-mounted robotic systems (ROBA-8-OL), the manipulation systems, (ROBA-16-OL), and the End-of-Arm Tooling (ROBA-23 through -26-OL) required for the sorting and repackaging of RH-TRU waste. **VI. Surveillance and Inspection** R/A provides the vehicles or mobile platforms (ROBA-1-OL) and sensors (ROBA-43 through -46-OL) required for the periodic surveillance and inspection of waste containers in above-ground storage areas.	Refer to Vol. 1, Pt. A, Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Robotics/Automation	Mechanical-Mobility	M Transportation Systems for Mobile Platforms ROBA-12-OL *Ranking:* M-3-1 ($0.5M;N)*	**Accepted** for small robotic platforms **Predemonstration** for large platforms or unique devices **Efficacy:** Low. **Waste:** No waste. The purpose of the technology is to minimize decontamination waste. **TTP Match**	Development: -Light-weight containers for medium and heavy duty mobile platform. -Containers that can be easily decontaminated.	-No unusual needs -Development Costs: $0.5M
						E Data/Signal Transmission ROBA-13-OL *Ranking:* E-5-1 ($1M;N)*	**Accepted** **Efficacy:** High. An essential technology. Specific application may determine type of system required. **Waste:** None. **TTP Match**	None	-Testing in representative environments. -Development Costs: $1.0M
					Mechanical-Manipulation	H Long-Reach Manipulator-Light Duty ROBA-14-OL *Ranking:* H-4-2 ($2M;N)*	**Predemonstration** **Efficacy:** Medium. Positioning accuracy and control may be problems. **Waste:** Hydraulic fluid during operation; decon fluid after use. **TTP Match**	Development: -Flexible body control -End-point sensing. -Collision avoidance. -Light-weight, small cross section design.	-Cold test beds, -Extensive operator training. -Development Costs: $2.0M
						M Long-Reach Manipulator-Heavy Duty ROBA-15-OL *Ranking:* M-4-3 ($5M;N)*	**Predemonstration** **Efficacy:** Low. Positioning accuracy and control may be problem **Waste:** Hydraulic fluid during operation; decon fluid after use. **TTP Match**	Development: -Flexible body control -End-point sensing. -Collision avoidance. -Weight-to-payload ratio reduction.	-Cold test beds. - Extensive operator training. -Development Costs: $5.0M
						E Dexterous Manipulators ROBA-16-OL *Ranking:* E-5-1 ($1M;N)*	**Demonstration** **Efficacy:** High. An essential technology. **Waste:** Possible hydraulic fluid during use and decon fluid after use. **TTP Match**	Development: -Redundant manipulator planning and control. -Modular design. -Nonreplica master/slave operation. -Cooperating and coordinated dual arm control.	-Operator Training on nonreplica master controllers. -Development Costs: $1.0M
						H Compact, High Capacity Manipulators ROBA-19-OL *Ranking:* H-5-1 ($1M;N)*	**Evolving** **Efficacy:** High. Constrained access may require this technology.	Development: -Compact, high-output, electrical motors. -Design/fabrication/testing of compact arms.	-No unusual needs -Development Costs: $1.0M
					Mechanical-Mechanisms	H Precise Programmable Motions ROBA-20-O *Ranking:* H-5-1 ($0.5M;N)*	**Demonstration** **Efficacy:** High. Particularly useful in analytical laboratory. **Waste:** None. **TTP Match**	Improvement: -Standardization of mechanical interfaces.	-No unusual needs -Development Costs: $0.5M
						H Tool Caddies ROBA-21-OL *Ranking:* H-4-1 ($0.5M;N)*	**Demonstration** **Efficacy:** High. Will increase efficiency of operations and minimize waste. **Waste:** Decontamination after use.	None	-No unusual needs -Development Costs: $0.5M
						M Stabilization/Support Mechanisms or Booms ROBA-22-OL *Ranking:* M-3-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. Some applications may require secondary support due to deteriorating condition of facility. **Waste:** Minimal. Some decon waste.	Improvement: -Use of high-strength advanced materials.	-No unusual needs -Development Costs: $0.5M

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Robotics and Automation for Decontamination and Decomissioning

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						M End-Effector Changeout Mechanisms ROBA-24-OL *Ranking:* M-3-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. Applications may be limited. **Waste:** Minimal decon waste. **TTP Match**	None	-Integration and testing with specific robotic systems. -Development Costs: $0.5M
						H General Gripper/Tool Interface ROBA-25-OL *Ranking:* H-4-1 ($0.5M;N)*	**Accepted** **Efficacy:** High. Many potential applications for tool/sensor gripping. **Waste:** Minimal decon waste.	None	-No unusual needs. -Development Costs: $0.5M
						M Force Limiting/Compliant Mechanisms ROBA-26-OL *Ranking:* M-3-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. Limited applications in D&D. **Waste:** Minimal	None	-No unusual needs. -Development Costs: $0.5M
					Controls-Algorithms	**E** Control Modes ROBA-27-OL *Ranking:* E-5-N ($N;N)*	**Accepted** for Teleoperation **Demonstration** for Preprogramming **Predemonstration** for other modes **Efficacy:** High. An essential technology. Type of control mode will depend on application. **Waste:** None.	Development: -Operator assistance technologies. -Sensor interpretation. -Task planning. Improvement: -Better human-machine interfaces.	-University level research. -Development Costs: $N
						E Vehicle/Mobility-Driving ROBA-28-OL *Ranking:* E-5-1 ($0.5M;N)*	**Accepted** **Efficacy:** High. An essential technology. Many potential applications. **Waste:** None.	Development: -Integration of driving algorithms with human-machine interface. -Fuzzy logic driving algorithms.	-Operator training. - Development Costs: $0.5M
						M Vehicle/Mobility-Navigation ROBA-29-OL *Ranking:* M-4-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. Few applications in D&D. **Waste:** None. **TTP Match**	Development: -Path planning with nonholonomic constraints. -Real-time sensor feedback.	-Operator training in Global Positioning Systems. -Development Costs: $0.5M
						H Joint Control ROBA-30-OL *Ranking:* H-4-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. Applications may be limited. Usage assumes desired trajectory is known. **Waste:** None. **TTP Match**	Development: -Special purpose control algorithms.	-University level research. -Development Costs: $0.5M
						H Cartesian Control ROBA-31-OL *Ranking:* H-4-1 ($1M;N)*	**Demonstration** **Efficacy:** Medium. Applications limited for D&D. Operator interaction is more intuitive than other control schemes. **Waste:** None	None	-No unusual needs. -Development Costs: $1.0M

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Robotics and Automation for Decontamination and Decomissioning

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						Redundomry Control ROBA-33-OL M *Ranking:** *M-3-2 ($2M;N)*	**Predemonstration** **Efficacy:** Medium. Arms with greater than 6 D.O.F. may be required for constrained areas. **Waste:** None. **TTP Match**	Development: -Advanced testbeds for testing and evaluating candidate algorithms.	-Software development. -Development Costs: $2.0M
• Facility Decontamination and Decommissioning (D&D)						Combined Mobility/Manipulation ROBA-34-OL M *Ranking:** *M-2-2 ($1M;N)*	**Evolving** **Efficacy:** Low. Minimal improvements in efficiency could be realized. **Waste:** None.	Development: -Redundancy resolution. -real-time task planning.	-Software development. -Development costs: $1.0M
						Safety-Collision Avoidance ROBA-35-OL H *Ranking:** *H-4-1 ($1M;N)*	**Accepted** **Efficacy:** Medium. An increase in efficiency would be realized and potential damage to equipment minimized. **Waste:** None. **TTP Match**	None	-Use of customized sensor sites. - Development Costs: $1.0M
						Safety-Load/Rate Limiting ROBA-36-OL H *Ranking:** *H-3-1 ($0.5M;N)*	**Accepted** **Efficacy:** Medium. An increase in efficiency would be realized and potential damage to equipment minimized. **Waste:** None.	Improvement: -Testing of load- and rate-limiting algorithms.	-Software development. -Development Costs: $0.5M
						Emergency Shutdown ROBA-37 E *Ranking:** *E-4-1 ($0.5M;N)*	**Accepted** for Teleoperation **Predemonstration** for automated shutdown. **Efficacy:** High. An essential technology to prevent catastrophic damage to equipment. **Waste:** None.	None	-Software Development. -Development Costs: $0.5M
• Remedial Action (RA)—Soils, Ground Water and Surface Water					**Control Human/Machine**	Console-Fixed/Mobile/Suitcase ROBA-38-OL E *Ranking:** *E-5-1 ($0.5M;N)*	**Demonstrated** for fixed or mobile stations. **Evolving** for suitcase control stations. **Efficacy:** High. An essential technology for use of robotics/automation. **Waste:** None.	Improvement: -Reliability and capacity of data links requires improvements.	-Improved human-machine interfaces. -Development costs: $0.5M
						Console-Data Handling Methods ROBA-39-OL M *Ranking:** *M-3-1 ($1M;N)*	**Evolving** **Efficacy:** Medium for D&D activities. The need to process, store, and retrieve data is limited. **Waste:** None. **TTP Match**	Development: -Design of heterogeneous data base management systems. -Integration of heterogeneous data sources. -Data fusion.	-Development Costs: $1.0M
						Operator Interface Command Input ROBA-40-OL H *Ranking:** *H-3-1 ($0.5M;N)*	**Evolving** **Efficacy:** High. Minimizes human error and increases operational efficiency. **Waste:** None. **TTP Match**	Development: -Language expansion. -Validation of eye-gaze measures/parameters. -Head tracking	-Specialized operator training. -Development Costs: $0.5M
• Waste Management (WM)									

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Robotics and Automation for Decontamination and Decomissioning

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						Operator Interface Status/Alert System ROBA-42-OL *Ranking:** *E-5-1 ($0.5M;N)*	**Demonstration** for most functions **Evolving** for other functions **Efficacy:** High. An essential technology to prevent damage to equipment/tools/sensors. **Waste:** None. **TTP Match**	Development: -Display navigation. -Sensor/data fusion.	-Extensive operator training. -Development Costs: $0.5M
					Sensors-Perception	Vision/Aural Systems ROBA-43-OL *Ranking:** *E-5-1 ($1M;N)*	**Demonstration** for 3-D and HDTV. **Predemonstration** for directional aural. **Efficacy:** High. An essential technology for Robotics/Automation. **Waste:** None.	Development: -Sensor fusion. -Increased processing speed. -Advanced visualization.	-No unusual needs -Development Costs: $1.0M
						Range Finders ROBA-44-OL *Ranking:** *M-3-2 ($1.5M;N)*	**Accepted** **Efficacy:** Medium. Applications are limited. **Waste:** None. **TTP Match**	Improvement: -Speed/accuracy improvement.	-No unusual needs -Development Costs: $1.5M
						Proximity Probes ROBA-45-OL *Ranking:** *M-2-2 ($1M;N)*	**Predemonstration** **Efficacy:** Medium. Alternatives to probes may be more cost effective. **Waste:** None. **TTP Match**	Improvement: -Increased range and improved presentation to operator.	-No unusual needs -Development Costs: $1.0M
						Force/Torque Sensors ROBA-46-OL *Ranking:** *M-2-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. Applications for D&D are very limited. **Waste:** None **TTP Match**	Improvement: -Testing of force sensing systems.	-No unusual needs -Development Costs: $0.5M
					Sensors/Control	Position/Velocity Sensors ROBA-48-OL *Ranking:** *E-5-1 ($0.5M;N)*	**Accepted** **Efficacy:** High for analytical laboratory applications or sensor sweeps. **Waste:** None.	None	-No unusual needs -Development Costs: $0.5M
						Force/Torque Sensors ROBA-50-OL *Ranking:** *H-3-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. Few applications in D&D activities. The need for force or torque control to prevent damage is limited. **Waste:** None. **TTP Match**	Improvement: -Impulse force resolution. -Stability.	-No unusual needs -Development Costs: $0.5M
						Proximity Sensors ROBA-51-OL *Ranking:** *H-3-1 ($1M;N)*	**Accepted** for small volumes. **Predemonstration** for large volumes. **Efficacy:** Medium. Alternatives to sensors may be more cost effective. **Waste:** None.	Improvement: -Increased range and better signal quality.	-No unusual needs -Development Costs: $1.0M

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					Other Technologies	Field Hardening ROBA-53-OL M *Ranking:** *M-3-1 ($0.5M;N)*	**Demonstration** **Efficacy:** Medium. The primary environmental concern in D&D is high radiation fields as described in ROBA-54-OL *Ranking:** The ability to be decontaminated is essential for mechanical devices. **Waste:** None **TTP Match**	None	-Testing of hardened systems. -Development Costs: $0.5M
						Radiation Hardening ROBA-54-OL E *Ranking:** *E-5-2 ($2M;N)*	**Demonstration** **Efficacy:** High. An essential technology for many D&D activities, particularly reactors and hot cells. **Waste:** None. **TTP Match**	None	-Extensive radiation testing of existing electronic chips. -Development Cost: $2.0M
						Integrated Automated Analytical Laboratory ROBA-55-OL E *Ranking:** *E-5-2 ($3M;N)*	**Predemonstration** for hardware systems. **Evolving** for data interpretation. **Efficacy:** High. High sample loading in analytical laboratories require maximum use of automation **Waste:** None. **TTP Match**	Development: -Development of Standard Laboratory Modules (SLM) for Sample Preparation, Analytical Instruments, and Data Interpretation.	-Extensive testing of SLM's. -EPA approval of SLM -Development Costs: $3.0M
						Information Management for Sample Handling ROBA-56-OL E *Ranking:** *E-5-1 ($1M;N)*	**Demonstration** **Efficacy:** High. **Waste:** None. **TTP Match**	Development: -Automatic data entry systems. -Improved reliability and auditabilty.	-No unusual needs -Development Costs: $1.0M
						Sample Collection ROBA-57-OL E *Ranking:** *E-5-1 ($1.5M;N)*	**Evolving** **Efficacy:** Medium. Alternative, but slower methods of sample collection are available and may be more cost effective. **Waste:** None. **TTP Match**	Development: -Mobile platforms to deploy and manipulate sample collection tools. -Suitable robotic end-effectors.	-No unusual needs -Development Costs: $1.5M
						Characterization Sensor Integration ROBA-58-OL M *Ranking:** *M-3-2 ($1M;N)*	**Demonstration** **Efficacy:** Low. May not be cost effective. **Waste:** None. **TTP Match**	Development: -Signal conditioning. -Data/Signal transmission.	-No unusual needs. -Development Costs: $1.0M
						Sample Preparation ROBA-59-OL E *Ranking:** *E-5-1 ($1M;N)*	**Evolving** **Efficacy:** Medium. Will minimize work to be performed in analytical laboratory. **Waste:** Usual amount of waste normally generated in sample preparation operations. **TTP Match**	None	-Adaptation of current sample preparation tools to robotic devices. -Development Costs: $1.0M

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