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DRAFT FINAL

PHASE II RFI/RI REPORT
903 PAD, MOUND, AND
EAST TRENCHES AREA
OPERABLE UNIT NO. 2

VOLUME 15

APPENDIX H
BASELINE HEALTH
RISK ASSESSMENT

APPENDIX I

U.S. Department of Energy
Rocky Flats Environmental Technology Site
Golden, Colorado

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TABLE OF CONTENTS

Section — Page

LIST OF ACRONYMS xlvii

VOLUME 1

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1-1

1.1 REPORT ORGANIZATION 1-2
1.2 INVESTIGATION OBJECTIVES 1-4
1.3 BACKGROUND 1-7

1.3.1 Plant Operations 1-7
1.3.2 OU-2 Individual Hazardous Substance Sites Locations 1-8

1.3.2.1 903 Pad IHSS Area 1-10
1.3.2.2 Mound Area 1-16

1.3.3 Previous Investigations 1-22

1.3.3.1 Regional and Plantwide Studies 1-22
1.3.3.2 OU-2 Phase I Investigation 1-26
1.3.3.3 Shallow, High Resolution Seismic Investigation 1-31
1.3.3.4 Observations on the Occurrence of Plutonium and Americium in Ground and Surface Water 1-32

1.4 SUMMARIES OF OU-2 PHASE II RFI/RI WORK PLANS AND TECHNICAL MEMORANDA 1-32

1.4.1 Summary of Technical Memorandum 1 - Final Phase II RFI/RI Work Plan (Alluvial) 1-34
1.4.2 Summary of TM2 - Addendum to Final Phase II RFI/RI Work Plans (Alluvial and Bedrock) Chemical Analysis Plan 1-37

Section Page

1.4.3 Summary of TM3 - Final Phase II RFI/RI Aquifer Test Work Plan 1-40
1.4.4 Summary of TM5 - Exposure Assessment 1-43

1.4.4.1 Present and Future Land Use 1-43
1.4.4.2 Potential Receptors 1-44
1.4.4.3 Receptor Locations and Exposure Areas 1-45
1.4.4.4 Potential Exposure Pathways 1-46
1.4.4.5 Exposure Parameters 1-48

1.4.5 Summary of TM6 - Human Health Risk Assessment Model Description 1-48
1.4.6 Summary of TM7 - Addendum to Final Phase II RFI/RI Work Plan 1-50
1.4.7 Summary of TM8 - Final Revised Phase II RFI/RI Work Plan (Bedrock) 1-52
1.4.8 Summary of TM9 - Chemicals of Concern 1-57
1.4.9 Summary of TM10 - Toxicity Assessment 1-61
1.4.10 Summary of Environmental Evaluation Work Plan 1-63

2.0 OU-2 FIELD INVESTIGATIONS 2-1

2.1 PHASE II ALLUVIAL INVESTIGATION 2-1

2.1.1 Subsurface Soils Investigation 2-2
2.1.2 Individual Hazardous Substance Site Characterization 2-4

2.1.2.1 Source Characterization Borehole Sampling . . . 2-5
2.1.2.2 Source Characterization Borehole Analytical Parameters 2-6
2.1.2.3 Data Management 2-7

2.1.3 Groundwater Investigation 2-7

2.1.3.1 Monitoring Well Installation 2-9
2.1.3.2 Monitoring Well Development and Groundwater Sampling 2-9
2.1.3.3 Hydraulic Testing Program 2-10

Section Page

2.1.4 Geological Investigation 2-11
2.1.5 Work Plan Deviations 2-13

2.1.5.1 Site Status Summary 2-13
2.1.5.2 Drilling Procedures 2-14
2.1.5.3 Sampling Deviations 2-15

2.2 PHASE II REVISED BEDROCK WORK PLAN INVESTIGATION . 2-16

2.2.1 Subsurface Soils Investigation 2-18
2.2.2 Individual Hazardous Substance Site Investigation 2-22

2.2.2.1 Source Characterization Borehole Sampling . . 2-23

2.2.3 Groundwater Investigation 2-25

2.2.3.1 Pilot Borehole 2-26
2.2.3.2 Monitoring Well Installation 2-27
2.2.3.3 Monitoring Well Development and Groundwater Sampling 2-31
2.2.3.4 Slug Testing 2-32

2.2.4 Geological Investigation 2-33
2.2.5 Work Plan Deviations 2-35

2.3 AIR QUALITY AND METEOROLOGICAL INVESTIGATION 2-37

2.3.1 Air Quality 2-37

2.3.1.1 Radionuclides Ambient Monitoring 2-37
2.3.1.2 Nonradionuclides Ambient Monitoring 2-38

2.3.2 Meteorology 2-38

2.4 SURFACE WATER AND SEDIMENT INVESTIGATION 2-39

2.4.1 Sample Locations, Collection, and Frequency 2-39
2.4.2 Seep and Sediment Analytical Parameters 2-41

Section Page

2.5 SURFACE SOIL INVESTIGATION 2-41

2.5.1 Surface Soil Sampling for Evaluating the Spatial Extent of Actinides 2-42

2.5.1.1 CDH Method Sampling 2-43
2.5.1.2 RFP Method Sampling 2-45

2.5.2 Soil Profile Investigation 2-45

2.5.2.1 Vertical Distribution Study of Actinides in Soils 2-46
2.5.2.2 Fate and Transport of Actinides in Soils 2-47

2.5.3 Surface Soil Sampling for Human Health Risk Assessment 2-48

2.5.3.1 Methodology 2-48
2.5.3.2 Work Plan Deviations 2-49

2.5.4 Background Surface Soil Sampling 2-49

2.5.4.1 Methodology 2-49
2.5.4.2 Work Plan Deviations 2-50

2.5.5 Data Management 2-50

2.6 ECOLOGICAL INVESTIGATION 2-50

2.6.1 Sampling Locations 2-51
2.6.2 Ecological Investigations 2-52

2.6.2.1 Vegetation 2-52
2.6.2.2 Small Mammals 2-53
2.6.2.3 Birds 2-53
2.6.2.4 Terrestrial Arthropods 2-54

Section Page

3.0 PHYSICAL CHARACTERISTICS OF OU-2 3-1

3.1 PHYSIOGRAPHIC FEATURES 3-1

3.1.1 Regional 3-1
3.1.2 Operable Unit 2 3-2

3.2 DEMOGRAPHICS AND LAND USE 3-3

3.2.1 Demographics 3-3
3.2.2 Off-Site Land Use 3-4

3.2.2.1 Current Land Use 3-4
3.2.2.2 Future Land Use 3-5

3.2.3 On-Site Land Use 3-6

3.2.3.1 Current Land Use 3-6
3.2.3.2 Future Land Use 3-6

3.3 METEOROLOGY AND CLIMATOLOGY 3-7
3.4 SOILS 3-8
3.5 GEOLOGY 3-9

3.5.1 Surficial Geology 3-11

3.5.1.1 Rocky Flats Alluvium 3-11
3.5.1.2 High Terrace Alluviums 3-24
3.5.1.3 Valley-Fill Alluvium 3-26
3.5.1.4 Colluvium 3-27
3.5.1.5 Debris Fans 3-28
3.5.1.6 Slumps 3-29
3.5.1.7 Man-made Deposits 3-30

3.5.2 Bedrock Geology 3-32

3.5.2.1 Arapahoe Formation No. 1 Sandstone 3-33
3.5.2.2 Upper Laramie Formation 3-37

Section Page

3.6 HYDROGEOLOGY 3-43

3.6.1 Regional Hydrogeology 3-43
3.6.2 OU-2 Hydrogeology 3-45

3.6.2.1 Definition of Hydrostratigraphic Units 3-46
3.6.2.2 Upper Hydrostratigraphic Unit 3-47
3.6.2.3 Lower Hydrostratigraphic Unit 3-66

3.7 SURFACE WATER HYDROLOGY 3-74

3.7.1 South Walnut Creek 3-75
3.7.2 Woman Creek 3-77

3.8 ECOLOGY 3-78

3.8.1 General Setting 3-78
3.8.2 Vegetation 3-78
3.8.3 Wildlife 3-80
3.8.4 Aquatic Organisms 3-82
3.8.5 Sensitive Habitats and Endangered Species 3-83
3.8.6 Location of OU-2 IHSSs Relative to Habitat Types 3-85

VOLUME 2

ES4.0 EXECUTIVE SUMMARY ES4-1

ES4.1 903 PAD SOURCE AREA SUMMARY ES4-1

ES4.1.1 Surface Soil ES4-2
ES4.1.2 Subsurface Soil ES4-3

ES4.1.2.1 Western Portion ES4-3
ES4.1.2.2 Central Portion ES4-7
ES4.1.2.3 Eastern Portion ES4-9

ES4.1.3 UHSU Groundwater ES4-9
ES4.1.4 LHSU Groundwater ES4-12

Section		Page
ES4.1.5	Seep Surface Water and Seep Sediment	ES4-13
ES4.1.6	Air	ES4-16
ES4.2	MOUND SOURCE AREA SUMMARY	ES4-16
ES4.2.1	Surface Soil	ES4-17
ES4.2.2	Subsurface Soil	ES4-18
ES4.2.3	UHSU Groundwater	ES4-19
ES4.2.4	LHSU Groundwater	ES4-21
ES4.2.5	Seep Surface Water and Seep Sediment	ES4-22
ES4.2.6	Air	ES4-24
ES4.3	NORTHEAST TRENCHES SOURCE AREA SUMMARY	ES4-24
ES4.3.1	Surface Soil	ES4-24
ES4.3.2	Subsurface Soil	ES4-25
ES4.3.3	UHSU Groundwater	ES4-27
ES4.3.4	LHSU Groundwater	ES4-29
ES4.3.5	Seep Surface Water and Seep Sediment	ES4-30
ES4.3.6	Air	ES4-30
ES4.4	SOUTHEAST TRENCHES SOURCE AREA	ES4-30
ES4.4.1	Surface Soil	ES4-30
ES4.4.2	Subsurface Soil	ES4-31
ES4.4.3	UHSU Groundwater	ES4-32
ES4.4.4	LHSU Groundwater	ES4-33
ES4.4.5	Seep Surface Water and Seep Sediment	ES4-33
ES4.4.6	Air	ES4-33
ES4.5	EAST OF IHSSs SOURCE AREA	ES4-34
ES4.5.1	Surface Soil	ES4-34
ES4.5.2	Subsurface Soil	ES4-36
ES4.5.3	UHSU Groundwater	ES4-37
ES4.5.4	LHSU Groundwater	ES4-38
ES4.5.5	Seep Surface Water and Seep Sediment	ES4-39
ES4.5.6	Air	ES4-39

Section Page

4.0 NATURE AND EXTENT OF POTENTIAL CONTAMINATION 4-1

4.1 DESCRIPTION OF CHEMICAL DATA USED 4-2

4.1.1 OU-2 Chemical Data 4-3

4.1.1.1 Surface Soil Data 4-4
4.1.1.2 Subsurface Soil Data 4-5
4.1.1.3 Groundwater Data 4-7
4.1.1.4 Seep Surface Water and Seep Sediment Data . . 4-8
4.1.1.5 Air Data 4-9

4.1.2 Chemical Data Evaluation 4-10

4.1.1.1 Potential Laboratory and Other Non Site-Related Contaminants 4-10
4.1.2.2 Detection Limits Definition 4-12
4.1.2.3 Quality Assurance Summary 4-13

4.1.3 Background Chemical Data 4-15

4.1.3.1 Background Surface Soil Data 4-15
4.1.3.2 Background Subsurface Soil Data 4-16
4.1.3.3 Background Groundwater Data 4-16
4.1.3.4 Background Groundwater Geochemistry 4-17
4.1.3.5 Background Seep Surface Water and Seep Sediment Data 4-19

4.1.4 Comparison of OU-2 Data to Background Data 4-19

4.1.4.1 Data Aggregation 4-19
4.1.4.2 Statistical Background Comparison 4-20
4.1.4.3 Professional Judgement 4-22
4.1.4.4 Background Comparison Results 4-23

4.1.5 Identification of Source Areas 4-24
4.1.6 Identification of Chemicals of Concern 4-26
4.1.7 Applicable or Relevant and Appropriate Requirements . . . 4-27

Section Page

4.2 SURFACE SOIL CHEMICAL RESULTS 4-28

4.2.1 Background Surface Soil Chemical Results (Rock Creek Area) 4-29
4.2.2 OU-2 Surface Soil Chemical Results 4-29

4.2.2.1 Semivolatile Organic Compound Results 4-30
4.2.2.2 Pesticides/PCB Results 4-31
4.2.2.3 Metal Results 4-32
4.2.2.4 Radionuclide Results 4-33

4.2.3 Summary of Nature and Extent of Potential Contamination In Surface Soils 4-35
4.2.4 Investigations of Actinide Distribution in the Soil Environment 4-36

4.2.4.1 Spatial Analysis of Actinides in Soils East of the RFETS Industrial Area 4-37
4.2.4.2 Vertical Distribution and Physicochemical Characteristics of Actinides in Soils East of the RFETS Industrial Area 4-42

4.3 SUBSURFACE SOIL CHEMICAL RESULTS 4-47

4.3.1 903 Pad Source Area (Western Portion) 4-49

4.3.1.1 Trench T-2 (IHSS 109) 4-49
4.3.1.2 903 Drum Storage Site (IHSS 112) 4-54
4.3.1.3 Reactive Metal Destruction Site (IHSS 140) . . 4-59
4.3.1.4 903 Lip Site (IHSS 155) 4-64
4.3.1.5 Gas Detoxification Site (IHSS 183) 4-69
4.3.1.6 903 Pad Source Area (Western Portion) (Non-IHSS Locations) 4-70

4.3.2 903 Pad Source Area (Central Portion) 4-74

4.3.2.1 Trench T-9 (IHSS 111.6) 4-74
4.3.2.2 Trench T-10 (IHSS 111.7) 4-78

Section			Page
	4.3.2.3	Trench T-11 (IHSS 111.8)	4-80
	4.3.2.4	Trench T-12	4-84
	4.3.2.5	Trench T-13	4-86
	4.3.2.6	903 Pad Source Area (Central Portion) (Non-IHSS Locations)	4-87
4.3.3	903 Pad Source Area (Eastern Portion)		4-91
	4.3.3.1	East Spray Field (IHSS 216.2)	4-91
	4.3.3.2	East Spray Field (IHSS 216.3)	4-92
	4.3.3.3	903 Pad Source Area (Eastern Portion) (Non-IHSS Locations)	4-96
4.3.4	Mound Area		4-96
	4.3.4.1	Trench T-1 (IHSS 108)	4-97
	4.3.4.2	Mound Site (IHSS 113)	4-100
	4.3.4.3	Oil Burn Pit No. 2 Site (IHSS 153)	4-104
	4.3.4.4	Pallet Burn Site (IHSS 154)	4-106
	4.3.4.5	Mound Area (Non-IHSS Locations)	4-109
4.3.5	Northeast Trenches Source Area		4-111
	4.3.5.1	Trench T-3 (IHSS 110)	4-112
	4.3.5.2	Trench T-4 (IHSS 111.1)	4-120
	4.3.5.3	Northeast Trenches Source Area (Non-IHSS Locations)	4-125
4.3.6	Southeast Trenches Source Area		4-127
	4.3.6.1	Trench T-5 (IHSS 111.2)	4-127
	4.3.6.2	Trench T-6 (IHSS 111.3)	4-131
	4.3.6.3	Trench T-7 (IHSS 111.4)	4-133
	4.3.6.4	Trench T-8 (IHSS 111.5)	4-136
	4.3.6.5	Southeast Trenches (Non-IHSS Locations)	4-141
4.3.7	Subsurface Soil Results East of IHSSs Source Area		4-142

Section | Page

4.4 UPPER HYDROSTRATIGRAPHIC UNIT GROUNDWATER 4-145

4.4.1 UHSU Groundwater Geochemistry 4-147

4.4.1.1 pH 4-147
4.4.1.2 Anion/Cation Characteristics 4-147
4.4.1.3 Comparison of OU-2 and Background Groundwater Chemistry 4-149

4.4.2 Potential Chemicals of Concern 4-149

4.4.2.1 903 Pad Source Area 4-151
4.4.2.2 Mound Source Area 4-157
4.4.2.3 Northeast Trenches Source Area 4-160
4.4.2.4 Southeast Trenches Source Area 4-164
4.4.2.5 Area East of OU-2 IHSSs 4-165
4.4.2.6 Potential Occurrence of DNAPLs in the UHSU 4-168

4.5 LOWER HYDROSTRATIGRAPHIC UNIT GROUNDWATER 4-168

4.5.1 LHSU Groundwater Geochemistry 4-170
4.5.2 LHSU Groundwater Chemical Results 4-172

4.5.2.1 Volatile Organic Compounds 4-172
4.5.2.2 Semi-Volatile Organic Compounds 4-175
4.5.2.3 Pesticides and PCBs 4-176
4.5.2.4 Metals 4-176
4.5.2.5 Radionuclides 4-177

4.6 SEEP SURFACE WATER AND SEEP SEDIMENT 4-179

4.6.1 903 Pad Source Area 4-180

4.6.1.1 Historical Information 4-181
4.6.1.2 Chemical Results 4-181

Section Page

4.6.2 Mound Source Area 4-185

4.6.2.1 Historical 4-185
4.6.2.2 Chemical Results 4-185

4.7 AIR 4-187

5.0 FATE AND TRANSPORT OF CHEMICALS OF CONCERN 5-1

5.1 TRANSPORT PROCESSES 5-2

5.1.1 Vadose Zone 5-2
5.1.2 Groundwater 5-4
5.1.3 Surface Water and Sediment Processes 5-5
5.1.4 Air Processes 5-6

5.2 MOBILITY AND BEHAVIOR OF CHEMICALS OF CONCERN 5-8

5.2.1 Primary Physical and Chemical Processes that Influence the Mobility and Behavior of Contaminants 5-8
5.2.2 Physical and Chemical Properties of the Media that Affect Mobility and Behavior 5-12
5.2.3 Physical and Chemical Properties of Chemicals that Influence Mobility and Behavior 5-16

5.2.3.1 Volatile Organic Compounds 5-16
5.2.3.2 Semivolatile Organic Compounds 5-19
5.2.3.2 Metals 5-20
5.2.3.4 Radionuclides 5-21

5.2.4 Mobility and Behavior of Chemicals of Concern 5-22

5.2.4.1 Mobility and Behavior of Organic Compound COCs 5-22
5.2.4.2 Mobility and Behavior of Radionuclides and Metals 5-26

Section Page

5.3 OU-2 CONTAMINANT MIGRATION PATHWAYS 5-32

5.3.1 903 Pad Source Area 5-33
5.3.2 Northeast Trenches Source Area 5-36
5.3.3 Southeast Trenches Source Area 5-38
5.3.4 Mound Source Area 5-39
5.3.5 Source Area East of OU-2 IHSSs 5-40
5.3.6 Potential Contaminant Migration in the LHSU 5-41

5.3.6.1 903 Pad Source Area 5-44
5.3.6.2 Northeast Trenches Source Area 5-46
5.3.6.3 Southeast Trenches Source Area 5-48
5.3.6.4 Mound Source Area 5-48
5.3.6.5 Source Area East of OU-2 IHSSs 5-49

5.4 QUANTITATIVE EVALUATION OF FATE AND TRANSPORT OF CHEMICALS OF CONCERN FOR RISK ASSESSMENT 5-49

5.4.1 Groundwater Flow and Contaminant Fate and Transport Modeling 5-50

5.4.1.1 Simplified Conceptual Model 5-52
5.4.1.2 MODFLOW Groundwater Flow Model 5-55
5.4.1.3 MT3D Groundwater Fate and Transport Model 5-56
5.4.1.4 ONED3 Colluvium Groundwater Fate and Transport Model 5-58

5.4.2 Surface Water Contaminant Fate and Transport Modeling . 5-60

5.4.2.1 Introduction 5-60
5.4.2.2 Hydrologic and Contaminant Conditions at OU-2 5-61
5.4.2.3 Model Overview and Assumptions 5-62
5.4.2.4 Hydrologic Simulations 5-64
5.4.2.5 Simulation of Contaminant Loads 5-67
5.4.2.6 Volatile Organic Compound Volatilization . . . 5-69
5.4.2.7 Modeling Results 5-71

Section Page

5.4.3 Air Modeling Approach and Results 5-72

5.4.3.1 Introduction 5-72
5.4.3.2 Model Selection 5-72
5.4.3.3 Modeling Setup 5-73
5.4.3.4 Results 5-74

5.4.4 Fate and Transport of Actinides in Soils near Rocky Flats Plant: An Empirical Approach 5-76

VOLUME 5

6.0 HUMAN HEALTH RISK ASSESSMENT 6-1

6.1 INTRODUCTION 6-1

6.1.1 Site Description 6-1
6.1.2 Guidance Documents 6-2
6.1.3 Human Health Risk Assessment Organization 6-2

6.2 DATA EVALUATION AND AGGREGATION 6-3

6.2.1 Chemical Analytical Results Used in Risk Assessment 6-3
6.2.2 Chemical Data Qualifiers 6-5
6.2.3 Data Aggregation for Risk Assessment 6-5

6.3 CHEMICALS OF CONCERN (COCs) 6-8

6.3.1 Process For Selecting OU-Wide COCs 6-8
6.3.2 Summary of COCs 6-11

6.4 EXPOSURE SCENARIOS 6-12

6.4.1 Current and Future Land Use 6-12
6.4.2 Onsite Exposure Areas 6-14
6.4.3 Receptors Selected For Quantitative Risk Assessment 6-14
6.4.4 Exposure Pathways 6-16

Section | Page

6.5 EXPOSURE POINT CONCENTRATIONS 6-17

6.5.1 Calculating the Concentration Term 6-17
6.5.2 Surface Soil 6-18
6.5.3 Subsurface Soil 6-19
6.5.4 Groundwater 6-19
6.5.5 Air Concentrations from Wind Erosion of Surface Soil . . 6-20
6.5.6 Onsite Air Concentrations from Construction Activities . . 6-21
6.5.7 Basement Air 6-21
6.5.8 Indoor VOCs from Domestic Use of Groundwater 6-21
6.5.9 Surface Water/Sediment 6-22
6.5.10 Root Uptake of Contaminants from Surface Soil 6-23
6.5.11 Deposition of PM_{10} on Garden Produce 6-24
6.5.12 Offsite Soil Concentrations from Deposition of PM_{10} 6-25

6.6 ESTIMATING CHEMICAL INTAKES 6-25

6.6.1 General Intake Equation 6-26
6.6.2 Pathway-Specific Intake Equations and Exposure Factors . 6-27
6.6.3 Age-weighted Soil Ingestion Rate 6-27
6.6.4 Chemical-Specific Exposure Factors 6-28
6.6.5 Area Weighting Factor for Current Onsite Worker 6-28

6.7 TOXICITY ASSESSMENT 6-29
6.8 RISK CHARACTERIZATION 6-29

6.8.1 Hazard Index For Noncarcinogenic Effects 6-30
6.8.2 Carcinogenic Risk 6-31
6.8.3 AOC No. 1 6-32
6.8.4 Maximum Exposure Areas in AOC No. 1 6-33
6.8.5 AOC No. 2 6-35
6.8.6 Offsite Residents 6-35
6.8.7 Summary of Cumulative Hazard/Risk Results 6-36
6.8.8 Evaluation of Health Hazards from Potential Exposure to Lead in OU-2 6-37

Section Page

6.9 RADIATION DOSE CALCULATIONS 6-39

6.9.1 Calculating Annual Radiation Doses 6-39
6.9.2 Radiation Protection Standards 6-41
6.9.3 Radiation Dose Estimates 6-41

6.10 UNCERTAINTIES AND LIMITATIONS 6-42

6.10.1 Identification of COCs 6-43
6.10.2 Exposure Point Concentrations 6-43
6.10.3 Exposure Scenarios and Pathways 6-44
6.10.4 Toxicity Assessment 6-44
6.10.5 Evaluation of Risk Associated with Special-Case COCs . . 6-45

6.11 SUMMARY AND CONCLUSIONS 6-46

6.11.1 Summary 6-46
6.11.2 Conclusions 6-49

7.0 CONCLUSIONS AND RECOMMENDATIONS 7-1

7.1 SUMMARY 7-1
7.2 RECOMMENDATIONS 7-5

A MASTER REFERENCE LIST IS INCLUDED IN EACH VOLUME.

LIST OF APPENDIXES

VOLUMES 6, 7, 8, AND 9

APPENDIX A OU-2 GEOLOGICAL DATA

A1 OU-2 PHASE II SURVEY DATA
A2 OU-2 PHASE II GEOTECHNICAL DATA
A3 OU-2 STRATIGRAPHIC DATA (HISTORICAL, PHASE II AND OTHER INVESTIGATIONS)
A4 OU-2 BOREHOLE LITHOLOGY AND MONITORING WELL CONSTRUCTION LOGS

VOLUME 9

This report has one set containing all volumes and another that does not contain Volumes 10, 11, and 12. The second set contains a disk copy of Appendix C, Analytical Data. The disk is at the end of Volume 9 for the second set.

APPENDIX B OU-2 HYDROGEOLOGIC DATA

B1 ESTIMATION OF HYDRAULIC CONDUCTIVITY BASED ON 1993 RBWP SLUG TESTING
B2 OU-2 HISTORICAL AND PHASE II ALLUVIAL AND BEDROCK MONITORING WELL INSTALLATION DATA
B3 OU-2 GROUNDWATER ELEVATION DATA AND HYDROGEOLOGIC DATA
B4 OU-2 GROUNDWATER ELEVATION HYDROGRAPHS

VOLUMES 10, 11, AND 12

APPENDIX C ANALYTICAL DATA

C1 BACKGROUND SURFACE SOIL: SVOCs, PESTICIDES/PCBs, METALS, INORGANIC, RADIONUCLIDES
C2 SURFACE SOIL: SVOCs, PESTICIDES/PCBs, METALS, INORGANICS, RADIONUCLIDES
C3 SUBSURFACE SOIL: VOCs, SVOCs, PESTICIDES/PCBs, METALS, INORGANICS, RADIONUCLIDES

C4 UHSU GROUNDWATER: VOCs, SVOCs, PESTICIDES/PCBs, UNFILTERED METALS, FILTERED METALS, INORGANICS, UNFILTERED RADIONUCLIDES, FILTERED RADIONUCLIDES
C5 LHSU GROUNDWATER: VOCs, SVOCs, PESTICIDES/PCBs, UNFILTERED METALS, FILTERED METALS, INORGANICS, UNFILTERED RADIONUCLIDES, FILTERED RADIONUCLIDES
C6 SEEP SURFACE WATER: VOCs, SVOCs, PESTICIDES/PCBs, UNFILTERED METALS, FILTERED METALS, INORGANICS, UNFILTERED RADIONUCLIDES, FILTERED RADIONUCLIDES
SEEP SEDIMENT: VOCs, SVOCs, PESTICIDES/PCBs, METALS, INORGANICS, RADIONUCLIDES
C7 FIELD PARAMETERS

VOLUME 13

APPENDIX D INVESTIGATIONS OF ACTINIDE DISTRIBUTION, FATE AND TRANSPORT IN SOIL

D1 SPATIAL ANALYSIS OF PLUTONIUM-239 IN SOIL AROUND ROCKY FLATS PLANT
D2 SPATIAL ANALYSIS OF AMERICIUM-241 IN SOIL AROUND ROCKY FLATS PLANT
D3 SPATIAL ANALYSIS OF URANIUM ISOTOPES IN SOIL AROUND ROCKY FLATS PLANT
D4 SOIL CLASSIFICATION, MINERALOGY, AND MORPHOLOGY
D5 VERTICAL DISTRIBUTION AND PHYSICOCHEMICAL CHARACTERIZATION OF ACTINIDES IN SOIL EAST OF ROCKY FLATS PLANT
D6 FATE AND TRANSPORT OF ACTINIDES IN SOIL AT ROCKY FLATS PLANT: AN EMPIRICAL APPROACH
D7 MODELING THE VADOSE ZONE IN SOIL OF ROCKY FLATS PLANT

VOLUME 14

APPENDIX E GROUNDWATER MODELING

E1 INTRODUCTION
E2 HYDROGEOLOGIC AND CONTAMINATION CONDITIONS
E3 SIMPLIFIED CONCEPTUAL MODEL FOR APPLICATION OF MATHEMATICAL MODELS
E4 NUMERICAL GROUNDWATER FLOW MODEL FOR THE ROCKY FLATS ALLUVIUM AND NO. 1 SANDSTONE

APPENDIX F SURFACE WATER MODELING

F1 INTRODUCTION
F2 CONCEPTUAL MODEL FOR THE HYDROLOGIC AND CONTAMINANT CONDITIONS
F3 MODELING APPROACH AND ASSUMPTIONS
F4 HYDROLOGIC SIMULATIONS

APPENDIX G AIR MODELING

G1 MODEL SELECTION
G2 MODELING SETUP
G3 MODEL INPUT PARAMETERS
G4 RESULTS

VOLUME 15

APPENDIX H BASELINE HEALTH RISK ASSESSMENT

H1 INTRODUCTION
H2 DATA EVALUATION AND AGGREGATION
H3 CHEMICALS OF CONCERN
H4 EXPOSURE SCENARIOS
H5 EXPOSURE POINT CONCENTRATIONS
H6 ESTIMATING CHEMICAL INTAKES
H7 TOXICITY FACTORS
H8 RISK CHARACTERIZATION
H9 RADIATION DOSE CALCULATIONS
H10 UNCERTAINTIES AND LIMITATIONS

H11 SUMMARY AND CONCLUSIONS
H12 REFERENCES

APPENDIX I ENVIRONMENTAL EVALUATION

VOLUME 16

APPENDIX J QUALITY ASSURANCE

J1 PRECISION RFP CALCULATIONS
J2 EQUIPMENT RINSATE DATA
J3 TRIP BLANK DATA

°C	degrees Celsius
%R	percent recovery
µCi/L	microcuries per liter
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µCi/yr	microcuries per year
µm	micrometers
1,1-DCE	1,1-dichloroethene
1,1,1-TCA	1,1,1-trichloroethane
1,2-DCA	1,2-dichlorethane
1,2-DCE	1,2-dichloroethene
ac-ft	acre feet
AEC	Atomic Energy Commission
AET	actual evapotranspiration
Ag	silver
AGL	above ground level
AGS	above ground surface
Al	aluminum
ALARA	as low as reasonably achievable
Am	americium
Am-241	americium-241
$Am_2(CO_3)_3$	americium carbonate
AmO_2	americium dioxide
ANOVA	Analysis of Variance
ANOVA	Analysis of Variance
AOC	Area of Concern
AR	activity ratio
ARARs	applicable or relevant and appropriate requirements
As	arsenic
ASTM	American Society for Testing and Materials
ATD	At time of drilling
atm-m^3/mole	Atmosphere-cubic meter per mole
Ba	barium
BCF	bioconcentration factor
Be	beryllium
BEHP	bis(2-ethylhexyl)phthalate
BGS	below ground surface
BH	borehole
BNA	base neutral acid extractable
Bq	Becquerel
BSL	Background Screening Level

BW	body weight
c/f	coarse fine limit
Ca	calcium
CAS	Chemical Abstract Services
CCl_4	carbon tetrachloride
Cd	cadmium
CDH	Colorado Department of Health
CDPHE	Colorado Department of Public Health and Environment
Ce	cesium
CEARP	Comprehensive Environmental Assessment & Response Program
CEC	cation exchange capacity
CEDE	committed effective dose equivalent
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfm	cubic feet per minute
CHC	chlorinated hydrocarbon
$CHCl_3$	chloroform
Ci	curies
Cis-1,2-DCE	cis-1,2-dichloroethene
CLP	Contract Laboratory Program
cm	centimeter
cm/hr	centimeters per hour
cm/s	centimeters per second
cm^3	cubic centimeter
CME	Central Mine Equipment
CMS/FS	Corrective Measures Study/Feasibility Study
Co	cobalt
COC	chemical of concern
COI	chemicals of interest
cpm	counts per minute
Cr	chromium
Cr VI	chromium hexavalent
CRDL	contract required detection limit
CRQL	contract required quantitation limit
CS	claystone
Cs-134	cesium-34
Cs-137	cesium-137
CSM	conceptual site model
CSU	Colorado State University
CT	central tendency
Cu	copper
Cu	copper
CUHP	Colorado Urban Hydrograph Procedure
DCG	Derived Concentration Guide

DCN	document change notice
DF10 qualifier	10x dilution
DF50 qualifier	50x dilution
DMR	document modification request
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOE	Department of Energy
dpm/g	disintegrations per minute per gram
DQO	Data Quality Objective
DRCOG	Denver-Regional Council of Governments
DW	dry weight
ECAO	Environmental Criteria and Assessment Office
ED	exposure duration
EDE	effective dose equivalent
EE	Environmental Evaluation
EF	exposure frequency
EG&G	EG&G Rocky Flats, Inc.
EIS	Environmental Impact Statement
EM	electromagnetics
EMC	event mean concentrations
EMD	Environmental Management Department
EPA	Environmental Protection Agency
ER	Environmental Restoration
ERA	Environmental Risk Assessment
ERDA	Energy Research and Development Administration
ERM	Environmental Restoration Management
ET	evapotranspiration
FDM	Fugitive Dust Model
Fe	iron
f_i	fractional uptake
FID	flame ionization detectors
FIDLER	field instrument for the detection of low-energy radiation
FS	feasibility study
FSP	field sampling plan
ft^2/min	square feet per minute
FWHM	full width half maximum
FWS	U.S. Fish and Wildlife Service
g/l	grams per liter
g/cm^3	gram per cubic centimeter
g/s	grams per second
g	grams
GC/MS	gas chromatography/mass spectrometry
GI	gastrointestinal
GIS	geographical information system

gpd/ft^2	gallons per day per square foot
gpm	gallons per minute
GPMPP	Groundwater Protection and Monitoring Program Plan
GPR	ground-penetrating radar
GRRASP	General Radiochemistry and Routine Analytical Services Protocol
GSSI	Geophysical Survey Systems, Inc.
GUI	Graphical User Interface
Gy	gray
HASL	Health and Safety Laboratory
HEPA	High Efficiency Particulate Air
Hg	mercury
HHRA	Human Health Risk Assessment
HI	hazard index
HPGe	high purity germanium
HQ	Hazard Quotient
HRR	Historical Release Report
HSA	hollow-stem auger
HSL	Hazardous Substances List
HSPF	Hydrologic Simulation Program in Fortran
HSU	hydrostratigraphic unit
IA	Industrial Area
IAG	Interagency Agreement
ICRP	International Commission on Radiological Protection
ID	inside diameter
IDL	instrument detection limit
IEUBK	Integrated Exposure Uptake Biokinetic
IHSS	Individual Hazardous Substance Site
IM/IRA	Interim Measures/Interim Remedial Action
IR	intake rate
K	potassium
K	hydraulic conductivity
K_1	Cretaceous Laramie formation
Ka	Cretaceous Arapahoe formation
kg	kilogram
km^2	square kilometer
LCS	laboratory control samples
LF	lateral flow
LHSU	lower hydrostratigraphic unit
Li	lithium
LNAPL	light non-aqueous phase liquid
LOAEL	lowest-observed-adverse-effect level
LR	laboratory replicate
m/s	meters per second
m	meter

m^2	square meter
m^2/g	square meters per gram
mCi	microcurie
MDA	minimal detectable activity
MDL	method detection limit
ME	matrix effect
meg/l	milliequivalents per liter
mg	milligram
mg/kg	milligrams per kilogram
mg/l	milligrams per liter
Mg	magnesium
MKV	Mean Kriging Variance
mm	millimeters
Mn	manganese
Mo	molybdenum
mrem	millirem
MSA	Method of Standard Addition
MSE	mean square error
MW	monitoring well
Na	sodium
NA	not applicable
NAAQS	National Ambient Air Quality Standards
NAPL	Non-aqueous phase liquid
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
ND	not definitive
NE	northeast
NE	not encountered
Ni	nickel
NI	not installed
nm	nanometer
NO_2	nitrite
NO_3	nitrate
NOAEL	no-observed-adverse-effect level
NP	non-plastic
NPDES	National Pollutant Discharge Elimination System
OB	observation well
OD	outside diameter
OH	hydroxide ion
OU	Operable Unit
OVM	organic vapor monitor
PA	protected area
PAH	polynuclear aromatic hydrocarbon

PARCC	precision, accuracy, representativeness, completeness, and comparability
Pb	lead
PC	permeability constant
PCB	polychlorinated biphenyl
PCE	tetrachloroethylene
pcf	pounds per cubic foot
pCi/m^3	picocuries per cubic meter
pCi/ml	picocuries per milliliter
pCi/g	picocuries per gram
pCi/l	picocuries per liter
PCOC	potential chemicals of concern
PERC	perchloroethylene
PID	photoionization detector
PM_{10}	particle matter less than or equal to 10 micrometers in diameter
Po	polonium
ppb	parts per billion
ppm	parts per million
PQL	practical quantitation limit
PRG	preliminary remediation goal
PTFE	polyethylene tetrafluoride
Pu	Plutonium
Pu-239/240	plutonium-239,240
Pu-239	plutonium-239
PVC	polyvinyl chloride
PW	pumping well
QA/QC	quality assurance/quality control
QAA	Quality Assurance Addendum
Qal	valley fill alluvium
QAPP	Quality Assurance Project Plan
Qc	colluvium
QC	quality control
Qrf	Rocky Flats Alluvium
R	radius of influence
Ra	radium
Ra-226	radium-226
Ra-228	radium-228
RAAMP	Radiological Ambient Air Monitoring Program
RAD screen	radiological screen
RAD	radiological
RAO	Remedial Action Objectives
RBC	risk-based concentrations
RBWP	Revised Bedrock Work Plan
RCRA	Resource Conservation and Recovery Act

RDL	required detection limit
RFA	Rocky Flats Alluvium
RfC	Reference Air Concentration
RfD	Reference Dose
RFEDS	Rocky Flats Environmental Database System
RFETS	Rocky Flats Environmental Technology Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFP	Rocky Flats Plant
RI	remedial investigation
RME	reasonable maximum exposure
RNS	rinsate blank results
ROD	Record of Decision
RPD	relative percent difference
SA	Sample Management
SAFER	Streamlined Approach for Environmental Restoration
SAP	sampling and analysis plan
Sb	antimony
SB	source borehole
SCS	Soil Conservation Service
Se	selenium
Se	selenium
SE	southeast
SEAM	Superfund Exposure Assessment Manual
SED	Sediment Sampling Location
SERA	Superfund Amendments and Reauthorization
SF	slope factor
Si	silicon
SID	South Interceptor Ditch
SIR	Subsurface Interface Ratio
SIR	Subsurface Interface Radar
SLTST	siltstone
SM	sample management
Sn	tin
SOP	Standard Operating Procedure
SOW	Statement of Work
SQL	sample quantitation limit
Sr	strontium
Sr-89,90	Strontium-89,90
SS	sandstone
Sv	sievert
SVE	soil vapor extraction
SVOC	semivolatile organic compound
SWL	sample
SWMS	Soil Water Monitoring System

SWMU	Solid Waste Management Unit
TAL	target analyte list
TCE	trichloroethene
TCL	Target Compound List
TD	total depth
TDR	time domain reflectometry
TDS	total dissolved solids
TEDE	total effective dose equivalent
Th	thorium
TIC	tentatively identified compound
TM	Technical Memorandum
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TR	trench
TRC	total residual chlorine
TS	tension sampler
TSP	total suspended particulate
TSS	total suspended solids
U	uranium
U-234	uranium-234
U-235	uranium-235
U-238	uranium-238
UCL	upper confidence limit
UDFCD	Urban Drainage and Flood Control District
UHSU	upper hydrostratigraphic unit
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
UTL	upper tolerance limit of the background data
V	vanadium
VF	volatilization factor
VOC	volatile organic compound
VVDM	Ventilated Valley Dispersion Model
WARP	Well Abandonment and Replacement Program
WQPL	Water Quality Parameter List
WW	wet weight
WWC	Woodward-Clyde Consultants
WWTP	Waste Water Treatment Plant
Z	zinc
Zn	zinc
ZTS	zero tension samplers
ZTS	sero tension samplers

TABLE OF CONTENTS

Section			Page
EXECUTIVE SUMMARY			H.ES-1
H1.0	INTRODUCTION		H1-1
	H1.1	PURPOSE AND AUTHORITY	H1-1
	H1.2	SITE DESCRIPTION	H1-1
	H1.3	SCOPE OF OU-2 FIELD INVESTIGATIONS	H1-3
	H1.4	GUIDANCE DOCUMENTS	H1-5
	H1.5	REPORT ORGANIZATION	H1-6
H2.0	DATA EVALUATION AND AGGREGATION		H2-1
	H2.1	CHEMICAL ANALYTICAL DATABASE	H2-1
		H2.1.1 Data Sets Used in Risk Assessment	H2-1
		H2.1.2 Chemical Data Qualifiers	H2-4
	H2.2	DATA AGGREGATION FOR RISK ASSESSMENT	H2-5
H3.0	CHEMICALS OF CONCERN		H3-1
	H3.1	PROCESS FOR SELECTING OU-WIDE COCs	H3-1
		H3.1.1 Background Comparison	H3-1
		H3.1.2 Essential Nutrients/Major Cations and Anions	H3-2
		H3.1.3 Frequency of Detection	H3-2
		H3.1.4 Concentration/Toxicity Screens	H3-2
		H3.1.5 Professional Judgement	H3-2
		H3.1.6 Evaluation of Infrequently Detected Compounds	H3-3
		H3.1.7 Chemicals Without EPA Toxicity Values	H3-4
	H3.2	SURFACE SOIL COCs	H3-4
		H3.2.1 Concentration/Toxicity Screens	H3-4
		H3.2.2 Special-Case COCs in Surface Soil	H3-6

Section Page

H3.3 SUBSURFACE SOIL COCs H3-6

H3.3.1 Concentration/Toxicity Screens H3-6
H3.3.2 Special-Case COCs in Groundwater H3-8

H3.4 GROUNDWATER COCs H3-8

H3.4.1 Concentration/Toxicity Screens H3-9
H3.4.2 Special-Case COCs in Subsurface Soil H3-9

H3.5 CHEMICALS OF CONCERN IN OU-2 . . . . . H3-10

H4.0 EXPOSURE SCENARIOS H4-1

H4.1 CURRENT AND FUTURE LAND USE H4-1
H4.2 ONSITE EXPOSURE AREAS H4-4
H4.3 RECEPTORS SELECTED FOR QUANTITATIVE RISK ASSESSMENT H4-5

H4.3.1 Current Use H4-5
H4.3.2 Future Use H4-5

H4.4 EXPOSURE PATHWAYS H4-7

H4.4.1 Site-wide Incomplete or Negligible Exposure Pathways H4-8
H4.4.2 Current Onsite Worker H4-9
H4.4.3 Current Offsite Resident H4-10
H4.4.4 Future Onsite Industrial/Office Workers H4-12
H4.4.5 Future Construction Workers H4-13
H4.4.6 Future Ecological Researcher H4-13
H4.4.7 Future Onsite Open Space Use H4-14
H4.4.8 Hypothetical Onsite Resident H4-14
H4.4.9 Future Offsite Residents H4-16

H5.0 EXPOSURE POINT CONCENTRATIONS H5-1

H5.1 CALCULATING THE CONCENTRATION TERM H5-1
H5.2 SURFACE SOIL H5-2

Section Page

H8.6 OFFSITE RESIDENTS H8-12

H8.6.1 Noncarcinogenic Hazard Index H8-13
H8.6.2 Carcinogenic Risk H8-13

H8.7 EVALUATION OF HEALTH HAZARDS FROM EXPOSURE TO LEAD H8-13

H8.7.1 Surface Soil H8-14
H8.7.2 Subsurface Soil H8-14
H8.7.3 Groundwater H8-14

H8.8 SUMMARY OF CUMULATIVE HAZARD/RISK RESULTS H8-15

H9.0 RADIATION DOSE CALCULATIONS H9-1

H9.1 METHODOLOGY H9-1

H9.1.1 Definitions H9-1
H9.1.2 Calculating Annual Radiation Doses H9-3
H9.1.3 Radiation Protection Standards H9-7

H9.2 AOC No. 1 . . . . . H9-7
H9.3 MAXIMUM EXPOSURE AREAS IN AOC No. 1 . . . . . H9-10

H9.3.1 Hypothetical Onsite Resident (10-acres) H9-11
H9.3.2 Future Industrial/Office Worker (30-acres) H9-11
H9.3.3 Future Onsite Ecological Worker (50-acres) H9-12

H9.4 AOC No. 2 . . . . . H9-12
H9.5 OFFSITE RESIDENTS H9-13
H9.6 SUMMARY OF RESULTS H9-14

H9.6.1 AOC No. 1 . . . . . H9-14
H9.6.2 AOC No. 2 . . . . . H9-15
H9.6.3 Offsite Receptors H9-15

Section Page

H10.0 UNCERTAINTIES AND LIMITATIONS H10-1

H10.1 CHIEF UNCERTAINTIES H10-1

H10.1.1 Identification of COCs H10-1
H10.1.2 Exposure Point Concentrations H10-4
H10.1.3 Exposure Scenarios and Pathways H10-6
H10.1.4 Toxicity Assessment H10-8

H10.2 EVALUATION OF RISK ASSOCIATED WITH SPECIAL-CASE COCs H10-9

H10.2.1 Metals in Groundwater in OU-2 . . . . . H10-9
H10.2.2 Risk at Background Levels of Metals in Groundwater H10-11
H10.2.3 Vinyl Chloride in Groundwater H10-12
H10.2.4 PAHs in Surface Soil H10-14

H11.0 SUMMARY AND CONCLUSIONS H11-1

H11.1 SUMMARY H11-1
H11.2 CONCLUSIONS H11-4

LIST OF TABLES

TABLE ES-1	SUMMARY OF ESTIMATED HEALTH RISKS
TABLE H3-1	DETECTED CHEMICALS WITHOUT EPA TOXICITY FACTORS
TABLE H3-2	ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY SURFACE SOIL
TABLE H3-3	ORGANIC COMPOUNDS AND METALS DETECTED AT LESS THAN 5% FREQUENCY SURFACE SOIL
TABLE H3-4	CONCENTRATION/TOXICITY SCREEN SURFACE SOIL NONCARCINOGENS
TABLE H3-5	CONCENTRATION/TOXICITY SCREEN SURFACE SOIL CARCINOGENS
TABLE H3-6	CONCENTRATION/TOXICITY SCREEN SURFACE SOIL RADIONUCLIDES
TABLE H3-7	CONCENTRATION RANGES OF SELECTED PAHs AT RANDOM AND BIASED SURFACE SOIL SAMPLING LOCATIONS
TABLE H3-8	ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY SUBSURFACE SOIL
TABLE H3-9	ORGANIC COMPOUNDS AND METALS DETECTED AT LESS THAN 5% FREQUENCY SUBSURFACE SOIL
TABLE H3-10	CONCENTRATION/TOXICITY SCREEN SUBSURFACE SOIL NONCARCINOGENS
TABLE H3-11	CONCENTRATION/TOXICITY SCREEN SUBSURFACE SOIL CARCINOGENS
TABLE H3-12	CONCENTRATION/TOXICITY SCREEN SUBSURFACE SOIL RADIONUCLIDES
TABLE H3-13	ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY UHSU GROUNDWATER
TABLE H3-14	ORGANIC COMPOUNDS AND METALS DETECTED AT LESS THAN 5% FREQUENCY UHSU GROUNDWATER
TABLE H3-15	CONCENTRATION/TOXICITY SCREEN UHSU GROUNDWATER NONCARCINOGENS
TABLE H3-16	CONCENTRATION/TOXICITY SCREEN UHSU GROUNDWATER CARCINOGENS
TABLE H3-17	CONCENTRATION/TOXICITY SCREEN UHSU GROUNDWATER RADIONUCLIDES
TABLE H3-18	SUMMARY OF CHEMICALS OF CONCERN
TABLE H4-1	SUMMARY OF CURRENT AND FUTURE LAND USES
TABLE H4-2	POTENTIALLY COMPLETE EXPOSURE PATHWAYS TO BE QUANTITATIVELY EVALUATED

TABLE H5-1	EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN SURFACE SOILS
TABLE H5-2	EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN SUBSURFACE SOILS
TABLE H5-3	EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN GROUNDWATER
TABLE H5-4	AIR CONCENTRATIONS AND DEPOSITION RATES OF CHEMICALS OF CONCERN AT ONSITE EXPOSURE POINTS
TABLE H5-5	AIR CONCENTRATIONS AND DEPOSITION RATES OF CHEMICALS OF CONCERN AT OFFSITE EXPOSURE POINTS
TABLE H5-6	ANNUAL AVERAGE AIR CONCENTRATIONS CONSTRUCTION SCENARIO, AOC NO. 1
TABLE H5-7	5-YEAR MAXIMUM ANNUAL AVERAGE AIR CONCENTRATIONS CONSTRUCTION SCENARIO, AOC NO. 2
TABLE H5-8	SUMMARY OF AIR CONCENTRATIONS OF CHEMICALS OF CONCERN CONSTRUCTION SCENARIO
TABLE H5-9	BASEMENT AIR CONCENTRATIONS OF VOCs RELEASED FROM SUBSURFACE SOIL AND GROUNDWATER (mg/m^3)
TABLE H5-10	INDOOR AIR CONCENTRATIONS FROM DOMESTIC USE OF GROUNDWATER
TABLE H5-11	REASONABLE MAXIMUM 30-YEAR AVERAGE SURFACE WATER/SEDIMENT CONCENTRATIONS AT INDIANA STREET BASED ON 100 HYDROLOGIC SIMULATIONS
TABLE H5-12	CHEMICAL CONCENTRATIONS IN HOMEGROWN PRODUCE FROM ROOT UPTAKE
TABLE H5-13	ESTIMATED FRACTION OF HOMEGROWN PRODUCE AFFECTED BY DEPOSITION
TABLE H5-14	CHEMICAL CONCENTRATIONS IN HOMEGROWN PRODUCE FROM DEPOSITION OF PARTICULATE MATTER (ONSITE AREAS)
TABLE H5-15	CHEMICAL CONCENTRATIONS IN HOMEGROWN PRODUCE FROM DEPOSITION OF PARTICULATE MATTER (OFFSITE LOCATIONS)
TABLE H5-16	CHEMICAL CONCENTRATIONS IN SURFACE SOIL FROM DEPOSITION OF PARTICULATE MATTER (OFFSITE LOCATIONS)
TABLE H6-1	AGE-WEIGHTED SOIL INGESTION RATES FOR CARCINOGENS AND RADIONUCLIDES
TABLE H6-2	SOIL MATRIX EFFECTS
TABLE H6-3	DERIVATION OF 0.5 SOIL MATRIX EFFECT
TABLE H6-4	DERMAL ABSORBED FRACTION AND AQUEOUS PERMEABILITY CONSTANTS FOR COCs IN SOIL AND SURFACE WATER

TABLE H7-1	TOXICITY FACTORS FOR CHEMICALS OF CONCERN: ORGANIC COMPOUNDS AND METALS
TABLE H7-2	SLOPE FACTORS FOR RADIONUCLIDES
TABLE H7-3	EFFECTIVE DOSE COEFFICIENTS FOR RADIONUCLIDES
TABLE H8-1	SUMMARY OF ESTIMATED HEALTH RISKS FOR AOC NO. 1
TABLE H8-2	SUMMARY OF ESTIMATED HEALTH RISKS FOR MAXIMUM EXPOSURE AREAS IN AOC NO. 1
TABLE H8-3	SUMMARY OF ESTIMATED HEALTH RISKS FOR AOC NO. 2
TABLE H8-4	SUMMARY OF ESTIMATED HEALTH RISKS FOR OFFSITE RESIDENTS
TABLE H9-1	EFFECTIVE DOSE COEFFICIENTS FOR SELECTED RADIONUCLIDES
TABLE H9-2	SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR AOC NO. 1
TABLE H9-3	SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR MAXIMUM EXPOSURE AREAS
TABLE H9-4	SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR AOC NO. 2
TABLE H9-5	SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR OFFSITE RESIDENTS
TABLE H10-1	SUMMARY OF ESTIMATED HEALTH RISKS FOR SPECIAL-CASE CHEMICALS OF CONCERN
TABLE H11-1	SUMMARY OF ESTIMATED HEALTH RISKS

LIST OF FIGURES

FIGURE H1-1 LOCATION OF OU-2
FIGURE H1-2 REMEDIAL INVESTIGATION AREAS AND INDIVIDUAL HAZARDOUS SUBSTANCE SITES
FIGURE H2-1 SOURCE AREAS AND AREAS OF CONCERN
FIGURE H2-2 MAXIMUM EXPOSURE AREAS AREA OF CONCERN NO. 1 10-ACRE, 30-ACRE, AND 50-ACRE
FIGURE H3-1 PROCESS FOR IDENTIFYING CHEMICALS OF CONCERN
FIGURE H4-1 OFFSITE RECEPTOR LOCATIONS
FIGURE H4-2 CONCEPTUAL SITE MODEL FOR HUMAN EXPOSURE PATHWAYS
FIGURE H5-1 1993 SURFACE SOIL SAMPLING LOCATIONS AND PCBs DETECTED IN SURFACE SOILS (ppm)
FIGURE H5-2 1991 SURFACE SOIL SAMPLING LOCATIONS
FIGURE H5-3 HISTOGRAMS OF SIMULATED RADIONUCLIDE ACTIVITIES IN WALNUT CREEK
FIGURE H5-4 HISTOGRAMS OF SIMULATED RADIONUCLIDE ACTIVITIES IN WOMAN CREEK

LIST OF ATTACHMENTS

ATTACHMENT H1 ESTIMATING THE CONCENTRATION TERM
ATTACHMENT H2 EXPOSURE FACTOR TABLES
ATTACHMENT H3 HEALTH RISK CALCULATIONS
ATTACHMENT H4 RADIATION DOSE CALCULATIONS
ATTACHMENT H5 TOXICITY PROFILES

A Human Health Risk Assessment (HHRA) was performed for OU-2 at the Rocky Flats Environmental Technology Site (RFETS) as part of the Phase II RFI/RI Report, as required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). OU-2 occupies approximately 1,100 acres; it is bounded on the west by the industrialized portion of RFETS, on the north by South Walnut Creek, on the south by Woman Creek, and on the east by Indiana Street. OU-2 contains twenty-two Individual Hazardous Substances Sites (IHSSs), grouped in the 903 Pad, Mound, Northeast Trenches, and Southeast Trenches areas. In addition, it contains a large portion of the RFETS buffer zone extending to Indiana Street.

The HHRA is intended to estimate the level of health risk from potential exposures to chemicals at or released from contaminant source areas within OU-2. The health risk estimates are used to support the determination of appropriate cleanup levels or other risk management measures in keeping with current and future land uses.

In accordance with the Interagency Agreement (IAG), regulatory responsibilities for OU-2 are shared jointly by the Colorado Department of Public Health and Environment (CDPHE), pursuant to its authority under RCRA and the Colorado Hazardous Waste Act, and the United States Environmental Protection Agency (EPA) Region VIII, pursuant to its authority under CERCLA. The HHRA was performed following EPA guidance for risk assessment and in keeping with procedures for selection of COCs, data aggregation, and exposure assessment that were agreed upon by the EPA, CDPHE, and the U.S. Department of Energy (DOE). These procedures are documented in various technical memoranda and correspondence cited in the HHRA.

Samples collected from surface soil, subsurface soil, and groundwater during the OU-2 Phase I (1987) and Phase II (1991 - 1993) field investigations and from RFETS-wide sampling programs were used to characterize contamination in OU-2 and select COCs for risk assessment. COCs identified for evaluation in the quantitative risk assessment were those with concentration distributions in soil or groundwater in OU-2 that are statistically significantly different than background distributions and that could contribute significantly to

overall health risk. COCs were evaluated in transport modeling and in risk assessment and will be the focus of remedy selection. COCs in surface soil, subsurface soil, and groundwater were determined on an OU-wide basis following a multi-step process: (1) statistical background comparison; (2) frequency of detection screen (infrequently detected compounds were reserved for separate evaluation of toxicity); (3) concentration/toxicity screens; (4) scientific and professional judgment.

Chemicals of concern are summarized below:

OU-WIDE CHEMICALS OF CONCERN

Surface Soil	Subsurface Soil	Groundwater
Aroclor-1254	Tetrachloroethene	Carbon Tetrachloride
Aroclor-1260	Arsenic	Chloroform
Bis(2-ethylhexyl)phthalate	Cadmium	1,1-Dichloroethene
Chromium	Mercury	Methylene Chloride
Americium-241	Americium-241	Trichloroethene
Plutonium-239/240	Plutonium-239/240	Tetrachloroethene
	Uranium-233,234	Americium-241
	Uranium-235	Plutonium-239/240
	Uranium-238	

Exposure scenarios for risk assessment were based on current use and possible future use at the site, in keeping with recommendations of local planning groups and the Rocky Flats Future Site Uses Working Group. Land use in OU-2 is likely to remain restricted for the foreseeable future. If access becomes unrestricted, use as open space or an ecological reserve is possible. Industrial/commercial development in portions of the plant could also occur.

Receptors (exposed individuals) evaluated in the risk assessment under the current use scenarios were the onsite worker (security personnel in OU-2) and current offsite residents. Receptors under future use scenarios were the industrial/office worker, ecological researcher, open-space recreational user, construction worker, and offsite residents. These receptors were evaluated for exposure via soil ingestion, inhalation, soil dermal contact, external irradiation from soil, contact with surface water and sediment, and ingestion of garden produce (offsite residents).

Future residential development at RFETS is not likely and is not recommended by planning groups or regulatory agencies, and remedies will not be selected based on possible future residential use. However, a hypothetical residential scenario was also evaluated in the risk assessment to help support risk management decisions, particularly for low-hazard areas in OU-2.

Health risks were evaluated for onsite receptors in two large Areas of Concern (AOCs) in OU-2. AOC No. 1 consists of all the IHSSs and contiguous groundwater contaminant plumes. AOC No. 2 contains no IHSSs. In addition, risks were evaluated in three maximum contaminant areas: a 10-acre area at the 903 Pad (hypothetical onsite residential); a 30-acre area (future industrial/office worker); and a 50-acre area (ecological researcher). The 30- and 50-acre areas each contain the 10-acre maximum contaminant area.

Exposure concentrations (usually the 95% upper confidence limit on the mean) were calculated for each COC in each sampled medium and for each exposure area. Air dispersion modeling, groundwater modeling, and surface water modeling were also conducted to estimate exposure point concentrations in air and surface water in Woman and Walnut Creeks.

Health risks are estimated by combining estimates of intake factors, chemical concentration at the exposure point, and toxicity factors. The toxicity factors are EPA-established reference doses (RfDs) for noncarcinogens and cancer slope factors (SFs) for carcinogens. Noncarcinogenic hazard indexes (HIs) and cancer risk estimates were calculated using both central tendency (CT) and reasonable maximum exposure (RME) assumptions for each scenario. In addition, annual radiation doses were estimated for comparison to national radiation protection standards (100 mrem/year).

Results of the risk assessment for each exposure area are summarized in Table ES-1 and described briefly below.

<u>AOC No. 1:</u> HIs and cancer risk estimates were below levels of concern for all current and possible future land use scenarios in AOC No. 1, while those for the hypothetical resident exceeded levels of concern. These results are described below.

- The future industrial/office worker is the maximum exposed individual under current and possible future land use scenarios in AOC No. 1. Pathways evaluated were exposure to surface soil, airborne PM_{10}, and indoor VOCs from soil gas. Cumulative HIs were below 1, indicating no threat of adverse noncarcinogenic effects. RME (8E-05) and CT (3E-06) cancer risk estimates for this receptor in AOC No. 1 are within EPA's target cancer risk range of 1E-06 to 1E-04. Ingestion of Pu-239/240 in surface soil was the greatest contributor to overall risk (Attachment H3).

- Cumulative HIs were below 1 for current workers and for future ecological workers, open space users, and construction workers in AOC No. 1 indicating that no adverse noncarcinogenic health hazards are expected for these nonresidential exposure scenarios. RME cancer risk estimates for these receptors ranged from 3E-07 to 1E-05. These values are within or below EPA's target cancer risk range of 1E-06 to 1E-04. The contaminants that contributed most to estimated health risk for nonresidential onsite receptors are Pu-239/240 and Am-241 in surface soil.

- Chlorinated solvents in groundwater in AOC No. 1 would pose unacceptable risk if directly ingested (hypothetical onsite residential scenario). However, drinking water for current onsite workers is provided by a municipal water supply, and it is expected that drinking water for future onsite receptors will also be provided from a public water supply. Therefore, ingestion of UHSU groundwater is an incomplete pathway for all current and possible future receptors in OU-2. Additionally, migration of groundwater via surface water

to offsite locations is not significant, even using conservative modeling assumptions.

Maximum Exposure Areas: HIs were below levels of concern and cancer risk estimates were at or below levels of concern for future industrial/office workers and ecological researchers in 30- and 50-acre maximum exposure areas. Hazard/risk estimates for hypothetical onsite residents in a 10-acre maximum exposure area exceeded levels of concern. These results are described below.

- Chlorinated solvents in groundwater in the 10-acre maximum exposure area in AOC No.1 would pose an unacceptable risk if directly ingested (hypothetical onsite residential scenario). However, groundwater ingestion is an incomplete pathway for all current and possible future receptors in OU-2.

- Cumulative HIs were below 1 for the future industrial/office worker in the 30-acre maximum exposure area, indicating no threat of adverse noncarcinogenic effects. The CT cancer risk estimate for this receptor is within EPA's target risk range of 1E-06 to 1E-04, whereas the RME cancer risk estimate (2E-04) exceeds this range. RME cancer risk estimates for this receptor are likely to significantly overestimate actual risk because overly conservative assumptions resulted in overestimation of intake values for ingestion and inhalation of soil. Ingestion of Pu-239/240 in surface soil was the greatest contributor to overall risk (see Attachment 3). However, the concentration term for Pu-239/240 in surface soil in the 30-acre maximum exposure area was biased by an extreme value in one sample and other samples in the data set had significantly lower concentrations.

- Cumulative HIs were below 1 and cancer risk estimates were within EPA's target risk range of 1E-06 to 1E-04 for the future ecological worker in the 50-acre maximum exposure area.

AOC No. 2: Cumulative HIs were below 1 and cancer risk estimates were equal to or below 1E-06 for onsite receptors in AOC No. 2 (including the hypothetical onsite resident).

Offsite Receptors: HIs and cancer risk estimates for offsite residential receptors were negligible.

Thus, for all current and possible future receptors in OU-2, conservative estimates of cancer risk were 2E-04 or below and HIs were 8E-02 or below.

In general, when cancer risk levels that do not exceed 1E-04 are combined with HIs that do not exceed 1, that conclusion is that environmental contamination does not pose a threat to public health (EPA 1991d). For all current and possible future receptors in OU-2, conservative estimates of cancer risk were 2E-04 or below and HIs were 8E-02 or below. These results suggest that the surface and subsurface soil in OU-2 may not pose a threat to human health.

Concentrations of chlorinated solvents in UHSU groundwater in AOC No. 1 would pose an unacceptable health risk if used as a drinking water supply on site. However, UHSU groundwater is not used as a water supply and is not expected to provide drinking water in the future. All UHSU groundwater discharges on site in surface seeps. Migration of groundwater contaminants via surface water to offsite locations is not significant, even using conservative modeling assumptions.

TABLE ES-1*
SUMMARY OF ESTIMATED HEALTH RISKS

	Average Exposure (CT)		Reasonable Maximum Exposure (RME)	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
AOC No. 1**				
Current Worker	6E-07	2E-03	1E-05	1E-02
Future Industrial/Officer Worker	2E-06	6E-03	8E-05	4E-02
Future Ecological Worker	1E-06	5E-03	4E-06	2E-02
Future Open Space Use	2E-07	5E-04	1E-05	1E-02
Future Construction Worker	1E-07	4E-03	3E-07	2E-02
Hypothetical Resident	4E-04	2E+01	8E-03	1E+02
Maximum Exposure Areas				
Hypothetical Resident (10 Acres)	1E-03	2E+01	2E-02	2E+02
Future Industrial/Officer Worker (30 Acres)	5E-06	1E-02	2E-04	8E-02
Future Ecological Worker (50 Acres)	2E-06	8E-03	6E-06	4E-02
AOC No. 2**				
Current Worker	9E-09	3E-07	2E-07	2E-06
Future Industrial/Officer Worker	4E-08	9E-07	1E-06	1E-05
Future Ecological Worker	2E-08	2E-04	7E-08	3E-04
Future Open Space Use	6E-09	3E-05	3E-07	4E-04
Future Construction Worker	3E-08	3E-03	1E-07	2E-02
Hypothetical Resident	8E-07	1E-03	1E-05	6E-03
Offsite Receptors***				
Current Resident, Southeast	1E-09	0	1E-08	0
Current Resident, Indiana South	7E-13	0	8E-12	0
Future Resident, Walnut Cr./Indiana	8E-09	9E-05	2E-07	6E-04
Future Resident, Woman Cr./Indiana	2E-09	3E-05	5E-08	2E-04

* Same as Table H11-1.

** Area of concern boundaries are illustrated in Figure H2-1.

*** Results shown correspond to the higher of estimated air impacts from AOC No. 1 and AOC No. 2.

CT = Central Tendency

RME = reasonable maximum exposure

H1.0
INTRODUCTION

H1.1 PURPOSE AND AUTHORITY

The Human Health Risk Assessment (HHRA) is presented as part of the Phase II RCRA Facility Investigation/Remedial Investigation (RFI/RI) Report for Operable Unit No. 2 (OU-2) at the U.S. Department of Energy (DOE) Rocky Flats Environmental Technology Site (RFETS) in Golden, Colorado. The HHRA is required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; also known as Superfund) (40 CFR 300.430) as part of the RI process. The HHRA is intended to estimate the level of health risk from potential exposures to chemicals at or released from contaminant source areas within OU-2. The estimate of health risk is used to support the determination of appropriate cleanup levels or other risk management measures in keeping with current and future land uses. Health risks are estimated for both central tendency (CT) and reasonable maximum exposure (RME) conditions, in keeping with EPA guidance (EPA 1989a; 1992k).

An ecological risk assessment (ERA) is also a requirement of the RFI/RI process under CERCLA and RCRA. ERAs for RFETS are being conducted on a watershed basis and will be included in the risk assessment for OU5 (Woman Creek watershed) and OU6 (Walnut Creek watershed).

The Phase II RFI/RI is being conducted pursuant to the DOE Environmental Restoration Program; a Compliance Agreement among DOE, the U.S. Environmental Protection Agency (EPA), and the Colorado Department of Public Health and Environment (CDPHE); and the Federal Facility Agreement and Consent Order (Interagency Agreement, or IAG) signed in 1991.

H1.2 SITE DESCRIPTION

RFETS consists of an industrialized area of about 400 acres surrounded by an undeveloped buffer zone of about 6,150 acres. OU-2 is bounded on the west by the industrialized portion of RFETS, on the north by South Walnut Creek, on the south by Woman Creek, and on the

east by Indiana Street (Figure H1-1). OU-2 encompasses the 903 Pad, Mound, and East Trenches areas as well as a large portion of the RFETS buffer zone. Twenty-two Individual Hazardous Substance Sites (IHSSs) where past waste disposal activities or releases occurred are located in the 903 Pad, Mound, and East Trenches areas. A detailed description of the site location, general site conditions, and description of the IHSSs is included in Sections 1.0 and 3.0 of the Phase II RFI/RI Report for OU-2. The OU-2 IHSS names and numbers are listed below and locations are shown on Figure H1-2:

903 Pad Area

- 903 Pad Site (IHSS 112): Former drum storage (solvents, oils, and radionuclides); drums were removed in 1968 and the site has been covered with gravel, fill, and asphalt.

- 903 Lip Area (IHSS 155): Radionuclide-contaminated surface soil to the south and east of the 903 Pad; portions have been excavated and backfilled.

- Trench T-2 (IHSS 109): Used in 1969 and 1970 for disposal of solvents and thinners.

- Reactive Metal Destruction Site (IHSS 140): Used in the 1950s and 1960s primarily for the destruction of lithium metal and of smaller quantities of other metals and solvents.

- Gas Detoxification Site (IHSS 183): Used in 1982 and 1983 to neutralize bottled gases such as nitrogen oxides and chlorine.

Mound Area

- Mound Site (IHSS 113): Former disposal site for drums containing metal- and radionuclide-contaminated lathe coolant; some drums contained solvents. A cleanup of the site was performed in 1970.

- Trench T-1 (IHSS 108): Contains approximately 125 drums of depleted uranium chips.

- Oil Burn Pit No. 2 (IHSS 153): Used in early 1960s to burn drums of uranium-contaminated oil. In 1978 the area was excavated and contaminated soil and other materials were removed. IHSS 153 is located within the Protected Area (PA) of RFETS and could not be sampled.

- Pallet Burn Site (IHSS 154): Reportedly used to destroy wooden pallets, possibly contaminated by spills; reportedly remediated in the 1970s. IHSS 154 is located within the fence surrounding the PA and could not be sampled.

East Trenches Area

- Eleven burial trenches (Trenches T-3 through T-11 are numbers IHSSs 110 and 111.1 through 111.8; Trenches T-12 and T-13 do not have IHSS numbers): Used from 1954 to 1968 for disposal of radionuclide-contaminated sewage sludge and empty drums. The wastes in these trenches have not been removed.

- Two spray fields (IHSSs 216.2 and 216.3): Used for spray irrigation of wastewater treatment plant effluent.

H1.3 SCOPE OF OU-2 FIELD INVESTIGATIONS

The OU-2 field investigations were conducted in two phases. Phase I investigations of subsurface soil and groundwater were conducted in 1987. Phase II investigations of surface soil, subsurface soil, and groundwater were conducted in 1991 through 1993. Three other field programs also provided data used to characterize soil and groundwater in OU-2: a 1989 seismic investigation, a 1992 well replacement program, and a 1993 soil vapor extraction (SVE) program. Samples were collected at IHSSs and at locations outside IHSS boundaries and in the buffer zone. The field investigations of surface soil, subsurface soil, and groundwater in OU-2 are described briefly in this section. A detailed description of the field investigations appears in Section 2.0 of the RFI/RI Report.

Surface Soil

Surface soil samples were collected across the entire OU in the Phase II investigation (1991-1993). Sampling locations were based on grids, although several "biased" samples were collected at specific IHSSs. Samples were analyzed for some or all of the following analyte groups: semivolatile organic compounds (SVOCs), pesticides/polychlorinated biphenyls (PCBs), metals, and radionuclides.

Subsurface Soil

Subsurface soil samples were collected from boreholes installed during the OU-2 Phase I (1987) and Phase II (1991-1993) field investigations, as well as from the seismic (1989) and SVE (1993) drilling programs. Many boreholes installed for the OU-2 field investigations are located within current IHSS boundaries. However, boundaries of a few IHSSs were revised following publication of the Historical Release Report (DOE 1992a); some OU-2 boreholes installed prior to these revisions are outside current IHSS boundaries. Some boreholes from the seismic and SVE programs are within IHSS boundaries and some are not.

Laboratory analyses of borehole samples were based on project-specific work plans, but generally included the following analyte groups: volatile organic compounds (VOCs), SVOCs, pesticides/PCBs, metals, and radionuclides.

Seep Water and Sediment

Samples of water and sediment were collected on a quarterly basis from several seeps on slopes near Walnut Creek and South Woman Creek under the RFETS-wide surface water sampling program. The sample results are described in Section 4.0 of the RFI/RI Report. They were used as a reasonableness check on the results of groundwater transport modeling to seep discharge points but were not otherwise used in risk assessment.

Groundwater

Groundwater samples were collected from monitoring wells on a quarterly basis under the RFETS-wide groundwater sampling program. Samples were collected from over 80 wells installed during OU-2 Phase I and Phase II investigations and during other investigations conducted in 1987 and 1989 in the OU-2 area. Samples collected from the Upper Hydrostratigraphic Unit (UHSU) in the second quarter 1991 through the fourth quarter 1992 were used to characterize groundwater concentrations for risk assessment.

Groundwater samples were generally analyzed for VOCs, SVOCs, pesticides/PCBs, filtered and unfiltered metals, filtered and unfiltered radionuclides, and water quality parameters.

H1.4 GUIDANCE DOCUMENTS

The HHRA was performed using EPA guidance provided in Risk Assessment Guidance for Superfund (EPA 1989a and 1991c), Dermal Exposure Assessment: Principles and Applications (EPA 1992c), the Exposure Factors Handbook (EPA 1989b), and Guidance for Data Useability in Risk Assessment (Parts A and B) (EPA 1992d and 1992e). Other guidance documents and scientific literature were consulted as needed and are cited where used. In addition, letters and memoranda from EPA Region VIII and CDPHE provided recommendations for identification of potential receptors (exposed individuals), exposure areas, and chemicals of concern (COCs). Specific correspondence from EPA and CDPHE is cited in the relevant sections of the HHRA.

Four technical memoranda (TMs) were written in support of the HHRA. These memoranda are TM No. 5, Exposure Assessment (DOE 1994a); TM No. 6, Model Description (DOE 1993b); TM No. 9, Chemicals of Concern (DOE 1994b); and TM No. 10, Toxicity Assessment (DOE 1994c). These memoranda have been submitted to EPA and CDPHE and have provided the basis for performing the HHRA.

H1.5 REPORT ORGANIZATION

The HHRA consists of the following sections:

H2.0 Data Evaluation and Aggregation: This section describes the chemical analytical data used in the HHRA and how the data were aggregated for exposure assessment.

H3.0 Chemicals of Concern: This section describes the approach taken to identify COCs for quantitative evaluation in the HHRA. COCs in each sampled medium (surface soil, subsurface soil, and groundwater) were selected on an OU-wide basis. In addition, special-case COCs were identified. These include infrequently detected compounds that have high toxicity and selected metals in groundwater. Special-case COCs are evaluated in the uncertainties section (H10.0) of the HHRA.

H4.0 Exposure Scenarios: This section summarizes current and future land use and describes the exposure areas, potential receptors, and exposure pathways evaluated in the HHRA.

H5.0 Exposure Point Concentrations: This section presents the exposure point concentrations that were calculated for each COC in each exposure medium and exposure area. In addition, it summarizes the results of air modeling and surface water modeling and describes the methods used to estimate chemical concentrations in garden produce.

H6.0 Estimating Chemical Intakes: This section describes the methodology and exposure parameters used to calculate chemical intake for each exposure pathway. This section also identifies the chemical-specific values used for soil matrix effects, dermal absorption from soil, and aqueous dermal permeability constants.

H7.0 Toxicity Assessment: This section describes the chemical-specific toxicity factors used in estimating noncarcinogenic and carcinogenic health risk from exposure to chemicals and radionuclides. It also presents the radiation dose coefficients used in calculating annual radiation doses.

H8.0 Risk Characterization: This section presents the results of the quantitative risk assessment for each exposure scenario.

H9.0 Radiation Dose Estimates: This section presents the results of the annual radiation dose calculations for each receptor and compares them to federal standards of acceptable radiation dose.

H10.0 Uncertainties and Limitations: This section identifies the chief sources of uncertainty in the quantitative risk assessment and discusses potential risk from special-case COCs.

H11.0 Summary and Conclusions: This section summarizes and draws conclusions from the results of the risk assessment.

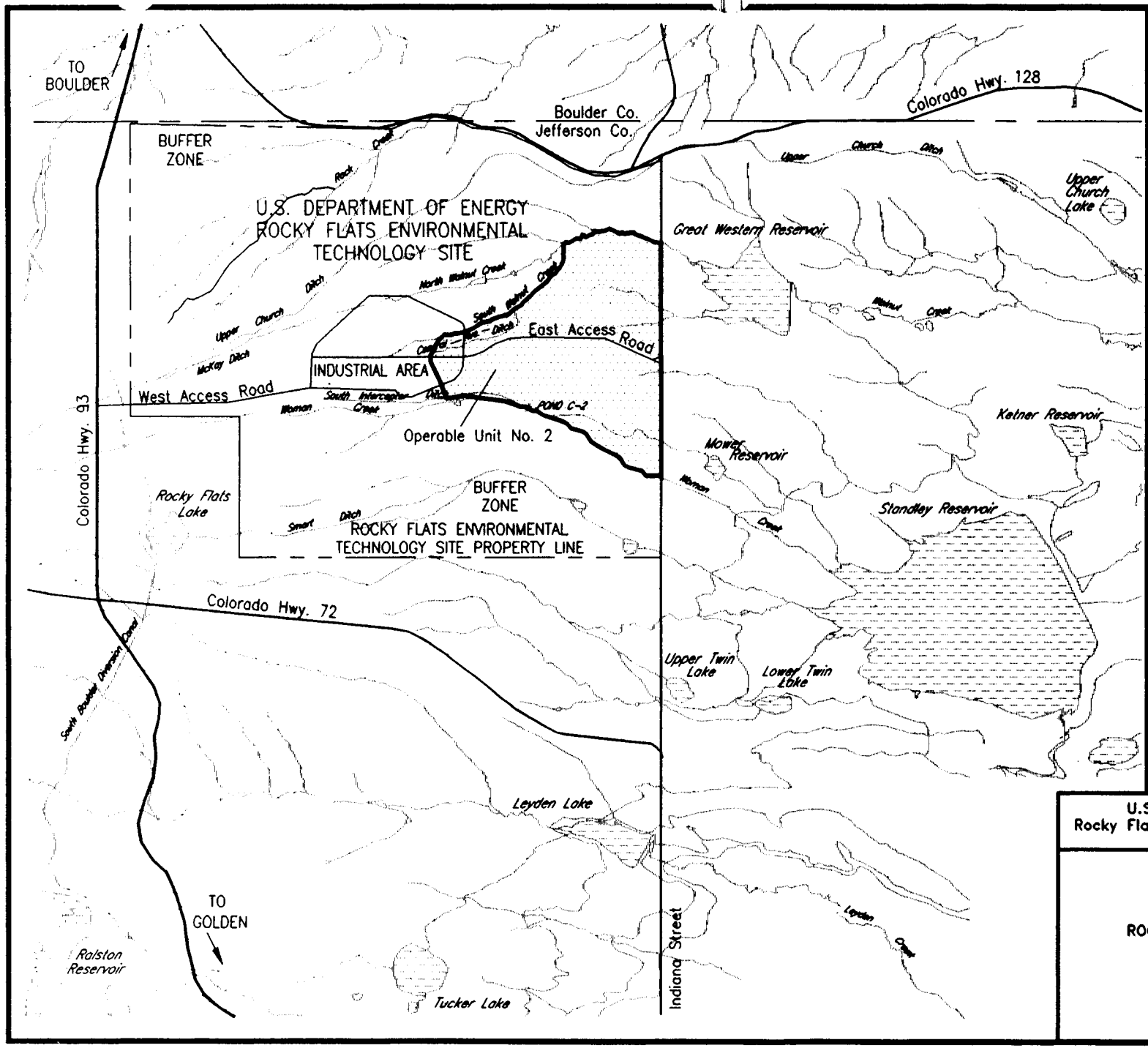
H12.0 References: This section lists the literature cited in the HHRA.

In addition, the following attachments provide detailed information on various aspects of the HHRA:

Attachment H1 Estimating the Concentration Term, discusses the statistical procedures used to determine exposure point concentrations of COCs and includes the tables of all sample results used in the calculations.

Attachment H2 Exposure Factors Tables, shows the numerical values for all exposure parameters for each receptor and exposure pathway evaluated in the HHRA.

Attachment H3	Health Risk Calculations, contains detailed spreadsheets showing health risk calculations for all chemicals, receptors, and pathways.
Attachment H4	Radiation Dose Calculations, contains detailed spreadsheets showing the calculation of annual radiation doses for each receptor.
Attachment H5	Toxicity Profiles, contains brief summaries of the toxic effects of the COCs that contribute most to overall risk.



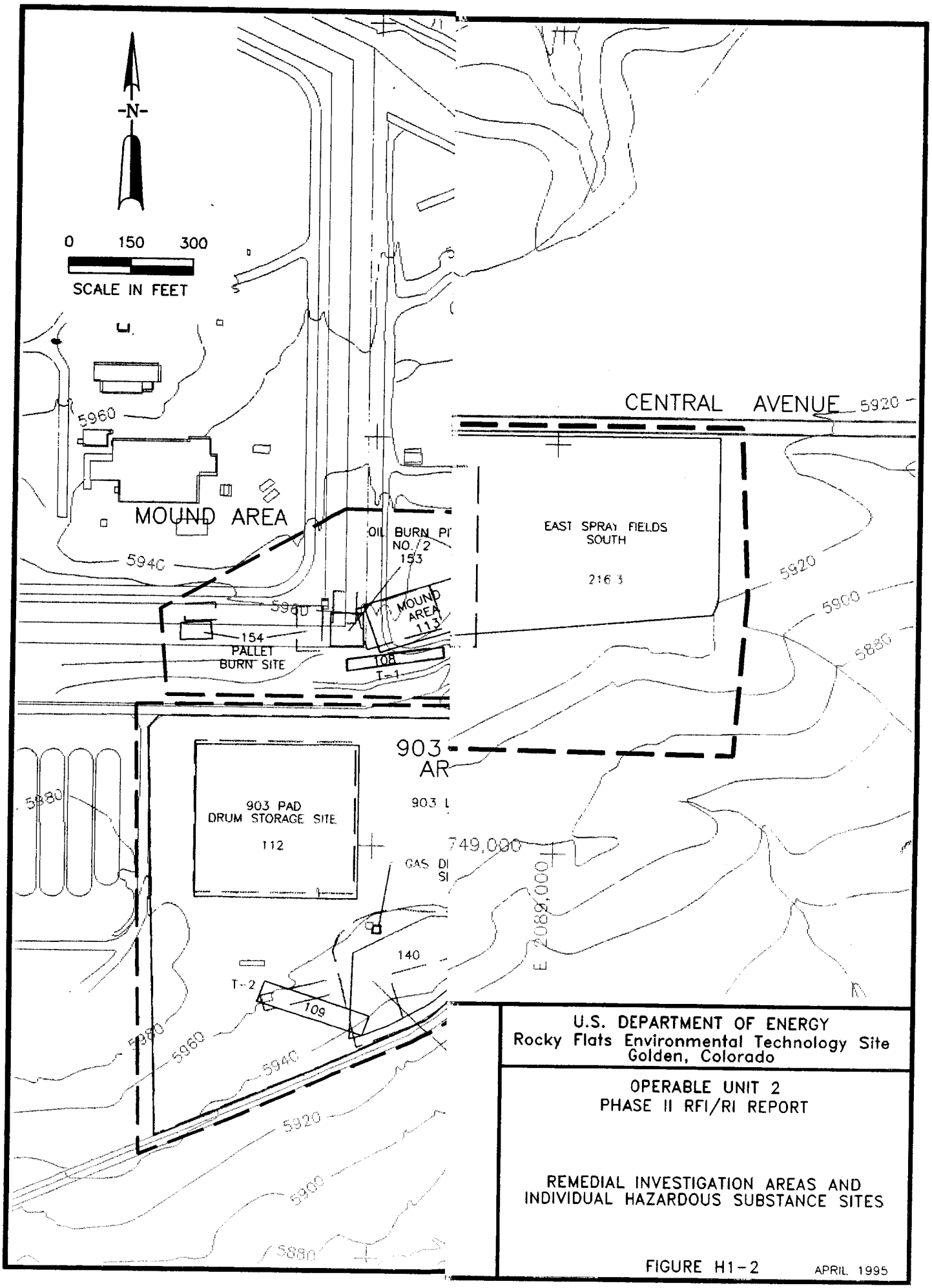
U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI REPORT

ROCKY FLATS ENVIRONMENTAL
TECHNOLOGY SITE
OPERABLE UNIT NO. 2

FIGURE H1-1 APRIL 1995

OU2RI680 1=1



U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT 2
PHASE II RFI/RI REPORT

REMEDIAL INVESTIGATION AREAS AND
INDIVIDUAL HAZARDOUS SUBSTANCE SITES

FIGURE H1-2 APRIL 1995

OU2RI681 1=300

Baseline Risk Assessment OU2 RI

H2.0
DATA EVALUATION AND AGGREGATION

This section provides a brief description of the development of the chemical analytical data set and data aggregation process used in the health risk assessment.

H2.1 CHEMICAL ANALYTICAL DATABASE

Chemical analytical data from environmental samples collected during the OU-2 Phase I and Phase II field investigations and from RFETS-wide sampling programs were used to characterize contamination in OU-2 and select COCs for risk assessment. The sampling and analytical programs followed approved work plans, and chemical analytical results were validated by a contractor in accordance with EPA and RFETS data validation guidelines. Summaries of the work plans and the OU-2 field investigations are presented in Sections 1.0 and 2.0 of the RFI/RI Report. Appendix J, Quality Assurance, describes the chemical analytical database and additional data review and editing (such as removal of duplicate results and treatment of non-validated B-qualified results) that was performed in establishing the final database used in the OU-2 RFI/RI Report.

H2.1.1 Data Sets Used in Risk Assessment

The data sets used for evaluation of surface soil, subsurface soil, and groundwater are described below.

Surface Soil

The results of two separate sampling and analytical protocols (1991-92 and 1993), using soil samples from two depths, were used to evaluate surface soil contamination in OU-2. The following programs were used:

- OU-2 Phase II investigations conducted in 1991 and 1992. Some of the samples were collected by the Colorado Department of Health (CDH) method (collects 0.25-inch-deep sample) and some were collected by the modified

Rocky Flats Plant (RFP) method (collects 2-inch-deep sample). The CDH and RFP sampling methods are described in Section 2.5 of the RFI/RI Report.

- OU-2 Phase II investigation conducted in 1993. These samples were collected using the RFP sampling method (collects 2-inch-deep sample).

The 1991 and 1992 surface soil samples were collected from 2.5- and 10-acre plots; samples were analyzed for radionuclides only. Samples collected using the CDH method were analyzed for americium, plutonium, and uranium. Samples collected using the modified RFP method were analyzed for americium and plutonium. The 1993 surface soil samples were collected from 100-by-150-foot plots using the RFP sampling method. They were analyzed for SVOCs, pesticides/PCBs, metals, and radionuclides (except for americium, plutonium, and uranium).

Analytical results from surface soil samples from the three different sampling programs (CDH, modified-RFP, and RFP) were used to evaluate the nature and extent of contamination and select COCs.

Subsurface Soil

Data used to evaluate contamination in subsurface soil were taken from five sources:

- OU-2 Phase I field investigation conducted in 1987
- Boreholes for seismic evaluation drilled in 1989
- OU-2 Phase II field investigation conducted in 1991 to 1993
- Well abandonment and replacement program conducted in 1992
- OU-2 SVE Pilot Program conducted in 1993

Many of the boreholes drilled for OU-2 investigations were within IHSS boundaries established prior to the time of sampling. However, a number of IHSS boundaries changed with publication of the Historical Release Report (DOE 1992a). Boreholes from the other programs used to evaluate OU-2 contamination were located both within and outside of IHSS boundaries.

Results from subsurface soil samples collected above high water table (defined as water level in May 1992) were used to select COCs to delineate subsurface soil contamination from possible cross-contamination from groundwater. Laboratory analyses of borehole samples were based on project-specific work plans but generally included the following analyte groups: VOCs, SVOCs, pesticides/PCBs, metals, and radionuclides.

Groundwater

Groundwater samples were collected from monitoring wells on a quarterly basis under the RFETS-wide groundwater sampling program. Samples were collected from over 80 wells installed during OU-2 Phase I and Phase II investigations and during other investigations conducted in 1987 and 1989 within the OU-2 area. Only wells completed in the Upper Hydrostratigraphic Unit (UHSU) were included in the groundwater data set for the selection of COCs for risk assessment. The UHSU includes the Rocky Flats Alluvium, colluvium, valley fill alluvium, the Arapahoe Formation No. 1 Sandstone, weathered claystone of the Arapahoe and/or Laramie formations, and subcropping Laramie Sandstones on the south-facing slope of the Woman Creek drainage. More detail on the hydrogeological characteristics of OU-2 is presented in Sections 3.5 and 3.6 of the RFI/RI Report.

Samples from the Lower Hydrostratigraphic Unit (LHSU) were not used in risk assessment because exposure to the LHSU does not occur and migration potential is minimal or nonexistent. (See Section 4.5 of the RFI/RI Report and the summary in Section H4.4.1 of this HHRA.)

The evaluation of contaminant concentrations in the UHSU was based on analytical results from samples collected from the second quarter 1991 through the fourth quarter 1992. The second quarter 1991 was the first quarterly groundwater sampling event for which standard operating procedures and validation criteria were in place. In general, the groundwater samples were analyzed for VOCs, SVOCs, pesticides/PCBs, filtered and unfiltered metals, filtered and unfiltered radionuclides, and water quality parameters.

H2.1.2 Chemical Data Qualifiers

Chemical data qualifiers are letter codes attached to analytical results by the laboratory or validator to indicate possible problems with chemical identification, quantification, or source of contamination. Use of qualified data in risk assessment depends upon the type of qualifier. Qualifiers used with the Rocky Flats data and use in risk assessment are summarized below.

- E qualifier for metals: Result is estimated due to interference. These data were used as reported.

- E qualifier for organics: Result exceeded calibration range. These results were replaced with the associated D-qualified results (diluted to within calibration range).

- B qualifier for metals: Result is greater than the instrument detection limit (IDL) but less than the Contract Required Quantitation Limit (CRQL) for that analyte. These data were used as reported.

- B qualifier for organics: The contaminant was detected in the associated laboratory blank. If validated and not U-qualified by the validator, the results were used as reported. Nonvalidated B-qualified results were either used as reported or were designated non-detect following guidelines described in EPA 1994a.

- J qualifier: The analyte was positively identified below the sample quantitation limit (SQL). The result is considered an estimate because of the uncertainty associated with quantifying low concentrations. Results were used as reported.

- U qualifier: The analyte was not detected above the SQL. U-qualified results were considered non-detect.

- R qualifier: The result was rejected during the validation process and was removed from the working data set. R-qualified data were not used in risk

assessment according to EPA guidance (EPA 1989a). Rejected data represented 2 percent of the overall data.

H2.2 DATA AGGREGATION FOR RISK ASSESSMENT

Data aggregation for risk assessment was performed in accordance with guidelines developed by CDPHE, EPA Region VIII, and DOE for application at RFETS (CDPHE/EPA/DOE 1994). First, contaminant source areas were identified on the basis of the spatial extent of contaminants in subsurface soil and groundwater. Source area boundaries included contaminated soil and associated groundwater contaminant plumes.

Five source areas were identified in OU-2; these are listed below and shown on Figure H2-1. IHSS locations are shown on Figure H2-2. The physical extent of source areas 1, 2, and 3 were largely determined by the extent of associated contaminant plumes in groundwater. The following are the five source areas:

(1) 903 Pad Source Area. This source area includes (a) IHSSs 109 (Trench T-2), 112 (903 Pad), 140 (Reactive Metal Destruction Site), 155 (903 Lip Area), and 183 (Gas Detoxification Area) at the 903 Pad Area; (b) a groundwater contaminant plume extending north and northeast of the 903 Pad Area toward the South Walnut Creek drainage and extending south and southeast of the 903 Pad Area toward the Woman Creek drainage; and (c) surface soil and subsurface soil within the area defined by the extent of the groundwater plume. The plume boundary incorporates a portion of Trench T-5 (IHSS 111.2); Trenches T-9 (IHSS 111.6), T-10 (IHSS 111.7), T-11 (IHSS 111.8), T-12 and T-13; and most of the East Spray Fields (IHSSs 216.2 and 216.3). These trenches and spray fields are located within the area defined by the extent of the groundwater contaminant plume but probably do not contribute to it.

(2) Mound Source Area. This source area includes (a) IHSSs 108 (Trench T-1), 113 (Mound Area), 153 (Oil Burn Pit No. 2), and 154 (Pallet Burn Site) in the Mound Area; (b) a groundwater contaminant plume extending north and northeast of the Mound Area toward the South Walnut Creek drainage; and (c)

surface soil and subsurface soil within the area approximately defined by (a) and (b).

(3) Northeast Trenches Source Area. This source area includes (a) Trenches T-3 and T-4 (IHSSs 110 and 111.1); (b) a groundwater contaminant plume extending north of Trenches T-3 and T-4 toward the South Walnut Creek drainage; and (c) surface soil and subsurface soil located within the area defined by the extent of the groundwater plume.

(4) Southeast Trenches Source Area. This source area includes (a) the portion of Trench T-5 (IHSS 111.2) that has no underlying groundwater and Trenches T-6 (IHSS 111.3), T-7 (IHSS 111.4), and T-8 (IHSS 111.5); and (b) surface soil and subsurface soil within the area approximately defined by (a). No UHSU groundwater is present in this area.

(5) East of IHSSs Source Area. This source area includes (a) UHSU groundwater east of the previously described source areas extending to Indiana Street and bounded by South Walnut Creek to the north and Woman Creek to the south and (b) surface soil and subsurface soil within the area defined in (a). There are no IHSSs in this area with the exception of a portion of the East Spray Field (IHSS 216.3).

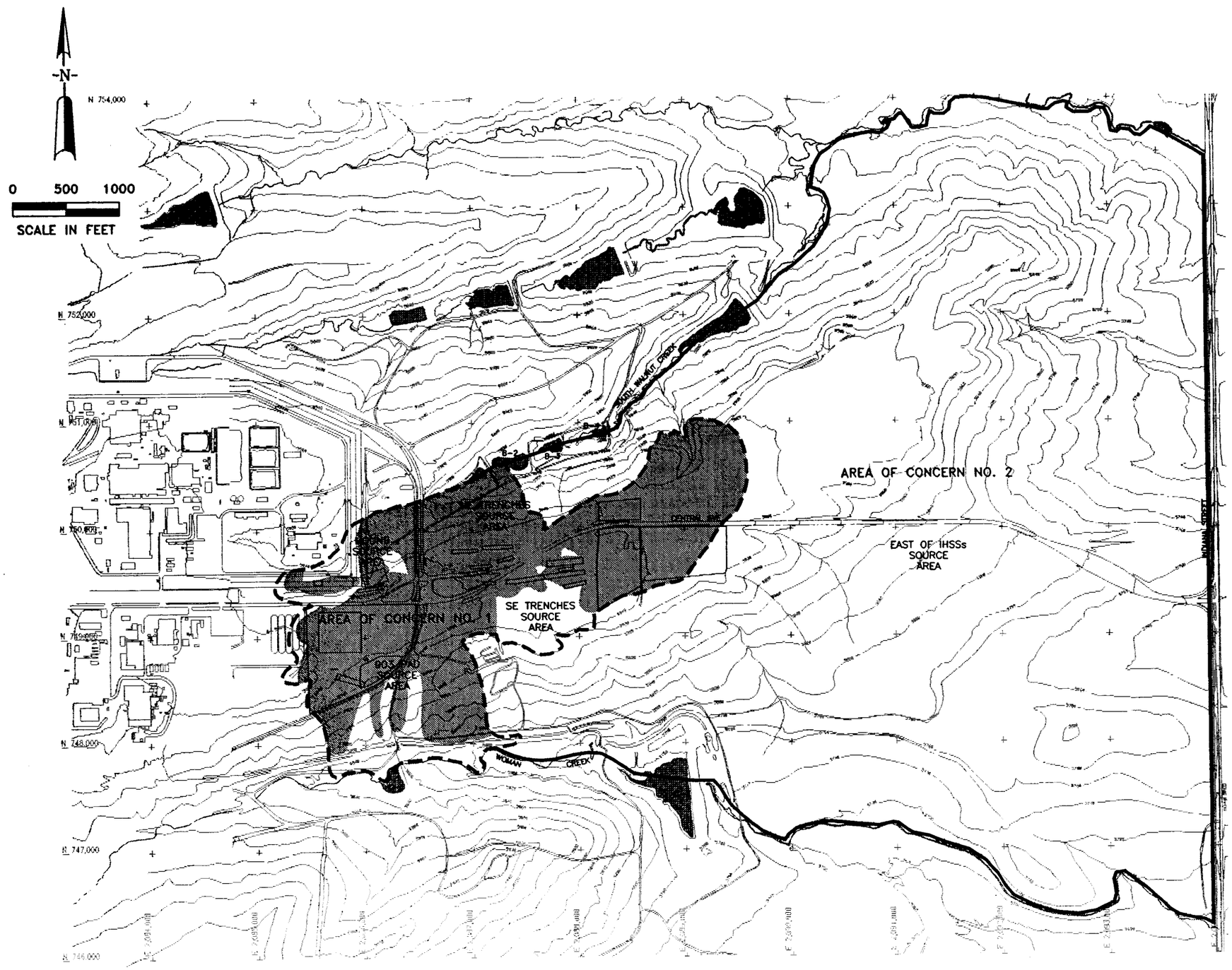
Following the identification of contaminant source areas, AOCs were delineated. AOCs were defined as one or several contaminant source areas that are close and can be evaluated as a unit in the HHRA. Two AOCs were identified in OU-2 (Figure H2-1). AOC No. 1 includes the 903 Pad, Mound, Northeast Trenches, and Southeast Trenches source areas, which contain all of the IHSSs that were investigated in OU-2. The 903 Pad, Mound, and Northeast Trenches source areas are hydrogeologically connected; the Southeast Trenches area does not contain groundwater. High concentrations of chlorinated hydrocarbons have been detected in groundwater in the 903 Pad, Mound, and Northeast Trenches source areas. The probable source of groundwater contamination is subsurface soil contamination. These source areas form a logical AOC based on their historical use for waste disposal and the presence of contiguous groundwater contaminant plumes.

AOC No. 2 is the East of the IHSSs area, located in the buffer zone between the IHSSs and Indiana Street (Figure H2-1). No IHSSs or other waste disposal areas are present in this AOC.

In addition, within AOC No. 1, maximum exposure areas of 10 acres, 30 acres, and 50 acres were delineated for purposes of evaluating reasonable maximum risk to individuals in a hypothetical residential neighborhood (10 acres), a future industrial or office park (30 acres), and in an ecological study area (50 acres) (Figure H2-2). The 10-acre maximum exposure area was identified as the area with the highest levels of soil and groundwater contamination. This area is in the 903 Pad Source Area. The 30-acre and 50-acre exposure areas each include the 903 Pad Source Area.

No maximum exposure areas were delineated in AOC No. 2 because the data set is relatively small for the entire AOC, which precludes the use of data from individual 10- or 30-acre plots. Contaminant levels are relatively low and the analytical results appear to characterize the area well. There is no evidence for "hot spots" that would warrant separate evaluation, and historical data indicate that no waste disposal occurred in this area.

Results from all samples collected in each AOC and in each maximum exposure area were aggregated for use in calculating the exposure concentrations for risk assessment. More detail on calculating the exposure concentrations is provided in Section H5.0.



EXPLANATION

- INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
- APPROXIMATE EXTENT OF GROUNDWATER CONTAMINATION
- AREA OF CONCERN NO. 1
- AREA OF CONCERN NO. 2

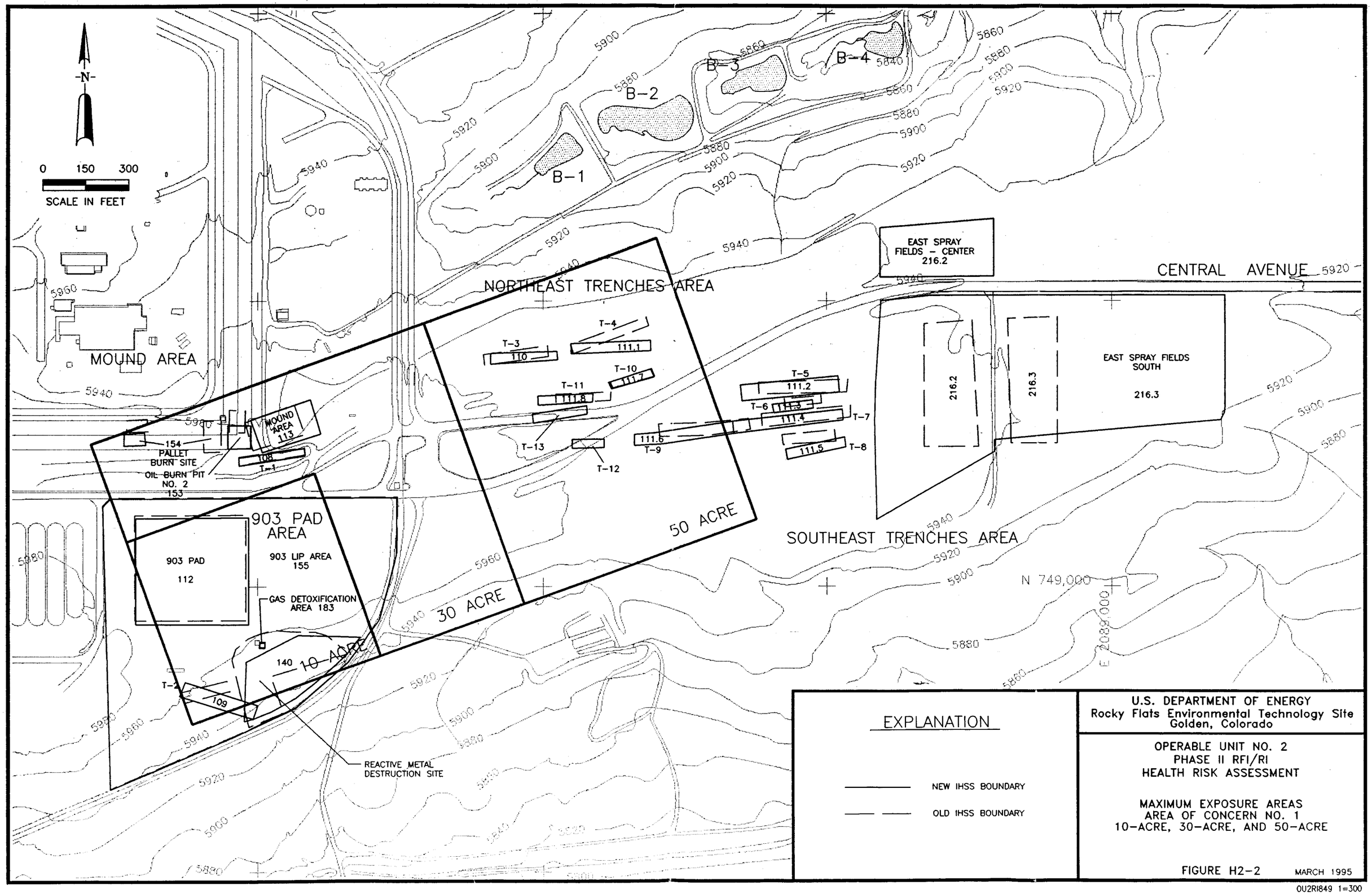
U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI
HEALTH RISK ASSESSMENT

SOURCE AREAS
AND AREAS OF CONCERN

FIGURE H2-1 MARCH 1995

OU2RI848 1=1000


-N-
0 150 300
SCALE IN FEET
MOUND AREA
NORTHEAST TRENCHES AREA
SOUTHEAST TRENCHES AREA
CENTRAL AVENUE
EAST SPRAY FIELDS – CENTER 216.2
EAST SPRAY FIELDS SOUTH 216.3
216.2
216.3
B-1
B-2
B-3
B-4
T-1
T-2
T-3
T-4
T-5
T-6
T-7
T-8
T-9
T-10
T-11
T-12
T-13
110
111.1
111.2
111.3
111.4
111.5
111.6
111.7
111.8
MOUND AREA 113
108
154 PALLET BURN SITE
OIL BURN PIT NO. 2 153
903 PAD AREA
903 PAD 112
903 LIP AREA 155
GAS DETOXIFICATION AREA 183
140
109
10 ACRE
30 ACRE
50 ACRE
REACTIVE METAL DESTRUCTION SITE
N 749,000
E 2089,000
EXPLANATION
NEW IHSS BOUNDARY
OLD IHSS BOUNDARY
U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado
OPERABLE UNIT NO. 2
PHASE II RFI/RI
HEALTH RISK ASSESSMENT
MAXIMUM EXPOSURE AREAS
AREA OF CONCERN NO. 1
10-ACRE, 30-ACRE, AND 50-ACRE
FIGURE H2-2
MARCH 1995
OU2RI849 1=300

COCs are organic chemicals, metals, and radionuclides in soil or groundwater in OU-2 with concentration distributions that differed significantly from background distributions and that are likely to contribute significantly to overall risk. COCs, which are a subset of all chemicals detected in the field investigations, are selected for quantitative evaluation in the risk assessment and are the focus of transport modeling, risk assessment, and remedy selection. This section describes the process for determining COCs in surface soil, subsurface soil, and groundwater. The process was developed and agreed upon by EPA, CDPHE, and DOE. More detail is provided in the TM 9 (DOE 1994b,d).

H3.1 PROCESS FOR SELECTING OU-WIDE COCs

COCs in each medium were determined on an OU-wide basis; that is, all sample results from each medium were pooled for the evaluation. Risk-based and other screening methods were used to identify COCs; i.e., the chemicals that are likely to pose the greatest potential risk to human health. The COC selection process is illustrated in Figure H3-1 and summarized in the sections below.

H3.1.1 Background Comparison

Analytical results for metals and radionuclides detected in soil and groundwater in OU-2 were compared to background results using four statistical tests: the Quantile test, Slippage test, Student's t-test, and the Gehan test (Gilbert 1993). In addition, analytical results were compared to the 99th percentile upper tolerance limit ($UTL_{99/99}$) of the background data. Any analyte that failed one or more of the statistical tests or that had one or more results exceeding the $UTL_{99/99}$ was retained as a potential COC. A detailed description of the statistical methodology used in the background comparison and tables showing results of the statistical tests are presented in Appendix A of TM 9 (DOE 1994b); summary tables also accompany Section 4.1 of the RFI/RI Report.

H3.1.2 Essential Nutrients/Major Cations and Anions

Ca, Fe, Mg, K, and sodium were eliminated from further consideration as COCs because they are essential nutrients, they occur naturally in the environment, and they are toxic only at very high doses. Cyanide, nitrate, and nitrite were retained for further evaluation, but other major cations and anions measured as water quality parameters, such as carbonates, were not evaluated.

H3.1.3 Frequency of Detection

Metals with concentration distributions in OU2 that were significantly different from background distributions and detected organic compounds were evaluated for frequency of detection. Chemicals that were detected at a frequency of 5 percent or greater were retained for further evaluation in concentration/toxicity screens to select OU-wide COCs. Organic chemicals and metals that were detected at less than 5 percent frequency were evaluated separately (Section H3.1.6). Radionuclides were assumed to be detected at 100 percent frequency for statistical analysis (i.e., negative, zero, and positive results were retained in the data set); thus, the radionuclides were not screened based on frequency of detection.

H3.1.4 Concentration/Toxicity Screens

Concentration/toxicity screens were conducted separately for noncarcinogens, carcinogens, and radionuclides within each medium (surface soil, subsurface soil, and groundwater). These screens were used to identify chemicals that, based on maximum concentration and toxicity, are likely to contribute 1 percent or more of the total potential risk in each category (noncarcinogens, carcinogens, and radionuclides) in each medium. These chemicals were identified as COCs for evaluation in the quantitative risk assessment.

H3.1.5 Professional Judgement

Some chemicals whose concentration distributions in OU2 were significantly different than background distributions based on results of the statistical tests were judged not to be OU-2 contaminants based on spatial and temporal distribution, geochemical characteristics, and TSS in groundwater. Chemicals and media were as follows:

- Surface soil: benzoic acid and PAHs
- Subsurface soil: Ba and Mn
- Groundwater: aluminum, antimony, beryllium, manganese, and vanadium

The evaluations and conclusions are described in detail in the TM 9 (DOE 1994b). However, to address concerns that some analytes, whether contaminants or not, could pose a health risk under long-term exposure to maximum detected concentrations, the following constituents were retained for consideration in a separate risk evaluation in Section H10.2 of the uncertainty section of the HHRA (CDPHE 1994; EPA 1994b; DOE 1994d):

- Surface soil: PAHs
- Groundwater: As, Sb, Be, and Mn

Arsenic (As) was included in the separate evaluation even though it had been excluded as a COC based on the results of the concentration/toxicity screens for UHSU groundwater.

H3.1.6 Evaluation of Infrequently Detected Compounds

For organic compounds and metals detected at less than 5 percent frequency, maximum concentrations were compared to screening levels equivalent to 1,000 times the risk-based concentrations (RBCs) to determine whether there was potential risk to human health on the basis of high concentration and toxicity even though the chemicals were rarely detected and exposure potential was low. RBCs were defined as chemical concentrations associated with an excess lifetime cancer risk of 1E-06 (1 in 1 million) or a hazard index of 1 for noncarcinogenic effects. RBCs for chemicals in surface soil were calculated assuming residential exposure via ingestion of soil, inhalation of airborne particulates, and external irradiation. RBCs for chemicals in subsurface soil were calculated assuming construction worker exposure via soil ingestion and inhalation of particulates and VOCs. RBCs for chemicals in groundwater were calculated assuming residential exposure via ingestion of water and inhalation of VOCs during water use.

Infrequently detected chemicals whose maximum concentrations exceeded 1,000 times the RBC were retained as special-case COCs for separate evaluation in the risk assessment. The

risk-based evaluation of infrequently detected chemicals is described in detail in Appendix B of the TM 9 (DOE 1994b).

Only vinyl chloride in groundwater was identified as exceeding 1,000 times the RBC.

H3.1.7 Chemicals Without EPA Toxicity Values

Detected chemicals that do not have EPA-established toxicity values are listed in Table H3-1. These compounds cannot be evaluated in a toxicity or risk-based screen to select COCs. However, their potential contribution to overall risk was evaluated qualitatively in Section H10.1.4 of the uncertainties section of the risk assessment.

H3.2 SURFACE SOIL COCs

The sample set used to characterize extent of contamination and select COCs in surface soil is summarized in Section H2.0. COCs were identified using the process outlined in Section H3.1.

H3.2.1 Concentration/Toxicity Screens

Detection frequencies and metals with concentration distributions statistically significantly different from background distributions are shown in Tables H3-2 and H3-3. Concentration/toxicity screens for analytes above background levels and detected at a frequency of 5 percent or greater are shown in Tables H3-4 through H3-6. In the screens, analytes that contributed 1 percent or more of the total risk factor were identified as COCs.

OU-Wide Chemicals of Concern
Surface Soil

Aroclor-1254
Aroclor-1260
Bis(2-ethylhexyl)phthalate
Cr
Am-241
Pu-239/240

PAHs were not included in the concentration/toxicity screens because their presence in surface soil may be related to anthropogenic sources not attributable to chemical waste releases or waste disposal practices at Rocky Flats. Instead, they are addressed as special-case COCs in the uncertainty section of the risk assessment (Section H3.2.2).

The following paragraphs discuss several factors pertinent to the selection of COCs in surface soil.

Pb and Cr were the only two metals with concentration distributions in OU2 that were significantly different than background (other than calcium and Fe, which were removed from further evaluation in Section H3.1.2). The maximum detected concentration of lead in surface soil (145 mg/kg) was less than EPA's screening level for residential soil (400 mg/kg; EPA 1994d). Because Pb does not have EPA-approved toxicity factors, it cannot be evaluated quantitatively in toxicity-based screens. However, it was retained for qualitative evaluation in Section H8.0, Risk Characterization.

The formal statistical tests indicated that the Cr distribution in OU-2 was not significantly different than background (Appendix A of TM 9, DOE 1994b). However, two sample results for chromium (26 mg/kg and 29.5 mg/kg) slightly exceeded the background $UTL_{99/99}$ of 24.8 mg/kg. The 26 mg/kg result was associated with sampling site SS200193, located on the western edge of IHSS 1450 (Reactive Metal Destruction Site), and the 29.5 mg/kg result was associated with sampling site SS200893, located on the southern edge of the Southeast Trenches Source Area (see Plate 4.2.3). Because two results exceeded the background $UTL_{99/99}$, chromium was retained as an OU-wide potential COC and was identified as a COC based on the results of the concentration/toxicity screen (Table H3-4). However, Cr does not appear to be an OU-wide contaminant because only two results slightly exceeded background levels.

Bis(2-ethylhexyl)phthalate (BEHP), a common laboratory and field contaminant, was detected in 23 percent of surface soil samples widely distributed across OU-2. The frequency of detection and concentrations observed in OU-2 samples (49J to 510J μg/kg) and in

background samples (35J to 140 μg/kg) were similar, suggesting that BEHP in OU-2 samples is not an environmental contaminant. (See discussion in Section 4.2 of this RFI/RI Report and in DOE 1994b.) However, it was retained as a potential COC because the maximum concentration (0.51 mg/kg) occurred in a sample from a contaminated area (the 903 Pad). This was the only concentration that exceeded the background range. BEHP was identified as an OU-wide COC based on the results of concentration/toxicity screen (Table H3-4).

Aroclor-1254 and Aroclor-1260, which are PCBs, were detected at only two sampling locations, both in the Mound Area; however, this constituted a 5 percent detection frequency. The PCBs were included as OU-wide potential COCs in the concentration/toxicity screen.

H3.2.2 Special-Case COCs in Surface Soil

None of the chemicals detected at low frequency in surface soil exceeded 1,000 times the RBC. Thus, no special-case COCs in soil were selected using this criterion.

PAHs were retained for separate evaluation as special-case COCs because their presence in surface soil is more likely due to common sources such as vehicle emissions rather than waste releases at RFETS. PAHs are common combustion byproducts from burning coal, wood, tobacco, and petroleum-based fuels. Of the total of 40 surface soil samples analyzed for PAHs in OU-2, 6 were collected at biased sampling locations (i.e., at IHSSs) and 34 were random (grid-based) samples collected across OU-2. Concentrations of PAHs measured in biased samples were comparable to those measured in the random samples (Table H3-7). Because similar PAH levels are found in random and biased samples, the detected PAHs are thought to be related to anthropogenic sources not attributable to OU-2 waste. However, to address concerns that some of these chemicals, although probably not contaminants, could pose a health risk under long-term exposure to maximum detected concentrations, parties to the IAG agreed that PAHs will be evaluated separately in the uncertainty section (Section H10.0) as special-case COCs in surface soil.

H3.3 SUBSURFACE SOIL COCs

The sample set used to characterize extent of contamination and to select COCs in subsurface soil is summarized in Section H2.0. COCs were identified using the process outlined in Section H3.1.

H3.3.1 Concentration/Toxicity Screens

Analytes whose concentration distributions in OU2 were statistically significantly different from background distributions and with a detection frequency of five percent or greater were included in the concentration/toxicity screens to select OU-wide COCs in subsurface soil.

Detection frequencies and metals above background levels are shown in Tables H3-8 and H3-9. Concentration/toxicity screens are shown in Tables H3-10 through H3-12.

In the concentration/toxicity screens, analytes that contributed at least 1 percent of the total risk factor were retained as OU-wide COCs. These are listed below.

OU-Wide Chemicals of Concern
Subsurface Soil

PCE	Am-241
As	Pu-239/240
Cd	U-233/234
Hg	U-235
	U-238

The following paragraphs discuss several factors pertinent to the selection of COCs in subsurface soil.

Barium and manganese concentration distributions were not significantly different than background based on four formal statistical tests described in Section H3.1.1. However, one or more results exceeded the background $UTL_{99/99}$. Because both Ba and Mn are common elements in soil, the analytical results were evaluated to ascertain whether the few elevated concentrations above background $UTL_{99/99}$ were likely to be naturally occurring or due to contamination. Based on spatial distribution and geochemical characteristics, it was concluded that the elevated levels were naturally occurring and that barium and manganese are not contaminants in subsurface soils in OU-2 (DOE 1994b). Therefore, they were eliminated from further evaluation.

A similar review was performed for As and Cd. These compounds were detected in elevated concentrations in some trenches, with other occurrences being scattered throughout OU-2. However, most of the elevated concentrations were reported in samples collected in 1987 (data not validated), and the elevated concentrations tended to be constant with depth, including depths below potential anthropogenic sources. Post-1987 samples from nearby locations did not confirm the presence of elevated concentrations. Based on the spatial and

temporal distributions of As and Cd, it is questionable whether these metals are environmental contaminants in subsurface soils. Nevertheless, as a conservative measure, they were included as potential COCs in the concentration/toxicity screens for subsurface soil and both were identified as COCs.

Hg concentration distributions were not significantly different from background distributions according to the four formal statistical tests identified in Section H3.1.1; however, two results exceeded the background $UTL_{99/99}$, one in Trench T-4 and one west of the 903 pad. Therefore, Hg was retained as a potential COC in the concentration/toxicity screen for subsurface soil and was identified as an OU-wide COC.

H3.3.2 Special-Case COCs in Subsurface Soil

None of the chemicals detected at low frequency in subsurface soil exceeded 1,000 times the RBC. Thus, there were no special-case COCs in subsurface soil.

H3.4 GROUNDWATER COCs

The sample set used to characterize extent of contamination and select COCs in groundwater is summarized in Section H2.0. Groundwater samples were analyzed for metals and radionuclides (in filtered and unfiltered samples) and for VOCs, SVOCs, pesticides/PCBs, and water quality parameters. Results from unfiltered samples were used in selecting COCs, using the process outlined in Section H3.1.

H3.4.1 Concentration/Toxicity Screens

Organic compounds that were detected at 5 percent or greater detection frequency and most metals and radionuclides with concentration distributions in OU2 significantly different from background distributions were included in concentration/toxicity screens to select OU-wide COCs in groundwater. Detection frequencies and metals above background levels are shown in Tables H3-13 and H3-14. Concentration/toxicity screens are shown in Tables H3-15 through H3-17.

In the concentration/toxicity screens, analytes that contributed at least 1 percent of the total risk factor were retained as OU-wide COCs. OU-wide chemicals of concern for groundwater are listed below.

OU-Wide Chemicals of Concern Groundwater
Carbon Tetrachloride
$CHCl_3$
1,1-DCE
CH_2Cl_2
TCE
PCE
Am-241
Pu-239/240

Five metals - Al, Sb, Be, Mn, and V were eliminated as contaminants and excluded from the concentration/toxicity screens because their presence in unfiltered samples was determined to be associated with local geochemical conditions (manganese) and with high levels of suspended solids in unfiltered samples (DOE 1994b). In fact, nearly all metals, including typical rock-forming elements such as Ca, Fe, and sodium, were above background levels. Their concentrations in groundwater are most likely related to local geochemical characteristics and to suspended solids in the samples. However, the five metals mentioned above were evaluated individually because, at their maximum concentrations, they would drive the results of the concentration/toxicity screens and the screens would fail to identify potentially hazardous organic contaminants as COCs.

H3.4.2 Special-Case COCs in Groundwater

Metals: To address concerns that some metals, although probably not OU-specific contaminants, could pose a health risk under long-term exposure to maximum detected concentrations, parties to the IAG have agreed that Sb, As, Be, and Mn will be evaluated in the uncertainty section of the HHRA as special-case COCs (CDPHE 1994; EPA 1994b; DOE 1994d).

Vinyl Chloride: Vinyl chloride is not an OU-wide COC because it was detected infrequently (in only 3 percent of groundwater samples collected in OU-2). However, vinyl chloride was identified as a special-case COC in groundwater because concentrations in some wells exceeded 1,000 times the RBC of 2.8 E-05 mg/L (1,000 x RBC = 0.03 mg/L).

H3.5 CHEMICALS OF CONCERN IN OU-2

The COCs identified for each medium, including special-case COCs, are summarized in Table H3-18.

TABLE H3-1
DETECTED CHEMICALS WITHOUT EPA TOXICITY FACTORS

Chemical	Detection Frequency % (1)
Surface Soil	
Benzo(ghi)perylene	3
delta-BHC	3
Lead	100
Subsurface Soil	
Copper	86
Lead	100
Benzo(ghi)perylene	0.5
Chloroethane	0.3
2-Chloroethylvinyl ether	1
Hexachlorobutadiene	0.5
2-Methylnaphthalene	1
4-Nitroaniline	0.5
Phenanthrene	2
Groundwater	
Copper	66
Lead	93
1,1,1,2-Tetrachloroethane	3
1,2,3-Trichlorobenzene	2
1,2,3-Trichloropropane	1
1,2,4-Trimethylbenzene	1
1,2-Dibromo-3-chloropropane	1
1,2-Dibromoethane	1
1,3-Dichlorobenzene	1
1,3-Dichloropropane	0.4
1,3,5-Trimethylbenzene	1
2-Hexanone	1
Bromobenzene	1
Bromochloromethane	2
Dibromomethane	0.4
Dichlorodifluoromethane	1
Hexachlorobutadiene	2
n-Butylbenzene	1
o-Chlorotoluene	0.4
p-Chlorotoluene	0.3
p-Cymene	3
Trichlorofluoromethane	3

(1) Detection frequency calculated without QA/QC duplicate samples.

TABLE H3-2
ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY SURFACE SOIL

	Maximum Detected Conc. (mg/kg)	Detection Frequency (1) (%)	> Background? (2)
Organic Compounds:			
Aroclor-1254	0.97	5	
Aroclor-1260	0.66	5	
Benzo(a)anthracene*	0.16	18	
Benzo(a)pyrene*	0.16	18	
Benzo(b)fluoranthene*	0.24	23	
Benzo(k)fluoranthene*	0.076	5	
Benzoic acid**	0.7	93	
Bis(2-ethylhexyl)phthalate	0.51	23	
Chrysene*	0.2	28	
Fluoranthene*	0.39	48	
Indeno(1,2,3-cd)pyrene*	0.083	5	
Phenanthrene*	0.23	30	
Pyrene*	0.35	55	
Metals:			
Aluminum	18,700	100	No
Arsenic	6.7	100	No
Barium	208	100	No
Beryllium	1.3	20	No
Cadmium	2.2	14	No
Chromium	29.5	100	Yes
Cobalt	10.2	100	No
Copper	20.5	100	No
Lead	145	100	Yes
Lithium	22.9	91	No
Manganese	1,110	100	No
Nickel	21.6	87	No
Selenium	1.1	28	No
Strontium	100	100	No
Thallium	0.5	6	No
Tin	93.3	29	No
Vanadium	51.1	100	No
Zinc	89.3	100	No

(1) Detection frequency calculated without QA/QC duplicate samples.

(2) Background comparison is detailed in Appendix A of Technical Memorandum No. 9 (USDOE 199

* Polycyclic aromatic hydrocarbons are evaluated as special-case chemicals of concern.

** Benzoic acid was concluded not to be a contaminant (DOE 1994b).

TABLE H3-3
ORGANIC COMPOUNDS AND METALS DETECTED AT LESS THAN 5% FREQUENCY
SURFACE SOIL

	Maximum Detected Conc. (mg/kg)	Detection Frequency (1) (%)	> Background? (2)	>1,000 x RBC?
Organic Compounds:				
4,4'-DDT	0.026	3		No
delta-BHC	0.023	3		-
Benzo(ghi)perylene	0.045	3		-
Di-n-butylphthalate	1.0	3		No
Metals:				
Cesium	8.7	2	No	
Molybdenum	5.3	2	No	
Silver	1.2	2	No	

(1) Detection frequency calculated without QA/QC duplicate samples.
(2) The background comparison and 1,000 x RBC screen are detailed in Appendixes A and B of Technical Memorandum No. 9 (DOE 1994b).
RBC - Risk-based concentration.
- Toxicity factors are not available and an RBC cannot be calculated.

TABLE H3-4
CONCENTRATION/TOXICITY SCREEN
SURFACE SOIL
NONCARCINOGENS

Chemical	Maximum Detected Conc. (mg/kg)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Chromium (1)	29.5	n/a	1.0E+00	3.0E+01	5.4E-01	53.6
Bis(2-ethylhexyl)phthalat	0.51	n/a	2.0E-02	2.6E+01	4.6E-01	46.4
Total Risk Factor				5.5E+01		

RfDs are in units of mg/kg-day.

n/a - not available.

Evaluated as Cr III based on results of speciation study (DOE 1994d).

TABLE H3-5
CONCENTRATION/TOXICITY SCREEN
SURFACE SOIL
CARCINOGENS

Chemical	Maximum Detected Conc. (mg/kg)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Aroclor-1254	0.97	n/a	7.7E+00	7.5E+00	5.9E-01	59.5
Aroclor-1260	0.66	n/a	7.7E+00	5.1E+00	4.0E-01	40.5
Bis(2-ethylhexyl)phthalate	0.59	n/a	1.40E-02	8.3E-03	6.6E-04	0.1
Total Risk Factor				1.3E+01		

Slope factors are in units of 1/(mg/kg-day).
n/a - not available.

TABLE H3-6
CONCENTRATION/TOXICITY SCREEN
SURFACE SOIL
RADIONUCLIDES

Chemical	Maximum Detected Conc. (pCi/g)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Plutonium-239,240	7300	3.8E-08	2.3E-10	2.8E-04	9.8E-01	98.1
Americium-241	160	3.2E-08	2.4E-10	5.1E-06	1.8E-02	1.8
Uranium-238	7.74	2.4E-08	2.0E-11	1.9E-07	6.6E-04	0.1
Uranium-233,234	3.581	2.6E-08	1.6E-11	9.3E-08	3.3E-04	0.0
Uranium-235	0.68	2.5E-08	1.6E-11	1.7E-08	6.0E-05	0.0
Radium-226	1.46	3.0E-09	1.2E-10	4.4E-09	1.5E-05	0.0
Strontium-89,90	2.09	6.2E-11	3.6E-11	1.3E-10	4.6E-07	0.0
Total Risk Factor				2.8E-04		

Slope factors are in units of 1/pCi.

TABLE H3-7
CONCENTRATION RANGES OF SELECTED PAHs AT RANDOM AND BIASED SURFACE SOIL SAMPLING LOCATIONS

	Detected Concentration mg/kg (1)	
	Random (grid-based)	Biased (IHSSs)
Benzo(a)anthracene	0.041 - 0.130	0.051 - 0.160
Benzo(a)pyrene	0.048 - 0.140	0.068 - 0.160
Benzo(b)fluoranthene	0.090 - 0.200	0.038 - 0.240
Pyrene	0.054 - 0.260	0.098 - 0.350

(1) Detected concentrations are all estimated values at or below the reporting limit (0.330 mg/kg).

TABLE H3-8
ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY SUBSURFACE SOIL

	Maximum Detected Conc. (mg/kg)	Detection Frequency (1) (%)	> Background? (2)
Organic Compounds:			
1,1,1-Trichloroethane	13	5	
1,2-Dichloroethane	0.12	9	
2-Butanone	0.15	6	
Acetone	26	38	
Bis(2-ethylhexyl)phthalate	12	38	
Di-n-butylphthalate	3.4	26	
Methylene chloride	29	28	
N-nitrosodiphenylamine	0.28	13	
Tetrachloroethene	13,000	13	
Toluene	7.6	38	
Metals:			
Aluminum	27,900	100	No
Antimony	26.8	8	No
Arsenic	30.8	94	Yes
Barium	589	83	Yes
Beryllium	22.9	49	No
Cadmium	10.5	34	Yes
Cesium	5.1	63	No
Chromium	127	98	Yes
Cobalt	38.5	53	Yes
Copper	132	86	Yes
Lead	86.4	100	Yes
Lithium	32.9	75	No
Manganese	3,160	100	Yes
Mercury	114	24	Yes
Molybdenum	18.7	22	No
Nickel	33.8	82	No
Silver	96.5	13	Yes
Strontium	459	78	No
Thallium	0.7	17	No
Tin	59.3	21	No
Vanadium	80.4	97	No
Zinc	437	100	Yes
Nitrate	4.3	42	

(1) Detection frequency calculated without QA/QC duplicate samples.
(2) Background comparison is detailed in Appendix A of Technical Memorandum No. 9 (DOE 1994b).

TABLE H3-9
ORGANIC COMPOUNDS AND METALS DETECTED AT LESS THAN 5% FREQUENCY
SUBSURFACE SOIL

	Maximum Detected Conc. (mg/kg)	Detection Frequency (1) (%)	> Background? (2)	>1,000 x RBC Screen?
Organic Compounds:				
1,1,2,2-Tetrachloroethane	0.005	0.3		No
1,2-Dichloroethene	0.09	1		No
1,3-Dichloropropene, cis	0.006	0.3		No
1,4-Dichlorobenzene	0.043	0.5		No
2-Chloroethyl vinyl ether	0.031	1		-
2-Methylnaphthalene	8.1	1		-
2-Methylphenol	0.45	0.5		No
4,4'-DDT	0.14	0.4		No
4-Methyl-2-pentanone	0.011	0.3		No
4-Methylphenol	2.9	0.5		No
4-Nitroaniline	1.6	0.5		-
Acenaphthene	0.28	1		No
Anthracene	0.26	0.5		No
Aroclor-1254	8.9	3		No
Benzene	0.012	0.3		No
Benzo(a)anthracene	0.53	0.5		No
Benzo(a)pyrene	0.48	1		No
Benzo(b)fluoranthene	0.82	0.5		No
Benzo(ghi)perylene	0.36	0.5		-
[illegible]ic acid	0.4	1		No
Butyl benzylphthalate	0.52	0.5		No
Carbon disulfide	0.14	0.3		No
Carbon tetrachloride	140	4		No
Chloroethane	0.007	0.3		No
Chloroform	8.8	3		No
Chrysene	0.42	1		No
Di-n-octylphthalate	0.26	0.5		No
Ethylbenzene	0.026	2		No
Fluoranthene	1	2		No
Fluorene	0.19	0.5		No
Hexachlorobutadiene	0.17	0.5		No
Hexachloroethane	1.1	0.5		No
Indeno(1,2,3-cd)pyrene	0.33	0.5		No
Naphthalene	2	1		No
Pentachlorophenol	0.095	1		No
Phenanthrene	2.7	2		No
Pyrene	1.3	2		No
Styrene	0.017	0.3		No
Total xylenes	0.23	4		No
Trichloroethene	120	4		No
Metals:				No
Selenium	0.5	4	No	No

(1) Detection frequency calculated without QA/QC duplicate samples.
(2) Background comparison and the 1,000 x RBC screen are detailed in Appendixes A and B of Technical Memorandum No. 9 (DOE 1994b).
RBC - Risk-based concentration.
- Toxicity factors are not available.

TABLE H3-10
CONCENTRATION/TOXICITY SCREEN
SUBSURFACE SOIL
NONCARCINOGENS

Chemical	Maximum Detected Conc. (mg/kg)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Tetrachloroethene	13,000	n/a	1.0E-02	1.3E+06	4.8E-01	48.1
Mercury	114	9.0E-05	n/a	1.3E+06	4.7E-01	46.9
Arsenic	30.8	n/a	3.0E-04	1.0E+05	3.8E-02	3.8
Silver	96.5	n/a	5.0E-03	1.9E+04	7.1E-03	0.7
Zinc	437.0	n/a	3.0E-01	1.5E+03	5.4E-04	0.1
Cadmium	10.5	n/a	1.0E-03	1.1E+04	3.9E-03	0.4
Cobalt	38	n/a	6.0E-02	6.3E+02	2.3E-04	0.0
Bis(2-ethylhexyl)p	12	n/a	2.0E-02	6.0E+02	2.2E-04	0.0
Methylene chloride	29	9.0E-01	6.0E-02	4.8E+02	1.8E-04	0.0
Acetone	26	n/a	1.0E-01	2.6E+02	9.6E-05	0.0
Toluene	7.6	1.1E-01	2.0E-01	6.9E+01	2.6E-05	0.0
1,1,1-Trichloroetha	13	2.9E-01	n/a	4.5E+01	1.7E-05	0.0
Di-n-butylphthalat	3.4	n/a	1.0E-01	3.4E+01	1.3E-05	0.0
Chromium III	127	n/a	1.0E+01	1.3E+01	4.7E-06	0.0
Nitrate	4.3	n/a	1.6E+00	2.7E+00	9.9E-07	0.0
2-Butanone	0.15	3.0E-01	6.0E-01	5.0E-01	1.8E-07	0.0
Total Risk Factor				2.7E+06		

RfDs are in units of mg/kg/day.
n/a - not available.

TABLE H3-11
CONCENTRATION/TOXICITY SCREEN
SUBSURFACE SOIL
CARCINOGENS

Chemical	Maximum Detected Conc. (mg/kg)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Tetrachloroethene	13000	2.0E-03	5.2E-02	6.8E+02	5.6E-01	56.1
Arsenic	30.8	1.5E+01	1.7E+00	4.6E+02	3.8E-01	38.4
Cadmium	10.5	6.3E+00	n/a	6.6E+01	5.5E-02	5.5
Methylene chloride	29	1.6E-03	7.5E-03	2.2E-01	1.8E-04	0.0
Bis(2-ethylhexyl)phthalate	12	n/a	1.4E-02	1.7E-01	1.4E-04	0.0
1,2-Dichloroethane	0.12	9.1E-02	9.1E-02	1.1E-02	9.1E-06	0.0
N-nitrosodiphenylamine	0.28	n/a	4.9E-03	1.4E-03	1.1E-06	0.0
Total Risk Factor				1.2E+03		

Slope factors are in units of 1/(mg/kg-day).
n/a - not available.

TABLE H3-12
CONCENTRATION/TOXICITY SCREEN
SUBSURFACE SOIL
RADIONUCLIDES

Chemical	Maximum Detected Conc. (pCi/g)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Plutonium-239,240	180	3.8E-08	2.3E-10	6.8E-06	4.4E-01	44.0
Uranium-233,234	191.7	2.6E-08	1.6E-11	5.0E-06	3.2E-01	32.1
Uranium-238	113.1	2.4E-08	2.4E-11	2.7E-06	1.7E-01	17.5
Americium-241	22	3.2E-08	2.4E-10	7.0E-07	4.5E-02	4.5
Uranium-235	11.5	2.5E-08	1.6E-11	2.9E-07	1.9E-02	1.9
Radium-228	6.32	6.6E-10	1.0E-10	4.2E-09	2.7E-04	0.0
Radium-226	1.9	3.0E-09	1.2E-10	5.7E-09	3.7E-04	0.0
Cesium-137	4.7	1.9E-11	2.8E-11	1.3E-10	8.5E-06	0.0
Strontium-89,90	1.1	6.2E-11	3.6E-11	6.8E-11	4.4E-06	0.0
Tritium	4.9	7.8E-14	5.4E-14	3.8E-13	2.4E-08	0.0
Total Risk Factor				1.6E-05		

Slope factors are in units of 1/pCi.

TABLE H3-13
ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY UHSU GROUNDWATER

	Maximum Detected Conc. (mg/L)	Detection Frequency (1) (%)	Background? (2
Organic Compounds:			
1,1,1-Trichloroethane	1	25	
1,1-Dichloroethane	0.66	13	
1,1-Dichloroethene	0.38	26	
1,2-Dichloroethene	0.17	34	
1,2-Dichloroethene, cis	1.70	45	
1,2-Dichloroethene, trans	0.03	8	
Acetone	0.28	6	
Benzene	0.038	5	
Bis(2-ethylhexyl)phthalate	0.017	29	
Bromodichloromethane	0.19	6	
Carbon tetrachloride	20	60	
Chloroform	39	55	
Diethyl phthalate	0.31	11	
Methylene chloride	35	18	
Naphthalene	0.085	9	
Tetrachloroethene	14	68	
Toluene	0.11	10	
Trichloroethene	150	61	
Metals and other inorganics (unfiltered samples):			
Aluminum	1,460	99	Yes
Antimony	0.297	22	Yes
Arsenic	0.021	60	Yes
Barium	11.3	94	Yes
Beryllium	0.114	43	Yes
Cadmium	0.078	25	Yes
Chromium	3.36	77	Yes
Cobalt	0.651	61	Yes
Copper	1.31	66	Yes
Lead	0.675	93	Yes
Lithium	0.842	86	Yes
Manganese	24	99	Yes
Mercury	0.005	13	Yes
Molybdenum	0.389	25	Yes
Nickel	2.01	76	Yes
Selenium	0.3	32	Yes
Silver	0.057	12	Yes
Strontium	4.24	100	Yes
Thallium	0.006	13	No
Tin	0.642	15	Yes
Vanadium	3.14	83	Yes
Zinc	5.29	96	Yes
Nitrate	444	92	

(1) Detection frequency calculated without QA/QC duplicate samples.
(2) Background comparison is detailed in Appendix A Technical Memorandum No. 9 (DOE 1994b).

TABLE H3-14
ORGANIC COMPOUNDS AND METALS DETECTED AT LESS THAN 5% FREQUENCY
UHSU GROUNDWATER

	Maximum Detected Conc. (mg/L)	Detection Frequency (1) (%)	> Background? (2)	>1,000 x RBC?
Organic Compounds:				
1,1,1,2-Tetrachloroethane	0.003	3		-
1,1,2,2-Tetrachloroethane	0.18	2		No
1,1,2-Trichloroethane	0.021	2		No
1,1-Dichloropropene	0.0001	0.4		No
1,2,3-Trichlorobenzene	0.0004	2		-
1,2,3-Trichloropropane	0.002	1		-
1,2,4-Trichlorobenzene	0.002	1		No
1,2,4-Trimethylbenzene	0.0006	1		-
1,2-Dibromo-3-chloropropane	0.004	1		-
1,2-Dibromoethane	0.013	1		-
1,2-Dichloroethane	0.006	2		No
1,2-Dichloropropane	0.001	0.2		No
1,3-Dichloropropene, cis	1.6	1		No
1,3-Dichloropropene, trans	0.008	1		No
1,3-Dichlorobenzene	0.002	1		-
1,3-Dichloropropane	0.0003	0.4		-
1,3,5-Trimethylbenzene	0.001	1		-
1,4-Dichlorobenzene	0.0003	1		No
2-Hexanone	0.005	1		-
4-Methyl-2-pentanone	0.01	1		No
Benzoic acid	0.056	3		No
Bromobenzene	0.001	1		-
Bromochloromethane	0.71	2		-
Bromoform	0.006	1		No
Bromomethane	0.001	0.3		No
Carbon disulfide	0.0005	1		No
Chlorobenzene	0.016	1		No
Chloroethane	0.002	1		No
Chloromethane	0.32	1		No
Di-n-butylphthalate	0.003	3		No
Dibromochloromethane	0.002	0.2		No
Dibromomethane	1.7	0.4		-
Dichlorodifluoromethane	0.005	1		-
Ethylbenzene	0.015	1		No
Heptachlor epoxide	0.00007	3		No
Hexachlorobutadiene	0.0006	2		-
m+p Xylene	0.0003	2		No
m-Xylene	0.0003	2		No
n-Butylbenzene	0.001	1		-
o-Chlorotoluene	0.0003	0.4		-
o-Xylene	0.0003	2		No

TABLE H3-14
ORGANIC COMPOUNDS AND METALS DETECTED AT LESS THAN 5% FREQUENCY
UHSU GROUNDWATER

	Maximum Detected Conc. (mg/L)	Detection Frequency (1) (%)	> Background? (2)	>1,000 x RBC?
Organic Compounds:				
p-Chlorotoluene	0.0003	0.3		No
p-Cymene	0.0001	3		-
p-Xylene	0.0002	1		No
sec-Butylbenzene	0.23	4		-
Styrene	0.014	2		No
tert-Butylbenzene	0.0004	0.3		-
Trichlorofluoromethane	0.0006	3		-
Vinyl chloride	0.86	3		Yes
Xylenes, total	0.053	1		No
Metals (unfiltered samples):				
Cesium	0.06	2	No	

(1) Detection frequency calculated without QA/QC duplicate samples.
(2) Background comparison and the 1,000 x RBC screen are detailed in Appendixes A and B of Technical Memorandum 9 (DOE 1994b).
RBC - Risk-based concentration.
- Toxicity factors are not available and RBCs cannot be calculated.

TABLE H3-15
CONCENTRATION/TOXICITY SCREEN
UHSU GROUNDWATER
NONCARCINOGENS

Chemical	Maximum Detected Conc. (mg/L)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Carbon tetrachloride	20	n/a	7.0E-04	2.9E+04	8.0E-01	80.0
Chloroform	39	n/a	1.0E-02	3.9E+03	1.1E-01	10.9
Tetrachloroethene	14	n/a	1.0E-02	1.4E+03	3.9E-02	3.9
Methylene chloride	35	9.0E-01	6.0E-02	5.8E+02	1.6E-02	1.6
Nitrate	444	n/a	1.6E+00	2.8E+02	7.8E-03	0.8
cis-1,2-Dichloroethene	1.7	n/a	1.0E-02	1.7E+02	4.8E-03	0.5
Barium	11.3	1.4E-04*	7.0E-02	1.6E+02	4.5E-03	0.5
Cadmium	0.078	n/a	5.0E-04	1.6E+02	4.4E-03	0.4
Nickel	2.01	n/a	2.0E-02	1.0E+02	2.8E-03	0.3
Molybdenum	0.389	n/a	5.0E-03	7.8E+01	2.2E-03	0.2
Arsenic	0.021	n/a	3.0E-04	7.0E+01	2.0E-03	0.2
Selenium	0.3	n/a	5.0E-03	6.0E+01	1.7E-03	0.2
Lithium	0.8	n/a	2.0E-02	4.2E+01	1.2E-03	0.1
1,1-Dichloroethene	0.38	n/a	9.0E-03	4.2E+01	1.2E-03	0.1
Zinc	5.29	n/a	3.0E-01	1.8E+01	4.9E-04	0.0
1,2-Dichloroethene	0.15	n/a	9.0E-03	1.7E+01	4.7E-04	0.0
Mercury	0.005	9.0E-05*	3.0E-04	1.7E+01	4.7E-04	0.0
Silver	0.057	n/a	5.0E-03	1.1E+01	3.2E-04	0.0
Tin	0.642	n/a	6.0E-01	1.1E+00	3.0E-05	0.0
Bromodichloromethane	0.19	n/a	2.0E-02	9.5E+00	2.7E-04	0.0
Strontium	4.24	n/a	6.0E-01	7.1E+00	2.0E-04	0.0
1,1-Dichloroethane	0.66	1.4E-01	1.0E-01	6.6E+00	1.8E-04	0.0
Cobalt	0.65	n/a	6.0E-02	1.1E+01	3.0E-04	0.0
Chromium	3.36	n/a	1.0E+00	3.4E+00	9.4E-05	0.0
Acetone	0.28	n/a	1.0E-01	2.8E+00	7.8E-05	0.0
Naphthalene	0.085	n/a	4.0E-02	2.1E+00	5.9E-05	0.0
trans-1,2-Dichloroethene	0.034	n/a	2.0E-02	1.7E+00	4.8E-05	0.0
Toluene	0.11	1.1E-01	2.0E-01	1.0E+00	2.8E-05	0.0
Bis(2-ethylhexyl)phthalate	0.017	n/a	2.0E-02	8.5E-01	2.4E-05	0.0
Diethyl phthalate	0.31	n/a	8.0E-01	3.9E-01	1.1E-05	0.0
1,1,1-Trichloroethane	1	2.9E-01	n/a	2.9E-01	8.1E-06	0.0
Total Risk Factor				3.6E+04		

RfDs are in units of mg/kg/day.
n/a - not available.

* Inhalation of metals from groundwater is an incomplete pathway. Therefore, oral toxicity values were used.

TABLE H3-16
CONCENTRATION/TOXICITY SCREEN
UHSU GROUNDWATER
CARCINOGENS

Chemical	Maximum Detected Conc. (mg/L)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Carbon tetrachloride	20	5.2E-02	1.3E-01	2.6E+00	3.0E-01	30.1
Trichloroethene	150	6.0E-03	1.1E-02	1.7E+00	1.9E-01	19.1
Tetrachloroethene	14	2.0E-03	5.2E-02	7.3E-01	8.4E-02	8.4
Methylene chloride	35	1.6E-03	7.5E-03	2.6E-01	3.0E-02	3.0
Chloroform	39	8.0E-02	6.1E-03	3.1E+00	3.6E-01	36.1
1,1-Dichloroethene	0.38	1.7E-01	6.0E-01	2.3E-01	2.6E-02	2.6
Arsenic	0.021	1.5E+01*	1.7E+00	3.6E-02	4.1E-03	0.4
Bromodichlorometha	0.19	n/a	6.2E-02	1.2E-02	1.4E-03	0.1
Benzene	0.038	2.9E-02	2.9E-02	1.1E-03	1.3E-04	0.0
Bis(2-ethylhexyl)phtl	0.017	n/a	1.4E-02	2.4E-04	2.8E-05	0.0
Cadmium	0.078	6.3E+00*	n/a	-	-	-
Total Risk Factor				8.6E+00		

Slope factors are in units of 1/(mg/kg-day).

n/a - not available.

* Inhalation of metals from groundwater is an incomplete pathway. Therefore, oral toxicity values were used.

TABLE H3-17
CONCENTRATION/TOXICITY SCREEN
UHSU GROUNDWATER
RADIONUCLIDES

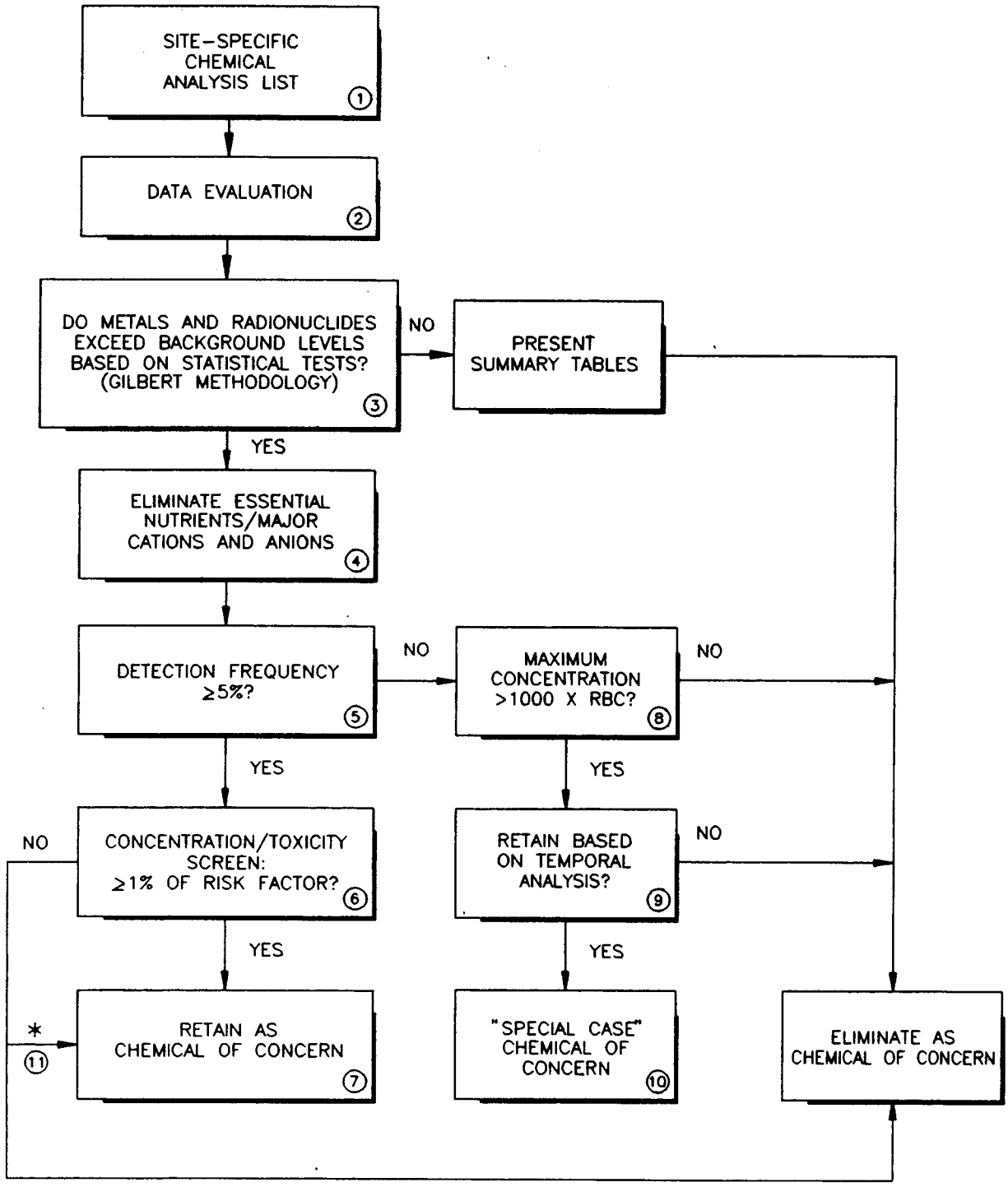
Chemical	Maximum Detected Conc. (pCi/L)	Inhalation Slope Factor (1)	Oral Slope Factor (1)	Risk Factor	Risk Index	% of Total Risk Factor
Plutonium-239/240	354.6	3.8E-08	2.3E-10	8.2E-08	8.8E-01	87.7
Americium-241	46.54	3.2E-08	2.4E-10	1.1E-08	1.2E-01	12.0
Strontium-89,90	6.7	6.2E-11	3.6E-11	2.4E-10	2.6E-03	0.3
Cesium-137	1.799	1.9E-11	2.8E-11	5.0E-11	5.4E-04	0.1
Total Risk Factor				9.3E-08		

Slope factors are in units of 1/pCi.

(1) Inhalation of radionuclides from groundwater is an incomplete pathway. Therefore, oral toxicity values were used in the screen.

TABLE H3-18
SUMMARY OF CHEMICALS OF CONCERN

Chemical of Concern	Surface Soil	Subsurface Soil	Groundwater
Aroclor-1254	X		
Aroclor-1260	X		
Bis(2-ethylhexyl)phthalate	X		
Carbon tetrachloride			X
Chloroform			X
1,1-Dichloroethene			X
Methylene chloride			X
Tetrachloroethene		X	X
Trichloroethene			X
Arsenic		X	
Cadmium		X	
Chromium	X		
Mercury		X	
Americium-241	X	X	X
Plutonium-239/240	X	X	X
Uranium-233,234		X	
Uranium-238		X	
Uranium-235		X	
Special - Case Chemicals			
Vinyl chloride			X
PAHs	X		
Manganese			X
Antimony			X
Arsenic			X
Beryllium			X



* PROFESSIONAL JUDGEMENT
RBC RISK-BASED CONCENTRATION

U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI
HEALTH RISK ASSESSMENT

PROCESS FOR IDENTIFYING CHEMICALS OF CONCERN

FIGURE H3-1 MARCH 1995

OU2R8850

This section describes the exposure scenarios (receptors, exposure areas, and exposure pathways) that are evaluated quantitatively in the risk assessment. Exposure scenarios for OU-2 are discussed in detail in OU-2 TM No. 5 (DOE 1994a).

Exposure scenarios were identified for both current and future site uses. Current and future exposure scenarios in OU-2 were based on:

- Identification of current onsite and offsite land uses and probable future land use scenarios
- Identification of potential receptors based on current and future land use scenarios
- Development of a conceptual site model (CSM) that summarizes information regarding chemical sources, chemical release mechanisms, environmental transport media, and human intake routes. The CSM is used to identify the complete exposure pathways that will be evaluated quantitatively in the risk assessment and to eliminate pathways that are incomplete or negligible.

H4.1 CURRENT AND FUTURE LAND USE

Table H4-1 summarizes the current patterns of land use on and near RFETS and categorizes future land use scenarios as (1) improbable (unlikely to occur) or (2) credible (could reasonably occur or is expected to occur).

Current Onsite Land Use: As described in Section H1.2, RFETS consists of an approximately 400-acre PA surrounded by an undeveloped buffer zone of approximately 6,150 acres. OU-2 lies almost entirely outside the PA. It includes the 903 Pad, Mound, and Northeast Trenches and Southeast Trenches areas, which contain all of the IHSSs in OU-2, as well as a large

portion of the buffer zone, described as the East of IHSSs Area, extending east to Indiana Street. The East of IHSSs area does not contain IHSSs or other waste disposal areas.

Current activities in OU-2 consist of environmental investigations, monitoring, cleanup, and routine security surveillance. No industrial or commercial operations occur in OU-2. The RFETS property is fenced and guarded, and trespassing does not occur. Activities in the industrialized portion of the plant include manufacturing, maintenance, waste management, and environmental restoration activities. Outside of OU-2, on the west side of the RFETS property, is an active gravel mine and processing plant.

Future Onsite Land Use: Future onsite land use at RFETS includes environmental restoration, decontamination and decommissioning, economic development, and waste management. The Rocky Flats Local Impact Initiative (RFLII 1992) is working with DOE and local economic development agencies to encourage business development at RFETS, using new or existing facilities. The Rocky Flats Future Site Uses Working Group is also developing recommendations regarding future use of the RFETS property. Residential development at RFETS has not been recommended by this group or by other planning groups. Commercial and industrial uses of developed portions of the site are considered beneficial. Commercial development in undeveloped portions of the property has not been ruled out, although preservation as open space is consistent with DOE policy, the Rocky Flats Future Site Uses Working Group preliminary recommendations, and the Jefferson County Planning Department's recommendations (Jefferson County 1990). The Jefferson County Board of Commissioners has also adopted a resolution stating its support of maintaining, in perpetuity, the undeveloped buffer zone of open space around Rocky Flats for environmental, safety, and health reasons (Jefferson County Board of Commissioners 1994).

Ecological surveys performed in compliance with the Threatened and Endangered Species Act indicate the presence of habitat that is potentially suitable to four plant species and several wildlife species of concern. The plant species are the forktip threeawn, Colorado butterfly plant, toothcup, and Diluvium lady's tresses (EG&G 1991f). The wildlife species include the bald eagle, peregrine falcon, whooping crane, Prebles meadow jumping mouse, and the black-footed ferret (DOE 1991h; FWS 1990; DOE 1994e). The Prebles meadow jumping mouse inhabits creek drainages and is a candidate for listing as an endangered species (DOE 1994e). Because of the undisturbed nature of the buffer zone and the presence of a rare species such

as the Prebles meadow jumping mouse, onsite commercial or other development in the buffer zone may be precluded.

Future onsite residential development is inconsistent with recommendations being considered for future onsite land use. The Future Site Use Working Group indicated that a residential scenario in OU-2 could be considered outside the range of what is reasonable for future land use at Rocky Flats (EPA 1995a). In addition, the Board of County Commissioners of Jefferson County unanimously passed a resolution requiring that the undeveloped buffer zone of "open space" around RFETS be maintained in perpetuity (DOE 1995b). Therefore, residential development in OU-2 is considered to be an improbable future land use scenario. Onsite agricultural development is considered to be improbable because of the decline of agriculture in the Northeast Jefferson County area.

In summary, future onsite land use in OU-2 will most likely be open space, although portions adjacent to or within the industrialized part of the plant could be developed for commercial use.

Current Offsite Land Use: Land adjacent to RFETS is lightly populated, with current use being primarily open space and grazing. A few residences and horse-boarding businesses are located east of RFETS. The nearest residence is located across Indiana Street at the southeast corner of the property line (Figure H4-1). Another nearby residence in the predominant wind direction (southeast) is located about 0.8 miles east of Indiana street, also near the southeast border of RFETS. Small cattle herds graze seasonally in fields east and southeast of the site. Commercial/industrial facilities, such as the TOSCO laboratory and Great Western Inorganics Plant, are located to the south.

Future Offsite Land Use: The "North Plains Community Plan" (Jefferson County 1990) was developed by representatives of Jefferson County, five cities in north Jefferson County near Rocky Flats (Arvada, Broomfield, Golden, Superior, and Westminster), and a variety of interest groups. Under the plan, the predominant future land uses to the south and southeast of Rocky Flats will consist of commercial, industrial, and office space. Directly to the east, zoning and land use are planned for open space, grazing, or vacant. Residential development is indicated for areas further removed from the RFETS property. Mixed land uses are planned for areas north of Rocky Flats that have been annexed by the cities of Broomfield

and Superior (Jefferson County 1990; City of Broomfield 1990; Boulder County 1991). Therefore, future offsite land use in areas adjacent to OU-2 is likely to continue to be mixed (open space, grazing, commercial, and residential).

H4.2 ONSITE EXPOSURE AREAS

Current and future onsite exposure scenarios were evaluated in the two AOCs identified in OU-2 and in three maximum exposure areas, which were described in Section H2.2 and shown in Figures H2-1 and H2-2.

Area of Concern No. 1: AOC No. 1 includes the 903 Pad, Mound, Northeast Trenches and Southeast Trenches areas, which contain all of the IHSSs in OU-2 (Figure H2-1). These source areas form a logical AOC based on their historical use for waste disposal and the presence of contiguous groundwater contaminant plumes. Data from samples collected in the entire AOC No. 1 were used to estimate exposure concentrations of COCs in this area.

Maximum Exposure Areas in AOC No. 1: Onsite exposures were also evaluated in portions of AOC No. 1 that would be expected to pose the maximum risk to health. These maximum exposure areas consist of plots within AOC No. 1 with appropriate dimensions for specific exposure scenarios. Thus, health risks were evaluated for a hypothetical onsite resident in a 10-acre maximum exposure area (comparable to a residential neighborhood), for a future industrial/office worker in a 30-acre maximum exposure area, and for an ecological researcher in a 50-acre area. Data from samples collected in each maximum exposure area were used to estimate exposure point concentrations of chemicals of concern in these areas. The maximum residential exposure area (a 10-acre area that would be expected to pose the maximum risk to health) is located at the 903 Pad Area. This area has the highest overall contaminant levels in soil and groundwater in AOC No. 1. The maximum exposure areas for the future onsite industrial/office worker and ecological researcher are the 30-acre and 50-acre areas, respectively, that include the 903 Pad Source Area and adjacent areas, as shown on Figure H2-2.

Area of Concern No. 2: AOC No. 2 is the East of IHSSs Area, located in the buffer zone between the IHSSs and Indiana Street (Figure H2-1). No IHSSs or other waste disposal areas

are present in this AOC. Data from samples collected in the entire East of IHSSs Area were used to estimate exposure concentrations of COCs.

H4.3 RECEPTORS SELECTED FOR QUANTITATIVE RISK ASSESSMENT

Receptors selected for quantitative evaluation in the HHRA are listed below.

H4.3.1 Current Use

Current Onsite Workers: Current onsite workers are RFETS plant security workers who are assumed to spend a portion of their time in OU-2 while conducting routine patrols in the buffer zone. Current onsite workers were evaluated for exposures in AOC No. 1 and AOC No. 2.

Current Offsite Residents: The two closest residences to RFETS are located near its southeast border (Figure H4-1). These were selected to represent current offsite receptor locations for purposes of evaluating impacts from airborne particulate matter released from surface soil in OU-2.

H4.3.2 Future Use

Future Onsite Industrial/Office Worker: The future onsite industrial or office worker is assumed to work indoors in a building complex surrounded by extensive paved areas or well-maintained landscaping. Future workers were evaluated for exposure in AOC No. 1, AOC No. 2, and in the 30-acre maximum exposure area in AOC No. 1. This receptor is the maximum exposed individual (has the highest exposure to chemicals and radionuclides) of all the current and future nonresidential receptors.

Future Onsite Ecological Researcher: The future onsite ecological researcher is assumed to perform specific field research projects of relatively limited duration involving contact with surface soil, surface water, and sediments. These research projects would involve a combination of periodic field work coupled with time in the library, office, or laboratory. Exposure areas are AOC No. 1, AOC No. 2, and the 50-acre maximum exposure area in AOC No. 1.

Future Open Space Use: An open space exposure scenario was developed to estimate risks from recreational use of open space areas at RFETS. Future open space use by children and adults is assumed to include recreational activities such as hiking and wading in creeks and to involve contact with surface soil, surface water, and sediments. An open space use scenario was evaluated in AOC No. 1 and AOC No. 2.

Future Onsite Construction Worker: The future onsite construction worker is assumed to contact subsurface soil during excavation activities associated with construction of commercial buildings in AOC No. 1 and AOC No. 2.

Hypothetical Onsite Residents: EPA, CDPHE, and DOE have agreed that evaluation of a future onsite residential scenario is not required in the HHRA because future land use at RFETS will not include residential development (DOE 1995b, EPA 1995a; CDPHE 1995). Nevertheless, an onsite residential exposure was evaluated in the HHRA as a hypothetical scenario to provide an upperbound estimate of risk that may support risk management decisions for low-hazard areas within OU-2. Because residential development is not a reasonable future land use in OU-2, actual risks to current and possible future receptors in OU-2 will be lower than those esetiamted for this scenario. Hypothetical residential exposures were evaluated in AOC No. 1, AOC No. 2, and in the 10-acre maximum exposure area in AOC No. 1.

Future Offsite Residents: Two hypothetical future residences located at Indiana Street were assessed: at Woman Creek at the southern boundary of OU-2 and at Walnut Creek at the northern boundary of OU-2. These receptor locations are at the RFETS property boundary, adjacent to surface water being discharged from the site and are located in the direction of the prevailing winds. Future offsite receptor locations are shown in Figure H4-1.

The nonresidential onsite receptors described above were selected to represent the potentially exposed populations based on current and probable future use. The onsite resident is an unlikely scenario and was evaluated only to provide an upperbound estimate of risk from exposure to COCs in soil and groundwater to help support risk management decisions for low-hazard areas in OU-2. Onsite industrial/office workers, open space use, and the onsite ecological researcher provide more realistic, yet still conservative, estimates of potential risk under various future-use scenarios.

H4.4 EXPOSURE PATHWAYS

This section identifies exposure pathways by which receptors could be exposed to chemicals in or released from sources in OU-2. A complete exposure pathway requires a chemical source, chemical release mechanism, environmental release medium, exposure point, and human intake route. If one of these elements is lacking, the pathway is incomplete and no human exposures can occur. Incomplete pathways were not evaluated in the HHRA.

Potentially complete pathways include all pathways for which human exposure is possible, no matter how trivial. Potentially complete pathways were further categorized as (1) significant, (2) relatively insignificant, or (3) negligible. Significant and relatively insignificant potentially complete pathways were evaluated quantitatively in the HHRA. Negligible pathways were not evaluated in the risk assessment.

A potentially complete pathway was considered to be negligible when, based on professional judgement and logic, the contribution of the pathway to overall exposure is likely to be orders of magnitude lower than exposure from other pathways and the pathway is not expected to contribute significantly to overall risk to the receptor (i.e., exposure and, therefore, risk from the pathway are considered "negligible"). These potentially complete but negligible pathways are unlikely to have any bearing on mathematical estimations of total risk to receptors so do not warrant further evaluation. Therefore, potentially complete but negligible pathways were not evaluated in the HHRA.

Figure H4-2 shows a CSM of potential human exposure pathways for OU-2. The CSM is a schematic representation of the chemical sources, chemical release mechanisms, environmental transport media, human intake routes, and human receptors for OU-2. Site-wide incomplete or negligible pathways are described in Subsection H4.4.1. Additional subsections describe the exposure pathways evaluated for each receptor and identify receptor-specific negligible or incomplete pathways. A summary of potentially complete exposure pathways evaluated in the risk assessment is provided in Table H4-2.

H4.4.1 Site-wide Incomplete or Negligible Exposure Pathways

The CSM indicates that the following exposure pathways are incomplete or negligible for all receptors. These pathways were not evaluated further in the risk assessment.

- Ingestion of fish in Woman Creek or Walnut Creek is an incomplete exposure pathway for all receptors because subsistence fishing is unlikely (due to intermittent flow in the creeks) and has not been observed to occur in the area.

- Ingestion of livestock is a negligible pathway for all receptors because beef ingestion is not an exposure pathway for occupational and open space use receptors and, even if nearby residents were to purchase and consume a locally grazed animal, exposure of cattle to contaminants from RFETS may be negligible (e.g., the intermittent flow in the creeks does not support consistent livestock watering). However, to further evaluate possible impacts, the beef ingestion pathway will be assessed in the residential scenario of the HHRA for OU-3.

- Inhalation of VOCs released to outdoor air through volatilization from soil or groundwater is a negligible pathway for all receptors because volatile chemicals in surface soils, if once present, will have already volatilized and volatile chemicals released from groundwater will be significantly retarded through the subsurface soil and diluted in the ambient air.

- Dermal uptake of metals and radionuclides from soil and sediment is considered a negligible pathway for all receptors because their permeability constants are low (EPA 1989a) and binding to a soil matrix further reduces absorption potential.

- Exposure to groundwater in the LHSU is incomplete for all receptors. This is discussed further in the following paragraphs. Additional information on the LHSU is presented in Section H4.5 of the RFI/RI report.

Exposure to contaminants by ingestion of water in the LHSU is an incomplete pathway because (1) the LHSU has insufficient capacity to provide a water supply for current or future use, (2) it has very limited hydraulic communication with the UHSU, which is the only potential contamination source in OU-2, and (3) the potential for contaminants to migrate within the LHSU to offsite locations is negligible. The LHSU is not capable of serving as a domestic or commercial water supply source because it does not meet the typical definition of an aquifer; i.e., it cannot transmit significant quantities of water at rates fast enough to supply wells for a domestic or commercial use (Freeze and Cherry 1979; Fetter 1980; Driscoll 1986). This is because the LHSU is comprised predominantly of very fine-grained claystones with some thin, discontinuous silty sandstone and clayey siltstone lenses that have relatively low permeability, resulting in negligible flow rates.

Because of the discontinuous nature and low permeability of the LHSU geologic units, the hydraulic communication between the UHSU and LHSU is very limited and the potential for migration of contaminants within the LHSU to offsite locations is negligible. Typically, over 100 feet of claystone separate the UHSU and the sandstone/siltstone lenses of the LHSU. Where LHSU sandstone and siltstone lenses are vertically close to the UHSU, there is some potential for UHSU groundwater to migrate into LHSU sandstones and siltstones at low rates. However, migration within the LHSU is inhibited by the low permeability of the sandstone and siltstone units and by the claystone intervals separating those units. Because the LHSU cannot provide an onsite water supply and does not appear to provide an offsite migration pathway for UHSU contaminants, it is considered an incomplete exposure pathway for all receptors.

H4.4.2 Current Onsite Worker

For the current onsite worker (security personnel), exposure pathways associated with wind suspension of particulates, direct contact with surface soils, and external irradiation from surface soil are potentially complete.

Pathways Evaluated:

- Inhalation of airborne particulates
- Surface soil ingestion and dermal contact
- External irradiation from radionuclides in surface soil

Receptor-Specific Negligible or Incomplete Pathways (not evaluated):

- Contact with surface water/sediments and with subsurface soil are incomplete exposure pathways for current onsite workers in OU-2.
- Ingestion of garden produce is an incomplete pathway for onsite workers because there are no onsite gardens.
- Exposure of current onsite workers to groundwater is an incomplete pathway because drinking water is supplied by a municipal water supply.
- Inhalation of VOCs migrating from subsurface soil or groundwater into buildings is an incomplete exposure pathway for current workers, who work outdoors in OU-2. (No offices or other permanent structures are located on OU-2.)

H4.4.3 Current Offsite Resident

For the current offsite resident, exposure pathways associated with wind suspension of particulates are potentially complete.

Pathways Evaluated

- Inhalation of airborne particulates

- Surface soil ingestion and dermal contact, following airborne deposition of particulates on soil

- Ingestion of vegetables following surface deposition of particulates

Receptor-Specific Negligible or Incomplete Pathways (not evaluated):

- Root uptake by garden produce of contaminants deposited on soil is considered negligible because this route is not expected to contribute measurably to overall risk estimated for offsite receptors. Current levels of the radionuclides Am-241 and Pu-239/240 in soil adjacent to RFETS are below health-protective risk-based levels (DOE 1994f, 1994g), and future concentrations would not be expected to increase due to windborne deposition from sources in OU-2. (See results of air modeling in Section H5.0.)

- Exposure to contaminants via contact with surface water/sediment in Walnut and Woman Creeks is considered a negligible pathway for current offsite residents because, under the RFETS surface water management plan, surface water is monitored and discharged at concentrations that meet applicable federal and state surface water requirements. Therefore, the water management plan eliminates or minimalizes transport of potential OU-2 contaminants from creeks to offsite receptors.

- Ingestion of groundwater is considered a negligible pathway for offsite residents (who reside in the Walnut and Woman Creek drainage areas) because UHSU groundwater does not discharge offsite as groundwater, and transport of potential OU2 contaminants first into surface water, followed by percolation into offsite groundwater, is likely negligible or incomplete.

- External irradiation exposures to offsite residents resulting from deposition of radionuclides in airborne particulate matter is considered a negligible pathway because current concentrations of radionuclides in offsite soil are below protective risk-based levels (DOE 1994f, 1994g). Modeled concentrations of radionuclides in air and soil at offsite locations resulting from wind erosion of

OU-2 surface soil are even lower. (See results of air modeling in Section H5.0.) Because offsite impacts from wind erosion were negligible, external irradiation from these sources is also considered negligible and was not quantified.

H4.4.4 Future Onsite Industrial/Office Workers

The future onsite industrial/office worker is assumed to work primarily indoors. However, for purposes of risk assessment, the worker is assumed to be exposed to air particulate matter and surface soil for the entire time at work.

Pathways Evaluated:

- Inhalation of airborne particulates
- Surface soil ingestion and dermal contact
- External irradiation from radionuclides in surface soil
- Inhalation of VOCs migrating from subsurface soil or groundwater through building foundations into indoor air

Receptor-specific negligible or incomplete pathways (not evaluated) are the same as described for the current onsite worker (Section H4.4.2) except that the future industrial/office worker is assumed to be exposed to indoor VOCs. Exposure of future onsite office workers to UHSU groundwater by ingestion is an incomplete pathway because, as with current onsite workers, drinking water is expected to be provided by a municipal water supply. In past and current operations at Rocky Flats, a municipal water supply has provided all of the drinking water for thousands of onsite workers. Therefore, future onsite workers are also expected to be provided a public water supply.

H4.4.5 Future Construction Workers

A future construction worker scenario was used to evaluate potential risk from exposure to subsurface soil.

Pathways Evaluated:

- Inhalation of airborne particulates from surface and subsurface soil
- Ingestion of and dermal contact with subsurface soil
- External irradiation from radionuclides in subsurface soil

Receptor-Specific Negligible or Incomplete Pathways (not evaluated):

- Exposure to surface water/sediments is considered an incomplete exposure pathway for construction workers because construction cannot occur in the drainage channels or flood plains.
- Other pathways not evaluated are the same as listed for the current onsite worker (Section H4.4.2).

H4.4.6 Future Ecological Researcher

The ecological researcher is assumed to be exposed to surface soil, airborne particulate matter, and surface water/sediment in Woman and Walnut Creeks during the course of field work in OU-2. COCs in surface water/sediment are COCs in groundwater and surface soil that have been transported via seeps and storm runoff to the creeks.

Pathways Evaluated:

- Inhalation of airborne particulates
- Surface soil ingestion and dermal contact

- Surface water/suspended sediment ingestion and dermal contact

- External irradiation from radionuclides in surface soil

Receptor-Specific Negligible or Incomplete Pathways (not evaluated):

- Ingestion of groundwater is an incomplete pathway because RFETS is supplied with public drinking water and ecological researchers are expected to carry their own water during field work.

- Ingestion of homegrown produce from onsite gardens is an incomplete pathway because ecological research does not include tending produce gardens at RFETS.

- Inhalation of VOCs indoors resulting from migration of soil gas through foundations is an incomplete pathway because onsite ecological research is conducted outdoors or in trailers that do not have foundations.

H4.4.7 Future Onsite Open Space Use

Pathways evaluated for the open space use scenario are the same as described for the future ecological researcher. Soil ingestion was evaluated for both children and adults.

H4.4.8 Hypothetical Onsite Resident

Future land use of RFETS will not include residential development. Hypothetical onsite residential exposures were retained for evaluation in the HHRA to support risk management decisions at low-hazard areas in OU-2.

In addition to exposure to surface soil, air, particulates, and indoor VOCs from soil gas, the hypothetical onsite resident is assumed to have a home garden and to have intermittent contact with surface water/sediment in Woman and Walnut Creeks. In addition, although no domestic or commercial-use wells are located at RFETS and yields from the UHSU may be

inadequate, it is assumed that groundwater in the UHSU will be used as the domestic water supply for the hypothetical resident.

Pathways Evaluated:

- Inhalation of airborne particulates
- Ingestion of and dermal contact with surface soil
- External irradiation from radionuclides in surface soil
- Groundwater ingestion
- Inhalation of VOCs released from groundwater during domestic use
- Inhalation of VOCs released from subsurface soil and groundwater and migrating into a basement
- Ingestion of homegrown produce (surface deposition of particulates and root uptake)
- Ingestion of and dermal contact with surface water/suspended sediment

Receptor-Specific Negligible or Incomplete Pathways (not evaluated):

- Exposure to subsurface soil
- Other site-wide negligible or incomplete pathways that were listed in Section H4.4.9.

H4.4.9 Future Offsite Residents

Potentially complete exposure pathways for hypothetical future offsite residents located at Woman Creek and Walnut Creek at Indiana Street are:

Pathways Evaluated:

- Inhalation of airborne particulates
- Surface soil ingestion and dermal contact, following airborne deposition of particulates on soil
- Ingestion of vegetables following surface deposition of particulates
- Incidental ingestion of and dermal contact with surface water/sediment in Walnut or Woman Creek

Negligible or incomplete pathways are the same as described for current offsite residents (Section H4.4.3), with the exception that future offsite residents are assumed to be exposed to OU-2 contaminants in Woman or Walnut Creeks.

TABLE H4-1
SUMMARY OF CURRENT AND FUTURE LAND USES

	Current		Future	
Land Use Category	**Off Site**	**On Site**	**Off Site**	**On Site**
Residential	Yes	No	Credible[a]	Improbable[b]
Occupational/Industrial	Yes	Yes	Credible	Credible
Open Space Use	Yes	No	Credible	Credible
Ecological Reserve	No	No	Improbable	Credible
Agricultural	Yes	No	Credible	Improbable
Gravel Mining	Yes	No	Credible	Improbable

[a] Credible is used to indicate scenarios that could reasonably occur.

[b] Improbable is used to indicate scenarios that are unlikely to occur.

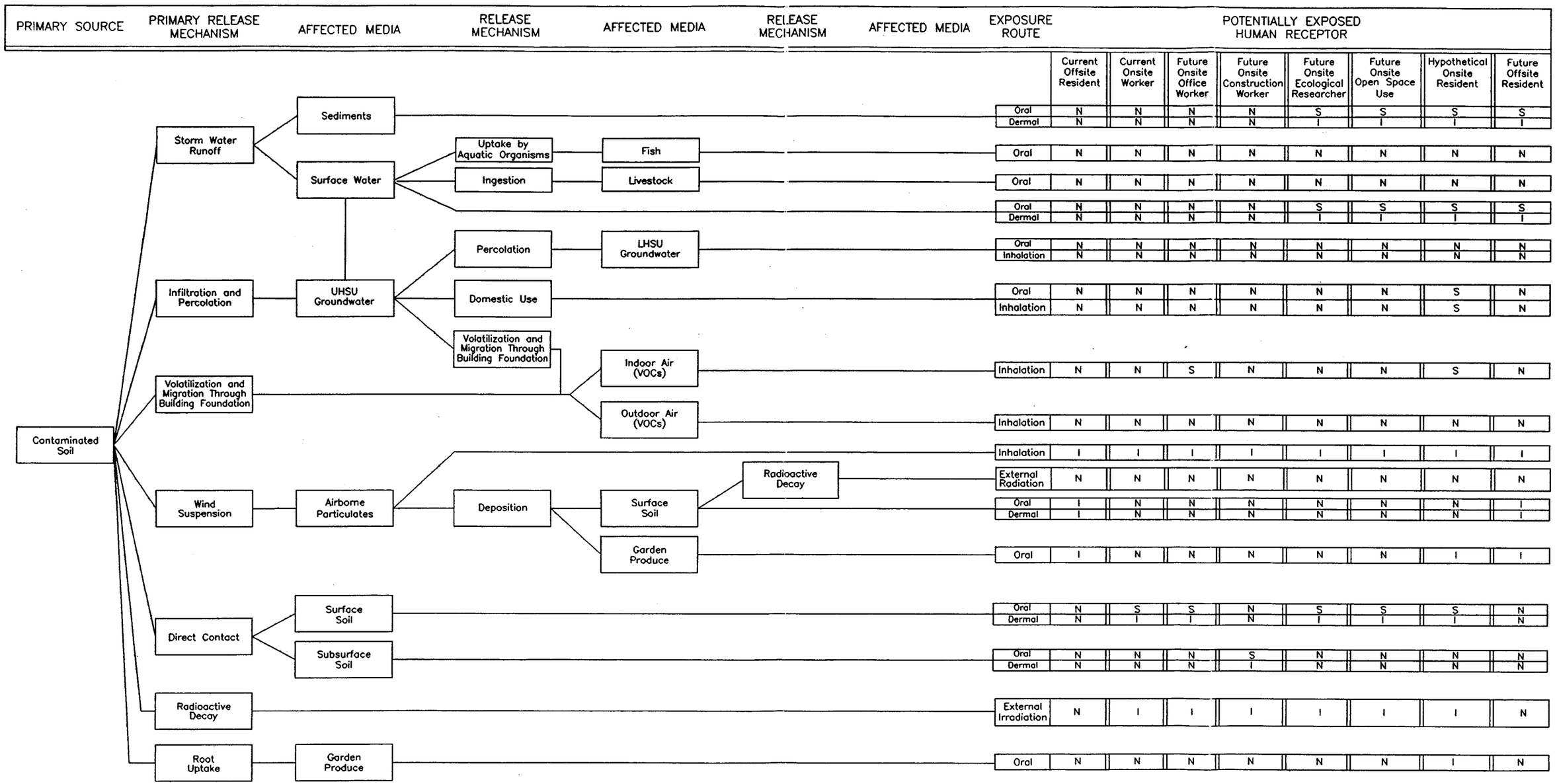
TABLE H4-2
POTENTIALLY COMPLETE EXPOSURE PATHWAYS TO BE QUANTITATIVELY EVALUATED

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
Offsite resident	Current	Inhalation of airborne particulates from OU2 surface soil
		Soil ingestion (following deposition of particulates)
		Dermal contact with soil (following deposition of particulates)
		Ingestion of garden produce (surface deposition of particulates)
Onsite worker	Current	Inhalation of airborne particulates from surface soil
		Ingestion of surface soil
		Dermal contact with surface soil
		External irradiation from surface soil
Hypothetical offsite resident	Future	Inhalation of airborne particulates from OU2 surface soil
		Ingestion of surface soil (following deposition of particulates)
		Dermal contact with soil (following deposition of particulates)
		Ingestion of surface water/suspended sediment
		Dermal contact with surface water/suspended sediment
		Ingestion of garden produce (surface deposition of particulates)
Onsite worker (industrial/office)	Future	Inhalation of airborne particulates from surface soil
		Ingestion of surface soil
		Dermal contact with surface soil
		External irradiation from surface soil
		Inhalation of indoor VOCs (from migration through foundation)
Onsite construction worker	Future	Inhalation of airborne particulates from subsurface soil
		Ingestion of subsurface soil
		Dermal contact with subsurface soil
		External irradiation from subsurface soil

TABLE H4-2
POTENTIALLY COMPLETE EXPOSURE PATHWAYS TO BE QUANTITATIVELY EVALUATED

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
Onsite ecological researcher	Future	Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Inhalation of airborne particulates Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil
Onsite open space use	Future	Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Inhalation of airborne particulates from surface soil Ingestion of surface soil Dermal contact with surface soil
Hypothetical onsite resident (1)	Future	Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Inhalation of airborne particulates from surface soil Inhalation of indoor VOCs (from domestic use and migration through foundation) Ingestion of groundwater Ingestion of surface soil External irradiation from surface soil Ingestion of vegetables (root uptake and surface deposition of particulates from surface soil)

(1) Future onsite land use in OU-2 will not include residential development (USDOE 1995; USEPA 1995a; CDPHE 1995). However, hypothetical onsite residential exposures were retained for evaluation in the HHRA to provide an upperbound estimate of risk that may support risk management decisions at low-hazard areas in OU-2.



LEGEND

- S Significant Potential Exposure Pathway
- I Insignificant Potential Exposure Pathway
- N Negligible or Incomplete Exposure Pathway
- UHSU Upper Hydrostratigraphic Unit
- LHSU Lower Hydrostratigraphic Unit

Note: Significant and insignificant potential exposure pathways are quantitatively evaluated.

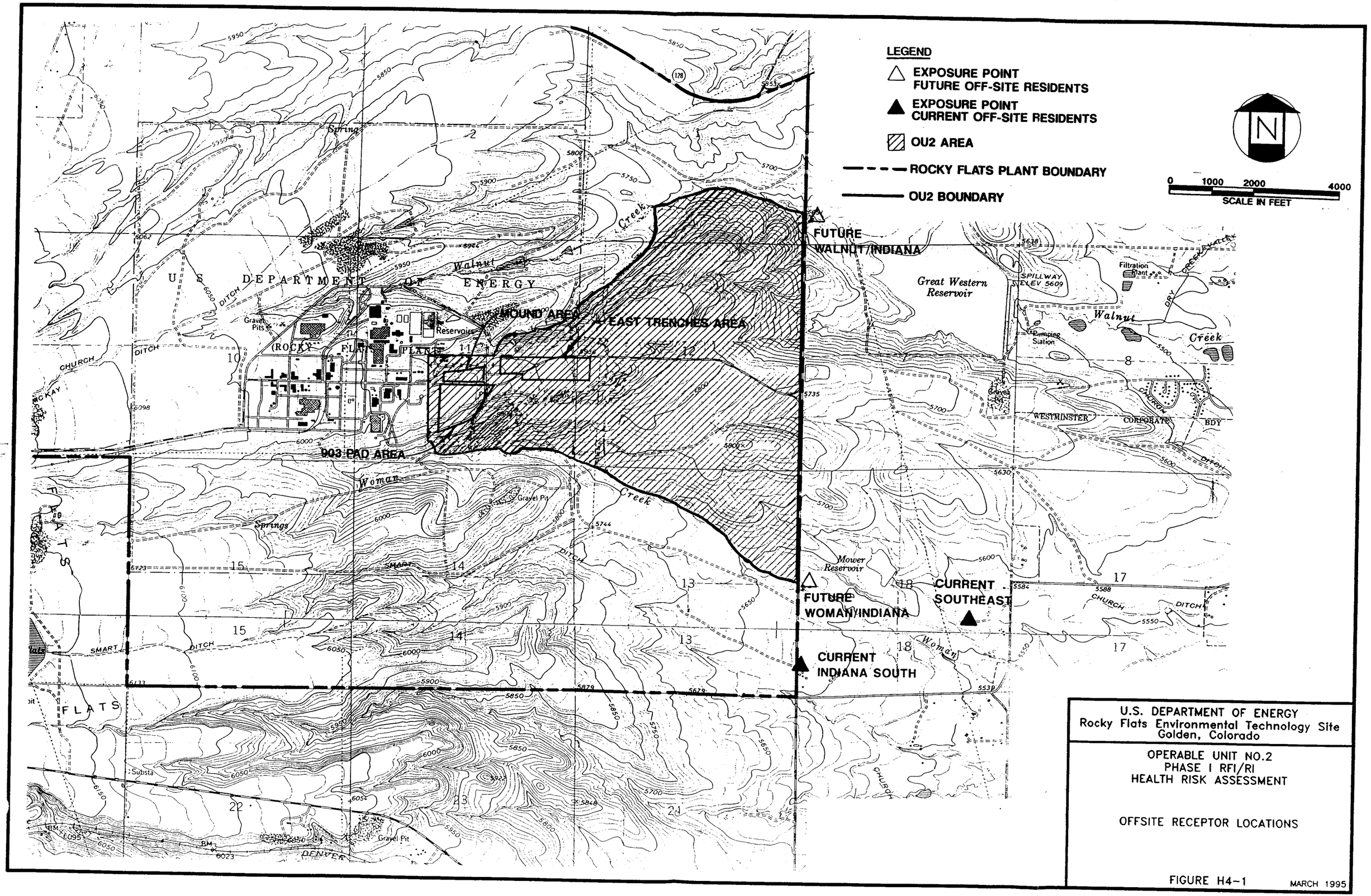
U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT 2
PHASE II RFI/RI

CONCEPTUAL SITE MODEL
FOR HUMAN EXPOSURE PATHWAYS

FIGURE H4-2 MARCH 1995

OU2RI852 1=1



U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT NO.2
PHASE I RFI/RI
HEALTH RISK ASSESSMENT

OFFSITE RECEPTOR LOCATIONS

FIGURE H4-1 MARCH 1995

H5
EXPOSURE POINT CONCENTRATIONS

Exposure point concentrations of COCs were calculated for each exposure area and exposure medium (surface soil, subsurface soil, groundwater, air, surface water/suspended sediment, and garden produce) evaluated in the risk assessment. The exposure point concentration of a chemical in a sampled medium (soil and groundwater) is usually the 95 percent upper confidence limit (95% UCL) on the arithmetic mean. The 95% UCL on the mean is a conservative estimate of the average concentration to which people would be exposed over time in the exposure area. Sometimes the maximum detected concentration was used as the exposure concentration if the data set did not permit a good estimate of the mean. This can occur with small data sets or in data sets with a high frequency of non-detects. If the calculated 95% UCL concentration exceeded the maximum detected concentration, the maximum was used as the exposure concentration (EPA 1989a). For convenience in this report, the 95% UCL or maximum concentration was referred to as the RME concentration. RME concentrations of COCs were used in estimating risk for both the CT and RME exposure conditions for each scenario described in Section H4.0.

H5.1 CALCULATING THE CONCENTRATION TERM

Tables H5-1 through H5-3 summarize the exposure concentrations of COCs in surface soil, subsurface soil, and groundwater for each exposure area evaluated in the HHRA. Attachment H1 shows analytical results used in the calculations. In calculating exposure concentrations from chemical analytical results, one-half the SQL was used to represent the concentration in samples that were "non-detect" for a chemical, provided that the chemical was detected in at least one other sample in the data set (EPA 1989a). An exception to this rule is when the nondetect SQL is unusually high due to sample dilution. The SQL for diluted samples can far exceed the measured concentrations of the chemical in other samples. EPA (1989a) recommends removal of unusually high nondetect SQLs from the data set when they would cause the calculated exposure concentration to exceed the maximum concentration. Therefore, samples were excluded from the calculation of the concentration term if they caused the arithmetic mean concentration to exceed the maximum detected concentration.

The same principle was applied when a compound was detected in very few samples and only at estimated quantities below the CRQL. If using one-half the CRQL for non-detects caused the arithmetic mean concentration to exceed the maximum reported concentration, those non-detect samples were excluded from the calculation.

Attachment H1 contains tables showing all analytical results in the data sets and the calculation of 95% UCL concentrations for surface soil, subsurface soil, and groundwater. The 95% UCL concentrations were calculated based on either a normal or lognormal distribution, as appropriate. Probability plots are also shown for selected data sets. In some cases, the calculation of the 95% UCL based on a lognormal distribution gave an unreasonable result (e.g., a value much higher than the maximum observation), even though the data appeared to fit a lognormal distribution. These cases were most common for small data sets and for larger data sets that had a range of several orders of magnitude between the minimum and maximum observations. When unreasonable results were obtained, other values (either the maximum concentration or the 95% UCL based on a normal distribution) were used as the exposure concentration for risk assessment. These cases are noted in Tables H5-1 through H5-3.

Attachment H1 also contains a discussion of the statistical treatment of data sets that contained greatly than 15 percent non-detects and data sets that contained negative or zero values, which was common for radionuclides.

H5.2 SURFACE SOIL

Table H5-1 summarizes the RME concentrations of COCs in onsite surface soil in each exposure area. COCs are aroclor-1254, aroclor-1260, BEHP, Cr, Am-241, and Pu-239/240. Exposure point concentrations were calculated for AOCs No. 1 and No. 2 and for the maximum exposure areas of 10, 30, and 50 acres in AOC No. 1.

Several factors regarding the surface soil exposure point concentrations are noteworthy:

- Aroclors (PCBs) were detected in only 2 of 40 surface soil samples, both collected in 1993 at the Mound Area (IHSS 113) (Figure H5-1). Nevertheless, aroclors were identified as OU-wide COCs using the selection process described in Section H3.1,

and exposure point concentrations were calculated for AOC No. 1 and the 30- and 50-acre maximum exposure areas within AOC No. 1. In fact, these areas are not ubiquitously contaminated with PCBs; instead, contamination is limited to the area near IHSS 113. Therefore, exposure potential is minimal and overall risk in the exposure areas will be overestimated by assuming the entire area is contaminated with RME concentrations of PCBs.

- Cr was not statistically different than background concentrations (Appendix A, TM 9, DOE 1994b). Nevertheless, in keeping with the COC selection process, it was identified as an OU-wide COC because two sample results exceeded the background $UTL_{99/99}$ of 24.8 mg/kg. These sample results were 26 mg/kg and 29.5 mg/kg. The samples were collected approximately 1,500 to 2,000 feet southeast and east of the 903 Pad Area, in plots PT36 and PT46 (Figure H5-2). These two results only slightly exceed the background $UTL_{99/99}$. Table H5-1 shows that the RME concentrations of Cr range from about 13 to 17 mg/kg, depending on the exposure area. These levels are well within background range (the background mean and maximum are 15 mg/kg and 20 mg/kg, respectively). Therefore, the risk calculated for exposure to Cr in surface soil is equivalent to risk at background levels.

- The RME concentration for Pu-239/240 in surface soil is lower in the 10-acre maximum exposure area than it is in AOC No. 1 or in the 30- and 50-acre areas. This is because two extreme values for Pu-239/240 (5,700 pCi/g and 7,300 pCi/g) were measured in two samples outside the 10-acre maximum exposure area. The sample locations were plots PT36 and PT46 (where slightly elevated Cr was detected). The next highest concentration was 950 pCi/g in plot PT29, closer to the 903 Pad. The extreme values in the two samples "drive" the 95% UCL concentrations for AOC No. 1 and for the 30- and 50-acre exposure areas.

The exposure concentrations in surface soil were used to estimate health risks associated with soil ingestion and dermal contact by onsite workers, future ecological researchers, future open space users, and hypothetical onsite residents. In addition, the concentrations were used in

air modeling to predict airborne particulate concentrations and deposition rates at onsite and offsite receptor locations.

H5.3 SUBSURFACE SOIL

Exposure concentrations of COCs in subsurface soil are summarized in Table H5-2. COCs are the radionuclides Am-241, Pu-239/240, U-233,-234, U-235, and U-238; the metals As, Cd, and Hg; and the VOC tetrachloroethene (PCE). The subsurface soil concentrations were used to estimate health risks associated with construction worker exposures and to model basement air concentrations of PCE. Exposure concentrations were calculated for AOCs No. 1 and No. 2, where future construction activities were assumed to occur. The 95% UCL concentrations of PCE were also calculated in the 10- and 30-acre exposure areas to support modeling of soil vapor migration into a building (hypothetical residential and future office worker scenarios).

H5.4 GROUNDWATER

Exposure concentrations of chemicals of concern in UHSU groundwater are summarized in Table H5-3. COCs are CCl_4, $CHCl_3$, 1,1-dichloroethene, CH_2Cl_2, PCE, TCE, and the radionuclides Am-241 and Pu-239/240. Because of variability in the number of sampling rounds at different wells, sample results from each well were averaged (arithmetic mean) before calculating 95% UCL concentrations for the exposure area so that each well is represented equally in the estimate of exposure concentrations. Wells where a COC was never detected were considered non-detect for that COC, and one-half the mean of the reporting limits was used in the calculation of the exposure concentration. Individual sample results and well averages are shown in the data tables in Attachment H1.

RME concentrations were calculated for AOCs No. 1 and No. 2 and for the 10-acre exposure area. The 95% UCL concentrations shown in Table H5-3 for the 10-acre area are based on a normal distribution. As noted in the table and in Attachment H1, calculating the 95% UCL concentrations on log-transformed data gave unreasonable results. Therefore, other values were used in risk assessment (the "normal" 95% UCL) and in soil gas modeling (the average concentration in the maximum contaminated well).

Exposure concentrations for COCs in groundwater in AOCs No. 1 and No. 2 and in the 10-acre area were used to estimate health effects from hypothetical residential use (ingestion and inhalation of VOCs released during domestic use). Future land use in OU-2 does not include residential development; however, the hypothetical residential exposure scenario was evaluated in the HHRA to help support risk management decisions, particularly for low hazard areas. Groundwater concentrations in the 30-acre exposure area were used only to estimate basement air concentrations in a building for the future office worker/industrial exposure scenario.

H5.5 OUTDOOR AIR (PARTICULATE-ASSOCIATED COCs)

Air emission and dispersion models were used to estimate air concentrations of SVOCs, metals, and radionuclides that are associated with particulate matter less than 10 microns in diameter (PM_{10}) released from surface soil by wind erosion and released from subsurface soil during construction activities. The air modeling approach and results are presented in detail in Appendix G.

H5.5.1 Onsite Air Concentrations and Deposition Rates from Wind Erosion of Surface Soil

Table H5-4 summarizes the modeling results for onsite air concentrations and deposition rates of COCs associated with PM_{10}. Onsite air concentrations from wind erosion of surface soil were estimated using the Ventilated Valley Dispersion Model, a box model that is often used to estimate ambient air concentrations in the immediate vicinity of an emission source. The box model incorporates a site-specific wind erosion emission rate for PM_{10} and other site-specific variables such as contaminated surface area, length and width of the contaminated area, threshold wind speed, mean annual wind speed, and mixing height. Deposition rates of PM_{10} were calculated using an equation from the California Air Toxics Program (CAPCOA 1993) that estimates deposition rate based on particle size.

The modeling was performed using five years of meteorological data (1989 - 1993) to yield five different estimates of annual average PM_{10} concentrations. Air concentrations of COCs were calculated by multiplying the PM_{10} concentration by the chemical concentration in

surface soil. The maximum of the five estimated annual average air concentrations was used in risk assessment.

COCs in surface soil are aroclor-1254, aroclor-1260, BEHP, Cr, Am-241, and Pu-239/240. Air concentrations were calculated for AOCs No. 1 and No. 2 and for the maximum exposure areas of 10, 30, and 50 acres in AOC No. 1. Air concentrations of COCs were used to estimate health risks associated with dust inhalation by onsite workers, construction workers, ecological researchers, open space users, and hypothetical residents. Onsite deposition rates for AOCs No. 1 and No. 2 and for the 10-acre maximum exposure area were used to estimate contaminant concentrations on exposed garden produce (hypothetical residential scenario).

H5.5.2 Offsite Air Concentrations and Deposition Rates from Wind Erosion of Surface Soil

Table H5-5 summarizes the modeling results for offsite air concentrations and deposition rates of COCs resulting from wind erosion of surface soil from AOC No. 1 and from AOC No. 2. Air impacts were estimated using the Fugitive Dust Model, a Gaussian dispersion model. Emission rates from the area sources were estimated based on a site-specific threshold wind speed and other variables as discussed in Appendix G. The model was executed using five years of meteorological data (1989 - 1993) to yield five different estimates of annual average PM_{10} concentrations and deposition rates. The maximum of the five estimated annual average air concentrations was used in risk assessment.

Air impacts were estimated at four offsite receptor locations, shown on Figure H4-1. Locations with either positive or zero (negligible) impacts are listed below. The model reports "zero" impacts when modeled PM_{10} concentrations are less than 0.0001 $\mu g/m^3$.

Air Impacts at Offsite Receptor Locations

	From AOC No. 1		From AOC No. 2	
Receptor Location	Air	Deposition	Air	Deposition
Current Southeast	+	0	+	+
Current Indiana South	0	0	+	0
Future Woman Cr./Indiana	+	0	+	+
Future Walnut Cr./Indiana	0	0	+	0

+ The model predicted air and dispositional impacts at these locations; see Table H5-5.

0 No impacts were predicted (PM_{10} <0.0001 $\mu g/m^3$ or deposition rate was negligible).

The air concentrations of COCs were used to estimate health risks associated with dust inhalation by current and future offsite residents. Deposition rates were used to estimate contaminant concentrations in surface soil and on garden produce at offsite receptor locations.

H5.5.3 Onsite Air Concentrations from Construction Activities

Tables H5-6, H5-7, and H5-8 summarize the estimated air concentrations of COCs adhered to airborne PM_{10} at future construction sites in AOC No. 1 and AOC No. 2. COCs for inhalation of PM_{10} are metals and SVOCs in surface and subsurface soils. Surface soil COCs are aroclor-1254, aroclor-1260, BEHP, Cr, Am-241, and Pu-239/240. Subsurface soil COCs are As, Cd, Hg, Am-241, Pu-239/240, U-233,-234, U-235, and U-238.

In the construction scenario, three air emission sources were evaluated: (1) wind erosion of surface soil in the AOC, (2) wind erosion of subsurface soil in a 10-acre excavation site, and (3) emissions during heavy construction (earth moving). Emissions from earth moving activities were estimated using a standard equation for heavy construction from AP-42 (EPA 1993a), and wind erosion was evaluated using a box model as described in Section H5.5.1. The exposure point concentrations are the sum of air concentrations resulting from wind erosion of surface soil, wind erosion of subsurface soil, and heavy construction activities.

H5.6 INDOOR AIR (VOCs)

Concentrations of VOCs in indoor air were calculated for two different exposure pathways: (1) migration of vapor-phase VOCs from groundwater and subsurface soil into a basement (residential and future office/industrial worker scenarios) and (2) volatilization from groundwater during domestic use (residential scenario). The modeling approaches and results are discussed in the following sections.

H5.6.1 Basement Air

Table H5-9 summarizes the exposure point concentrations of COCs in basement air from migration of VOCs from subsurface soil and groundwater through building foundations. The modeling approach and results are presented in detail in Appendix G of this RFI/RI Report. COCs are 1,1-DCE, CCl_4, $CHCl_3$, CH_2Cl_2, PCE, and TCE. Basement air concentrations were calculated for AOCs No. 1 and 2 and for maximum exposure areas of 10 acres (residential) and 30 acres (industrial). RME source concentrations were used in modeling soil gas in AOCs No. 1 and No. 2. However, maximum detected concentrations were used in modeling the 10- and 30-acre areas because of the uncertainties in calculating 95% UCL concentrations of VOCs in groundwater in these areas. Using maximum concentrations could significantly overestimate soil gas and basement air VOC concentrations because only a few wells are highly contaminated and the maximum concentrations are not characteristic of the entire exposure area.

The basement air concentrations were used to estimate health effects from inhalation by hypothetical onsite residents and future industrial/office workers.

H5.6.2 Domestic Use of Groundwater

Domestic use of groundwater at RFETS is not anticipated because residential development will not occur. However, a hypothetical onsite residential scenario, including domestic use of groundwater, was evaluated in the HHRA for OU-2 to help support risk management decisions at low hazard areas. Table H5-10 summarizes the RME concentrations of COCs in indoor air from domestic use of groundwater in AOC No. 1, AOC No. 2, and the 10-acre

maximum exposure area in AOC No. 1. COCs are VOCs in groundwater, namely, 1,1-DCE, CCl_4, $CHCl_3$, CH_2Cl_2, PCE, and TCE.

The indoor air concentrations were estimated using a simple model in which RME concentrations of VOCs in groundwater were multiplied by a constant volatilization factor (VF) to convert a water concentration (mg/L) to an air concentration (mg/m^3) (Andelman 1990). The model was derived primarily from experimental data on the volatilization of radon from household use of water. In the derivation, all uses of household water were considered (e.g., showering, laundering, dish washing.) Certain assumptions were made in water use by a family of four, the volume of the dwelling, and the air exchange rate. Furthermore, it was assumed that the average transfer efficiency weighted by the type of water use is 50 percent (i.e., half of the concentration of each chemical in water will be transferred into air by all types of water uses). A CT value was chosen for the volatilization factor since risks are evaluated for chronic exposure. This CT value would therefore best represent a chronic exposure situation.

To estimate an RME air concentration, a CT value for VF of 0.065 mg/m^3 air per mg/L water was multiplied by the RME concentration in groundwater to yield the RME indoor air concentration.

H5.7 SURFACE WATER/SEDIMENT

Currently, under the RFETS surface water management plan, both Woman and Walnut creeks are monitored, and surface water discharges meet applicable federal and state surface water quality requirements. The current water management plan eliminates or minimalizes transport of potential OU-2 contaminants from creeks to offsite receptors. Thus, there was assumed to be negligible current risk associated with contact with surface water in the creeks offsite. For hypothetical future exposure scenarios, however, it was assumed that the surface water is not monitored, intercepted by dams or diversion structures, or treated. A screening-level model was used to estimate future reasonable maximum 30-year average concentrations of COCs that could result from migration of OU-2 contaminants in UHSU groundwater to surface water and from transport of contaminated surface soil in storm runoff. Concentrations were estimated for Woman and Walnut creeks at Indiana Street. These were used as exposure concentrations for both onsite and offsite receptors. The 30-year averaging period

was selected to correspond to the reasonable maximum exposure duration for residential receptors. The groundwater modeling, used to estimate contaminant loads to the creeks, is described in Appendix E. The surface water model is described in Appendix F.

H5.7.1 Surface Water Modeling Approach

The surface water model consisted of two major portions: (1) hydrologic simulation of flow originating from the entire watersheds of Woman Creek and Walnut Creek upstream of Indiana Street, and (2) fate and transport simulation of contaminant loads from OU-2 groundwater and surface soil.

The following COCs were modeled:

Groundwater		Soil
Pu-239/240 (filtered fraction)	1,1-DCE	Pu-239/240
Am-241 (filtered fraction)	CH_2Cl_2	Am-241
CCl_4	PCE	
$CHCl_3$	TCE	

Other COCs in surface soil (BEHP, PCBs, and Cr) were not modeled as source loads to the creeks because they were detected above background levels at only one or two sampling locations and the mass flux of these COCs would be insignificant compared to mass flux of Pu-239/240 and Am-241, which were found at nearly all surface soil sampling locations.

The model included the following specific components: stochastic simulation of precipitation based on historical precipitation data; simulation of retention, infiltration, and surface runoff; simulation of interflow and groundwater seepage to creek flow; and estimates of soil erosion and nonpoint source contaminant loads. Surface runoff was simulated using the CUHP. Soil erosion was modeled with the Universal Soil Loss Equation.

The mass loads of groundwater COCs were estimated by groundwater modeling, described in Appendix E of the RFI/RI Report. The estimated maximum annual average loads were

used as input to the surface water model. Volatilization of VOCs was included in the surface water model since volatilization is a dominant fate process when VOCs are exposed to air. However, other fate processes, such as adsorption, desorption, dehalogenation, and biodegradation were ignored because it was assumed that over the short transport time simulated in the model these processes would have negligible impact on concentrations.

In estimating mass loads of radionuclides from OU-2 surface soil, it was conservatively assumed that surface soil concentrations of radionuclides remained constant. Source concentrations of radionuclides in each subbasin were the area-weighted average of surface soil sample results. For purposes of this simplified model, it was also assumed that all soil particles that reach the creeks remain in suspension and contribute to concentrations estimated at Indiana Street; that is, depositional processes and the effects of dams, ponds, and other structures were not included in the model. A reasonableness check on the estimate of sediment loads to the creeks was performed by comparing estimated TSS to observed TSS at gaging stations upgradient of the C-series ponds.

Thirty-six years of historical precipitation data from Denver's Stapleton Airport, adjusted to match mean annual precipitation measured at RFETS, were used in developing the hydrologic simulations. Monte Carlo methods were used to randomly generate 100 30-year time series of precipitation events. Final results were 100 simulated 30-year average concentrations for each modeled COC. Each 30-year concentration was calculated by summing the annual mass loads for 30 years, calculating the total 30-year flow volume, and dividing the total load by the total flow. Since source concentrations were constant, the variability in the results derives from the hydrology.

H5.7.2 Surface Water Modeling Results

The simulation results are shown in Table H5-11. The modeling results are expressed in terms of µg/L or pCi/L. For radionuclides, the results represent radionuclides associated with surface soil particles that are assumed to remain suspended in the water column, since deposition was not simulated.

Because the source of VOC loading is groundwater seeps, modeled concentrations of VOCs in surface water are inversely proportional to streamflow (i.e., maximum VOC concentrations

in the creeks are predicted for years of low average streamflow). The chief source of radionuclide loads is surface soil. Since soil loss is directly proportional to precipitation, maximum loads of radionuclides to the creeks are predicted for years of high average streamflow. Therefore, maximum surface water concentrations of VOCs and of radionuclides occur under different flow conditions and would not occur simultaneously. Nevertheless, reasonable maximum 30-year concentrations of VOCs and radionuclides were selected independent of flow conditions and used in risk assessment. For VOCs, the maximum modeled 30-year average concentration was used (Table H5-11). For radionuclides, the 90th percentile 30-year average concentration was selected as a conservative estimate of the reasonable maximum exposure concentration. These values are shown in Table H5-11 and displayed in histograms in Figures H5-3 and H5-4.

The surface water/suspended sediment concentrations were used to estimate potential health risks associated with ingestion and dermal contact by future ecological researchers and open space users and by onsite and offsite residents.

H5.8 HOMEGROWN PRODUCE

Concentrations of contaminants in homegrown produce were estimated for two exposure pathways: root uptake of contaminants in surface soil (estimated for hypothetical onsite residential receptors) and deposition of airborne particulate matter (estimated for onsite and offsite residential receptors). This section describes the methodology and results for the two pathways.

H5.8.1 Root Uptake of Contaminants from Surface Soil

Inorganics: Concentrations of metals and radionuclides in garden produce resulting from root uptake of chemicals in soil were estimated using the following equations (Baes et al. 1984):

$$C_l = C_{soil} \times B_v \times 0.428$$

$$C_r = C_{soil} \times B_r \times 0.428$$

where:

C_l	=	chemical concentration in the leafy vegetative portion of the plant (mg/kg wet weight)
C_r	=	chemical concentration in the reproductive and storage portions of the plant (mg/kg wet weight)
C_{soil}	=	chemical concentration in soil (mg/kg dry weight)
B_v	=	transfer coefficient for leafy vegetative portions (mg chemical/kg vegetable dry weight per mg chemical/kg soil)
B_r	=	transfer coefficient for reproductive and storage portions (mg chemical/kg vegetable dry weight per mg chemical/kg soil)
0.428	=	produce dry-to-wet weight conversion factor (Baes et al. 1984)

The transfer coefficients B_v and B_r for metals and radionuclides were taken from Baes et al. (1984). The transfer coefficients estimate the contaminant concentration in vegetable (dry weight) from the contaminant concentrations in soil. Transfer coefficients for the inorganic COCs in surface soil are:

Transfer Coefficients

COC	B_v	B_r
Cr	7.5E-03	4.5E-03
Am-241	5.5E-03	2.5E-04
Pu-239/240	4.5E-04	4.5E-05

Since fruit and vegetable intake rates are in terms of wet (fresh) weight, a dry-to-wet-weight conversion factor is included in the equation to yield a contaminant concentration in fresh produce. The factor 0.428 is a weighted overall average for nonleafy produce categories (Baes et al. 1984) and has been adopted as a conservative dry-to-wet-weight conversion factor for leafy vegetables as well.

B_r is the appropriate coefficient for estimating chemical concentrations in most fruits and vegetables (such as peas, beans, corn, potatoes, tomatoes, broccoli, cucumbers, and fruits in general) because these food items are the reproductive or storage portions of the plant. Leafy vegetables (such as lettuce, spinach, and cabbage) are the only group of food crops for which B_v is the appropriate transfer coefficient (Baes et al. 1984).

Leafy greens comprise a relatively small portion by weight of total produce intake. The estimated fraction of produce that is comprised of leafy vegetables is 0.058 (rounded to 0.06) (Baes et al. 1984, Table 2.2). This value is based on agricultural production data but was adopted as a reasonable estimate of dietary intake. Therefore, B_v was used to estimate inorganic contaminant concentrations in 6 percent of homegrown produce and B_r was used to estimate inorganic contaminant concentrations in 94 percent of homegrown produce.

The calculation of inorganic contaminant concentrations in nonleafy vegetables and fruits and in leafy vegetables is shown in Table H5-12. These concentrations were used in the risk calculation spreadsheets in Attachment H3.

Organics: Concentrations of PCBs and BEHP in garden produce resulting from root uptake were estimated using the following equation:

$$C_{plant} = C_{soil} \times BCF \times 0.428$$

where:

C_{plant}	=	chemical concentration in the plant (mg/kg wet weight)
C_{soil}	=	chemical concentration in soil (mg/kg dry weight)
BCF	=	bioconcentration factor (mg chemical/kg plant dry weight per mg chemical/kg soil)
0.428	=	produce dry-to-wet-weight conversion factor (Baes et al. 1984)

The BCFs were calculated using the following equation (Travis & Arms 1988):

$$\log BCF = 1.588 - 0.578 \log K_{ow}$$

where:

BCF	=	bioconcentration factor in above-ground vegetation
K_{ow}	=	octanol-water partition coefficient

This equation was derived using a geometric mean regression analysis of data from numerous studies, primarily of pesticides. The approach does not distinguish between leafy and reproductive portions of plants. Therefore, in this risk assessment, the BCF is used to estimate chemical concentration in all edible portions of produce.

Values for log K_{ow} were taken from Montgomery and Welkom (1989); where a range was given, a central value was selected. Calculation of BCFs using the above equation are shown below:

Calculation of BCFs

Chemical	log K_{ow}	log BCF	BCF
aroclor-1254	6.305	-2.06	8.8E-03
aroclor-1260	6.91	-2.41	3.9E-03
BEHP	4.20	-8.4	1.5E-01

The BCFs were used to estimate the contaminant concentrations in vegetable (dry weight) from the contaminant concentrations in soil. Since fruit and vegetable intake rates are in terms of wet (fresh) weight, the dry-to-wet-weight conversion factor of 0.428 (Baes et al. 1984) was included to yield a contaminant concentration in fresh produce. Table H5-12 shows the calculation of organic chemical concentrations in garden produce. These concentrations were used in the risk calculation spreadsheets in Attachment H3.

H5.8.2 Concentrations from Deposition of Airborne Particulate Matter

Concentrations of COCs in homegrown produce from deposition of airborne particulate matter were calculated for both onsite and offsite receptor locations. Deposition of particulate matter can contaminate produce that has an edible surface exposed to air. Garden produce with exposed edible surface include lettuce, spinach, summer squash, cucumbers, string beans,

tomatoes, apples, and berries. Products such as corn, melons, onions, peas, lima beans, carrots, and citrus fruit are considered unexposed.

The fraction of homegrown produce whose edible portions would be affected by deposition of particulate matter was estimated using information provided in EPA's Exposure Factors Handbook (EPA 1989b) Table 2-10, excluding juices. The data were based on a three-day dietary survey and could be biased by geographic location and season. Not all categories of fruits and vegetables in a typical diet are included in the table; for example, bananas, melons other than cantaloupe, asparagus, and radish are not listed. However, the information was deemed adequate for providing a useable estimate of the fraction of homegrown produce whose edible portions are exposed to air.

Table H5-13, Estimated Fraction of Produce Affected by Deposition, shows the calculation of the fraction of homegrown vegetables and fruits with exposed edible surface. The estimated fraction for vegetables is 0.3; the estimated fraction for fruit is 0.7. These fractions were used to estimate the amount of ingested produce that is contaminated by deposits of airborne PM_{10}.

A simple conservative approach was used to estimate contaminant concentration in homegrown produce resulting from deposition of PM_{10}. The following equation was used:

$$C_{produce} = \frac{DR \times T \times SA}{WT}$$

where:

$C_{produce}$	=	contaminant concentration on produce accumulated up to harvesting, mg/kg or pCi/kg
DR	=	deposition rate, mg/m^2-yr or pCi/m^2-yr
T	=	time to harvest, year
SA	=	surface area of produce exposed, m^2
WT	=	weight of produce, kg

The approach is conservative because:

- No weathering half-life, which represents removal of particulate matter from the plant surface due to wind, rain, or other natural processes, was included in the approach, although this parameter is quantified in Baes et al. (1984). Instead, the deposited amount is assumed to increase linearly during the entire time to harvest, T.

- Lettuce, which has a proportionately large surface area to weight ratio, was selected to represent all exposed fruits and vegetables.

Conservative values were selected for each parameter in the equation. Time to harvest, T, was estimated as 45 days, or 0.12 year. This is a conservative estimate of time to harvest, and represents the amount of time that deposited particulate matter is assumed to accumulate on the produce. Surface area, SA, was estimated as 0.05 m^2, or approximately one-half square foot. The weight of the lettuce was assumed to be 0.454 kg (1 pound). The deposition rate, DR, is provided by the results of air modeling described in Section H5.5.

Table H5-14 shows the calculation of contaminant concentrations on garden produce in AOC No. 1, AOC No. 2, and the 10-acre maximum exposure area in AOC No. 1. Table H5-15 shows the calculation of contaminant concentrations on garden produce at two offsite receptor locations (Current Southeast and Future Woman/Indiana), which are the only locations with depositional impacts from AOC No. 2. Modeling of wind erosion from AOC No. 1 did not result in depositional impacts at any offsite receptor location (Section H5.4.4).

H5.9 OFFSITE SOIL CONCENTRATIONS FROM DEPOSITION OF PARTICULATE MATTER

Chemical concentrations in offsite surface soil resulting from deposition of airborne PM_{10} were calculated using the following equation:

$$C_{soil} = \frac{DR \times 0.5\ AT}{d \times p}$$

where:

C_{soil}	=	average contaminant concentration in soil over the entire accumulation time, mg/kg or pCi/kg
DR	=	deposition rate, mg/m^2-yr or pCi/m^2-yr
AT	=	accumulation time, equivalent to reasonable maximum residential exposure duration, 30 yr
d	=	mixing depth, 0.0508 m (2 inches)
p	=	soil density, 1.84E+03 kg/m^3 (site-specific for RFETS)

These values result in a conservative estimate of average surface soil concentrations during a 30-year exposure duration because:

- Concentrations are assumed to increase linearly with time; no removal processes were included.

- A shallow mixing depth was selected. Mixing to greater depths would be expected if gardening, tilling, or construction occurred. The depth of 2 inches corresponds to the OU-2 surface soil sampling interval (RFP method).

The resulting surface soil concentrations, shown in Table H5-16, were used to evaluate ingestion and dermal contact exposure routes for offsite residents.

TABLE H5-1
EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN SURFACE SOILS

					AOC No. 1 Maximum Exposure Areas					
	AOC No.1		AOC No. 2		10-Acre		30-Acre		50-Acre	
Aroclor-1254 (ug/kg)										
Number of Samples	12		--		--		5		6	
Number of Detects	2		--		--		2		2	
Minimum Detected Concentration	190		--		--		190		190	
Maximum Detected Concentration	970		--		--		970		970	
95%UCL	299	n	--		--		614	n	518	n
RME Concentration	299		--		--		614		518	
Aroclor-1260 (ug/kg)										
Number of Samples	12		--		--		5		6	
Number of Detects	2		--		--		2		2	
Minimum Detected Concentration	240		--		--		240		240	
Maximum Detected Concentration	660		--		--		660		660	
95%UCL	234	n	--		--		444	n	381	n
RME Concentration	234		--		--		444		381	
Bis(2-ethylhexyl)phthalate (ug/kg)										
Number of Samples	12		7		2		5		6	
Number of Detects	4		5		1		2		2	
Minimum Detected Concentration	52		49		510		52		52	
Maximum Detected Concentration	510		110		510		510		510	
95%UCL	244	n	146	n	1,090	n	366	n	330	n
RME Concentration	244		110		510		366		330	
Chromium (mg/kg)										
Number of Samples	26		43		6		10		13	
Number of Detects	26		43		6		10		13	
Minimum Detected Concentration	5.4		6.0		5.4		5.4		5.4	
Maximum Detected Concentration	29.5		19.2		26.0		26.0		26.0	
95%UCL	13.6	n,ln	13.1	n,ln	16.7	n,d	13.5	n,d	12.9	n,d
RME Concentration	13.6		13.1		16.7		13.5		12.9	
Amercium-241 (pCi/g)										
Number of Samples	30		31		7		10		12	
Number of Detects	30		31		7		10		12	
Minimum Detected Concentration	0.06		0.09		0.69		0.69		0.69	
Maximum Detected Concentration	160		4.3		160		160		160	
95%UCL	29.5	n,d	1.5	n,d	87.7	n,d	69.4	n,d	58.8	n,d
RME Concentration	29.5		1.5		87.7		69.4		58.8	
Plutonium-239/240 (pCi/g)										
Number of Samples	39		33		8		12		18	
Number of Detects	39		33		8		12		18	
Minimum Detected Concentration	0.27		0.61		3.83		3.83		2.70	
Maximum Detected Concentration	7,300		50.3		950		7,300		7,300	
95%UCL	813	n,d	10.3	n,d	403	n,d	1,826	n,d	1,244	n,d
RME Concentration	813		10.3		403		1,826		1,244	

Note: Analytical results used in the calculation of 95% UCL concentrations are shown in Attachment H1.

RME - Reasonable maximum exposure.

-- - Not detected in this area

n - Based on normal distribution.

ln - Based on lognormal distribution.

d - See discussion in Attachment H1.

TABLE H5-2
EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN SUBSURFACE SOILS

					AOC No. 1 Maximum Exposure Areas			
	AOC No.1		AOC No. 2		10-Acre		30-Acre	
Tetrachloroethene (ug/kg)								
Number of Samples	359		--		51		86	
Number of Detects	48		--		7		24	
Minimum Detected Concentration	1		--		1		1	
Maximum Detected Concentration	13,000,000		--		130		180	
95%UCL	250,760	ln	--		48	ln	81	ln
RME Concentration	250,760		--		48		81	
Arsenic (mg/kg)								
Number of Samples	289		11		NE		NE	
Number of Detects	271		11		NE		NE	
Minimum Detected Concentration	0.63		1.30		NE		NE	
Maximum Detected Concentration	30.8		25.93		NE		NE	
95%UCL	6.4	ln	11.9	ln	NE		NE	
RME Concentration	6.4		11.9		NE		NE	
Cadmium (mg/kg)								
Number of Samples	244		10		NE		NE	
Number of Detects	85		1		NE		NE	
Minimum Detected Concentration	0.88		1.10		NE		NE	
Maximum Detected Concentration	10.5		1.10		NE		NE	
95%UCL	1.2	ln	0.49	n	NE		NE	
RME Concentration	1.2		0.49		NE		NE	
Mercury (mg/kg)								
Number of Samples	283		--		NE		NE	
Number of Detects	73		--		NE		NE	
Minimum Detected Concentration	0.06		--		NE		NE	
Maximum Detected Concentration	114		--		NE		NE	
95%UCL	0.09	ln	--		NE		NE	
RME Concentration	0.09		--		NE		NE	
Americium-241 (pCi/g)								
Number of Samples	254		12		NE		NE	
Number of Detects	217		9		NE		NE	
Minimum Detected Concentration	-0.06		0.004		NE		NE	
Maximum Detected Concentration	22		0.85		NE		NE	
95%UCL	0.32	ln	1.06	ln	NE		NE	
RME Concentration	0.32		0.85		NE		NE	
Plutonium-239/240 (pCi/g)								
Number of Samples	271		12		NE		NE	
Number of Detects	249		12		NE		NE	
Minimum Detected Concentration	-0.08		0.00		NE		NE	
Maximum Detected Concentration	180		2.3		NE		NE	
95%UCL	4.15	ln	2516	ln	NE		NE	
RME Concentration	4.15		2.3		NE		NE	

TABLE H5-2
EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN SUBSURFACE SOILS

				AOC No. 1 Maximum Exposure Areas	
	AOC No.1		AOC No. 2	10-Acre	30-Acre
Uranium-233, 234 (pCi/g)					
Number of Samples	269		2	NE	NE
Number of Detects	269		2	NE	NE
Minimum Detected Concentration	0.05		0.85	NE	NE
Maximum Detected Concentration	191.7		1.20	NE	NE
95%UCL	0.82	ln		NE	NE
RME Concentration	0.82		1.20	NE	NE
Uranium-238 (pCi/g)					
Number of Samples	276		2	NE	NE
Number of Detects	276		2	NE	NE
Minimum Detected Concentration	0.08		0.87	NE	NE
Maximum Detected Concentration	113.1		1.11	NE	NE
95%UCL	0.87	ln		NE	NE
RME Concentration	0.87		1.11	NE	NE
Uranium-235 (pCi/g)					
Number of Samples	170		2	NE	NE
Number of Detects	158		2	NE	NE
Minimum Detected Concentration	-0.04		0.07	NE	NE
Maximum Detected Concentration	11.5		0.07	NE	NE
95%UCL	0.07	ln		NE	NE
RME Concentration	0.07		0.07	NE	NE

Note: Analytical results used in the calculation of 95% UCL concentrations are shown in Attachment H1.
-- Not detected in this area.
RME - Reasonable maximum exposure.
ln - Based on lognormal distribution.
n - Based on normal distribution.
NE - Not evaluated: exposure to subsurface soil was not evaluated in these areas.

TABLE H5-3
EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN GROUNDWATER

	AOC No.1		AOC No. 2		AOC No. 1 Maximum Exposure Areas 10-Acre		AOC No. 1 Maximum Exposure Areas 30-Acre
1,1-Dichloroethene (ug/L)							
Number of Wells Sampled	99		--		16		32
Number of Wells where Detected	41		--		12		19
Minimum Well Average[a]	0.1		--		0.1		0.1
Maximum Well Average[a]	351		--		351		351
95%UCL[a]	4	ln	--		68	n,d	
RME Concentration	4		--				
Carbon Tetrachloride (ug/L)							
Number of Wells Sampled	100		--		17		33
Number of Wells where Detected	75		--		17		26
Minimum Well Average	0.1		--		0.1		0.08
Maximum Well Average	16,000		--		16,000		16,000
95%UCL	3,478	ln	--		3,569	n,d	
RME Concentration	3,478		--				
Chloroform (ug/L)							
Number of Wells Sampled	100		11		17		33
Number of Wells where Detected	78		2		16		25
Minimum Well Average	0.1		0.2	sr	0.1		0.1
Maximum Well Average	30,667		0.4	sr	30,667		30,667
95%UCL	104	ln			5,178	n,d	
RME Concentration	104		0.4				
Methylene Chloride (ug/L)							
Number of Wells Sampled	100		11		17		33
Number of Wells where Detected	47		4		6		16
Minimum Well Average	0.20		0.3	sr	0.70		0.40
Maximum Well Average	20,433		3.3	sr	20,433		20,433
95%UCL	13.6	ln			3,346	n,d	
RME Concentration	13.6		3.3				
Tetrachloroethene (ug/L)							
Number of Wells Sampled	100		11		17		33
Number of Wells where Detected	81		4		17		30
Minimum Well Average	0.1		0.1	sr	0.3		0.1
Maximum Well Average	11,033		0.62	sr	11,033		11,033
95%UCL	1,148	ln			2,022	n,d	
RME Concentration	1,148		0.62				
Trichloroethene (ug/L)							
Number of Wells Sampled	100		11		17		33
Number of Wells where Detected	79		3		15		27
Minimum Well Average	0.07		0.2	sr	0.1		0.07
Maximum Well Average	97,000		0.7	sr	97,000		97,000
95%UCL	1,103	ln			16,025	n,d	
RME Concentration	1,103		0.7				

TABLE H5-3
EXPOSURE POINT CONCENTRATIONS OF CHEMICALS OF CONCERN IN GROUNDWATER

					AOC No. 1 Maximum Exposure Areas		
	AOC No.1		AOC No. 2		10-Acre		30-Acre
Americium-241 (pCi/L)							
Number of Wells Sampled	69		5		14		NE
Number of Wells where Detected	69		5		14		NE
Minimum Well Average	-0.01		0.00		0.01		NE
Maximum Well Average	31.5		0.22		31.5		NE
95%UCL	0.19	ln	42.2	ln	6.7	n,d	NE
RME Concentration	0.19		0.22				NE
Plutonium-239/240 (pCi/L)							
Number of Wells Sampled	70		5		15		NE
Number of Wells where Detected	70		5		15		NE
Minimum Well Average	0.00		0.00		0.01		NE
Maximum Well Average	225		1.13		225		NE
95%UCL	2.4	ln	1.6E+05	ln	43.7	n,d	NE
RME Concentration	2.4		1.13				NE

-- Not detected in this area.
ln - Based on lognormal distribution.
n - Based on normal distribution.
d - See discussion in Attachment H1.
sr - Sample result (not a well average).
NE - Inorganic chemicals in groundwater were not evaluated in the 30-acre exposure area.
(1) Sampling results from each well were averaged (arthimetic mean) and those values were used to determine minimum, maximum, and 95% UCL values.

TABLE H5-4
AIR CONCENTRATIONS AND DEPOSITION RATES OF CHEMICALS OF CONCERN AT ONSITE EXPOSURE AREAS

	Aroclor-1254		Aroclor-1260		Bis(2-ethylhexyl)phthalate		Chromium		Americium-241		Plutonium-239/240	
Year	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)
AOC No. 1												
1989	3.67E-11	5.95E-06	2.87E-11	4.67E-06	3.00E-11	4.85E-06	1.67E-09	2.71E-04	3.61E-06	5.87E-01	1.00E-04	1.63E+01
1990	4.15E-09	6.75E-04	3.25E-09	5.29E-04	3.39E-09	5.51E-04	1.89E-07	3.07E-02	4.09E-04	6.65E+01	1.13E-02	1.84E+03
1991	1.95E-10	3.18E-05	1.53E-10	2.49E-05	1.60E-10	2.59E-05	8.90E-09	1.45E-03	1.93E-05	3.12E+00	5.34E-04	8.66E+01
1992	8.64E-11	1.41E-05	6.77E-11	1.10E-05	7.06E-11	1.15E-05	3.94E-09	6.39E-04	8.52E-06	1.38E+00	2.36E-04	3.82E+01
1993	2.34E-10	3.80E-05	1.83E-10	2.98E-05	1.91E-10	3.10E-05	1.07E-08	1.73E-03	2.30E-05	3.75E+00	6.39E-04	1.04E+02
Average	9.40E-10	1.53E-04	7.36E-10	1.20E-04	7.68E-10	1.25E-04	4.28E-08	6.96E-03	9.26E-05	1.506E+01	2.57E-03	4.171E+02
Maximum	4.15E-09	6.75E-04	3.25E-09	5.29E-04	3.39E-09	5.51E-04	1.89E-07	3.07E-02	4.09E-04	6.646E+01	1.13E-02	1.841E+03
AOC No. 2												
1989	--	--	--	--	1.43E-11	2.33E-06	1.71E-09	2.77E-04	1.88E-07	3.06E-02	1.35E-06	2.19E-01
1990	--	--	--	--	1.62E-09	2.64E-04	1.93E-07	3.14E-02	2.13E-05	3.46E+00	1.53E-04	2.48E+01
1991	--	--	--	--	7.64E-11	1.24E-05	9.09E-09	1.48E-03	1.00E-06	1.63E-01	7.19E-06	1.17E+00
1992	--	--	--	--	3.38E-11	5.48E-06	4.02E-09	6.53E-04	4.43E-07	7.20E-02	3.18E-06	5.16E-01
1993	--	--	--	--	9.14E-11	1.49E-05	1.09E-08	1.77E-03	1.20E-06	1.96E-01	8.64E-06	1.40E+00
Average	--	--	--	--	3.67E-10	5.97E-05	4.37E-08	7.11E-03	4.83E-06	7.845E-01	3.47E-05	5.625E+00
Maximum	--	--	--	--	1.62E-09	2.64E-04	1.93E-07	3.14E-02	2.13E-05	3.461E+00	1.53E-04	2.482E+01
AOC No. 1 10-Acre Maximum Exposure Area												
1989	--	--	--	--	4.35E-11	7.08E-06	1.42E-09	2.31E-04	7.45E-06	1.21E+00	3.45E-05	5.58E+00
1990	--	--	--	--	4.92E-09	7.99E-04	1.61E-07	2.61E-02	8.45E-04	1.37E+02	3.90E-03	6.33E+02
1991	--	--	--	--	2.32E-10	3.76E-05	7.57E-09	1.23E-03	3.98E-05	6.45E+00	1.84E-04	2.99E+01
1992	--	--	--	--	1.02E-10	1.66E-05	3.35E-09	5.44E-04	1.76E-05	2.85E+00	8.13E-05	1.32E+01
1993	--	--	--	--	2.77E-10	4.49E-05	9.06E-09	1.47E-03	4.74E-05	7.72E+00	2.20E-04	3.58E+01
Average	--	--	--	--	1.11E-09	1.81E-04	3.65E-08	5.92E-03	1.91E-04	3.098E+01	8.84E-04	1.436E+02
Maximum	--	--	--	--	4.92E-09	7.99E-04	1.61E-07	2.61E-02	8.45E-04	1.367E+02	3.90E-03	6.333E+02
AOC No. 1 30-Acre Maximum Exposure Area												
1989	6.37E-11	NA	4.61E-11	NA	3.79E-11	NA	1.40E-09	NA	7.18E-06	NA	1.90E-04	NA
1990	7.21E-09	NA	5.22E-09	NA	4.29E-09	NA	1.59E-07	NA	8.11E-04	NA	2.15E-02	NA
1991	3.39E-10	NA	2.45E-10	NA	2.02E-10	NA	7.48E-09	NA	3.81E-05	NA	1.01E-03	NA
1992	1.50E-10	NA	1.09E-10	NA	8.93E-11	NA	3.31E-09	NA	1.69E-05	NA	4.47E-04	NA
1993	4.06E-10	NA	2.94E-10	NA	2.42E-10	NA	8.96E-09	NA	4.57E-05	NA	1.22E-03	NA
Average	1.63E-09	NA	1.18E-09	NA	9.72E-10	NA	3.60E-08	NA	1.84E-04	NA	4.88E-03	NA
Maximum	7.21E-09	NA	5.22E-09	NA	4.29E-09	NA	1.59E-07	NA	8.11E-04	NA	2.15E-02	NA

TABLE H5-4
AIR CONCENTRATIONS AND DEPOSITION RATES OF CHEMICALS OF CONCERN AT ONSITE EXPOSURE AREAS

	Aroclor-1254		Aroclor-1260		Bis(2-ethylhexyl)phthalate		Chromium		Americium-241		Plutonium-239/240	
Year	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)
AOC No. 1 50-Acre Maximum Exposure Area												
1989	5.68E-11	NA	4.18E-11	NA	3.62E-11	NA	1.41E-09	NA	6.42E-06	NA	1.37E-04	NA
1990	6.43E-09	NA	4.73E-09	NA	4.10E-09	NA	1.60E-07	NA	7.28E-04	NA	1.55E-02	NA
1991	3.03E-10	NA	2.23E-10	NA	1.93E-10	NA	7.52E-09	NA	3.42E-05	NA	7.28E-04	NA
1992	1.34E-10	NA	9.84E-11	NA	8.52E-11	NA	3.32E-09	NA	1.51E-05	NA	3.22E-04	NA
1993	3.63E-10	NA	2.67E-10	NA	2.31E-10	NA	9.00E-09	NA	4.09E-05	NA	8.71E-04	NA
Average	1.46E-09	NA	1.07E-09	NA	9.29E-10	NA	3.63E-08	NA	1.65E-04	NA	3.52E-03	NA
Maximum	6.43E-09	NA	4.73E-09	NA	4.10E-09	NA	1.60E-07	NA	7.28E-04	NA	1.55E-02	NA

Notes:

Air concentrations and deposition rates are based on five annual simulations from 1989 through 1993 detailed in Appendix G of this RFI/RI Report.
Deposition rates reported as ug/m^2-day in Appendix G were converted to mg/m^2-year using a conversion factor of 0.365 days-mg/year-ug.
Radionuclides reported in ug were converted to pCi using specific activities for Am-241 of 3.435E+06 pCi/ug
and for Pu-239/240 of 7.32E+04 pCi/ug. The specific activity for Pu is the sum of the relative activities for Pu-238, Pu-239, and Pu-240 based on isotopic composition of Pu used at Rocky Flats (EG&G 1993e, Table 6-1).
-- Aroclors were not detected in these areas.
NA - Not applicable for exposure assessment because deposition onto home grown produce is an incomplete pathway for the 30- and 50-acre exposure acres.

TABLE H5-5
AIR CONCENTRATIONS AND DEPOSITION RATES
OF CHEMICALS OF CONCERN AT OFFSITE EXPOSURE POINTS

	Aroclor-1254		Aroclor-1260		Bis(2-ethylhexyl)phthalate		Chromium		Americium-241		Plutonium-239/240	
Year	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)
Impacts from AOC No. 1												
Current: Southeast												
1989	8.96E-14	0	7.02E-14	0	7.32E-14	0	4.08E-12	0	8.86E-09	0	2.44E-07	0
1990	6.57E-13	0	5.15E-13	0	5.36E-13	0	2.99E-11	0	6.49E-08	0	1.79E-06	0
1991	1.19E-13	0	9.36E-14	0	9.75E-14	0	5.44E-12	0	1.18E-08	0	3.26E-07	0
1992	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0
Average	1.73E-13	0	1.36E-13	0	1.41E-13	0	7.88E-12	0	1.71E-08	0	4.73E-07	0
Maximum	6.57E-13	0	5.15E-13	0	5.36E-13	0	2.99E-11	0	6.49E-08	0	1.79E-06	0
Future: Woman/Indiana												
1989	5.97E-14	0	4.68E-14	0	4.88E-14	0	2.72E-12	0	5.91E-09	0	1.63E-07	0
1990	3.88E-13	0	3.04E-13	0	3.17E-13	0	1.77E-11	0	3.85E-08	0	1.06E-06	0
1991	5.97E-14	0	4.68E-14	0	4.88E-14	0	2.72E-12	0	5.91E-09	0	1.63E-07	0
1992	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0
Average	1.01E-13	0	7.95E-14	0	8.29E-14	0	4.63E-12	0	1.01E-08	0	2.78E-07	0
Maximum	3.88E-13	0	3.04E-13	0	3.17E-13	0	1.77E-11	0	3.85E-08	0	1.06E-06	0
Impacts from AOC No. 2												
Current: Southeast												
1989	--	--	--	--	9.90E-14	0	1.18E-11	0	1.30E-09	0	9.22E-09	0
1990	--	--	--	--	7.26E-13	3.47E-07	8.65E-11	4.13E-05	9.51E-09	4.55E-03	6.76E-08	3.23E-02
1991	--	--	--	--	1.21E-13	0	1.44E-11	0	1.59E-09	0	1.13E-08	0
1992	--	--	--	--	0	0	0	0	0	0	0	0
1993	--	--	--	--	3.30E-14	0	3.93E-12	0	4.33E-10	0	3.07E-09	0
Average	--	--	--	--	1.96E-13	6.94E-08	2.33E-11	8.26E-06	2.57E-09	9.10E-04	1.82E-08	6.46E-03
Maximum	--	--	--	--	7.26E-13	3.47E-07	8.65E-11	4.13E-05	9.51E-09	4.55E-03	6.76E-08	3.23E-02
Current: Indiana South												
1989	--	--	--	--	0	0	0	0	0	0	0	0
1990	--	--	--	--	0	0	0	0	0	0	0	0
1991	--	--	--	--	0	0	0	0	0	0	0	0
1992	--	--	--	--	0	0	0	0	0	0	0	0
1993	--	--	--	--	1.10E-14	0	1.31E-12	0	1.44E-10	0	1.02E-09	0
Average	--	--	--	--	2.20E-15	0	2.62E-13	0	2.89E-11	0	2.05E-10	0
Maximum	--	--	--	--	1.10E-14	0	1.31E-12	0	1.44E-10	0	1.02E-09	0

TABLE H5-5
AIR CONCENTRATIONS AND DEPOSITION RATES OF CHEMICALS OF CONCERN AT OFFSITE EXPOSURE POINTS

	Aroclor-1254		Aroclor-1260		Bis(2-ethylhexyl)phthalate		Chromium		Americium-241		Plutonium-239/240	
Year	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (mg/m^3)	Deposition Rate (mg/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)	Air Concentration (pCi/m^3)	Deposition Rate (pCi/m^2-year)
Future: Walnut/Indiana												
1989	--	--	--	--	0	0	0	0	0	0	0	0
1990	--	--	--	--	0	0	0	0	0	0	0	0
1991	--	--	--	--	3.30E-14	0	3.93E-12	0	4.33E-10	0	3.07E-09	0
1992	--	--	--	--	0	0	0	0	0	0	0	0
0 1993	--	--	--	--	0	0	0	0	0	0	0	0
Average	--	--	--	--	6.60E-15	0	7.86E-13	0	8.66E-11	0	6.15E-10	0
Maximum	--	--	--	--	3.30E-14	0	3.93E-12	0	4.33E-10	0	3.07E-09	0
Future: Woman/Indiana												
1989	--	--	--	--	5.50E-14	0	6.55E-12	0	7.21E-10	0	5.12E-09	0
1990	--	--	--	--	4.07E-13	3.47E-07	4.85E-11	4.13E-05	5.32E-09	4.55E-03	3.79E-08	3.23E-02
1991	--	--	--	--	6.60E-14	0	7.86E-12	0	8.66E-10	0	6.15E-09	0
1992	--	--	--	--	0	0	0	0	0	0	0	0
0 1993	--	--	--	--	2.20E-14	0	2.62E-12	0	2.89E-10	0	2.05E-09	0
Average	--	--	--	--	1.10E-13	6.94E-08	1.31E-11	8.26E-06	1.44E-09	9.10E-04	1.02E-08	6.46E-03
Maximum	--	--	--	--	4.07E-13	3.47E-07	4.85E-11	4.13E-05	5.32E-09	4.55E-03	3.79E-08	3.23E-02

Notes:

Air concentrations and deposition rates are based on five annual simulations from 1989 through 1993 detailed in Appendix G of the RFI/RI report for OU2.

Deposition rates reported as ug/m^2-day in Appendix G were converted to mg/m^2-year using a conversion factor of 0.365 days-mg/year-ug.

Deposition rates for radionuclides reported as ug/mg^2-day were converted to pCi/m2-year using specific activities for Am-241 of 3.425E+06 pCi/ug and for Pu-239/240 of 7.32E+04 pCi/ug and 1 year/365 days.

Radionuclides reported in ug were converted to pCi using specific activities for Am-241 of 3.435E+06 pCi/ug and for Pu-239/240 of 7.32E+04 pCi/ug. The specific activity for Pu is the sum of the relative activities for Pu-238, Pu-239, and Pu-240 based on isotopic composition of Pu used at Rocky Flats (1993e, Table 6-1).

-- Aroclors were not detected in AOC No. 2.

0 - No measurable impacts (The model reports "0" when modeled PM_{10} concentrations are less than 0.001 ug/m^3).

TABLE H5-6
ANNUAL AVERAGE AIR CONCENTRATIONS
CONSTRUCTION SCENARIO, AOC NO. 1

	Surface Soil Wind Erosion Maximum (1990) (ug/m³)	Subsurface Soil Wind Erosion Maximum (1990) (ug/m³)	Heavy Construction Emissions (ug/m³)	Construction Total (ug/m³)	Construction Total (pci/m³) (1)
Semivolatile Organics					
Aroclor-1254	4.15E-06	-	-	4.15E-06	
Aroclor-1260	3.25E-06	-	-	3.25E-06	
Bis(2-ethylhexyl)phthalate	3.39E-06	-	-	3.39E-06	
Metals					
Arsenic	-	7.67E-09	6.47E-08	7.24E-08	
Cadmium	-	1.44E-09	1.21E-08	1.35E-08	
Chromium	1.89E-04	-	-	1.89E-04	
Mercury	-	1.08E-10	9.10E-10	1.02E-09	
Radionuclides					
Americium-241	1.19E-10	2.96E-16	2.50E-15	1.19E-10	4.09E-04
Plutonium-239/240	1.55E-07	6.81E-14	5.75E-13	1.55E-07	1.13E-02
Uranium-233,234	-	1.59E-13	1.34E-12	1.50E-12	9.29E-09
Uranium-235	-	3.92E-11	3.30E-10	3.70E-10	7.92E-10
Uranium-238	-	3.13E-09	2.64E-08	2.95E-08	9.82E-09

Note: The construction scenario includes air impacts from wind erosion of surface soil in the AOC; wind erosion from subsurface soil in a 10-acre excavation, and emissions from heavy construction activities. Concentrations are based on the maximums of five annual simulations from 1989 through 1993. See Appendix G for more detail.

(1) Air modeling results reported as ug/m³ were converted to pCi/m³ using the following specific activities:
Am-241 = 3.435E+06 pCi/ug
Pu-239/240 = 7.32E+04 pCi/ug (sum of relative specific activities for Rocky Flats plutonium; EG&G 1993e, Table 6-1)
U-233,234 = 6.19E+03 pCi/ug
U-235 = 2.14E+00 pCi/ug
U-238 = 3.33E-01 pCi/ug

- Not a chemical of concern in this medium.

TABLE H5-7
5-YEAR MAXIMUM ANNUAL AVERAGE AIR CONCENTRATIONS
CONSTRUCTION SCENARIO, AOC NO. 2

	Surface Soil Wind Erosion Maximum (1990) (ug/m³)	10-Acre Disturbed Construction Area Wind Erosion Maximum (1990) (ug/m³)	Heavy Construction Emissions (ug/m³)	Construction Total (ug/m³)	Construction Total (pci/m³) (1)
Semivolatile Organics					
Bis(2-ethylhexyl)phthalate	1.62E-06	-	-	1.62E-06	
Metals					
Arsenic	-	1.43E-08	1.20E-07	1.34E-07	
Cadmium	-	5.87E-10	4.95E-09	5.54E-09	
Chromium	1.93E-04	-	-	1.93E-04	
Radionuclides					
Americium-241	6.20E-12	2.96E-16	2.50E-15	6.21E-12	2.13E-05
Plutonium-239/240	2.09E-09	3.77E-14	3.18E-13	2.09E-09	1.53E-04
Uranium-233,234	-	2.33E-13	1.96E-12	2.20E-12	1.36E-08
Uranium-235	-	3.92E-11	3.30E-10	3.70E-10	7.92E-10
Uranium-238	-	3.99E-09	3.37E-08	3.76E-08	1.25E-08

Note: The construction scenario includes air impacts from wind erosion of surface soil in the AOC; wind erosion from subsurface soil in a 10-acre excavation, and emissions from heavy construction activities. Concentrations are based on the maximums of five annual simulations from 1989 through 1993. See Appendix G for more detail.

(1) Air modeling results reported as ug/m³ were converted to pCi/m³ using the following specific activities:
Am-241 = 3.435E+06 pCi/ug
Pu-239/240 = 7.32E+04 pCi/ug (sum of relative specific activities for Rocky Flats plutonium; EG&G 1993e, Table 6-1)
U-233,234 = 6.19E+03 pCi/ug
U-235 = 2.14E+00 pCi/ug
U-238 = 3.33E-01 pCi/ug

- Not a chemical of concern in this medium.

TABLE H5-8
SUMMARY OF AIR CONCENTRATIONS OF CHEMICALS OF CONCERN
CONSTRUCTION SCENARIO

Chemical of Concern	AOC No. 1	AOC No. 2
Aroclor-1254 (mg/m^3)	4.15E-09	--
Aroclor-1260 (mg/m^3)	3.25E-09	--
Bis(2-ethylhexyl)phthalate (mg/m^3)	3.39E-09	1.62E-09
Arsenic (mg/m^3)	7.12E-11	1.34E-10
Cadmium (mg/m^3)	1.35E-11	5.54E-09
Chromium (mg/m^3)	1.89E-07	1.93E-07
Mercury (mg/m^3)	1.30E-11	--
Americium-241 (pCi/m^3)	4.12E-04	2.13E-05
Plutonium-239/240 (pCi/m^3)	1.13E-02	1.53E-04
Uranium-233, -234 (pCi/m^3)	9.29E-09	1.36E-08
Uranium-235 (pCi/m^3)	7.92E-10	7.92E-10
Uranium-238 (pCi/m^3)	9.82E-09	1.25E-08

NOTE:
The construction scenario includes air impacts from wind erosion of surface soil in the AOC; wind erosion from subsurface soil in a 10-acre excavation, and emissions from heavy construction activities. Concentrations are based on the maximums of five annual simulations from 1989 through 1993; detailed in Appendix G of this RFI report.

-- Not detected in this area.

TABLE H5-9
BASEMENT AIR CONCENTRATIONS OF VOCs RELEASED FROM SUBSURFACE SOIL AND GROUNDWATER
(mg/m^3)

			AOC No. 1 Maximum Exposure Areas (1)	
	AOC No.1	AOC No. 2	10-Acre	30-Acre
1,1-Dichloroethene	1.94E-10	--	1.54E-09	3.21E-09
Carbon Tetrachloride	2.73E-07	--	1.13E-07	2.36E-07
Chloroform	1.10E-09	3.84E-11	2.91E-08	6.09E-08
Methylene Chloride	8.94E-11	1.97E-10	1.21E-08	2.53E-08
Tetrachloroethene	3.62E-03	2.62E-10	1.76E-07	5.83E-07
Trichloroethene	3.34E-08	1.93E-10	2.64E-07	5.52E-07

Source: Soil gas modeling results, Appendix G.

-- Not detected in this area.

(1) Maximum detected concentrations of VOCs in groundwater and subsurface soil were used as source concentrations. This could significantly overestimate basement air concentrations in the 10- and 30-acre areas because only a few sampling locations were highly contaminated.

TABLE H5-10
INDOOR AIR CONCENTRATIONS FROM DOMESTIC USE OF GROUNDWATER

	AOC No. 1		AOC No. 2		10-Acre	
	Groundwater Conc. (mg/L)	Air Conc. (mg/m^3)	Groundwater Conc. (mg/L)	Air Conc. (mg/m^3)	Groundwater Conc. (mg/L)	Air Conc. (mg/m^3)
1,1-Dichloroethene	4.00E-03	2.60E-04	–	–	6.80E-02	4.42E-03
Carbon Tetrachloride	3.48E+00	2.26E-01	–	–	3.57E+00	2.32E-01
Chloroform	1.04E-01	6.76E-03	4.00E-04	2.60E-05	5.18E+00	3.37E-01
Methylene Chloride	1.36E-02	8.84E-04	3.30E-03	2.15E-04	3.35E+00	2.17E-01
Tetrachloroethene	1.15E+00	7.46E-02	6.20E-04	4.03E-05	2.02E+00	1.31E-01
Trichloroethene	1.10E+00	7.17E-02	7.00E-04	4.55E-05	1.60E+01	1.04E+00

RME air concentrations were derived from RME groundwater concentrations (mg/L) using an average volatilization factor of 0.065 L/m^3. This is a constant that defines the relationship between the concentration in household water and the average concentration of volatilized contaminant in air from all domestic uses (e.g., showering, laundering, dish washing) (Andelman 1990).

– Not detected in this area.

TABLE H5-11
REASONABLE MAXIMUM 30-YEAR AVERAGE SURFACE WATER/SEDIMENT CONCENTRATIONS AT INDIANA STREET BASED ON 100 HYDROLOGIC SIMULATIONS

	Groundwater VOCs						Surface Soil Radionuclides	
	Carbon Tetrachloride (mg/L)	Chloroform (mg/L)	PCE (mg/L)	TCE (mg/L)	1,1-DCE (mg/L)	Methylene Chloride (mg/L)	Pu-239/240 (pCi/L)	Am-241 (pCi/L)
Woman Creek								
Minimum	0.00E+00	0.00E+00	0.00E+00	1.00E-06	0.00E+00	0.00E+00	5.34E-01	1.40E-02
Maximum	2.62E-04	2.15E-04	1.16E-04	9.25E-04	2.00E-06	1.00E-01	3.84E+00	1.02E-01
RME (1)	2.62E-04	2.15E-04	1.16E-04	9.25E-04	2.00E-06	1.06E-04	2.37E+00	6.3E-02
Walnut Creek								
Minimum	1.92E-04	3.00E-05	3.36E-04	2.20E-03	1.00E-06	9.00E-06	1.10E-02	2.00E-03
Maximum	4.81E-04	9.30E-05	8.03E-04	6.24E-03	5.00E-06	3.80E-05	3.10E-02	6.00E-03
RME (1)	4.81E-04	9.30E-05	8.03E-04	6.24E-03	5.00E-06	3.80E-05	2.60E-02	5.00E-03

Note:
The concentrations were calculated using the results of 100 simulated 30-year average surface water/suspended sediment concentrations. Surface water /sediment concentrations include aqueous-phase VOCs discharged to creeks in groundwater and Am-241 and Pu-239/240 adhered to surface soil particles and transported to the creeks in overland flow. Radionuclide transport in groundwater is negligible compared to transport in surface runoff and was neglected in the modelling.
(1) For VOCs, RME concentrations are the maximum 30-year average. For radionuclides, RME concentrations are the 90th percentile of the distribution (Figures H5-3 and H5-4).

TABLE H5-12
CHEMICAL CONCENTRATIONS IN HOMEGROWN PRODUCE FROM ROOT UPTAKE

$$C_{repro} = B_r \times 0.428 \times C_{soil}$$
$$C_{leafy} = B_v \times 0.428 \times C_{soil}$$

Nonleafy Vegetables and Fruits

			AOC No. 1		AOC No. 2		10-Acre	
Chemical	**B_r or BCF**	**WW CF**	**C_{soil}**	**C_{repro}**	**C_{soil}**	**C_{repro}**	**C_{soil}**	**C_{repro}**
Aroclor-1254 (mg/kg)	8.80E-03	0.428	3.00E-01	1.13E-03	--		--	
Aroclor-1260 (mg/kg)	3.90E-03	0.428	2.30E-01	3.84E-04	--		--	
BEHP (mg/kg)	1.50E-01	0.428	2.40E-01	1.54E-02	1.10E-01	7.06E-03	5.10E-01	3.27E-02
Chromium (mg/kg)	4.50E-03	0.428	1.36E+01	2.62E-02	1.31E+01	2.52E-02	1.67E+01	3.22E-02
Am-241 (pCi/kg)	2.50E-04	0.428	2.95E+04	3.16E+00	1.50E+03	1.61E-01	8.77E+04	9.38E+00
Pu-239/240 (pCi/kg)	4.50E-05	0.428	8.13E+05	1.57E+01	1.03E+04	1.98E-01	4.03E+05	7.76E+00

Leafy Vegetables

			AOC No. 1		AOC No. 2		10-Acre	
Chemical	**B_l or BCF**	**WW CF**	**C_{soil}**	**C_{leafy}**	**C_{soil}**	**C_{leafy}**	**C_{soil}**	**C_{leafy}**
Aroclor-1254 (mg/kg)	8.80E-03	0.428	3.00E-01	1.13E-03	--		--	
Aroclor-1260 (mg/kg)	3.90E-03	0.428	2.30E-01	3.84E-04	--		--	
BEHP (mg/kg)	1.50E-01	0.428	2.40E-01	1.54E-02	1.10E-01	7.06E-03	5.10E-01	3.27E-02
Chromium (mg/kg)	7.50E-03	0.428	1.36E+01	4.37E-02	1.31E+01	4.21E-02	1.67E+01	5.36E-02
Am-241 (pCi/kg)	5.50E-03	0.428	2.95E+04	6.94E+01	1.50E+03	3.53E+00	8.77E+04	2.06E+02
Pu-239/240 (pCi/kg)	4.50E-04	0.428	8.13E+05	1.57E+02	1.03E+04	1.98E+00	4.03E+05	7.76E+01

B_r - Transfer coefficient, inorganic compounds, to reproductive and storage portions of plants (Baes et al. 1984).
B_l - Transfer coefficient, inorganic compounds, to leafy portions of vegetables (Baes et al. 1984).
BCF - Bioconcentration factor for organic compounds; see text.
WW CF - Wet weight conversion factor (Baes et al. 1984).
BEHP - Bis(2-ethylhexyl)phthalate
-- Not detected in these areas.

TABLE H5-13
ESTIMATED FRACTION OF HOMEGROWN PRODUCE AFFECTED BY DEPOSITION

Produce Category	50th Percentile Homegrown Intake (g/day) (1)		% Individuals Consuming (1)	Weighted Homegrown Intake (g/day)
Raw vegetables				
White potatoes	7.4		74.4	5.5
Cabbage, coleslaw	3.2		9.7	0.3
Carrots	2.7		5	0.1
Cucumbers	9.1		5.6	0.5
Lettuce	1.3		50.7	0.7
Onions	0.7		8.5	0.1
Tomatoes	14.6		27.8	4.1
Cooked vegetables				
Broccoli	2.1		6.2	0.1
Cabbage	8.1		4.7	0.4
Carrots	4		9.8	0.4
Corn	60.9		25	15.2
Lima Beans	21.8		2.8	0.6
Mixed Veg	15.5	(2)	3.4	0.5
Peas	22	(2)	2.9	0.6
Green peas	14	(2)	18.3	2.6
Spinach	6.8		4.5	0.3
String beans	15.1		27.3	4.1
Summer squash	18	(2)	2.8	0.5
Sweet potatoes	6.7		4.1	0.3
Cucumber pickles	4.3		9.2	0.4
Total homegrown vegetable intake (g/day)				37
Exposed vegetable intake (g/day)				11
Ratio exposed/total				0.3
Fruits				
Grapefruit	10.1		4.7	0.5
Oranges	4.5		9	0.4
Apples	7.6		18.2	1.4
Applesauce	7.1		9.8	0.7
Cantaloupe	9.6		3.3	0.3
Peaches	15.1		4.5	0.7
Pears	15.7		3.1	0.5
Strawberries	12.3		2.1	0.3
Total homegrown fruit intake (g/day)				4.8
Total exposed fruit intake (g/day)				3.6
Ratio exposed/total				0.7454

(1) From Exposure Factors Handbook (USEPA 1989b), Table 2-10.

(2) Homegrown fraction is not available. Therefore, the amount is estimated using 50th percentile total average daily intake from Table 2-10 (USEPA 1989b) and assuming 50 percent is homegrown.

Exposed edible surface

TABLE H5-14
CHEMICAL CONCENTRATIONS IN HOMEGROWN PRODUCE FROM DEPOSITION OF PARTICULATE MATTER (ONSITE AREAS)

$C_{plant} = (DR \times T \times SA) / WT$

Chemical	T	SA	WT	AOC No. 1		AOC No. 2		10-Acre	
				DR	C_{plant}	DR	C_{plant}	DR	C_{plant}
Aroclor-1254 (mg/kg)	0.12	0.05	0.454	6.75E-04	8.92E-06	--		--	
Aroclor-1260 (mg/kg)	0.12	0.05	0.454	5.29E-04	6.99E-06	--		--	
BEHP (mg/kg)	0.12	0.05	0.454	5.51E-04	7.28E-06	2.64E-04	3.49E-06	7.99E-04	1.06E-05
Chromium (mg/kg)	0.12	0.05	0.454	3.07E-02	4.06E-04	3.14E-02	4.15E-04	2.61E-02	3.45E-04
Am-241 (pCi/kg)	0.12	0.05	0.454	6.45E+01	8.52E-01	3.46E+00	4.57E-02	1.37E+02	1.81E+00
Pu-239/240 (pCi/kg)	0.12	0.05	0.454	1.84E+03	2.43E+01	2.48E+01	3.28E-01	6.33E+02	8.37E+00

T - Time to harvest, yr.

SA - Surface area, m^2. SA of 0.05 m^2 represents lettuce, which is used as a surrogate for all exposed garden produce.

WT - Weight of produce, kg.

DR - Deposition rate, mg/m^2-yr or pCi/m^2-yr. Maximum value from Table H5-4.

C_{plant} - Concentration on plant, mg/kg or pCi/kg.

TABLE H5-15
CHEMICAL CONCENTRATIONS IN HOMEGROWN PRODUCE FROM DEPOSITION OF PARTICULATE MATTER (OFFSITE LOCATIONS)

$C_{plant} = (DR \times T \times SA) / WT$

				Current Southeast		Woman Cr./Indiana	
Chemical	**T**	**SA**	**WT**	**DR**	**C_{plant}**	**DR**	**C_{plant}**
BEHP (mg/kg)	0.12	0.05	0.454	3.47E-07	4.59E-09	3.47E-07	4.59E-09
Chromium (mg/kg)	0.12	0.05	0.454	4.13E-05	5.46E-07	4.13E-05	5.46E-07
Am-241 (pCi/kg)	0.12	0.05	0.454	4.55E-03	6.01E-05	4.55E-03	6.01E-05
Pu-239/240 (pCi/kg)	0.12	0.05	0.454	3.23E-02	4.27E-04	3.23E-02	4.27E-04

Note: "Zero" depositional impacts were estimated at the two other offsite receptor locations.

T - Time to harvest, yr.

SA - Surface area, m^2. SA of 0.05 m^2 represents lettuce, which is used as a conservative surrogate for exposed produce.

WT - Weight of produce, kg.

DR - Maximum deposition rate, mg/m^2-yr or pCi/m^2-yr. From Table H5-5.

C_{plant} - Concentration on plant, mg/kg or pCi/kg.

TABLE H5-16
CHEMICAL CONCENTRATIONS IN SURFACE SOIL FROM DEPOSITION OF PARTICULATE MATTER (OFFSITE LOCATIONS)

C_{soil} = (DR x 0.5 AT) / (d x p)

					Current Southeast		Woman Cr./Indiana	
Chemical	**0.5**	**AT**	**d**	**p**	**DR**	**C_{soil}**	**DR**	**C_{soil}**
BEHP (mg/kg)	0.5	30	0.0508	1.84E+03	3.47E-07	5.57E-08	3.47E-07	5.57E-08
Chromium (mg/kg)	0.5	30	0.0508	1.84E+03	4.13E-05	6.63E-06	4.13E-05	6.63E-06
Am-241 (pCi/kg)	0.5	30	0.0508	1.84E+03	4.55E-03	7.30E-04	4.55E-03	7.30E-04
Pu-239/240 (pCi/kg)	0.5	30	0.0508	1.84E+03	3.23E-02	5.19E-03	3.23E-02	5.18E-03

Note: Modeled depositional impacts were zero at the two other offsite receptor locations.

C_{soil} - Chemical concentration in surface soil, mg/kg or pCi/kg.

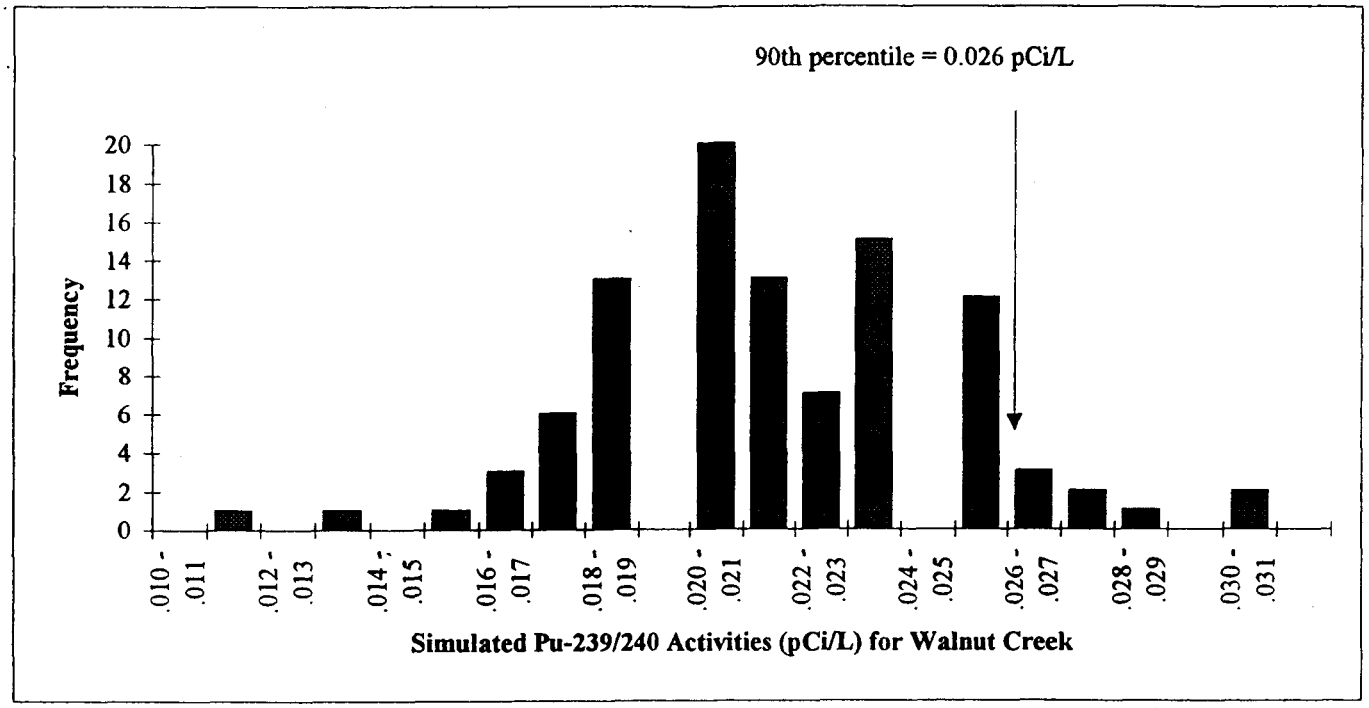
0.5 - Averaging factor, to yield average concentration over accumulation time.

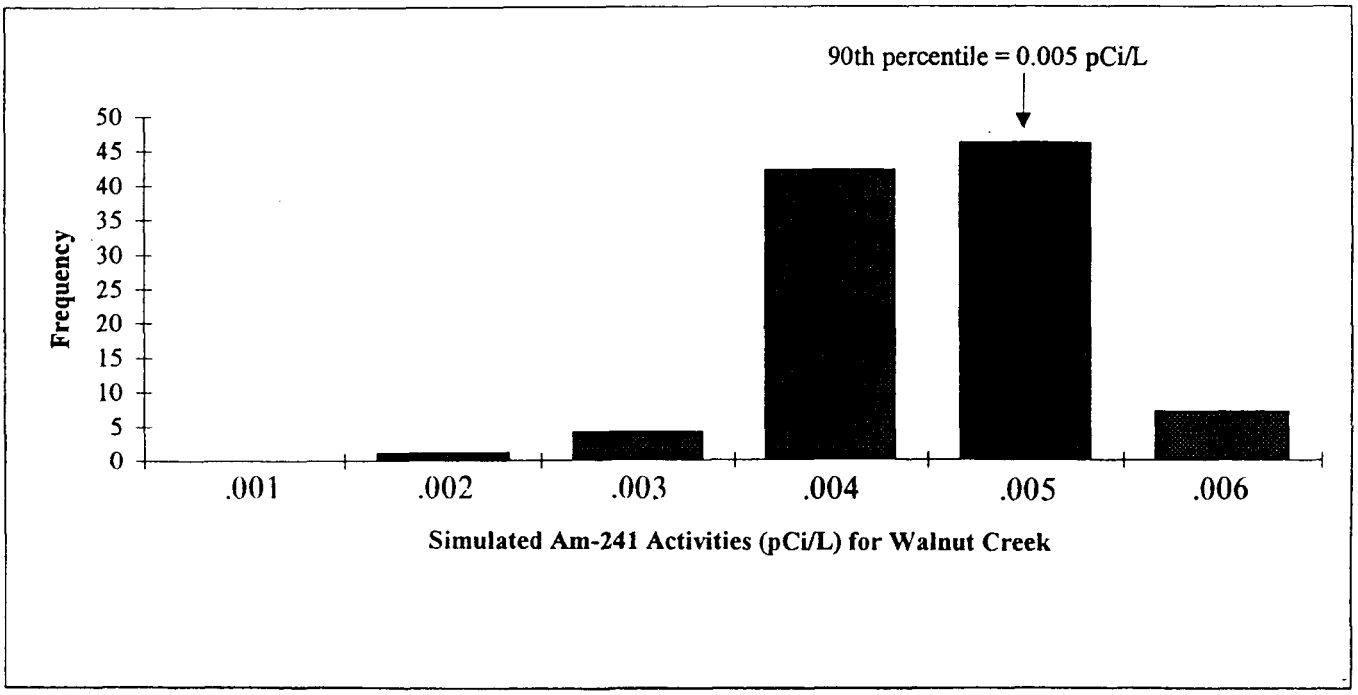
AT - Accumulation time (equal to RME residential exposure duration).

d - Depth of mixing, 0.0508 m (2 inches). This depth corresponds to the RFP surface soil sampling interval.

p - Soil density, kg/m^3.

DR - Deposition rate, mg/m^2-yr or pCi/m^2-yr. Maximum value from Table H5-5.





U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT NO.2
RFI/RI REPORT
HEALTH RISK ASSESSMENT

HISTOGRAMS OF SIMULATED
RADIONUCLIDE ACTIVITIES
IN WALNUT CREEK

FIGURE H5-3

MARCH 1995

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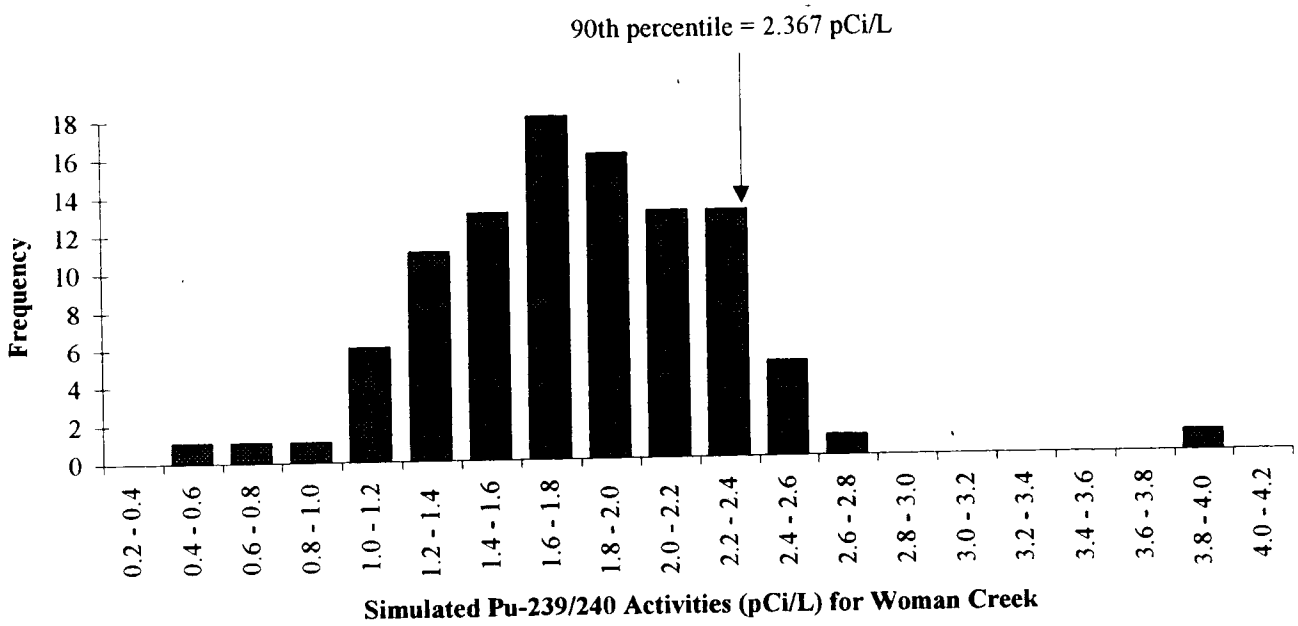

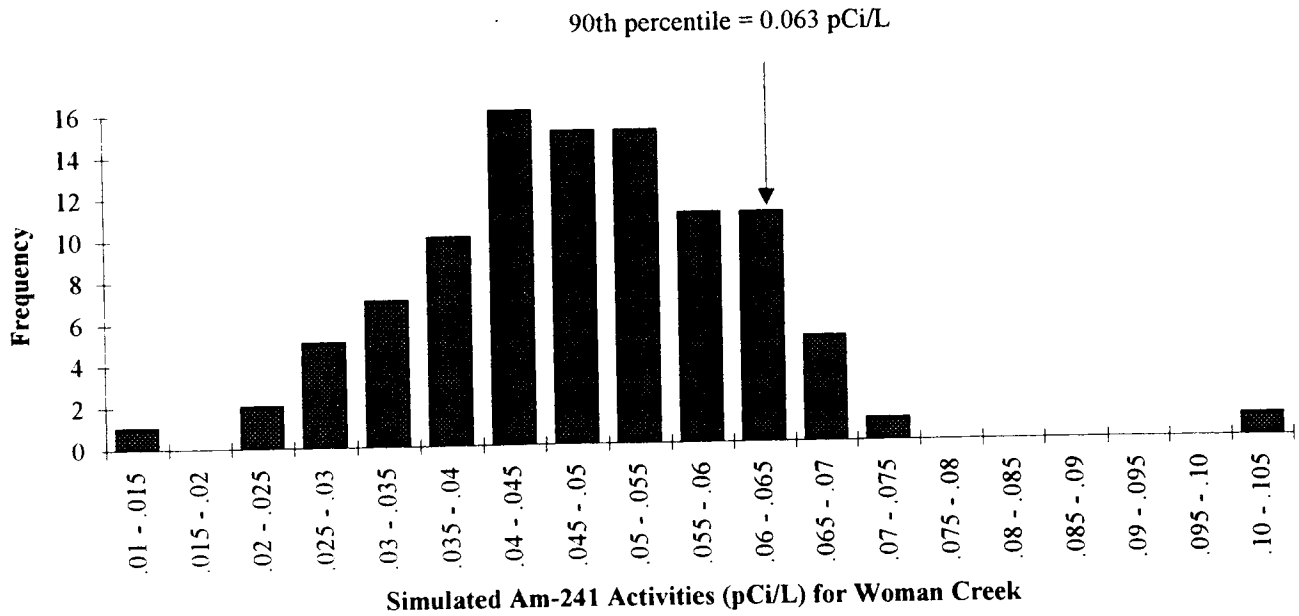

U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT NO.2
RFI/RI REPORT
HEALTH RISK ASSESSMENT

HISTOGRAMS OF SIMULATED
RADIONUCLIDE ACTIVITIES
IN WOMAN CREEK

FIGURE H5-4

MARCH 1995

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This section describes the methodology and equations for estimating intake of chemicals and radionuclides. Tables showing the numerical values for CT and RME exposure factors for each receptor and exposure pathway are presented in Attachment H2.

H6.1 GENERAL METHOD FOR CALCULATING INTAKE

Chemical intake is expressed in terms of milligram (mg) chemical ingested, inhaled, or dermally absorbed per kilogram body weight per day (mg/kg-day). Intake of radionuclides is expressed simply in terms of pCi total intake. Intakes were estimated following guidance in Risk Assessment Guidance for Superfund (EPA 1989a), the Exposure Factors Handbook (EPA 1989b), other EPA guidance documents, relevant scientific literature, and professional judgment regarding probable site-specific exposure conditions. Intakes are based on reasonable estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, frequency and duration of exposure, and chemical concentration.

Intakes were estimated for CT and for RME conditions, as recommended by EPA (EPA 1992c). The RME is estimated by selecting values for exposure variables so that the combination of all variables results in the maximum exposure that can reasonably be expected to occur at the site. The CT is estimated by selecting average values for exposure variables.

The following discussion focusses on the methodology for calculating chemical intakes. Special features of estimating intake of radionuclides are discussed in Section H6.3.

The general equation for calculating chemical intake in terms of mg/kg-day is:

$$\text{Intake} = \frac{\text{chemical concentration} * \text{intake rate} * \text{exposure frequency} * \text{exposure duration}}{\text{body weight} * \text{averaging time}}$$

with corresponding units of:

$$\text{mg/kg-day} = \frac{\text{mg/volume or mass} * \text{volume or mass/day} * \text{day/year} * \text{year}}{\text{kg} * \text{day}}$$

The variable "averaging time" is expressed in days to calculate daily intake. For noncarcinogenic chemicals, intakes are calculated by averaging over the exposure duration to yield an average daily intake for the period of exposure. For carcinogens, intakes are calculated by averaging the total dose over a 70-year lifetime, yielding "lifetime average daily intake." Different averaging times are used for carcinogens and noncarcinogens because it is thought that their effects occur by different mechanisms. The approach for carcinogens is based on the scientific opinion and EPA policy that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime, and that even very low doses of carcinogens have the potential to cause cancer. Therefore, the intake of a carcinogen is averaged over a 70-year lifetime (EPA 1989a). Intake of noncarcinogens is averaged only over the period of exposure in order to compare an estimate of daily dose during the exposure to a reference dose considered to be without appreciable risk of adverse effects during long-term exposure.

Omitting chemical concentration from the intake equation yields an "intake factor" for each exposure pathway/receptor combination. The intake factor can then be multiplied by the concentration of each chemical to obtain the pathway/receptor-specific intake of that chemical. Intake factors were calculated for each potentially exposed receptor and exposure pathway identified in Section H4.0. Except for soil ingestion, intake rates, such as dermal absorption, food intake, and inhalation are approximately proportional to body weight, and therefore adult exposure parameters are considered adequately protective for calculating chemical doses used in estimating risk for all exposed populations, including children. While it is acknowledged that body surface area is not exactly proportional to body weight and that age-specific ratios of inhalation rate to body weight may differ (by about a factor of two or less), these differences are assumed to be negligible. Therefore, child intakes are not estimated for any exposure pathway except soil ingestion because children age 0 to 6 are thought to ingest considerably more soil and dust per kg body weight than adults.

H6.2 PATHWAY-SPECIFIC INTAKE EQUATIONS

This section presents the intake equations for each pathway evaluated in risk assessment. Values for exposure factors shown in Attachment H2 are used in the equations to yield numerical intake factors for each receptor/pathway combination evaluated in the risk assessment.

H6.2.1 Soil Ingestion

Chemical intake from soil ingestion is estimated using the following equation:

$$\text{Intake} = \frac{\text{Conc.} \times \text{IR} \times \text{FC} \times \text{ME} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}}$$

where:

Intake	=	Chemical intake, mg/kg-day
Conc.	=	Chemical concentration in soil, mg/kg
IR	=	Soil ingestion rate, mg/day
FC	=	Fraction contaminated, unitless
ME	=	Soil matrix effect, unitless
EF	=	Exposure frequency, days/year
ED	=	Exposure duration, years
CF	=	Conversion factor, 10^{-6} kg/mg
BW	=	Body weight, kg
AT	=	Averaging time, days

Parameter values shown in Attachment H2 are used to calculate intake for each receptor evaluated.

Age-Adjusted IRs: Both child and adult soil ingestion rates were evaluated in the residential and open space use exposure scenarios. For noncarcinogens, child and adult soil ingestion were evaluated separately, using the equation shown above and values listed in Attachment H2. This approach yields separate hazard indexes for children and adults for the

soil ingestion exposure route. The separate hazard index for children is a more protective estimate of potential noncarcinogenic hazard for this age group because it accounts for the greater amount of soil ingested by children relative to body weight and the possibility of toxic effects occurring from the higher dose.

For carcinogens, a combined child and adult weighted ingestion rate was calculated, combining the soil IR, BW, EF, and ED for both age groups. It is not necessary to calculate separate cancer risk estimates for children and adults because, according to theories of carcinogenesis currently advocated by EPA, a higher dose of a potential carcinogen over a short period of time is thought to have the same carcinogenic potential as a lower dose over a longer period of time. The calculation of age-adjusted soil ingestion rates for carcinogenic chemicals is explained in Table H6-1.

Matrix Effect: The soil matrix effect (ME) describes the reduced bioavailability of a contaminant bound to a soil matrix compared to the same contaminant in solution. For COCs in soil whose toxicity factors were derived from studies in which the agent was administered in solution, a soil matrix factor of 0.5 was used in calculating chemical intake for risk assessment. Chemical-specific soil matrix effects for COCs in soil are listed in Table H6-2. The matrix effect of 0.5 is a conservative value derived from a review of literature, summarized in Table H6-3. The matrix effect is used to account for decreased bioavailability of ingested compounds bound to a solid matrix relative to their bioavailability from drinking water or other solutions commonly used in bioassays such as corn oil. Adjustments of this type may be necessary if "the medium of exposure in the site exposure assessment differs from the medium of exposure assumed by the toxicity value" (EPA 1989a). The EPA guidance further states that "a substance might be more completely absorbed following exposure to contaminated drinking water than following exposure to contaminated food or soil (e.g., if the substance does not desorb from soil in the gastrointestinal tract)."

The matrix effects developed for soil are also applicable to other solid exposure media, such as sediment and homegrown produce that is potentially affected by both root uptake of contaminants from soil and by deposition of airborne particulate matter.

The literature values for soil matrix effects shown in Table H6-3 are discussed in more detail below.

There are several EPA precedents for assuming decreased bioavailability of inorganics from food and soil compared to that in water. For example, cadmium and manganese each have two oral RfDs, one for ingestion in food and one for ingestion in water. In deriving media-specific RfDs for cadmium, EPA assumed that 5 percent of cadmium ingested in water is bioavailable, compared to 2.5 percent for cadmium ingested in food (EPA 1995b). The corresponding matrix effect for cadmium ingested in food is 0.5. The RfD for manganese ingested in water is 28 times smaller than the RfD for manganese ingested in food (EPA 1995b). Although relative bioavailability of manganese in food and water is not discussed in IRIS, one explanation for a 28-fold decrease in toxicity of manganese ingested in food is a matrix effect resulting in greatly decreased bioavailability. Another example of media-specific differences in toxicity is suggested by EPA's RfD for cyanide. In deriving the RfD for cyanide, based on a dietary study in rats, EPA included a safety factor of 5 to protect for an expected increase in toxicity of cyanide ingested in water (EPA 1995b). The use of this safety factor implies that cyanide ingested in food is 0.2 times less toxic than cyanide ingested in water, corresponding to a matrix effect of 0.2.

Other evidence in the literature indicates that absolute absorption of inorganics ingested in food is less than that from water. Sixty percent of radiolabeled lead chloride administered to adult humans in water was bioavailable, compared to 3 percent for lead chloride ingested in food (Heard and Chamberlain 1982). Similarly, nickel chloride administered to adult humans in food was much less bioavailable (0.7 percent) than nickel chloride administered in water (28 percent) (Sunderland et al. 1989). Increased blood levels of manganese were observed in humans ingesting high doses in water, but not when similar doses of manganese were ingested with food (Bales et al. 1987).

The absolute absorption of inorganics ingested in soil is also less than that from water. This is expected because inorganics only partially desorb from soil. EPA's Integrated Exposure Uptake Biokinetic (IEUBK) lead model assumes that the bioavailability of lead ingested in soil is 30 percent, compared to 50 percent bioavailability for lead ingested in water. The corresponding soil matrix value is 0.6. In rats, the bioavailability of lead ingested in soil was 8 percent of that for lead acetate ingested in water (Freeman et al. 1992). Arsenic administered in soil to rabbits was much less bioavailable (28 percent) than arsenic administered in water to rabbits (59 percent), corresponding to a soil matrix effect of 0.47 (Freeman et al. 1993).

Several studies show that organic chemicals, including pesticides, also bind tightly to soil, reducing their bioavailability through both oral and dermal exposure. Clays and organic colloids have a large surface area and cation exchange capacity, which permits significant adsorption of virtually all classes of pesticides. Furthermore, the adsorbed fraction desorbs slowly and is effectively a bound fraction that increases over time as the soil-pesticide bond "ages" (Calderbank 1989). The bound fraction is estimated to be about 20 to 70 percent of the total amount applied. McConnell et al. (1984) showed, using soil containing TCDD (a dioxin), that 3 μg/kg-bw TCDD in corn oil resulted in 6/6 deaths among treated guinea pigs and 13.3 ppb TCDD in the liver; but 3.3 μg/kg-bw TCDD from soil caused only 2/6 deaths and 1.4 ppb in the liver, indicating about 10 percent relative bioavailability of TCDD from the soil. Shu et al. (1988) conducted further studies on TCDD and found an average 43 percent (range, 25 to 50 percent) bioavailability of TCDD to rats from soils from Times Beach, Missouri. Goon et al. (1991) showed that benzo(a)pyrene that had aged 6 months in soil was only 34 and 51 percent orally bioavailable for clayey and sandy soils, respectively, relative to benzo(a)pyrene administered alone to rats. PCBs, DDT, chlordane, and heptachlor may be expected to adsorb strongly to soil similarly to benzo(a)pyrene (Ney 1990), resulting in reduced bioavailability due to this matrix effect. These studies support a conservative estimate of 50 percent relative bioavailability of SVOCs in soil compared to those in solution.

A matrix factor of 0.5 was used in the health risk assessment to account for the decreased toxicity of chemicals of concern in soil, in suspended sediment, and in homegrown produce relative to that in water or other solution. This value is based in part on EPA-derived relative bioavailability factors for cadmium in food (0.5) and lead in soil (0.6), a literature-derived relative bioavailability factor of 0.47 for arsenic in soil (Freeman et al. 1993; EPA 1995b), and the evidence supporting a 50 percent relative bioavailability of SVOCs in soil. Note that several studies indicate that the decrease in bioavailability from the matrix effects of food and soil can be substantially greater than 50 percent (as much as 95 percent), indicating that a matrix effect of 0.5 is conservative (Freeman et al. 1992; Heard and Chamberlain 1982; Sunderland et al. 1989; EPA 1995b).

As shown in Table H6-2, the following chemicals of concern in surface and subsurface soil have toxicity values that were derived from studies using drinking water or other solution and were therefore evaluated using a matrix effect: Aroclors, tetrachloroethene, arsenic, and mercury. The following special-case chemicals of concern in surface soil were also evaluated

using a matrix effect of 0.5: fluoranthene and pyrene. If the critical toxicity study was dietary but no vehicle was indicated in IRIS, a default matrix effect of 1 was used.

For radionuclides, ingestion slope factors were calculated using gastrointestinal absorption factors (f_1) for soluble forms of each radionuclide; consequently, it would be appropriate to consider matrix effects as well as mineralized form to estimate carcinogenic effects from ingestion of radionuclides in a soil matrix (Nelson 1995). However, the reduction in potential toxic effects cannot be quantified simply using a matrix effect because the adjustment must account for differential effects on target organs. Therefore, a matrix effect of 1 has been adopted for radionuclides in the present risk assessment, even though this factor probably overestimates the effects of radionuclides ingested in soil.

H6.2.2 Inhalation of Airborne Particulate Matter and of Indoor VOCs

Chemical intake through inhalation exposure routes is estimated using the following equation:

$$\text{Intake} = \frac{\text{Conc.} \times \text{IR} \times \text{DF} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

where:

Intake	=	Chemical intake, mg/kg-day
Conc.	=	Chemical concentration in air, mg/m^3
IR	=	Inhalation rate, m^3/hour
DF	=	Particulate deposition factor in lung, unitless
ET	=	Exposure time, hr/day
EF	=	Exposure frequency, days/year
ED	=	Exposure duration, years
BW	=	Body weight, kg
AT	=	Averaging time, days

Parameter values shown in Attachment H2 were used to calculate chemical intake via inhalation for each receptor evaluated.

H6.2.3 Soil Dermal Contact

Chemical intake through absorption of organic chemicals through skin is estimated using the following equation:

$$\text{Intake} = \frac{\text{Conc.} \times SA \times AB \times AD \times FC \times EF \times ED \times CF}{BW \times AT}$$

where:

Intake	=	Chemical intake, mg/kg-day
Conc.	=	Chemical concentration in soil, mg/kg
SA	=	Surface area, cm^2/day
AB	=	Absorption factor, unitless
AD	=	Soil adherence factor, mg/cm^2
FC	=	Fraction contacted that is contaminated, unitless
EF	=	Exposure frequency, days/year
ED	=	Exposure duration, years
BW	=	Body weight, kg
AT	=	Averaging time, days
CF	=	Conversion factor, kg soil/mg soil

Parameter values shown in Attachment H2 were used to calculate intake via dermal contact with soil for each receptor evaluated.

Absorption Factors: The parameter AB is a chemical-specific value describing the fraction of organic contaminant in soil that is absorbed by the skin. Table H6-4 lists the values and sources for AB used in this risk assessment. Dermal absorption of metals (other than mercury) was not considered a significant uptake route, because metals bind strongly to soil, greatly reducing their bioavailability. Most metals form strong bonds with other soil constituents, and due to polarity and solubility, metals are not absorbed well across the skin (EPA 1991e). Therefore, dermal uptake of metals other than mercury was considered negligible and was not evaluated in this risk assessment. Likewise for radionuclides, EPA guidance states that "dermal uptake is generally not an important route of uptake for

radionuclides, which have small dermal permeability constants" (EPA 1989a). Dermal permeability constants describe the rate at which dissolved (aqueous phase) chemicals permeate the skin. Absorption of radionuclides adhered to soil is also expected to be negligible.

H6.2.4 Groundwater Ingestion

Chemical intake from groundwater ingestion is estimated using the following equation:

$$\text{Intake} = \frac{\text{Conc.} \times \text{IR} \times \text{FC} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

where:

Intake	=	Chemical intake, mg/kg-day
Conc.	=	Chemical concentration in groundwater, mg/L
IR	=	Ingestion rate, L/day
FC	=	Fraction ingested from contaminated source, unitless
EF	=	Exposure frequency, days/year
ED	=	Exposure duration, years
BW	=	Body weight, kg
AT	=	Averaging time, days

Parameter values shown in Attachment H2 were used to calculate chemical intake via groundwater ingestion for hypothetical onsite residential receptors.

H6.2.5 Surface Water/Sediment Ingestion

Chemical intake via ingestion of surface water and suspended sediment transported to creeks from OU-2 surface soil is estimated using the following equation:

$$\text{Intake} = \frac{\text{Conc.} \times \text{IR} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

where:

Intake	=	Chemical intake, mg/kg-day
Conc.	=	Chemical concentration in water, mg/L
IR	=	Ingestion rate, L/hour
ET	=	Exposure time, hr/day
EF	=	Exposure frequency, days/year
ED	=	Exposure duration, years
BW	=	Body weight, kg
AT	=	Averaging time, days

Parameter values shown in Attachment H2 were used to calculate intake for each receptor evaluated.

H6.2.6 Surface Water Dermal Contact

Chemical intake through absorption of VOCs in water through skin is estimated using the following equation:

$$\text{Intake} = \frac{\text{Conc.} \times \text{SA} \times \text{PC} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}}$$

where:

Intake	=	Chemical intake, mg/kg-day
Conc.	=	Chemical concentration in water, mg/L
SA	=	Surface area, cm^2/day
PC	=	Permeability constant, cm/hr (chemical-specific)
ET	=	Exposure time, hr/day
EF	=	Exposure frequency, days/year
ED	=	Exposure duration, years
CF	=	Conversion factor, L/cm^3
BW	=	Body weight, kg
AT	=	Averaging time, days

Parameter values shown in Attachment H2 were used to calculate intake for each receptor evaluated.

Permeability constants (PCs): PCs are chemical-specific factors that describe the rate at which dissolved (aqueous-phase) chemicals permeate the skin. Absorption of metals and radionuclides adhered to suspended sediment is assumed to be negligible and was not evaluated. PCs for organic contaminants modeled in surface water are listed in Table H6-4.

H6.2.7 Ingestion of Homegrown Produce

Chemical intake through ingestion of homegrown produce is estimated using the following equation:

$$\text{Intake} = \frac{\text{Conc.} \times \text{IR} \times \text{WO} \times \text{ME} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}}$$

where:

Intake	=	Chemical intake, mg/kg-day
Conc.	=	Chemical concentration in produce, mg/kg
IR	=	Ingestion rate, mg/day
WO	=	Wash-off factor, unitless
ME	=	Matrix effect, unitless
EF	=	Exposure frequency, days/yr
ED	=	Exposure duration, yr
CF	=	Conversion factor, 10^{-6} kg/mg
BW	=	Body weight, kg
AT	=	Averaging time, days

Parameter values shown in Attachment H2 were used to calculate intake for residential receptors.

H6.3 CALCULATING INTAKE OF RADIONUCLIDES

Exposure to radionuclides was evaluated in two ways. First, the total intake or external irradiation exposure for each radionuclide was calculated and multiplied by the respective carcinogenic slope factor to provide an estimate of lifetime excess cancer risk, following EPA risk assessment guidance (EPA 1989a). The equations for estimating total intake of radionuclides by ingestion and inhalation and for estimating external irradiation exposure are described in this section.

Second, the annual radiation dose (more precisely, the annual committed effective dose equivalent) was calculated and compared to annual radiation protection standards. Radiation dose calculations and protection standards are discussed in Section H9.0.

H6.3.1 Intake of Radionuclides from Ingestion and Inhalation

Intake of radionuclides was calculated using equations similar to those for calculating intake of chemicals. Intake of radionuclides by either ingestion or inhalation is a function of radionuclide activity concentration, intake rate (or the amount of contaminated medium contacted per unit time or event), and exposure frequency and duration. The only difference between calculating intake for radionuclides and nonradioactive substances is that averaging time and body weight are excluded from the intake equations for radionuclides.

To estimate lifetime excess cancer risk, intake is calculated using the following equation:

$$\text{Intake} = C \times IR \times EF \times ED$$

where:

Intake	=	Lifetime internal radionuclide intake via inhalation or ingestion, pCi
C	=	Activity concentration of a radionuclide at the exposure point, pCi/m^3, pCi/L, or pCi/kg
IR	=	Intake rate, m^3/day, L/day, or kg/day
EF	=	Exposure frequency, days/yr
ED	=	Exposure duration, yr

Excess lifetime cancer risk is then estimated by multiplying the total intake in pCi by the cancer slope factor expressed in units of risk/pCi.

H6.3.2 External Irradiation

For estimating lifetime excess cancer risk, external irradiation exposure is estimated using the following equation:

$$ER = C \times (1\text{-}Se) \times Te \times EF \times ED$$

where:

ER	=	External irradiation exposure, pCi/g soil per year (pCi-yr/g)
C	=	Mass activity concentration of a radionuclide at the exposure point, pCi/g soil
Se	=	Gamma shielding factor, unitless
Te	=	Gamma exposure time factor, fraction of day (unitless)
EF	=	Exposure frequency, fraction of year (unitless)
ED	=	Exposure duration, years

Excess lifetime cancer risk is then estimated by multiplying ER in pCi-yr/g by the slope factor for external irradiation expressed in risk/pCi-yr/g.

TABLE H6-1
AGE-WEIGHTED SOIL INGESTION RATES FOR CARCINOGENS AND RADIONUCLIDES

For carcinogens:
Age-weighted soil ingestion rates for residential exposures and open space use are calculated using the following formula:

$$IRadj = \frac{(IRc \times EDc \times FCc)}{BWc} + \frac{IRa \times EDa \times FCa}{BWa}$$

where:

IRadj = Age-weighted soil ingestion rate (mg-yr/day-kg)
IRc = Childhood soil ingestion rate (mg/day)
EDc = Childhood exposure duration (yr)
FCc = Fraction ingested from contaminated source (child) (unitless)
BWc = Child body weight (kg)
IRa = Adult soil ingestion rate (mg/day)
EDa = Adult exposure duration (yr)
FCa = Fraction ingested from contaminated source (adult) (unitless)
BWa = Adult body weight (kg)

Applying exposure factors from Attachment H2 for residential and open space use soil ingestion yields the following weighted IRs for estimating chemical intake from soil:

			Residential	Open Space Use
CT	IRadj	=	14 mg-yr/day-kg	2.8 mg-yr/day-kg
RME	IRadj	=	114 mg-yr/day-kg	57 mg-yr/day-kg

For radionuclides:
For radionuclides, the equation for IRadj does not include BW.
IRadj for radionuclides are:

			Residential	Open Space Use
CT	IRadj	=	388 mg-yr/day	86 mg-yr/day
RME	IRadj	=	3,600 mg-yr/day	1,800 mg-yr/day

CT - Central tendency
RME - Reasonable maximum exposure

TABLE H6-2
SOIL MATRIX EFFECTS

Chemical of Concern	Type of Critical Study (1)		Soil Matrix Effect (2)
	Oral Reference Dose	Oral Slope Factor	
Aroclor-1254	Glycerol & corn oil vehicle (monkeys)	By analogy to Aroclor-1260	0.5
Aroclor-1260	By analogy to Aroclor-1254	Corn oil vehicle, stirred in food (rats)	0.5
Bis(2-ethylhexyl)phthalate	Dietary; vehicle not specified (guinea pigs)	Dietary; vehicle not specified (rats)	1
Tetrachloroethene	Corn oil gavage (mice)	Corn oil gavage (ECAO-CIN)	0.5
Arsenic	Drinking water (humans)	Drinking water (humans)	0.8 (3)
Cadmium	Dietary (humans)		1
Chromium	Dietary (rats)		1
Mercury	Parenteral HgCl2 (rats)		0.5
Americium-241		Soluble form in food or water (4)	1
Plutonium-239/240		Soluble form in food or water (4)	1
Uranium-233/234		Soluble form in food or water (4)	1
Uranium-235		Soluble form in food or water (4)	1
Uranium-238		Soluble form in food or water (4)	1
Special-Case Chemicals of Concern			
Benzo(a)pyrene (5)		Dietary; vehicle not specified (rats, mice, dogs)	1
Fluoranthene	Gavage (mice)		0.5
Pyrene	Gavage (mice)		0.5

(1) Source: IRIS (EPA 1995b), unless otherwise noted.
(2) A soil matrix effect of 0.5 is supported by literature review; see text and Table H6-3.
(3) EPA Region VIII.
(4) Personal communication (Nelson 1995).
Retardation of radionuclide intake from soil matrix is appropriate to consider but cannot be quantified using a simple soil matrix effect because the adjustment must account for differential effects on target organs. Therefore, a matrix effect of 1 is adopted for radionuclides, even though it probably overestimates bioavailability of mineralized forms of radionuclides in soils at Rocky Flats.
(5) Adopted for all carcinogenic PAHs in soil.

TABLE H6-3
DERIVATION OF 0.5 SOIL MATRIX EFFECT

Compound (Species)	Fraction Absorbed from Food or Soil (Fm)	Fraction Absorbed from Water (Fw)	Matrix Effect	Source
Cadmium (adults)	2.5	5	0.50 (1)	EPA 1995b; Kjellstrom and Nordberg, 1978
Manganese (adults)	--	--	0.04 (2)	EPA 1995b
Cyanide (rats)	--	--	0.20 (3)	EPA 1995b
Lead (children)	0.3	0.5	0.60 (1)	EPA 1994e
Lead (adults)	0.03	0.6	0.05 (1)	Heard and Chamberlain (1982)
Lead (rats)	--	--	0.08 - 0.20 (4)	Freeman et al. 1993
Nickel (adults)	0.007	0.28	0.03 (1)	Sunderland et al. 1989
Arsenic (rabbits)	0.28	0.59	0.47 (1)	Freeman et al. 1994
TCDD (guinea pigs)	--	--	0.10 (5)	McConnell et al. 1984
Benzo(a)pyrene (rats)	--	--	0.34-0.51 (6)	Goon et al. 1991
Matrix Effect Selected for Use in HHRA			0.5	

(1) Based on Fm/Fw.
(2) Based on relative toxicity of manganese in water vs food (RfD water = 5E-03 mg/kg-d; RfD food = 1.4E-01 mg/kg-d; ratio = 0.04).
(3) Based on relative toxicity of cyanide in food and water; see text.
(4) Based on relative retention of lead in blood, bone, and liver
(5) Based on relative retention of TCDD in liver
(6) Based on relative bioavailability from soil compared to water
TCDD = 2,3,7,8 - Tetrachlorodibenzo-p-dioxin

TABLE H6-4
DERMAL ABSORBED FRACTION AND AQUEOUS PERMEABILITY CONSTANTS FOR COCs IN SOIL AND SURFACE WATER

Chemical	Soil Absorbed Fraction	Aqueous Permeability Constant (cm/hr)	Source
Aroclor-1254	0.06	-	1
Aroclor-1260	0.06	-	1
Bis(2-ethylhexyl)phthalate	0.01	-	2
Carbon tetrachloride	-	0.022	3
Chloroform	-	0.13	4
1,1-Dichloroethene	-	0.016	3
Methylene Chloride	-	0.0045	3
Tetrachloroethene	0.03	0.37	5,4
Trichloroethene	-	0.23	4
Mercury	0.001	-	6

Sources:

1. Experimentally measured. EPA 1992i, Table 6-3.
2. EPA 1992h. New Interim Region IV Guidance recommending 1 percent absorption factors for all organics.
3. Estimated Kp. EPA 1992i,, Table 5-8.
4. Measured Kp. EPA 1992i, Table 5-8.
5. Dollarhide, Joan S. 1992. Dermal Absorption Factors for Multiple Chemicals (Union Carbide Corporation, Marietta Memo from Joan S. Dollarhide, Superfund Health Risk Technical Support Center, to Kathleen Warren, USEPA Region V.
6. EPA Region 4, New Interim Region IV Guidance, February 11, 1992, recommending 0.1% absorption for inorganics. Dermal absorption of metals other than mercury from soil is considered negligible (see text).

- Not a chemical of concern in this medium.

H7.1 INTRODUCTION

This section describes the toxicity factors for COCs evaluated in the HHRA. The toxicity factors used in the HHRA are EPA-verified or provisional carcinogenic slope factors (SFs) and noncarcinogenic reference doses (RfDs) or reference air concentrations (RfCs) for the COCs in OU-2. The toxicity factors presented in Tables H7-1 and H7-2 are the most current factors available at this writing.

The principal indices of toxicity for chemicals with noncarcinogenic effects are the oral RfD and inhalation RfC. RfDs and RfCs can be considered threshold doses or exposure levels. At chemical doses or exposures below threshold values, adverse effects are not expected to occur. RfDs and RfCs incorporate a number of safety factors to ensure that they are protective of the health of all human populations, including sensitive subgroups (e.g., children and the elderly).

Oral and inhalation SFs are used to characterize the potency of carcinogens. A SF is a dose-response factor used to relate carcinogenic response to chemical dose. SFs are used to estimate the upperbound probability of an individual developing cancer as a result of exposure to a potential carcinogen. EPA policy assumes that carcinogenic responses have no threshold, and that exposure to a carcinogen may result in some finite cancer risk at any dose, no matter how small (EPA 1989a).

SFs for internal doses of radionuclides are derived considering the energy level of the radionuclide and residence time of the radionuclide in various body tissues. Duration of exposure is determined by the residence time of the radionuclide. SFs for external exposure to radionuclides are determined by the energy level of the radionuclide and duration of the exposure (i.e., time spent at the exposure point).

EPA assumes that any dose of a radionuclide has the potential to produce carcinogenic effects (no threshold). EPA does not recommend the evaluation of noncarcinogenic effects of

radionuclides because the noncarcinogenic impacts have been shown to be insignificant compared to carcinogenic effects at most Superfund sites with radionuclide contamination (EPA 1989a). EPA has developed both internal (i.e., inhalation and ingestion) and external SFs for the carcinogenic response to radionuclide exposure (EPA 1994c).

Note on assessing effects of dermal exposure to chemicals: EPA recommends using oral toxicity factors, adjusted if possible by gastrointestinal absorption fraction, to evaluate toxic effects from dermal absorption of chemicals from contaminated media (EPA 1989a; 1992c). The oral toxicity factor relates toxic response to an administered dose of chemical, only some of which may be absorbed by the body, whereas chemical intake from dermal contact is estimated as an absorbed dose, whose toxic effects could be underestimated by using unadjusted oral toxicity factors. Therefore, EPA (EPA 1989a) suggests adjusting the oral toxicity factors by chemical-specific gastrointestinal absorption fractions, if available, to yield adjusted toxicity factors for dermally absorbed chemicals. When chemical-specific gastrointestinal absorption rates are not available, gastrointestinal absorption is assumed to be 100 percent, and the unadjusted oral toxicity factor is used to assess response to dermal absorption.

Regarding using oral toxicity factors to evaluate response to dermal exposure, EPA (EPA 1992c) states:

> Until more appropriate dose-response factors are available, it is recommended that assessors use the oral factors.... Alternatively, if estimates of the gastrointestinal absorption fraction are available for the compound of interest in the appropriate vehicle, then the oral dose-response factor, unadjusted for absorption, can be converted to an absorbed dose basis.... Lacking this information, the oral factor should be used as is accompanied by a strong statement of the uncertainty involved. (pp. 10-9, 10-10)

Because chemical-specific gastrointestinal absorption rates are not available for most chemicals, unadjusted oral toxicity factors were used to assess effects of dermal absorption. If dermal absorption of particular chemicals is demonstrated to be a potential significant contributor to overall risk in the risk assessment, a more detailed analysis of the toxicity by dermal absorption may be warranted.

EPA guidance (EPA 1989a) states that it is inappropriate to use oral SFs to evaluate the risks associated with dermal exposure to PAHs, which can cause skin cancer through direct action at the point of application. In accordance with EPA guidance, generally only a qualitative assessment of risks from dermal exposure to PAHs is possible. In addition, PAHs do not have RfCs or SFs for the inhalation pathway. Therefore, only oral exposures to PAHs were evaluated quantitatively in the risk assessment.

The RfDs, RfCs, and SFs that are used in the risk assessment were obtained from the following sources:

- EPA's Integrated Risk Information System on-line database (EPA 1995b)
- EPA's Health Effects Assessment Summary Tables (EPA 1994c)
- EPA's Environmental Criteria and Assessment Office (ECAO) for interim and provisional values.

H7.2 REFERENCE DOSES AND REFERENCE CONCENTRATIONS

The noncarcinogenic effects of chemicals are generally thought to have a threshold dose below which there are no observable adverse health effects. In developing a toxicity value for noncarcinogenic effects, the approach used by EPA is to identify a no-observed-adverse-effect level (NOAEL) through studies with laboratory animals or from epidemiological (human) studies. A NOAEL is defined as an experimentally (or epidemiologically) determined highest dose at which there was no observed statistically or biologically significant effect of concern. For certain substances, only a lowest-observed-adverse-effect level (LOAEL) has been determined. This is the lowest dose of a substance that produces either a statistically or biologically significant indication of the critical toxic effect. The RfD is usually based on the most sensitive animal species tested (i.e., the species that experiences adverse effects at the lowest dose). RfDs are typically calculated by dividing the NOAEL (or LOAEL) by uncertainty factors, which may range from 10 to 10,000. Uncertainty factors (usually a factor of 10 each) are used to account for protection of sensitive individuals, extrapolation from animal studies to humans, extrapolation from subchronic studies to chronic exposure, and extrapolation from LOAELs to NOAELs. In addition, modifying factors ranging from >0 to 10 may be included to reflect a qualitative assessment of additional uncertainties in the derivation of the RfD or RfC.

The majority of our toxicological knowledge of chemicals comes from experiments on laboratory animals. Experimental animal data historically have been relied upon by regulatory agencies and other expert groups to assess the hazards of human chemical exposures, although uncertainty is inherent in this approach because there are known interspecies differences in chemical absorption, metabolism, excretion, and toxic responses. There are also uncertainties concerning the relevance of animal studies using exposure routes (i.e., intravenous injection) that differ from the human exposure routes under consideration. Additionally, the extrapolation of results from short-term or subchronic animal studies to long-term exposures in humans has inherent uncertainty (EPA 1989a).

Despite the limitations of experimental animal data, such information is essential for chemical toxicity assessment, especially in the absence of human epidemiological evidence. The uncertainty factors used in the derivation of RfDs and RfCs are intended to compensate for data limitations. The use of uncertainty factors is conservative by design and results in toxicity values that are likely to be protective, and may well be overly protective (EPA 1989a).

The RfD is expressed in units of intake of milligrams of chemical per kilogram of body weight per day (mg/kg-day) for oral exposure. The methodology for deriving RfDs is described in detail in the EPA's human health risk assessment guidance (EPA 1989a).

Potential hazards from inhalation exposures may be estimated by comparing an air concentration of a chemical to the RfC. RfCs are expressed in concentration units of milligrams of chemical per cubic meter of air (mg/m^3). For the purposes of the OU-2 risk assessment, in order to assess cumulative effects of oral, dermal, and inhalation exposures, the RfCs are converted to inhalation RfDs so that chemical intake, rather than inhalation exposure, can be evaluated. A body weight of 70 kg and a respiration rate of 20 m^3/day are used to convert the RfC to the RfD (mg/kg-day) using the following equation:

$$\text{RfD (mg/kg-day)} = \frac{\text{RfC (mg/m}^3\text{) x 20 m}^3\text{/day}}{\text{70kg}}$$

Oral and inhalation RfDs for COCs and the inhalation RfCs used in the derivation of the inhalation RfDs are presented in Table H7-1.

H7.3 SLOPE FACTORS FOR CHEMICAL CARCINOGENS

In estimating the risk posed by potential chemical carcinogens, it is EPA practice to assume that any exposure level is associated with a finite probability, however minute, of producing a carcinogenic response. In other words, it is assumed that a small number of molecular events can evoke changes in a single cell that can lead to uncontrolled cellular proliferation. This mechanism for carcinogenicity is referred to as "non-threshold" since there is theoretically no level of exposure that does not pose a small probability of producing a carcinogenic response. This is a conservative (protective) assumption that may overestimate the response to low doses of some suspected carcinogens, especially those for which there is scientific evidence of a threshold dose.

SFs for most chemicals are based upon the results of animal studies which, as previously discussed, involve uncertainty. It is not certain that all animal carcinogens are carcinogenic in humans. While many chemical substances are carcinogenic in one or more animal species, only a small number of chemical substances are known to be human carcinogens. The EPA assumes that humans are as sensitive to all animal carcinogens as the most sensitive animal species. This policy decision is designed to prevent underestimating risk and introduces the potential to overestimate carcinogenic risk (EPA 1989a).

The EPA also uses an evaluation process in which the chemical is assigned a cancer weight-of-evidence classification. The weight-of-evidence classification describes the degree of confidence or likelihood, based on scientific evidence, that the substance is a human carcinogen. EPA cancer weight-of-evidence classifications are shown at the bottom of Table H7-1.

SFs are calculated from experimentally based or epidemiological data that quantitatively define the relationship between average lifetime dose and carcinogenic risk (EPA 1989a). A number of mathematical models and procedures have been developed to extrapolate from carcinogenic responses observed at high doses in laboratory animals to potential responses expected at low doses in humans. EPA uses a conservative mathematical model, the linearized multistage model, for low-dose extrapolation. EPA identifies the SF as the upper 95th percentile confidence limit on the slope of the resulting dose-response curve. The SF is expressed in units of risk per mg/kg-day, or $(mg/kg\text{-}day)^{-1}$, and is used to estimate excess

incremental lifetime cancer risk from the lifetime average daily intake of a chemical. This represents an estimation of an upperbound probability that an individual will develop cancer as a result of exposure to the potential carcinogen. This model provides a conservative (protective) estimate of cancer risk at low doses and is likely to overestimate the actual cancer risk. SFs for chemicals of concern in OU-2 are presented in Table H7-1.

H7.4 SLOPE FACTORS FOR RADIONUCLIDES

EPA's Health Effects Assessment Summary Tables (EPA 1994c) list cancer SFs for selected radionuclides of potential concern at Superfund sites. These values were calculated by the Office of Radiation Programs and are intended for use in human health risk assessments. EPA classifies all radionuclides as Group A (human) carcinogens based on the extensive weight-of-evidence provided by epidemiological studies of radiation-induced cancers in humans.

Radionuclides that enter the body may become incorporated into body tissues and emit alpha, beta, or gamma radiation for the duration of the radionuclide's lifetime. The potential adverse effects of radiation are proportional to energy deposition. The energy deposited in tissues is proportional to the decay rate and the type of radiation (alpha, beta, gamma) rather than the mass of the radionuclide (EPA 1989a). Radionuclide intake is typically expressed in terms of activity, either Curies (Ci) or Becquerels (Bqs) rather than mass (mg). Activity refers to the number of nuclear disintegrations per unit time. The historic unit of activity is the Ci, which is equal to 3.7×10^{10} disintegrations per second. The SI (Systeme Internationale) unit of activity is the Bq, equal to one disintegration per second (1 Bq = 2.7×10^{-11} Ci). EPA SFs are provided in both units, risk per picocurie (pCi or 1×10^{-12} Ci) and risk per Bq. Table H7-2 shows the SFs for radionuclides of concern expressed in risk per pCi.

EPA SFs for radionuclides are characterized as best estimates (median or 50th percentile) of the age-averaged, lifetime excess total cancer incidence (fatal and nonfatal) risk per unit exposure to a radionuclide. The SFs are based on the unique chemical, metabolic, and radiological properties of individual radionuclides. They were calculated using a non-threshold, linear dose-response model. The model accounts for the amount of radionuclide

absorbed into the body, distribution, and retention, as well as the age, sex, and weight of an average individual. Therefore, EPA SFs for radionuclides are not expressed as a function of body weight or time, and do not require corrections for absorption or lung transfer efficiencies. These slope factors include daughter (decay) products when appropriate (EPA 1994c).

Ingestion and inhalation SFs, expressed as risk/pCi, estimate risk per unit of radioactivity that is ingested or inhaled. External exposure SFs are best estimates of risk for each year of exposure to external irradiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil. They are expressed as risk/yr per pCi/gram soil. It should be noted that the dose delivered to tissues from external irradiation occurs only while the radiation field is present. However, the dose delivered to body tissues due to intake of radionuclides consumed in soil, water, or food continues long after intake of the contaminated medium has ceased.

Because the SFs for external irradiation from Pu-239 and Pu-240 are different (Table H7-2), a site-specific external irradiation SF for RFETS Pu-239/240 was estimated by the specific activity-weighted average of the slope factors for Pu-239 and Pu-240, as shown in the following equation:

$$SF_W = (SF_{239} \times F_{239}) + (SF_{240} \times F_{240})$$

where:

SF_W	=	Weighted external irradiation SF for RFETS Pu-239/240 (1.9E-11 per pCi-year/g)
SF_{239}	=	External irradiation SF for Pu-239 (1.7E-11 per pCi-year/g)
SF_{240}	=	External irradiation SF for Pu-240 (2.7E-11 per pCi-year/g)
F_{239}	=	Fraction of RFETS Pu-239/240 specific activity that is attributable to Pu-239 (0.8153; EG&G Rocky Flats 1993e)
F_{240}	=	Fraction of RFETS Pu-239/240 specific activity that is attributable to Pu-240 (0.1847; EG&G Rocky Flats 1993e)

This weighted SF (1.9E-11) is a site-specific estimate of the carcinogenic potential of RFETS Pu-239/240.

Radionuclide concentrations in air, water, or soil are multiplied by intake rates for internal exposure, or by exposure times for external exposure, and then multiplied by SFs to estimate potential health risk.

Radionuclide intake can also be multiplied by a dose coefficient to estimate equivalent dose in terms of millirems (mrems), which can then be compared to a radiation protection standard. Differences in the biological effects of different types of ionizing radiation (i.e., alpha, beta, gamma) are accounted for in the dose coefficients. Table H7-3 lists the dose coefficients for Am-241, Pu-239, U-234, U-235, and U-238. Coefficients for Pu-239 and U-234 were used to evaluate Pu-239/240 and U-233/234, respectively.

TABLE H7-1
TOXICITY FACTORS FOR CHEMICALS OF CONCERN: ORGANIC COMPOUNDS AND METALS

Analyte	Slope Factors		EPA Cancer Weight of Evidence	Reference Doses		RfC
	Oral	Inhalation		Oral	Inhalation	
1,1-Dichloroethene	6.0E-01 (1)	1.7E-01 (1)	C	9.0E-03 (1)	-	-
Antimony	-	-	-	4.0E-04 (1)	-	-
Aroclor-1254	7.7E+00 (1)	-	B2	2.0E-05 (1)	-	-
Aroclor-1260	7.7E+00 (1)	-	B2	2.0E-05 (1)	-	-
Arsenic	1.7E+00 (5)	1.5E+01 (5)	A	3.0E-04 (1)	-	-
Benzo(a)anthracene	7.3E-01 (2)	-	B2	-	-	-
Benzo(a)pyrene	7.3E+00 (2)	-	B2	-	-	-
Benzo(b)fluoranthene	7.3E-01 (2)	-	B2	-	-	-
Benzo(k)fluoranthene	7.3E-02 (2)	-	B2	-	-	-
Beryllium	4.3E+00 (1)	8.4E+00 (1)	B2	5.0E-03 (1)	-	-
Bis(2-ethylhexyl)phthalate	1.4E-02 (1)	-	B2	2.0E-02 (1)	-	-
Cadmium (food)	-	6.3E+00 (1)	B1	1.0E-03 (1)	-	-
Cadmium (water)	-	-	B1	5.0E-04 (1)	-	-
Carbon tetrachloride	1.3E-01(1)	5.2E-02 (1)	B2	7.0E-04 (1)	-	-
Chloroform	6.1E-03 (1)	8.0E-02 (1)	B2	1.0E-02 (1)	-	-
Chromium III	-	-	-	1.0E+00 (1)	-	-
Chrysene	7.3E-02 (2)	-	B2	-	-	-
Fluoranthene	-	-	-	4.0E-02 (1)	-	-
Indeno(1,2,3-cd)pyrene	7.3E-01 (2)	-	B2	-	-	-
Manganese (food)	-	-	D	1.4E-01 (1)	1.4E-05	5.0E-05 (1)
Manganese (water)	-	-	D	5.0E-03 (1)	-	-
Mercury	-	-	D	3.0E-04 (3)	9.0E-05	3.0E-04 (3)
Methylene chloride	7.5E-03 (1)	1.6E-03 (1)	B2	6.0E-02 (1)	9.0E-01	3.0E+00 (3)
Pyrene	-	-	D	3.0E-02 (1)	-	-
Tetrachloroethene	5.2E-02 (4)	2.0E-03 (4)	B2	1.0E-02 (1)	-	-
Trichloroethene	1.1E-02 (4)	6.0E-03 (4)	B2	-	-	-
Vinyl chloride	1.9E+00 (3)	3.0E-01 (3)	A	-	-	-

Sources:

1 - IRIS (EPA 1995b).

2 - EPA 1993b.

3 - EPA 1994c.

4 - Joan S. Dollarhide, Superfund Health Risk Technical Support Center. "Carcinogenicity Characterization of Perchloroethylene (PERC) and Trichloroethylene (TCE) (Luke Air Force Base, Arizona)." ECAO.

5 - Converted from IRIS unit risks. Oral proposed U.R. = 5.00E-05/μg/L. Inhalation U.R. = 4.30E-03/μg/m^3.
Oral SF = 5.00E-05 x 1,000μg/mg x 70kg/2L. Inhalation SF = 4.30E-03/μg/m^3 x 1,000μg/mg x 70kg/20m^3.

EPA Cancer Weight of Evidence :

A - Human carcinogen

B1 - Probable human carcinogen (limited human data)

B2 - Probable human carcinogen (animal data only)

C - Possible human carcinogen

D - Noncarcinogenic (inadequate evidence)

- Not classifiable or not carcinogenic

TABLE H7-2
SLOPE FACTORS
FOR RADIONUCLIDES

Analyte	GI Absorption Factor (F_i)[1]	Oral (Risk/pCi)	ICRP Lung Class [2]	Inhalation (Risk/pCi)	External (Risk/pCi-year/g)	EPA Cancer Weight of Evidence
Americium-241	1E-03	2.4E-10	W	3.2E-08	4.9E-09	A
Plutonium-239	1E-03	2.3E-10	Y	3.8E-08	1.7E-11	A
Plutonium-240	1E-03	2.3E-10	Y	3.8E-08	2.7E-11	A
Plutonium-239/240[3]	--	2.3E-10	--	3.8E-08	1.9E-11	A
Uranium-233, -234[4]	5E-02	1.6E-11	Y	2.6E-08	3.0E-11	A
Uranium-235 +D	5E-02	1.6E-11	Y	2.5E-08	2.4E-07	A
Uranium-238 +D	5E-02	2.2E-11	Y	2.4E-08	5.1E-08	A

Source: EPA 1994c. Note: HEAST 1994 Supplement No. 2 was not available in time to incorporate revised slope factors for radionuclides in risk calculations. They will be included in the Final HHRA.

[1] Gastrointestinal (GI) absorption factors are the fractional amounts of each radionuclide absorbed across the GI tract into the bloodstream.

[2] Lung clearance classification recommended by the International Commission on Radiological Protection (ICRP 1990): Y= year, W=week, D=day.

[3] The external irradiation slope factor for plutonium-239/240 at RFETS was calculated based on the slope factors for plutonium-239 and -240, weighted for site-specific specific activities of the two isotopes at RFETS (Section H7.4).

[4] Slope factors shown are for U-234.

A - Class A (human) carcinogen.

+D - Risks from radioactive decay products included.

TABLE H7-3
EFFECTIVE DOSE COEFFICIENTS FOR RADIONUCLIDES

Radionuclide	f_1 [1]	Ingestion (Sv/Bq)	Class [2]	Inhalation (Sv/Bq)	External [3]
Americium-241	1.00E-03	9.84E-07	W	1.20E-04	2.99E+00
Plutonium-239[4]	1.00E-03	9.56E-07	W	1.16E-04	3.78E-02
	1.00E-04	9.96E-08	Y	8.33E-05	
	1.00E-05	1.40E-08			
Uranium-234[5]	5.00E-02	7.66E-08	D	7.37E-07	8.07E-02
	2.00E-03	7.06E-09	W	2.13E-06	
			Y	3.58E-05	
Uranium-235	5.00E-02	7.19E-08	D	6.85E-07	1.71E+01
	2.00E-03	7.22E-09	W	1.97E-06	
			Y	3.32E-05	
Uranium-238	5.00E-02	6.88E-08	D	6.62E-07	6.46E-02
	2.00E-03	6.42E-09	W	1.90E-06	
			Y	3.20E-05	

Sources: DOE 1988b, EPA 1988c.

[1] Fractional uptake from small intestine to blood.
[2] Lung clearance class: D = days; W = weeks; Y = years
[3] In units of millirem/yr per microcurie/square meters.
[4] Used to evaluate Pu-239/240.
[5] Used to evaluate U 233/234.

Risk characterization is the final step of the risk assessment process. In this step, the toxicity factors (RfDs and SFs) for the COCs are applied in conjunction with estimated chemical intakes to predict noncarcinogenic and carcinogenic health risks to exposed individuals.

H8.1 HAZARD INDEX FOR NONCARCINOGENIC EFFECTS

The potential for noncarcinogenic effects is characterized by comparing estimated chemical intakes with chemical-specific RfDs. The resulting ratio is called a hazard quotient (HQ). It is derived in the following manner:

$$\text{Noncancer Hazard Quotient} = \frac{\text{Chemical Intake (mg/kg-day)}}{\text{RfD (mg/kg-day)}}$$

Use of the RfD assumes that there is a level of intake (the RfD) below which it is unlikely that even sensitive individuals will experience adverse health effects over a lifetime of exposure. If the average daily intake exceeds the RfD (that is, if the HQ exceeds 1), there may be cause for concern for potential noncancer effects (EPA 1989a). It should be noted, however, that the level of concern does not increase linearly as the RfD is approached or exceeded. This is because all RfDs are not equally accurate and are not based on the same severity of toxic effects. Since the HQ does not define a dose-response relationship, its numerical value cannot be construed as a direct estimate of risk (EPA 1986).

To assess exposures to multiple chemicals, the hazard quotients for each chemical are summed to yield a HI. The assumption of additive effects reflected in the HI is most properly applied to substances that induce the same effect by the same mechanism (EPA 1986). Consequently, summing hazard quotients for substances that are not expected to induce the same type of effect could overestimate the potential for adverse effects. The HI provides a measure of the potential for adverse effects, but it is conservative and dependent on the quality of experimental evidence.

Where an individual may be exposed by multiple pathways, the HIs from all relevant pathways are summed to obtain the total HI for that receptor. If the total HI is less than or equal to 1, multiple-pathway exposures to COCs at the site are judged unlikely to result in an adverse effect. If the sum is greater than 1, further evaluation of exposure assumptions and toxicity, including consideration of specific target organs affected and mechanisms of toxic actions of COCs, is warranted to ascertain if the cumulative exposure would in fact be likely to harm exposed individuals.

H8.2 CARCINOGENIC RISK

Potential carcinogenic effects are characterized in terms of the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen. Excess lifetime cancer risk is estimated from the projected lifetime daily average intake and the cancer SF, which represents an upperbound estimate of the dose-response relationship. Excess lifetime cancer risk is calculated by multiplying the average daily chemical intake by the cancer SF as follows:

$$\text{Cancer Risk} = \text{Chemical Intake (mg/kg-day)} \times \text{SF (mg/kg-day)}^{-1}$$

EPA states that carcinogenic risks estimated using SFs are upperbound estimates. This means that the actual risk is likely to be less than the predicted risk (EPA 1989a). RME cancer risks could be significantly overestimated because they are calculated by multiplying together 95th percentile estimates of cancer potency, 95% UCLs of concentrations, and high-end estimates of several exposure parameters.

The risks resulting from exposure to multiple carcinogens are assumed to be additive. The total cancer risk is estimated by summing the risks estimated for each COC and for each pathway. This is a highly conservative approach that results in an artificially elevated estimate of cancer risk, especially if several carcinogens are present, because 95th percentile estimates are not strictly additive (EPA 1989a).

EPA policy must be considered in order to interpret the significance of the cancer risk estimates. In the National Oil and Hazardous Substances Pollution Contingency Plan (EPA 1990d), EPA states that: "For known or suspected carcinogens, acceptable exposure levels are

generally concentration levels that represent an excess upperbound lifetime cancer risk of between 10^{-4} and 10^{-6}." Additionally, where cumulative carcinogenic risk to an individual based on RME exposure is less than 10^{-4} and the total HI does not exceed 1, action is generally not warranted for protection of public health (EPA 1991d). EPA recommends that cancer risk be evaluated separately for radionuclides and nonradionuclides (EPA 1989a). In the current assessment, separate estimates of radionuclide and nonradionuclide cancer risk were presented in Attachment H3, Health Risk Calculations. However, to reduce complexity in the following sections, cancer risks from radionuclide and nonradionuclide exposures were added and reported as total cancer risk.

H8.3 AOC No. 1

As discussed in Section H4.4, health hazard/risks for onsite receptors were evaluated in two AOCs identified in the operable unit, AOC No. 1 and AOC No. 2. Onsite receptors evaluated in these exposure areas include current workers, future industrial/office workers, future ecological workers, future open space users, future construction workers, and hypothetical residents. Hazards/risks for hypothetical future residents, future industrial/office workers, and future ecological workers were also estimated in 10-, 30-, and 50-acre maximum exposure areas, respectively, in AOC No. 1. Risk results for the maximum exposure areas are discussed in Section H8.4.

AOC No. 1 includes the 903 Pad, Mound, Northeast Trenches, and Southeast Trenches, which contain all of the IHSSs that were investigated in OU-2. Hazard/risks results for current and future receptors evaluated in AOC No. 1 are summarized in Table H8-1 and detailed in Attachment H3.

H8.3.1 Noncarcinogenic Hazard Index

The cumulative HIs for noncarcinogenic health effects for current and future onsite nonresidential receptors in AOC No.1 are 4E-02 or less for the average and RME conditions (Table H8-1). Because the HIs are less than 1, no adverse noncancer health effects are expected even for sensitive individuals exposed under RME conditions. Results for each receptor are discussed below:

Current Worker: Exposure pathways evaluated for the current worker were:

- Inhalation of airborne particulates
- Surface soil ingestion and dermal contact
- External irradiation from decay of radionuclides in surface soil

The cumulative HIs indexes for noncarcinogenic health effects for current onsite workers are 2E-03 and 1E-02 for the average and RME conditions, respectively (Table H8-1). These values are below 1, indicating that no adverse noncancer effects are expected for the current worker in AOC No. 1.

Future Industrial/Office Worker: Exposure pathways evaluated for the future industrial/office worker were the same as for the current worker with the addition of inhalation of VOCs migrating from subsurface soil and groundwater to indoor air.

The cumulative HIs for noncarcinogenic health effects for the future industrial/office worker are 6E-03 and 4E-02 for the average and RME conditions, respectively (Table H8-1). These values are below 1, indicating that no adverse noncancer effects are expected for the future industrial/office worker in AOC No. 1.

Future Ecological Worker: Exposure pathways evaluated for the ecological worker were:

- Inhalation of airborne particulates
- Surface soil ingestion and dermal contact
- Surface water and sediment ingestion and dermal contact (Woman and Walnut creeks)

The cumulative HIs for noncarcinogenic health effects for the future ecological worker are 5E-03 and 2E-02 for the average and RME conditions, respectively (Table H8-1). These values are below 1, indicating that no adverse noncancer effects are expected for the future ecological worker in AOC No. 1.

Future Open Space Use: Exposure pathways evaluated for open space use were the same as for the ecological receptor with the addition of soil ingestion by young children. The

cumulative HIs for noncarcinogenic health effects for the future open space user are 5E-04 and 1E-02 for the average and RME conditions, respectively (Table H8-1). These values are below 1, indicating that no adverse noncancer effects are expected from future open space use in AOC No. 1.

Future Construction Worker: The future construction worker was evaluated for the following exposure pathways:

- Inhalation of airborne particulates from subsurface and surface soil
- Subsurface soil ingestion and dermal contact
- External irradiation from decay of radionuclides in subsurface soil

The cumulative hazard indexes for noncarcinogenic health effects for the future construction worker are 4E-03 and 2E-02 for the average and RME conditions, respectively (Table H8-1). These values are below 1, indicating that no adverse noncancer effects are expected for the future construction worker in AOC No. 1.

Hypothetical Onsite Resident: Future land use at RFETS will not include residential development (DOE 1995b; EPA 1995a; CDPHE-1995). Nevertheless, an onsite residential exposure was evaluated in the HHRA as a hypothetical scenario to provide an upperbound estimate of risk that may support risk management decisions for low-hazard areas within OU-2. Because residential development is not a reasonable future land-use scenario in OU-2, actual risks to current and possible future receptors in OU-2 will be lower than those estimated for this scenario. Exposure pathways evaluated were:

- Inhalation of airborne particulates
- Surface soil ingestion and dermal contact
- Surface water and sediment ingestion and dermal contact (Walnut and Woman creeks)
- Groundwater ingestion
- Inhalation of VOCs indoors
- Ingestion of homegrown produce (surface deposition of particulates and root uptake)
- External irradiation from surface soil

The cumulative HIs for noncarcinogenic health effects for the onsite residential exposure in AOC No. 1 are 2E+01 and 1.4E+02 for the average and RME conditions, respectively (Table H8-1). Ingestion of groundwater is the only pathway that contributes significantly to the total HI. The cumulative HIs exceed 1, indicating possible cause for concern for potential noncancer effects from ingestion of groundwater in AOC No. 1. HIs for other exposure pathways are negligible. Carbon tetrachloride, with an HQ for ingestion in groundwater of 1.4E+02, contributes the largest fraction (97 percent) of the total HI, while tetrachloroethene has an HQ of 3E+00 (see detail in Attachment H3). RME HQs for other COCs in groundwater were 3E-01 or less, indicating that no adverse noncancer health effects are expected from hypothetical long-term residential exposure to chemicals other than carbon tetrachloride and tetrachloroethene in groundwater in AOC No. 1.

H8.3.2 Carcinogenic Risk

Excess lifetime cancer risk estimates for onsite receptors in AOC No. 1 are summarized in Table H8-1 and detailed in Attachment H3. Results for each receptor and the chief contributors to risk are discussed below.

Current Worker: Exposure pathways evaluated for the current worker were the same as described in Section H8.3.1.

The estimated excess lifetime cancer risk for the current worker in AOC No. 1 is 7E-07 (7 in 10 million) under the average exposure condition and 1E-05 (1 in 100,000) under the RME condition (Table H8-1). These levels are less than or within the EPA target cancer risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) for exposure to chemicals released from hazardous waste sites (EPA 1989a). Exposure to Pu-239/240 in surface soil by the ingestion and inhalation pathways accounted for 90 percent of the estimated RME excess lifetime cancer risk for this receptor. (See detail in Attachment H3.)

Future Industrial/Office Worker: Exposure pathways evaluated for the future industrial/office worker were the same as for the current worker (Section H8.3.1), with the addition of inhalation of VOCs migrating from subsurface soil or groundwater to indoor air. The estimated excess lifetime cancer risk for the future industrial/office worker in AOC No. 1 is 3E-06 (3 in 1 million) under the average exposure condition and 8E-05 (8 in 100,000) under

the RME condition (Table H8-1). These levels are within the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) for exposure to chemicals released from hazardous waste sites (EPA 1989a). Exposure to Pu-239/240 in surface soil by the ingestion and inhalation pathways accounted for 92% of the estimated RME excess lifetime cancer risk for this receptor. (See detail in Attachment H3.)

Future Ecological Worker: Exposure pathways evaluated for the ecological worker were described in Section H8.3.1. The estimated excess lifetime cancer risk for the future ecological worker in AOC No. 1 is 1E-06 (1 in 1 million) under the average exposure condition and 4E-06 (4 in 1 million) under the RME condition (Table H8-1). These levels are near the EPA "point of departure" of 1E-06 (1 in 1 million) for evaluating risk associated with exposure to chemicals released from hazardous waste sites (EPA 1989a) and indicate negligible risk for this receptor.

Future Open Space Use: Exposure pathways for future open space use were described in Section H8.3.1. The estimated excess lifetime cancer risk for future open space use in AOC No. 1 is 2E-07 (2 in 10 million) under the average exposure condition and 1E-05 (1 in 100,000) under the RME condition (Table H8-1). These levels are below or within the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) for exposure to chemicals released from hazardous waste sites (EPA 1989a).

Future Construction Worker: Exposure pathways for the future construction worker were described in Section H8.3.1. The cumulative excess lifetime cancer risk is 2E-07 (1 in 10 million) under the average exposure condition and 3E-07 (3 in 10 million) under the RME condition. These levels are below the EPA "point of departure" of 1E-06 (1 in 1 million) for evaluating risk associated with exposure to chemicals released from hazardous waste sites (EPA 1989a) and indicate negligible risk for this receptor.

Hypothetical Onsite Resident: As discussed in Section H8.3.1, future land use at RFETS will not include residential development. Because residential development is not a reasonable future land-use scenario in OU-2, actual risks to current and possible future receptors in OU-2 will be lower than those estimated for this scenario. However, the estimates do provide insight into potential sources of health risk in OU-2. The exposure pathways evaluated for the onsite resident are listed in Section H8.3.1. The estimated excess lifetime cancer risk

assuming residential use is 4E-04 (4 in 10,000) under the average exposure condition and 8E-03 (8 in 1,000) under the RME condition. These levels exceed the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) for exposure to chemicals released from hazardous waste sites (EPA 1989a).

Most of the health hazards/risks derive from assumed exposure to groundwater. For example, the average and RME cancer risk estimates for the groundwater pathways (ingestion and inhalation of VOCs) were 4E-04 and 7E-03, respectively. The average and RME cancer risk estimates for surface soil pathways (ingestion and inhalation of PM_{10}) were 3E-05 and 3E-04, respectively. Note that risk from soil exposure pathways under the average scenario are within EPA's target risk range. Other exposure routes posed relatively little or negligible risk.

Chief contributors to risk from groundwater exposure are carbon tetrachloride and tetrachloroethene. The chief contributor to risk from exposure to surface soil (ingestion and inhalation routes) is Pu-239/240. Chemical-specific risks for all pathways are detailed in Attachment H3.

H8.4 MAXIMUM EXPOSURE AREAS IN AOC No. 1

As discussed in Section H4.4, hazards/risks were also estimated for three maximum exposure areas in AOC No. 1. These areas are as follows:

- A 10-acre hypothetical residential neighborhood at the area of maximum soil and groundwater contamination in OU-2
- A 30-acre industrial/office park incorporating the maximum contaminated area in OU-2
- A 50-acre ecological study area incorporating the maximum contaminated area in OU-2.

Hazard/risk results for each receptor/exposure area are summarized in Table H8-2 and are discussed below. Detailed chemical- and pathway-specific results are presented in Attachment H3.

H8.4.1 Hypothetical Onsite Resident (10-acres)

Cumulative HIs and cancer risks were estimated for hypothetical onsite residential exposure in a 10-acre maximum exposure area, approximately equivalent to the 903 Pad Area. Pathways evaluated were listed for the onsite resident in AOC No. 1 (Section H8.3.1). Because future use will not include residential development, actual risks in this area will be lower than those estimated for this scenario.

Noncarcinogenic Hazard Index: The cumulative hazard indexes for noncarcinogenic health effects for future onsite residents are 2E+01 and 1.6E+02 for the average and RME conditions, respectively (Table H8-2). The HIs exceed 1, indicating possible cause for concern for noncancer effects from ingestion of groundwater from the 10-acre maximum exposure area. Ingestion of groundwater is the only pathway that contributes significantly to the total HIs. HIs for other exposure routes were negligible for the average exposure and RME conditions. Ingestion of carbon tetrachloride, chloroform, and tetrachloroethene account for most of the total average and RME HIs. (See detail in Attachment H3.)

Carcinogenic Risk: The estimated excess lifetime cancer risk is 1E-03 (1 in 1,000) under the average exposure conditions and 1.5E-02 (1.5 in 100) under RME conditions. These levels exceed the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) for exposure to chemicals released from hazardous waste sites (EPA 1989a). Ingestion of groundwater, inhalation of indoor VOCs from domestic use of groundwater, and ingestion of surface soil are the pathways that contribute significantly to overall risk (Table H8-2). RME cancer risks from other exposure pathways are 3E-05 or less.

As in AOC No. 1, the average estimated cancer risk of 1E-05 for surface soil exposure routes is within EPA's target risk range. The RME cancer risk of 2E-04 for surface soil exposure routes exceeds EPA's target risk range.

Chief contributors to hazard/risk estimates for groundwater exposure are carbon tetrachloride, chloroform, trichloroethene, tetrachloroethene, and 1,1-dichloroethene. The chief contributor to cancer risk estimates for soil exposures is plutonium. Chemical-specific risks from all pathways are detailed in Attachment H3.

H8.4.2 Future Industrial/Office Worker (30-acres)

Noncarcinogenic Hazard Index: The exposure pathways evaluated for the future onsite worker were surface soil ingestion and dermal contact, inhalation of PM_{10}, and inhalation of indoor VOCs. The cumulative HIs for this receptor in the 30-acre maximum exposure area are 1E-02 for the average exposure condition and 8E-02 for the RME condition (Table H8-2). These values are below 1, indicating that no adverse noncancer health effects are expected for the future onsite industrial/office worker in this exposure area.

Carcinogenic Risk: The estimated excess lifetime cancer risk is 5E-06 (5 in 1 million) for the average exposure condition and 2E-04 (2 in 10,000) under the RME condition (Table H8-2). The RME cancer risk level exceeds the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) for exposure to chemicals released from hazardous waste sites (EPA 1989a), whereas the average risk estimate is within EPA's risk range. RME cancer risks estimates for this receptor are likely to significantly overestimate actual risk because overly conservative assumptions resulted in overestimation of intake values for ingestion and inhalation of soil. Exposure to Pu-239/240 in surface soil by the ingestion and inhalation pathways accounted for most of the estimated excess lifetime cancer risk for this receptor. The exposure point concentration of Pu-239/240 of 1.8E+06 pCi/kg is driven by one high sample result (7.3E+06 pCi/kg) in the 30-acre maximum exposure area. The next highest concentration was 9.5E+05 pCi/kg. The single high value the estimates of exposure concentration and risk for the entire 30-acre area.

H8.4.3 Future Onsite Ecological Worker (50-acres)

Noncarcinogenic Hazard Index: Exposure pathways for the ecological worker are listed in Section H8.3.2. The cumulative HIs for this receptor in the 50-acre maximum exposure area are 8E-03 for the average exposure condition and 4E-02 for the RME condition (Table H8-2). These values are well below 1, indicating that no adverse noncancer health effects are expected for the future onsite ecological worker.

Carcinogenic Risk: The estimated excess lifetime cancer risk is 2E-06 (2 in 1 million) for the average exposure condition and 7E-06 (7 in 1 million) for the RME condition (Table

H8-2). These levels are within EPA's target risk range of 1E-06 to 1E-04 for exposure to chemicals released from hazardous waste sites (EPA 1989a).

H8.5 AOC NO. 2

AOC No. 2 is the East of IHSSs area, located in the buffer zone between the IHSSs and Indiana Street. No IHSSs or other waste disposal areas are present in AOC No. 2. Hazard/risk results for current and future receptors located in AOC No. 2 are summarized in Table H8-3 and detailed in Attachment H3.

H8.5.1 Noncarcinogenic Hazard Index

For all current and future onsite receptors, including the hypothetical onsite resident, the cumulative HIs for noncarcinogenic health effects in AOC No. 2 are 2E-02 or less for the average and RME conditions. Because the HIs are well below 1, no adverse noncancer health effects are expected even for sensitive individuals exposed under RME conditions. Results for each receptor are summarized below.

Hazard Index for Receptors in AOC No. 2

Receptor	CT	RME
Current Worker	2.9E-07	1.9E-06
Future Industrial/Office Worker	9.0E-07	1.0E-05
Future Ecological Worker	1.6E-04	3.0E-04
Future Open Space Use	3.1E-05	3.8E-04
Future Construction Worker	3.2E-03	1.8E-02
Hypothetical Onsite Resident	9.6E-04	6.0E-03

H8.5.2 Carcinogenic Risk

Current and Future Nonresidential Onsite Receptors: For current and future nonresidential onsite receptors, the estimated excess lifetime cancer risks in AOC No. 2 are 1E-06 (1 in 1 million) or less (Table H8-3). These levels are at or below the EPA "point of departure" of

1E-06 (1 in 1 million) for evaluating risk from exposure to chemicals released from hazardous waste sites (EPA 1989a), and indicate that cancer risks are negligible for each of these receptors.

Future Onsite Resident: Although onsite residential use will not occur in OU-2, excess lifetime cancer risks were estimated for onsite residential exposure in AOC No. 2 to provide an upperbound estimate of risk that may support risk management decisions in this relatively low-hazard area.

The estimated excess lifetime cancer risk for the hypothetical future onsite receptor in AOC No. 2 is 8E-07 (8 in 10 million) under the average exposure condition and 1E-05 (1 in 100,000) under RME conditions (Table H8-3). These levels are within or below the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) for exposure to chemicals released from hazardous waste sites (EPA 1989a). Ingestion and inhalation of Pu-239/240 in surface soil and ingestion of Pu-239/240 in groundwater accounted for most of the estimated excess lifetime cancer risk for this receptor. (See detail in Attachment H3.) Cancer risk results for each receptor are listed below.

Cancer Risk Estimates for Receptors in AOC No. 2

Receptor	CT	RME
Current Worker	9.9E-09	2.0E-07
Future Industrial/Office Worker	3.9E-08	1.2E-06
Future Ecological Worker	2.4E-08	6.7E-08
Future Open Space Use	5.8E-09	2.6E-07
Future Construction Worker	2.8E-08	1.4E-07
Hypothetical Onsite Resident	7.6E-07	1.3E-05

H8.6 OFFSITE RESIDENTS

Current and future offsite residential receptors were evaluated for exposure to chemicals transported in air from AOC No. 1 and from AOC No. 2. Current offsite receptors selected for evaluation are the closest residence to RFETS (Current Resident, Indiana South) and the

closest residence to RFETS in the prevailing southeast wind direction (Current Resident, Southeast), each located east of Indiana Street near RFETS southeast corner. Exposure pathways evaluated for current offsite residents were inhalation of airborne particulates from AOC No. 1 and AOC No. 2 and ingestion of particulate matter deposited on surface soil and homegrown produce. Future offsite receptors were evaluated at two hypothetical residences, located on Indiana Street adjacent to Walnut Creek (Future Resident, Walnut Creek/Indiana) or Woman Creek (Future Resident, Woman Creek/Indiana). Exposure pathways for future offsite receptors include those for current offsite receptors, plus oral and dermal exposure to surface water/sediments in Woman Creek or Walnut Creek. Hazard/risk results for current and future offsite receptors are summarized in Table H8-4 and detailed in Attachment H3.

H8.6.1 Noncarcinogenic Hazard Index

For all current and future offsite receptor locations, the total HIs for noncarcinogenic health effects from offsite impacts from chemicals released to air or surface water from either AOC No. 1 or AOC No. 2 are 6E-04 or less for the average and RME conditions (Table H8-4). When the total HIs for impacts from AOC No. 1 and AOC No.2 are summed, the HIs for offsite receptors are 1E-03 or less for the average and RME conditions. Because these hazard indexes are well below 1, no adverse noncancer health effects are expected even for sensitive individuals exposed under RME conditions.

H8.6.2 Carcinogenic Risk

For all current and future offsite receptor locations, the estimated excess lifetime cancer risks are 2E-07 (2 in 10 million) or less (Table H8-4). When cancer risk from impacts from AOC No. 1 and AOC No.2 are summed, the estimated cancer risks for offsite receptors are 4E-07 (4 in 10 million) or less for the average and RME conditions. These levels are below the EPA "point of departure" of 1E-06 (1 in 1 million) for evaluation of risk from exposure to chemicals released from hazardous waste sites (EPA 1989a), and indicate negligible cancer risk from offsite exposure to suspended or deposited particulate matter or to surface water/suspended sediments.

H8.7 EVALUATION OF HEALTH HAZARDS FROM EXPOSURE TO LEAD

Lead was detected in greater than 5 percent of surface soil, subsurface soil, and groundwater samples in OU-2. EPA-established toxicity factors for lead were not available at this writing, and hazard indexes and cancer risk cannot be estimated for lead. In this section, the potential for health hazards from exposure to lead in soil and groundwater are discussed.

H8.7.1 Surface Soil

Concentration distributions of lead in surface soil in OU-2 were not significantly different than background distributions according to statistical background comparisons (DOE 1994a, Appendix A). However, three sample results from surface soil exceeded the background $UTL_{99/99}$ of 61.4 mg/kg. EPA's Revised Interim Soil Lead Guidance recommends a screening level of 400 ppm (400 mg/kg) for residential scenarios (EPA 1994d). The maximum detected concentration of lead in surface soil in OU-2 (145 mg/kg) was less than EPA's screening level for residential soil indicating that lead in surface soil would not be expected to pose a health risk.

H8.7.2 Subsurface Soil

Concentration distributions of lead in subsurface soil in OU-2 were not significantly different than background distributions according to statistical background comparison (DOE 1994a, Appendix A). However, three sample results from subsurface soil exceeded the background $UTL_{99/99}$ of 31 mg/kg. The maximum detected concentration of lead in subsurface soil in OU-2 (86.4 mg/kg) was less than EPA's screening level of 400 mg/kg for residential soil (EPA 1994d) indicating that lead in subsurface soil would not be expected to pose a health threat.

H8.7.3 Groundwater

Lead concentration distributions in OU-2 were statistically significantly different from background distributions in unfiltered groundwater samples but not in filtered groundwater samples (DOE 1994a, Appendix A). The maximum concentration of lead in filtered

groundwater (13.8 µg/L) did not exceed the federal standard for tap water (15 µg/L). A summary of lead concentrations in OU-2 and background samples is shown below:

Concentrations of Lead in Groundwater, µg/L

Sample Type	Background Mean	Site Mean	Background Maximum	Site Maximum	$UTL_{99/99}$	No. > $UTL_{99/99}$
Unfiltered	3.8	29	52.5	675	19.3	97
Filtered	2.4	1.5	64	13.8	15.8	0

Total suspended solids (TSS) in OU-2 groundwater samples were much higher than in background samples. As a result, unfiltered groundwater samples collected in OU-2 had elevated levels of numerous metals, including lead, that are associated with TSS. Based on comparing concentrations of lead in unfiltered and filtered samples, lead in groundwater in OU-2 is not considered to be a site contaminant but rather the result of high TSS in the samples.

H8.8 SUMMARY OF CUMULATIVE HAZARD/RISK RESULTS

Hazard/risk characterization was performed for six onsite receptors in two AOCs in RFETS OU-2. In addition, residential, industrial, and ecological researcher scenarios were evaluated in 10-, 30-, and 50-acre maximum exposure areas, respectively. Four offsite receptor locations were also evaluated. Results are summarized in Tables H8-1 through H8-5 and detailed in Attachment H3.

AOC No. 1 and Maximum Exposure Areas: Cumulative HIs were less than 1 and cancer risk estimates were below 2E-04 for all nonresidential receptors.

HIs for the onsite residential scenario ranged from 2E+01 (CT, AOC No. 1) to 1.6E+02 (RME, 10-acre area) and cancer risk estimates ranged from 4E-04 (CT, AOC No. 1) to 2E-02 (RME, 10-acre area), chiefly due to VOCs in groundwater. These results for the residential scenario indicate that hazard/risks from domestic use of groundwater in AOC No. 1 and the 10-acre maximum exposure area would be expected to exceed levels of concern. However,

total HIs associated with other exposure pathways were less than 1, and cancer risk estimates ranged from 1.5E-05 (CT, 10-acre area) to 4E-04 (RME, AOC No. 1) for other exposure pathways. Residential use of groundwater will not occur in OU-2 because future land use at RFETS will not include residential development (DOE 1995b; EPA 1995a; CDPHE 1995). Drinking water for current onsite workers is provided by a municipal water supply, and it is expected that drinking water for future onsite receptors will also be provided from a public water supply. Therefore, since direct ingestion of groundwater is an incomplete pathway for all current and possible future receptors in OU-2, chemicals in groundwater do not pose a risk to human health.

The next highest hazard/risk estimates were associated with future industrial/office worker exposures in AOC No. 1 and in the 30-acre maximum exposure area. This receptor is the reasonable maximum exposed individual under credible future use scenarios. Hazard/risk results for this receptor are summarized below.

Hazard/Risk Summary for Future Onsite Industrial/Office Worker

	Hazard Index		Cancer Risk		Risk Driver
	CT	RME	CT	RME	
AOC No. 1	6E-03	4E-02	3E-06	8E-05	Pu-239/240 in surface soil
30-Acres	1E-02	8E-02	5E-06	2E-04	Pu-239/240 in surface soil

The low HIs for the future industrial/office worker in OU-2 indicate that no noncancer health effects are expected from inhalation of airborne particulates, ingestion of surface soil, or dermal contact with surface soil. Groundwater exposures were not evaluated for nonresidential receptors because it is expected that public supplies will continue to be provided to industrial and commercial future users.

However, excess lifetime cancer risk for future industrial/office workers under RME condition in the 30-acre maximum exposure area exceeds the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000). RME cancer risk estimates for this receptor are likely to significantly overestimate actual risk because overly conservative assumptions results in overestimation of intake values for ingestion and inhalation of soil.

Exposure to plutonium in surface soil via the ingestion and inhalation pathways accounts for 94 percent of the estimated RME excess lifetime cancer risk for this receptor. As discussed in Section H8.4.2, one relatively high concentration value for Pu-239/240 in surface soil drives estimates of Pu-239/240 exposure point concentrations for the entire 30 acres, which also drives estimates of cancer risk for future industrial/office workers. Other samples in the data set had significantly lower concentrations.

The average exposure and RME cancer risks for the future industrial/office worker in AOC No. 1 are each less than 1E-04.

Hazard/risk results for other receptors evaluated in AOC No. 1 (current worker, future ecological worker, future open space use, and future construction worker) did not exceed generally accepted levels of risk.

Area of Concern No. 2: Hazard/risk results are summarized in Table H8-3 and detailed in Attachment H3. A hypothetical onsite residential receptor was evaluated in AOC No. 2 to provide an upperbound estimate of risk to support risk management decisions in low hazard areas. Hazard/risk estimates for this "worst case scenario" did not exceed generally accepted levels of risk: the RME HI was 6E-03, well below 1, and the RME cancer risk was 1E-05, well within EPA's target risk range of 1E-06 to 1E-04. Hazard/risk estimates for other receptors evaluated in AOC No. 2 were well below levels of potential concern.

Offsite Receptors: Hazard/risk results are summarized in Table H8-4 and detailed in Attachment H3. Total HIs and lifetime cumulative excess cancer risk for offsite receptors were very low (HI of 6E-04 or less, cancer risk of 2E-07 or less), indicating that no adverse noncancer health effects are expected and cancer risk is negligible for these receptors. These results reflect insignificant impacts from airborne particulate matter from OU-2 sources and negligible risk associated with modeled concentrations of OU-2 COCs in surface water/sediment in Walnut Creek and Woman Creek.

TABLE H8-1
SUMMARY OF ESTIMATED HEALTH RISKS FOR AOC No. 1

Receptor/Exposure Pathway	Average Exposure		Reasonable Maximum Exposure	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
Current Industrial Worker				
-Ingestion of Surface Soil	2.6E-07	1.8E-04	1.0E-05	1.1E-03
-Inhalation of Particulates	3.9E-07		3.1E-06	
-Dermal Contact with Surface Soil	1.3E-08	1.4E-03	5.0E-07	9.0E-03
-External Irradiation from Surface Soil	9.8E-09		1.1E-07	
Total	6.8E-07	1.6E-03	1.4E-05	1.0E-02
Future Industrial/Office Worker				
-Ingestion of Surface Soil	7.7E-07	5.1E-04	6.1E-05	6.5E-03
-Inhalation of Particulates	1.8E-06		1.8E-05	
-Dermal Contact with Surface Soil	4.6E-08	5.2E-03	1.8E-06	3.3E-02
-Inhalation of VOCs from Infiltration of Soil Gas	1.6E-08	3.9E-12	1.7E-07	6.5E-12
-External Irradiation from Surface Soil	5.8E-08		6.5E-07	
Total	2.6E-06	5.7E-03	8.2E-05	3.9E-02
Future Ecological Worker				
-Ingestion of Surface Soil	9.4E-07	1.0E-03	3.4E-06	3.6E-03
-Inhalation of Particulates	4.3E-07		8.1E-07	
-Dermal Contact with Surface Soil	1.9E-08	3.4E-03	1.1E-07	1.9E-02
-Ingestion of Surface Water/Sediment	1.2E-10	3.3E-06	1.0E-09	2.8E-05
-Dermal Contact with Surface Water/Sediment	3.5E-09	1.6E-04	6.0E-09	2.7E-04
-External Irradiation from Surface Soil	1.7E-08		2.1E-08	
Total	1.4E-06	4.6E-03	4.3E-06	2.3E-02
Open Space Use				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	1.7E-07		8.8E-06	
-Ingestion of Surface Soil Child (Noncarcinogenic)		3.7E-04		6.1E-03
-Ingestion of Surface Soil Adult (Noncarcinogenic)		4.2E-05		6.5E-04
-Inhalation of Particulates	5.0E-08		2.3E-06	
-Dermal Contact with Surface Soil	7.4E-10	3.8E-05	2.7E-07	4.1E-03
-Ingestion of Surface Water/Sediment	3.9E-10	2.9E-06	1.6E-08	3.5E-05
-Dermal Contact with Surface Water/Sediment	2.2E-09	2.7E-05	8.9E-08	3.3E-04
-External Irradiation from Surface Soil	3.2E-09		6.5E-08	
Total	2.3E-07	4.7E-04	1.2E-05	1.1E-02
Future Construction Worker				
-Ingestion of Subsurface Soil	2.5E-08	3.1E-03	1.4E-07	1.7E-02
-Inhalation of Particulates	1.2E-07	1.2E-10	1.5E-07	1.5E-10
-Dermal Contact with Subsurface Soil	5.6E-09	7.5E-04	3.1E-08	4.2E-03
-External Irradiation from Subsurface Soil	1.2E-09		1.6E-09	
Total	1.5E-07	3.8E-03	3.2E-07	2.2E-02

TABLE H8-1
SUMMARY OF ESTIMATED HEALTH RISKS FOR AOC No. 1

Receptor/Exposure Pathway	Average Exposure		Reasonable Maximum Exposure	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
Hypothetical Resident				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	1.8E-05		2.5E-04	
-Ingestion of Surface Soil Child (Noncarcinogenic)		4.7E-02		1.7E-01
-Ingestion of Surface Soil Adult (Noncarcinogenic)		3.9E-03		1.8E-02
-Inhalation of Particulates	8.8E-06		9.3E-05	
-Dermal Contact with Surface Soils	7.4E-08	3.7E-03	7.7E-06	1.2E-01
-Ingestion of Groundwater	2.6E-04	2.0E+01	6.2E-03	1.4E+02
-Inhalation of VOCs from Infiltration of Soil Gas	8.1E-08	8.6E-12	6.4E-07	2.1E-11
-Inhalation of VOCs from Groundwater Use	1.5E-04	8.5E-05	1.2E-03	2.0E-04
-Ingestion of Garden Produce (Root Uptake)	1.1E-06	1.6E-02	1.3E-05	5.5E-02
-Ingestion of Garden Produce (Deposition)	1.4E-07	4.0E-05	3.3E-06	2.9E-04
-Ingestion of Surface Water/Sediment	3.1E-10	2.3E-06	1.9E-08	4.2E-05
-Dermal Contact with Surface Water/Sediment	8.9E-09	1.1E-04	2.1E-07	7.9E-04
-External Irradiation from Surface Soil	3.5E-07		3.7E-06	
Total	4.4E-04	2.0E+01	7.7E-03	1.4E+02

Notes:

Chemical- and pathway specific results are detailed in Attachment H3.

TABLE H8-2
SUMMARY OF ESTIMATED HEALTH RISKS FOR MAXIMUM EXPOSURE AREAS

Receptor/Exposure Pathway	Average Exposure		Reasonable Maximum Exposure	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
Hypothetical Resident (10 Acres)				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	1.0E-05		1.4E-04	
-Ingestion of Surface Soil Child (Noncarcinogenic)		1.5E-04		5.4E-04
-Ingestion of Surface Soil Adult (Noncarcinogenic)		1.2E-05		5.8E-05
-Inhalation of Particulates	3.5E-06		3.7E-05	
-Dermal Contact with Surface Soils	2.2E-11	6.0E-07	2.2E-09	1.9E-05
-Ingestion of Groundwater	4.3E-04	2.3E+01	1.0E-02	1.6E+02
-Inhalation of VOCs from Infiltration of Soil Gas	1.3E-10	1.2E-09	1.1E-09	2.8E-09
-Inhalation of VOCs from Groundwater Use	5.7E-04	2.1E-02	4.5E-03	5.0E-02
-Ingestion of Garden Produce (Root Uptake)	9.2E-07	6.8E-04	1.0E-05	2.4E-03
-Ingestion of Garden Produce (Deposition)	5.5E-08	8.9E-08	1.3E-06	6.4E-07
-Ingestion of Surface Water/Sediment	3.1E-10	2.3E-06	1.9E-08	4.2E-05
-Dermal Contact with Surface Water/Sediment	8.9E-09	1.1E-04	2.1E-07	7.9E-04
-External Irradiation from Surface Soil	9.5E-07		1.0E-05	
Total	1.1E-03	2.3E+01	1.5E-02	1.6E+02
Future Industrial/Office Worker (30 Acres)				
-Ingestion of Surface Soil	1.7E-06	1.0E-03	1.4E-04	1.3E-02
-Inhalation of Particulates	3.4E-06		3.5E-05	
-Dermal Contact with Surface Soil	9.0E-08	1.0E-02	3.6E-06	6.5E-02
-Inhalation of VOCs from Infiltration of Soil Gas	5.7E-11	1.1E-09	5.9E-10	1.8E-09
-External Irradiation from Surface Soil	1.4E-07		1.5E-06	
Total	5.3E-06	1.1E-02	1.8E-04	7.8E-02
Future Ecological Worker (50 Acres)				
-Ingestion of Surface Soil	1.5E-06	1.7E-03	5.2E-06	6.1E-03
-Inhalation of Particulates	6.0E-07		1.1E-06	
-Dermal Contact with Surface Soil	3.2E-08	5.8E-03	1.8E-07	3.2E-02
-Ingestion of Surface Water/Sediment	1.2E-10	3.3E-06	1.0E-09	2.8E-05
-Dermal Contact with Surface Water/Sediment	3.4E-09	1.4E-04	5.9E-09	2.6E-04
-External Irradiation from Surface Soil	3.4E-08		4.2E-08	
Total	2.1E-06	7.6E-03	6.5E-06	3.9E-02

Notes:

Chemical- and pathway specific results are detailed in Attachment H3.

TABLE H8-3
SUMMARY OF ESTIMATED HEALTH RISKS FOR AOC NO. 2

Receptor/Exposure Pathway	Average Exposure		Reasonable Maximum Exposure	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
Current Industrial Worker				
-Ingestion of Surface Soil	3.7E-09	2.4E-07	1.5E-07	1.6E-06
-Inhalation of Particulates	5.8E-09		4.6E-08	
-Dermal Contact with Surface Soil	7.9E-13	4.9E-08	3.1E-11	3.1E-07
-External Irradiation from Surface Soil	4.6E-10		5.2E-09	
Total	9.9E-09	2.9E-07	2.0E-07	1.9E-06
Future Industrial/Office Worker				
-Ingestion of Surface Soil	1.1E-08	7.2E-07	8.5E-07	9.1E-06
-Inhalation of Particulates	2.6E-08		2.7E-07	
-Dermal Contact with Surface Soil	2.9E-12	1.8E-07	1.1E-10	1.1E-06
-Inhalation of Basement Vapors	1.1E-14	8.5E-12	1.1E-13	1.4E-11
-External Irradiation from Surface Soil	2.7E-09		3.1E-08	
Total	3.9E-08	9.0E-07	1.2E-06	1.0E-05
Future Ecological Worker				
-Ingestion of Surface Soil	1.3E-08	1.4E-06	4.7E-08	5.0E-06
-Inhalation of Particulates	6.3E-09		1.2E-08	
-Dermal Contact with Surface Soil	1.2E-12	1.2E-07	6.6E-12	6.6E-07
-Ingestion of Surface Water/Sediment	1.2E-10	3.3E-06	1.0E-09	2.8E-05
-Dermal Contact with Surface Water/Sediment	3.5E-09	1.6E-04	6.0E-09	2.7E-04
-External Irradiation from Surface Soil	8.2E-10		1.0E-09	
Total	2.4E-08	1.6E-04	6.7E-08	3.0E-04
Open Space Use				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	2.3E-09		1.2E-07	
-Ingestion of Surface Soil Child (Noncarcinogenic)		5.1E-07		8.5E-06
-Ingestion of Surface Soil Adult (Noncarcinogenic)		5.8E-08		9.1E-07
-Dermal Contact with Surface Soil	4.7E-14	1.3E-09	1.7E-11	1.4E-07
-Inhalation of Particulates	7.3E-10		3.4E-08	
-Ingestion of Surface Water/Sediment	3.9E-10	2.9E-06	1.6E-08	3.5E-05
-Dermal Contact with Surface Water/Sediment	2.2E-09	2.7E-05	8.9E-08	3.3E-04
-External Irradiation from Surface Soil	1.5E-10		3.0E-09	
Total	5.8E-09	3.1E-05	2.6E-07	3.8E-04
Future Construction Worker				
-Ingestion of Subsurface Soil	2.5E-08	3.2E-03	1.4E-07	1.8E-02
-Inhalation of Particulates	1.8E-09		2.2E-09	
-External Irradiation from Subsurface Soil	1.5E-09		1.9E-09	
Total	2.8E-08	3.2E-03	1.4E-07	1.8E-02

TABLE H8-3
SUMMARY OF ESTIMATED HEALTH RISKS FOR AOC NO. 2

Receptor/Exposure Pathway	Average Exposure		Reasonable Maximum Exposure	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
Hypothetical Resident				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	2.5E-07		3.4E-06	
-Ingestion of Surface Soil Child (Noncarcinogenic)		6.5E-05		2.4E-04
-Ingestion of Surface Soil Adult (Noncarcinogenic)		5.5E-06		2.6E-05
-Inhalation of Particulates	1.3E-07		1.4E-06	
-Dermal Contact with Surface Soils	4.6E-12	1.3E-07	4.8E-10	4.0E-06
-Ingestion of Groundwater	3.1E-07	6.0E-04	7.4E-06	4.3E-03
-Inhalation of VOCs from Infiltration of Soil Gas	5.6E-14	1.9E-11	4.5E-13	4.5E-11
-Inhalation of VOCs from Groundwater Use	3.1E-08	2.0E-05	2.5E-07	4.9E-05
-Ingestion of Garden Produce (Root Uptake)	2.0E-08	1.5E-04	2.0E-07	5.4E-04
-Ingestion of Garden Produce (Deposition)	2.0E-09	6.0E-08	4.9E-08	4.3E-07
-Ingestion of Surface Water/Sediment	3.1E-10	2.3E-06	1.9E-08	4.2E-05
-Dermal Contact with Surface Water/Sediment	8.9E-09	1.1E-04	2.1E-07	7.9E-04
-External Irradiation from Surface Soil	1.6E-08		1.7E-07	
Total	7.6E-07	9.6E-04	1.3E-05	6.0E-03

Notes:

Chemical- and pathway specific results are detailed in Attachment H3.

TABLE H8-4
SUMMARY OF ESTIMATED HEALTH RISKS FOR OFFSITE RESIDENTS

Receptor/Exposure Pathway	Average Exposure Carcinogenic Risk	Average Exposure Hazard Index	Reasonable Maximum Exposure Carcinogenic Risk	Reasonable Maximum Exposure Hazard Index
AOC No. 1, Current Resident, Southeast				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	0 [1]		0	
-Ingestion of Surface Soil Child (Noncarcinogenic)		0		0
-Ingestion of Surface Soil Adult (Noncarcinogenic)		0		0
-Inhalation of Particulates	1.4E-09	0	1.5E-08	0
-Dermal Contact with Surface Soil	0	0	0	0
-Ingestion of Garden Produce (Deposition)	0	0	0	0
Total	1.4E-09	0	1.5E-08	0
AOC No. 1, Current Resident, Indiana South				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	0		0	
-Ingestion of Surface Soil Child (Noncarcinogenic)		0		0
-Ingestion of Surface Soil Adult (Noncarcinogenic)		0		0
-Inhalation of Particulates	0	0	0	0
-Dermal Contact with Surface Soils	0	0	0	0
-Ingestion of Garden Produce (Deposition)	0	0	0	0
Total	0	0	0	0
AOC No. 1, Future Resident, Walnut				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	0		0	
-Ingestion of Surface Soil Child (Noncarcinogenic)		0		0
-Ingestion of Surface Soil Adult (Noncarcinogenic)		0		0
-Inhalation of Particulates	0	0	0	0
-Dermal Contact with Surface Soil	0	0	0	0
-Ingestion of Garden Produce (Deposition)	0	0	0	0
-Ingestion of Surface Water/Sediment	4.8E-11	1.5E-06	2.9E-9	2.8E-05
-Dermal Contact with Surface Water/Sediment	7.7E-09	8.4E-05	1.8E-07	5.9E-04
Total	7.7E-09	8.5E-05	1.8E-07	6.2E-04
AOC No. 1, Future Resident, Woman				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	0		0	
-Ingestion of Surface Soil Child (Noncarcinogenic)		0		0
-Ingestion of Surface Soil Adult (Noncarcinogenic)		0		0
-Inhalation of Particulates	8.3E-10	0	8.7E-09	0
-Dermal Contact with Surface Soil	0	0	0	0
-Ingestion of Garden Produce (Deposition)	0	0	0	0
-Ingestion of Surface Water/Sediment	2.7E-10	8.0E-07	1.6E-08	1.5E-05
-Dermal Contact with Surface Water/Sediment	1.3E-09	2.8E-05	3.1E-08	2.0E-04
Total	2.4E-09	2.9E-05	5.5E-08	2.1E-04

[1] Hazard/risk estimates reported as 0 indicate that no air or depositional impacts were predicted by air modeling (see Section H5.5.2).

TABLE H8-4
SUMMARY OF ESTIMATED HEALTH RISKS FOR OFFSITE RESIDENTS

Receptor/Exposure Pathway	Average Exposure Carcinogenic Risk	Average Exposure Hazard Index	Reasonable Maximum Exposure Carcinogenic Risk	Reasonable Maximum Exposure Hazard Index
AOC No. 2, Current Resident, Southeast				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	1.2E-13		1.7E-12	
-Ingestion of Surface Soil Child (Noncarcinogenic)		3.3E-11		1.2E-10
-Ingestion of Surface Soil Adult (Noncarcinogenic)		2.8E-12		1.3E-11
-Inhalation of Particulates	5.7E-11	0	6.0E-10	0
-Dermal Contact with Surface Soil	2.4E-18	6.5E-14	2.4E-16	2.0E-12
-Ingestion of Garden Produce (Deposition)	2.6E-12	7.9E-11	6.3E-11	5.7E-10
Total	6.0E-11	1.1E-10	6.7E-10	7.0E-10
AOC No. 2, Current Resident, Indiana South				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	0		0	
-Ingestion of Surface Soil Child (Noncarcinogenic)		0		0
-Ingestion of Surface Soil Adult (Noncarcinogenic)		0		0
-Inhalation of Particulates	8.6E-13	0	9.1E-12	0
-Dermal Contact with Surface Soils	0	0	0	0
-Ingestion of Garden Produce (Deposition)	0	0	0	0
Total	8.6E-13	0	9.1E-12	0
AOC No. 2, Future Resident, Walnut				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	0		0.0E+00	
-Ingestion of Surface Soil Child (Noncarcinogenic)		0		0
-Ingestion of Surface Soil Adult (Noncarcinogenic)		0		0
-Inhalation of Particulates	2.6E-12	0	2.7E-11	0
-Dermal Contact with Surface Soil	0	0	0	0
-Ingestion of Garden Produce (Deposition)	0	0	0	0
-Ingestion of Surface Water/Sediment	4.8E-11	1.5E-06	2.9E-09	2.8E-05
-Dermal Contact with Surface Water/Sediment	7.6E-09	8.4E-05	1.8E-07	6.0E-04
Total	7.7E-09	8.5E-05	1.8E-07	6.2E-04
AOC No. 2, Future Resident, Woman				
-Ingestion of Surface Soil Child/Adult (Carcinogenic)	1.2E-13		1.7E-12	
-Ingestion of Surface Soil Child (Noncarcinogenic)		3.3E-11		1.2E-10
-Ingestion of Surface Soil Adult (Noncarcinogenic)		2.8E-12		1.3E-11
-Inhalation of Particulates	3.2E-11	0	3.4E-10	0
-Dermal Contact with Surface Soil	2.4E-18	6.5E-14	2.4E-16	2.0E-12
-Ingestion of Garden Produce (Deposition)	2.6E-12	7.9E-11	6.3E-11	5.7E-10
-Ingestion of Surface Water/Sediment	2.7E-10	8.0E-07	1.6E-08	1.5E-05
-Dermal Contact with Surface Water/Sediment	1.3E-09	2.8E-05	3.1E-08	2.0E-04
Total	1.6E-09	2.9E-05	4.7E-08	2.1E-04

Notes:

Chemical- and pathway-specific results are detailed in Attachment H3.

In this chapter, total radiation doses for one year of exposure (expressed as total effective dose equivalents, in mrem/year) were estimated for receptors exposed to radionuclides in soil, air, groundwater, and other media by the ingestion, inhalation, and external irradiation pathways. The estimated doses are compared to DOE radiation standards for protection of public health, also expressed in mrem/year (DOE 1990e).

H9.1 METHODOLOGY

This section defines the terms used in estimating annual radiation doses, explains how the doses are calculated, and describes the national annual radiation protection standards that are used for comparison to the calculated doses.

H9.1.1 Definitions

Ionizing Radiation: Ionizing radiation is radiation having sufficient energy to cause ionization of matter (removing electrons from atoms). Ionization and excitation (raising electrons to a higher energy state) of atoms in cells and tissues from absorption of ionizing radiation can result in damage to those cells and tissues (EPA 1989a).

Absorbed Dose (in grays): Radiation dose may be expressed in terms of an internal (absorbed) dose, defined as the average energy imparted by ionizing radiation per unit mass of exposed tissue. The unit for absorbed dose is the gray (Gy), equal to 1 joule of energy delivered per kg of tissue (EPA 1989a).

Dose Equivalent (in rems or sieverts): Different types of radiation can produce more or less tissue damage at the same absorbed dose level. Thus, absorbed dose (in grays) does not provide an adequate estimate of potential for biological effects. The dose equivalent is an expression of internal dose that is normalized for different biological effects produced by different types of radiation. The dose equivalent is based on absorbed dose, type of energy released by different radionuclides, and other modifying factors. The dose equivalent

provides a better correlation between radiation dose and potential for biological effects than does the absorbed dose. Units for the dose equivalent are the rem or the Sv, equal to 100 rem (EPA 1989a).

Effective Dose Equivalent (EDE) (in rems or Sv): The EDE, equal to the weighted sums of organ-specific dose equivalents, normalizes radiation doses and effects on a whole body basis (EPA 1989a).

Committed Effective Dose Equivalent (CEDE) (in rems or Sv): Because internal doses delivered to tissues by radionuclides continue long after intake of the radionuclide has ceased, internal doses to specific tissues and organs are usually reported in terms of the committed dose equivalent, which is defined as the integral of the dose equivalent in a particular tissue for 50 years after intake. The sum of committed dose equivalents weighted for specific tissues in the body is the committed effective dose equivalent CEDE, also expressed in rems or Sv. The CEDE represents a dose to the whole body integrated over a 50-year period (EPA 1989a).

CEDE only applies to pathways resulting in an internalized dose, and therefore does not apply to the external irradiation pathway. Radiation doses from the external irradiation pathway are expressed in terms of EDEs.

Total Effective Dose Equivalent (TEDE) (in rems or Sv): The TEDEs is the sum of doses from pathways that result in an internalized dose (expressed as CEDE) and doses from pathways that result in an external dose, such as external irradiation (expressed as EDE).

Dose Coefficients: Dose coefficients, also known as dose conversion factors, are radionuclide-specific constants that are used to convert total intake of radionuclides to dose equivalents. Committed effective dose coefficients are constants used to convert total intake of radionuclides to CEDEs (EPA 1989a).

Total Annual Radiation Dose (in rems/year or Sv/year): Total annual radiation dose is equal to the TEDE for one year of exposure. Annual radiation doses for specific pathways are equal to the CEDE or EDE for that pathway for one year of exposure. These doses are calculated using site-specific estimates of annual radionuclide intake from contaminated media

and radionuclide-specific committed effective dose coefficients and effective dose coefficients (EPA 1989a). The total annual radiation dose, is the sum of CEDEs and EDEs for all pathways for one year of exposure. Total annual radiation dose can be compared to annual radiation protection standards, also expressed as the TEDE for one year of exposure (DOE 1990e). Note: DOE's annual radiation protection standards are currently termed EDEs, but they are actually TEDEs equal to the sum of CEDEs and EDEs.

H9.1.2 Calculating Annual Radiation Doses

Selection of Dose Coefficients: Radionuclide-specific committed effective dose coefficients were used in the calculation of CEDEs for the ingestion and inhalation routes of exposure. Radionuclide-specific effective dose coefficients were used to calculate EDEs for the external irradiation route of exposure. These values were obtained from EPA's "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion" (EPA 1988c) for the inhalation and ingestion route of exposure and from DOE's "External Dose-Rate Conversion Factors for Calculation of Dose to the Public" (DOE 1988b) for external irradiation.

For some radionuclides, committed effective dose coefficients vary based on the chemical species (e.g., oxidation state or mineralized form) of the radionuclide. Differences in committed effective dose coefficients for the ingestion route of exposure reflect differences in fractional uptake (f_1) of radionuclide species from the small intestine to blood (Table H9-1). Less soluble radionuclide forms have smaller committed effective dose coefficients than more soluble forms because the less soluble forms are absorbed to a lesser degree from the gastrointestinal tract into the bloodstream (EPA 1988c).

Plutonium in soil at RFETS is probably the relatively insoluble PuO_2 form. Pu in most natural environments is stable in two oxidation states, Pu III or Pu IV. In acidic environments, Pu III is the dominant species, whereas under alkaline or oxidizing conditions the dominant species is Pu IV (solid plutonium dioxide, PuO_2) (Brookins 1988). As discussed in Section 5.2.3 of the RFI/RI Report, the alkaline and oxidizing conditions in soil at OU-2 favor the Pu IV species, suggesting that solid plutonium dioxide is the primary phase of plutonium in OU-2. Pu IV has very low solubility at near-neutral and oxidizing conditions (National Research Council [NRC] 1983).

Additional studies at RFETS have demonstrated low extraction of plutonium from soil, suggesting the presence of an insoluble species (EPA 1990e). EPA states that "analyses of soil samples from Rocky Flats have shown the presence of discrete particles of plutonium (probably the oxide) attached to larger soil particles." EPA further states that, because of the stability of Pu IV relative to other forms of plutonium "most if not all plutonium in environmental ... systems is in the Pu IV state."

The committed effective dose coefficient for plutonium for the ingestion route was selected assuming that the predominant species at RFETS is the less soluble PuO_2. Therefore, plutonium isotopes were assigned a f_i of 1E-05 and the committed effective dose coefficient for plutonium was selected corresponding to this fractional uptake estimate (Table H9-1). Only one committed effective dose coefficient is available for Am-241, corresponding to f_i of 1E-03.

Committed effective dose coefficients for the inhalation route of exposure also vary based on the chemical species of the radionuclide. The different committed effective dose coefficients reflect differences in the rates that radionuclide species are cleared from the lungs, with lung clearance rates classified as days (D), weeks (W), or years (Y). In general, less soluble forms of the radionuclide are cleared from the lungs more slowly than more soluble forms. The committed effective dose coefficient for plutonium for the inhalation route of exposure was selected assuming that the predominant species of Pu is the less soluble form, associated with a lung clearance class of Y (years) (Table H9-1).

In selecting the dose coefficients for uranium in OU-2, it was assumed that uranium is present in RFETS soil as the dioxide, UO_2 (i.e., U IV), although it may be present in the more oxidized and more soluble U VI state. Assuming the isotopes are present as UO_2, an f_i of 1E-03, a lung clearance class of Y, and the corresponding committed effective dose coefficients were selected (Table H9-1). (In fact, the selection of the committed effective dose coefficients for uranium has little or no impact on the calculation of annual radiation doses in OU-2). Only one committed effective dose coefficient is available for Am-241, corresponding to a lung clearance class of W (weeks).

For the external irradiation route of exposure, a single effective dose coefficient is available for each radionuclide (Table H9-1).

Ingestion and Inhalation Routes of Exposure: For the inhalation and ingestion routes of exposure, annual intake of the radionuclide, expressed in pCi/year, is first calculated using the following equation:

$$Intake_{int} = C * IR * EF$$

where:

$Intake_{int}$	=	Annual radionuclide intake via inhalation or ingestion (pCi/yr)
C	=	Activity concentration of a radionuclide at the exposure point (pCi/m^3, pCi/l, or pCi/kg)
IR	=	Intake rate (m^3/day, l/day, or kg/day)
EF	=	Exposure frequency (days/year)

Exposure factors used in calculating annual radionuclide intake for specific receptors and pathways are presented in Attachment H2. The annual intake of each radionuclide in pCi/year is multiplied by the committed effective dose coefficient (mrem/pCi) from Table H9-1 to estimate the CEDE for one year of exposure (mrem/year).

External Irradiation: For the external irradiation route of exposure, an areal activity concentration in soil (pCi/m^2) adjusted for a gamma shielding factor is first calculated.

$$AC = C * \frac{10^3 g}{kg} * SD * D * (1-Se)$$

where:

AC	=	Areal activity concentration in soil, adjusted for a gamma shielding factor (pCi/m^2)

C	=	Mass activity concentration of a radionuclide at the exposure point (pCi/g soil)
SD	=	Soil density (1.84E+03 kg/m^3) (site-specific for RFETS)
D	=	Soil depth (0.0508m) (2 inches)
Se	=	Gamma shielding factor (unitless)

Exposure factors used in calculating annual radionuclide intake for specific receptors and pathways are presented in Attachment H2. The areal activity concentration of each radionuclide in soil is multiplied by the number of hours of exposure per year to obtain the annual external irradiation exposure, as indicated in the following equation.

$$EI = AC * Te * EF * CF$$

where:

EI	=	Annual external irradiation exposure (pCi-hr/m^2-year)
AC	=	Areal activity concentration (pCi/m^2)
Te	=	Gamma exposure time factor (fraction of day) (unitless)
EF	=	Exposure frequency (days/year)
CF	=	Conversion faction (24 hours/day)

The annual irradiation exposure is then multiplied by the effective dose coefficient for external irradiation (mrem/hr per pCi/m^2) (Table H9-1) to estimate the EDE (mrem/year) for each radionuclide for one year of exposure.

Estimating Annual Radiation Dose: TEDEs are equal to the sum of CEDEs and EDEs for all radionuclides and all exposure pathways. Total annual radiation dose is equal to the

TEDE for one year of exposure and can be compared to annual radiation protection standards (also in terms of TEDEs for one year of exposure).

Annual radiation doses were estimated for all receptors and exposure areas (Attachment H4); results are summarized and compared to radiation protection standards in the following subsections.

H9.1.3 Radiation Protection Standards

The DOE occupational limit for radiological workers is 50 mSv/year (5,000 mrem/year) (DOE 1993i). The DOE annual radiation dose limit for members of the public is 1 mSv/year (100 mrem/year) for all routes of exposure (DOE 1990e). The occupational limit for general employees (i.e., those not considered to be radiological workers) may be 100 or 5,000 mrem/year depending on employment circumstances. DOE states, "The radiological worker dose limits ... also apply to general employees. However, general employees who have not completed Radiological Worker I or II Training are not permitted unescorted access to any area in which they are expected to receive doses in excess of 100 mrem in one year. General employees who have not received Radiological Worker I or II training are not normally expected to exceed 100 mrem in a year" (DOE 1994h). These values are for radiation doses received in addition to that from natural background radiation (U.S. average background radiation is approximately 300 mrem/year, including exposure from radon; National Council on Radiation Protection and Measurements [NCRP] 1987) and that received from routine medical treatments (U.S. average is approximately 50 mrem/year; NCRP 1987). Background levels in the Denver area are estimated to range from 350 to 700 mrem/year; these levels are higher than the national average because of high natural levels of radium, thorium, and radon and because radiation exposure increases with increased altitude (National Council on Radiation Protection and Measurements [NCRP] 1987).

H9.2 AOC No. 1

Annual radiation doses, in terms of mrem/year were calculated for onsite receptors in AOC No. 1, in AOC No. 2 and in 10-, 30-, and 50- acre maximum exposure areas in AOC No. 1. Results are summarized in Tables H9-2 through H9-4 and calculations are shown in Attachment H4.

Onsite receptors are current workers, future industrial/office workers, future ecological workers, future open space users, future construction workers, and hypothetical residents. Although no residential development is expected at RFETS, the hypothetical residential scenario was evaluated to provide an upper-bound estimate of risk that may support risk management decisions for low-hazard areas within OU-2.

This section describes the results of annual radiation dose estimates for receptors in AOC No. 1. AOC No. 1 includes the 903 Pad, Mound, Northeast Trenches, and Southeast Trenches, which contain all of the IHSSs that were investigated in OU-2. Annual radiation dose results for the maximum exposure areas are discussed in Section H9.3; results for AOC No. 2 are discussed in Section H9.4.

Current Worker: The following radionuclide exposure pathways were evaluated for the current worker:

- Inhalation of airborne particulates
- Ingestion of surface soil
- External irradiation from radionuclides in surface soil

The total annual radiation dose for the current worker in AOC No. 1 is 1 mrem/year for the average exposure condition and 2 mrem/year for the RME condition (Table H9-2). These values are below the DOE limits of 100 mrem/year for members of the public and 5,000 mrem/year for radiological workers exposures.

Future Industrial/Office Worker: Radionuclide exposure pathways evaluated for the future industrial/office worker were the same as for the current worker. The total annual radiation dose for the future industrial/office worker in AOC No. 1 is 5 mrem/year for the average exposure condition and 10 mrem/year for the RME condition (Table H9-2). Inhalation of Pu-239/240 was the major contributor to total annual radiation dose. These values are below the DOE limit of 100 mrem/year for members of the public.

Future Ecological Worker: Radionuclide exposure pathways evaluated for the ecological worker were:

- Ingestion of surface soil
- Inhalation of airborne particulates from surface soil
- Ingestion of surface water/sediment (Walnut and Woman creeks)
- External irradiation from radionuclides in surface soil

The total annual radiation dose for the ecological worker in AOC No. 1 is 2 mrem/year for the average exposure condition and 4 mrem/year for the RME condition (Table H9-2). These doses are below the DOE limit of 100 mrem/year for members of the public.

Future Open Space Use: Radionuclide exposure pathways evaluated for future open space use were:

- Ingestion of surface soil
- Inhalation of airborne particulates from surface soil
- Ingestion of surface water/sediment (Walnut and Woman creeks)
- External irradiation from surface soil

The total annual radiation dose for open space use in AOC No. 1 is 0.1 mrem/year for the average exposure condition and 1 mrem/year for the RME condition (Table H9-2). These doses are below the DOE limit of 100 mrem/year for members of the public.

Future Construction Worker: The future construction worker was evaluated for the following exposure pathways:

- Subsurface soil ingestion
- Inhalation of airborne particulates from subsurface and surface soil
- External irradiation from radionuclides in subsurface soil

The total annual radiation dose for the construction worker in AOC No. 1 is 1 mrem/year for both the average and RME exposure conditions (Table H9-2). This level is below the DOE limit of 100 mrem/year for members of the public.

Hypothetical Resident: Future land use at RFETS will not include residential development (DOE 1995b; EPA 1995a; CDPHE 1995). Nevertheless, onsite residential exposure was evaluated in the HHRA as a hypothetical scenario to provide an upper-bound estimate of risk that may support risk management decisions for low-hazard areas within OU-2. Because residential development is not a reasonable future land-use scenario in OU-2, cleanup levels will not be based on estimates of risk to this hypothetical receptor.

Annual radiation doses were estimated for onsite residential exposure in AOC No.1, a 10-acre maximum exposure area in AOC No. 1, and AOC No. 2. The hypothetical resident was evaluated for the following exposure pathways:

- Surface soil ingestion
- External irradiation from radionuclides in surface soil
- Inhalation of airborne particulates
- Groundwater ingestion
- Ingestion of surface water and sediment (Walnut Creek and Woman Creek)
- Ingestion of homegrown produce (surface deposition of particulates and root uptake)

The total annual radiation dose for the onsite resident in AOC No. 1 is 13 mrem/year for the average exposure condition and 42 mrem/year for the RME condition. Inhalation of airborne particulates (22 mrem/year), external irradiation from surface soil (9 mrem/year), and ingestion of surface soil (6 mrem/year) are the primary pathways contributing to the total RME annual radiation dose (Table H9-2). The annual radiation dose for all exposure pathways is below the DOE limit of 100 mrem/year for members of the public.

H9.3 MAXIMUM EXPOSURE AREAS IN AOC No. 1

Annual radiation doses, in terms of TEDE for one year of exposure (mrem/year), were also estimated for receptors in three maximum exposure areas in AOC No. 1:

- a 10-acre hypothetical residential neighborhood at the area of maximum soil and groundwater contamination in OU-2

- a 30-acre industrial/office park incorporating the maximum contaminated area in OU-2

- a 50-acre ecological study area incorporating the maximum contaminated area in OU-2.

Annual radiation doses for each receptor/exposure area are summarized in Table H9-3 and are discussed below. Detailed radionuclide- and pathway-specific results are presented in Attachment H4.

H9.3.1 Hypothetical Onsite Resident (10-acres)

The total annual radiation dose was estimated for a hypothetical onsite residential exposure in a 10-acre maximum exposure area, approximately equivalent to the 903 Pad Area. Pathways evaluated are the same as listed for the onsite resident in AOC No. 1 (Section H9.2.6). The total annual radiation dose for the onsite resident in the 10-acre maximum exposure area in AOC No. 1 is 17 mrem/year for the average exposure condition and 67 mrem/year for the RME condition. External irradiation from surface soil (20 mrem/year), groundwater ingestion (19 mrem/year), ingestion of surface soil (14 mrem/year), and inhalation of airborne particulates (11 mrem/year) were the primary pathways contributing to the total RME annual radiation dose (Table H9-3). The total annual dose is below the DOE limit of 100 mrem/year for members of the public.

H9.3.2 Future Industrial/Office Worker (30-acres)

Pathways evaluated were surface soil ingestion, particulate inhalation, and external irradiation. The total annual radiation dose for the future industrial/office worker in the 30-acre maximum exposure area in AOC No. 1 is 10 mrem/year for the average exposure condition and 20 mrem/year for the RME condition (Table H9-3). Inhalation of plutonium contributed to most of the annual dose. These doses are below the DOE limit of 100 mrem/year for members of the public.

H9.3.3 Future Onsite Ecological Worker (50-acres)

Pathways evaluated are the same as listed for the future ecological worker in AOC No. 1 (Section H9.2.3). The total annual dose for the future ecological worker in the 30-acre maximum exposure area in AOC No. 1 is 3 mrem/year for the average exposure condition and 7 mrem/year for the RME condition (Table H9-3). These doses are below the DOE limit of 100 mrem/year for members of the public.

H9.4 AOC No. 2

AOC No. 2 is the East of IHSSs area, located in the buffer zone between the IHSSs and Indiana Street. No IHSSs or other waste disposal areas are present in AOC No. 2. Annual radiation doses for current and future receptors located in AOC No. 2 are summarized in Table H9-4 and detailed in Attachment H4.

Exposure pathways evaluated for current and future onsite receptors in AOC No. 2 were the same as those evaluated in AOC No. 1. The total annual radiation dose, in terms of TEDE for one year of exposure, for current and future onsite nonresidential receptors in AOC No. 2 are 0.3 mrem/year or less for the average and RME conditions. Radiation dose results for each receptor are discussed below.

Current Onsite Worker: The total annual radiation dose for the current worker in AOC No. 2 is 0.02 mrem/year for the average exposure condition and 0.04 mrem/year for the RME condition.

Future Industrial/Office Worker: The total annual radiation dose for the future industrial office worker in AOC No. 2 is 0.1 mrem/year for the average exposure condition and 0.2 mrem/year for the RME condition.

Future Ecological Worker: The total annual radiation dose for the future ecological worker in AOC No. 2 is 0.05 mrem/year for the average exposure condition and 0.1 mrem/year for the RME condition.

Future Open Space Use: The total annual radiation dose for future open space use in AOC No. 2 is 0.002 mrem/year for the average exposure condition and 0.03 mrem/year for the RME condition.

Future Construction Worker: The total annual radiation dose for the future construction worker in AOC No. 2 is 0.03 mrem/year for the average exposure condition and 0.08 mrem/year for the RME condition.

Hypothetical Onsite Resident: The total annual radiation dose for the hypothetical onsite resident in AOC No. 2 is 0.4 mrem/year for the average exposure condition and 2 mrem/year for the RME condition.

H9.5 OFFSITE RESIDENTS

Current and future offsite residential receptors were evaluated for exposure to radionuclides transported in air from AOC No. 1 and from AOC No. 2. Current offsite receptor locations selected for evaluation are the closest residence to RFETS (Current Resident, Indiana South) and the closest residence to RFETS in the prevailing southeast wind direction (Current Resident, Southeast), each located east of Indiana Street near RFETS southeast corner. Exposure pathways evaluated for current offsite residents include inhalation of airborne particulates from AOC No. 1 and AOC No. 2 and ingestion of particulate matter deposited on soil or on homegrown produce.

Future offsite residential receptors were evaluated at two locations, both on Indiana Street adjacent to either Walnut Creek (Future Resident, Walnut Cr./Indiana) or Woman Creek (Future Resident, Woman Cr./Indiana). Exposure pathways for future offsite receptors include those for current offsite receptors, plus oral exposure to surface water/sediments in Woman Creek or Walnut Creek. Radiation dose results for current and future offsite receptors are summarized in Table H9-5 and detailed in Attachment H4.

The total annual radiation doses for offsite receptors were 0.004 mrem/year or less for the average and RME conditions (Table H9-5). When impacts from AOC No. 1 and AOC No. 2 are combined, the total annual radiation dose for offsite residents is 0.004 mrem/year or less.

These levels indicate negligible exposure to radionuclides in air, deposited particulate matter, or in surface water/suspended sediments in the creeks.

H9.6 SUMMARY OF RESULTS

Annual radiation dose, in terms of total effective dose equivalent (TEDE) for one year of exposure, was estimated for six onsite receptors in two AOCs in RFETS OU-2. In addition, residential, industrial, and ecological researcher scenarios were evaluated in 10-, 30-, and 50-acre maximum exposure areas, respectively. Four offsite receptor locations were also evaluated. Results are summarized in Tables H9-2 through H9-5 and detailed in Attachment H4.

H9.6.1 AOC No. 1

Annual radiation dose estimates for AOC No. 1 are summarized in Table H9-2. Estimated annual radiation doses were 20 mrem or lower for all non-residential receptors evaluated in AOC No. 1. These doses are below the DOE limit of 100 mrem/year for protection of public health and 5,000 mrem/year for radiological worker exposure. Estimated annual radiation doses for hypothetical residents ranged from 13 mrem/year (CT, AOC No. 1) to 67 mrem/year (RME, 10-acre).

These levels are also below DOE limits for protection of the public. Because onsite residential development will not occur in OU-2, the estimates of annual radiation dose to hypothetical onsite residents do not reflect actual doses expected under current and probable future land use at RFETS.

The next highest radiation dose results were associated with future industrial/office worker exposures in the 30-acre maximum exposure area. These were 10 mrem/year and 20 mrem/year for the CT and RME scenarios, respectively. These values are below the DOE limit of 100 mrem/year for members of the public. Exposure to Pu-239/240 in surface soil accounts for most of the estimated RME annual dose for this receptor (approximately 13 mrem/year). Annual radiation dose for the future industrial/office worker in the 30-acre maximum exposure area is biased by one relatively high value for Pu-239/240 in surface soil (7.3E+06 pCi/kg). This concentration, which is 7 times higher than any other

detected concentration, may bias the estimate of mean exposure concentration of Pu-239/240 in surface soil in the 30-acre maximum exposure area and also bias the estimate of annual radiation doses.

H9.6.2 AOC No. 2

Radiation dose calculations for AOC No. 2 are summarized in Table H9-4. Total annual radiation doses were 2 mrem/year or less for all onsite receptors in AOC No. 2, indicating that exposure to radionuclides in AOC No. 2 is negligible.

H9.6.3 Offsite Receptors

Total radiation doses for offsite receptors are very low (0.004 mrem/year or less). These results reflect insignificant impacts from airborne particulate matter from OU-2 sources and from radionuclides transported from OU-2 sources in surface water/sediment in Walnut and Woman Creeks.

TABLE H9-1
EFFECTIVE DOSE COEFFICIENTS FOR SELECTED RADIONUCLIDES

Radionuclide	f_i [1]	Ingestion (Sv/Bq)	Class [2]	Inhalation (Sv/Bq)	External [3]
Americium-241	1.00E-03	9.84E-07	W	1.20E-04	2.99E+00
Plutonium-239	1.00E-03	9.56E-07	W	1.16E-04	3.78E-02
	1.00E-04	9.96E-08	Y	8.33E-05	
	1.00E-05	1.40E-08			
Uranium-234	5.00E-02	7.66E-08	D	7.37E-07	8.07E-02
	2.00E-03	7.06E-09	W	2.13E-06	
			Y	3.58E-05	
Uranium-235	5.00E-02	7.19E-08	D	6.85E-07	1.71E+01
	2.00E-03	7.22E-09	W	1.97E-06	
			Y	3.32E-05	
Uranium-238	5.00E-02	6.88E-08	D	6.62E-07	6.46E-02
	2.00E-03	6.42E-09	W	1.90E-06	
			Y	3.20E-05	

[1] Fractional uptake from small intestine to blood.

[2] Lung clearance class: D = days; W = weeks; Y = years

[3] In units of millirem/yr per microcurie/square meters.

TABLE H9-2
SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR AOC NO. 1

Receptor/Exposure Pathway	Average Exposure (mrem/year)	Reasonable Maximum Exposure (mrem/year)
Current Worker		
-Ingestion of Surface Soil	5.0E-02	3.2E-01
-Inhalation of Particulates	8.2E-01	1.0E+00
-External Irradiation from Surface Soil	1.7E-01	3.1E-01
Total	1.0E+00	1.7E+00
Future Industrial/Office Worker		
-Ingestion of Surface Soil	1.5E-01	1.9E+00
-Inhalation of Particulates	3.6E+00	6.1E+00
-External Irradiation from Surface Soil	1.0E+00	1.8E+00
Total	4.8E+00	9.8E+00
Future Ecological Worker		
-Ingestion of Surface Soil	2.9E-01	1.0E+00
-Inhalation of Particulates	1.4E+00	2.7E+00
-Ingestion of Surface Water/Sediment	2.6E-05	2.2E-04
-External Irradiation from Surface Soil	4.8E-01	6.0E-01
Total	2.2E+00	4.3E+00
Future Open Space Use		
-Ingestion of Surface Soil	1.4E-02	2.2E-01
-Inhalation of Particulates	4.6E-02	6.4E-01
-Ingestion of Surface Water/Sediment	2.3E-05	2.8E-04
-External Irradiation from Surface Soil	2.5E-02	1.5E-01
Total	8.5E-02	1.0E+00
Hypothetical Construction Worker		
-Ingestion of Subsurface Soil	3.7E-03	2.1E-02
-Inhalation of Particulates	9.9E-01	1.2E+00
-External Irradiation from Surface Soil	4.9E-03	5.6E-03
Total	1.0E+00	1.3E+00
Hypothetical Resident		
-Ingestion of Surface Soil	1.5E+00	6.3E+00
-Inhalation of Particulates	8.1E+00	2.6E+01
-Ingestion of Groundwater	8.0E-02	5.7E-01
-Ingestion of Garden Produce (Root Uptake)	3.2E-01	1.2E+00
-Ingestion of Garden Produce (Deposition)	1.1E-02	8.2E-02
-Ingestion of Surface Water/Sediment	1.9E-05	3.4E-04
-External Irradiation from Surface Soil	2.7E+00	8.6E+00
Total	1.3E+01	4.2E+01

Notes:

Dose calculations are detailed in Attachment H4.
AOC = Area of Concern
mrem = millirem

TABLE H9-3
SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR MAXIMUM EXPOSURE AREAS

Receptor/Exposure Pathway	Average Exposure (mrem/year)	Reasonable Maximum Exposure (mrem/year)
Hypothetical Resident (10 Acres)		
-Ingestion of Surface Soil	3.3E+00	1.4E+01
-Inhalation of Particulates	3.5E+00	1.1E+01
-Ingestion of Groundwater	2.6E+00	1.9E+01
-Ingestion of Garden Produce (Root Uptake)	9.1E-01	3.3E+00
-Ingestion of Garden Produce (Deposition)	1.8E-02	1.3E-01
-Ingestion of Surface Water/Sediment	1.9E-05	3.4E-04
-External Irradiation from Surface Soil	6.3E+00	2.0E+01
Total	1.7E+01	6.7E+01
Future Industrial/Office Worker (30 Acres)		
-Ingestion of Surface Soil	3.4E-01	4.3E+00
-Inhalation of Particulates	6.9E+00	1.2E+01
-External Irradiation from Surface Soil	2.3E+00	4.3E+00
Total	9.6E+00	2.0E+01
Future Ecological Worker (50 Acres)		
-Ingestion of Surface Soil	5.4E-01	1.9E+00
-Inhalation of Particulates	2.0E+00	3.7E+00
-Ingestion of Surface Water/Sediment	2.6E-05	2.2E-04
-External Irradiation from Surface Soil	8.9E-01	1.1E+00
Total	3.4E+00	6.8E+00

Notes:

Dose calculations are detailed in Attachment H4.
mrem = millirem

TABLE H9-4
SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR AOC NO. 2

Receptor/Exposure Pathway	Average Exposure (mrem/year)	Reasonable Maximum Exposure (mrem/year)
Current Industrial Worker		
-Ingestion of Surface Soil	1.9E-03	1.2E-02
-Inhalation of Particulates	1.3E-02	1.6E-02
-External Irradiation from Surface Soil	6.8E-03	1.2E-02
Total	2.1E-02	4.0E-02
Future Industrial/Office Worker		
-Ingestion of Surface Soil	5.7E-03	7.3E-02
-Inhalation of Particulates	5.7E-02	9.4E-02
-External Irradiation from Surface Soil	4.0E-02	7.3E-02
Total	1.0E-01	2.4E-01
Future Ecological Worker		
-Ingestion of Surface Soil	1.1E-02	4.0E-02
-Inhalation of Particulates	2.2E-02	4.1E-02
-Ingestion of Surface Water/Sediment	2.6E-05	2.2E-04
-External Irradiation from Surface Soil	1.9E-02	2.4E-02
Total	5.2E-02	1.1E-01
Future Open Space Use		
-Ingestion of Surface Soil	5.6E-04	8.7E-03
-Inhalation of Particulates	7.0E-04	9.9E-03
-Ingestion of Surface Water/Sediment	2.3E-05	2.8E-04
-External Irradiation from Surface Soil	9.7E-04	6.1E-03
Total	2.3E-03	2.5E-02
Future Construction Worker		
-Ingestion of Subsurface Soil	8.4E-03	4.7E-02
-Inhalation of Particulates	1.5E-02	1.9E-02
-External Irradiation from Surface Soil	7.6E-03	9.2E-03
Total	3.1E-02	7.5E-02
Hypothetical Resident		
-Ingestion of Surface Soil	5.7E-02	2.4E-01
-Inhalation of Particulates	1.3E-01	3.9E-01
-Ingestion of Groundwater	8.5E-02	6.0E-01
-Ingestion of Garden Produce (Root Uptake)	1.5E-02	5.5E-02
-Ingestion of Garden Produce (Deposition)	4.8E-04	3.4E-03
-Ingestion of Surface Water/Sediment	1.9E-05	3.4E-04
-External Irradiation from Surface Soil	1.1E-01	3.4E-01
Total	3.9E-01	1.6E+00

Notes:

Dose calculations are detailed in Attachment H4.
AOC = Area of Concern
mrem = millirem

TABLE H9-5
SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR OFFSITE RESIDENTS

Receptor/Exposure Pathway	Average Exposure (mrem/year)	Reasonable Maximum Exposure (mrem/year)
AOC No. 1		
Current Resident, Southeast		
-Ingestion of Surface Soil	0 [1]	0
-Inhalation of Particulates	1.3E-03	4.0E-03
-Ingestion of Garden Produce (Deposition)	0	0
Total	1.3E-03	4.0E-03
Current Resident, Indiana South		
-Ingestion of Surface Soil	0	0
-Inhalation of Particulates	0	0
-Ingestion of Garden Produce (Deposition)	0	0
Total	0	0
Future Resident, Walnut Cr./Indiana		
-Ingestion of Surface Soil	0	0
-Inhalation of Particulates	0	0
-Ingestion of Surface Water/Sediment	9.7E-07	1.8E-05
-Ingestion of Garden Produce (Deposition)	0	0
Total	9.7E-07	1.8E-05
Future Resident, Woman Cr./Indiana		
-Ingestion of Surface Soil	0	0
-Inhalation of Particulates	7.6E-04	2.4E-03
-Ingestion of Surface Water/Sediment	1.8E-05	3.2E-04
-Ingestion of Soil Deposited on Vegetables	0	0
-Ingestion of Soil Deposited on Fruit	0	0
-Ingestion of Garden Produce (Deposition)	0	0
Total	7.8E-04	2.7E-03

[1] Cancer risk estimates reported as 0 indicate that no air or depositional impacts were predicted by air modeling (Section H5.5.2).
AOC = Area of Concern
mrem = millirem

TABLE H9-5
SUMMARY OF ESTIMATED ANNUAL RADIATION DOSE FOR OFFSITE RESIDENTS

Receptor/Exposure Pathway	Average Exposure (mrem/year)	Reasonable Maximum Exposure (mrem/year)
AOC No. 2		
Current Resident, Southeast		
-Ingestion of Surface Soil	2.9E-08	1.2E-07
-Inhalation of Particulates	5.5E-05	1.8E-04
-Ingestion of Garden Produce (Deposition)	6.3E-07	4.5E-06
Total	5.6E-05	1.8E-04
Current Resident, Indiana South		
-Ingestion of Surface Soil	0	0
-Inhalation of Particulates	8.4E-07	2.6E-06
-Ingestion of Garden Produce (Deposition)	0	0
Total	8.4E-07	2.6E-06
Future Resident, Walnut Cr./Indiana		
-Ingestion of Surface Soil	0	0
-Inhalation of Particulates	2.5E-06	7.9E-06
-Ingestion of Surface Water/Sediment Walnut Ck.	9.7E-07	1.8E-05
-Ingestion of Garden Produce (Deposition)	0	0
Total	3.5E-06	2.6E-05
Future Resident, Woman Cr./Indiana		
-Ingestion of Surface Soil	2.9E-08	1.2E-07
-Inhalation of Particulates	3.1E-05	9.8E-05
-Ingestion of Surface Water/Sediment	1.8E-05	3.2E-04
-Ingestion of Garden Produce (Deposition)	6.3E-07	4.5E-06
Total	4.9E-05	4.2E-04

Notes:

Dose calculations are detailed in Attachment H4.
AOC = Area of Concern
mrem = millirem

H10.0
UNCERTAINTIES AND LIMITATIONS

This section discusses the chief uncertainties and limitations of the risk assessment and how they affect the results and conclusions. It also provides an assessment of risk from exposure to special-case COCs and discusses their potential contribution to overall site risk.

Uncertainties and limitations are inherent in the risk assessment process. The level of certainty associated with the conclusions of the risk assessment are conditional upon the quality of data and models used to identify COCs and estimate chemical concentrations, the assumptions made in estimating exposure conditions, the methods used to develop toxicity values, and the methods used to characterize risk. Uncertainties in the risk assessment process could result in an overestimation or underestimation of risk. However, it is standard in risk assessment to adopt conservative approaches when uncertainty about a particular assumption exists, so as not to underestimate potential risk. Therefore, the risk assessment process is skewed toward overestimating rather than underestimating risk.

In the current assessment, there are uncertainties that could result in an overestimation or underestimation of risk. Sources of uncertainty that may contribute to an underestimation of risk include COCs for which risk could not be assessed because their toxicity is unknown and the use of unadjusted oral toxicity factors to estimate risk from dermal exposure (Section H10.1.4). However, in most cases of uncertainty, conservative assumptions were used so as not to underestimate risk. In doing this, it is likely that overall risk was overestimated. At all stages of this risk assessment, however, reasonable conservative assumptions were made so as not to underestimate potential risk. Furthermore, estimates of toxicity and carcinogenicity (RfDs and SFs) are very conservative and may result in an overestimate of risk. Therefore, the conclusions regarding identification of chief contaminants of concern, levels of potential health risk associated with direct and indirect exposures, and offsite migration potential are considered reliable.

The chief sources of uncertainty are discussed in Section H10.1. An evaluation of risk from special-case COCs is presented in Section H10.2.

H10.1 CHIEF UNCERTAINTIES

Uncertainties in the health risk assessment for OU-2 at RFETS lie in the identification of COCs, in the estimation of exposure point concentrations, and in the assumptions regarding human exposure scenarios at RFETS. Each of these is discussed below.

H10.1.1 Identification of COCs

The screening process used to select a subset of chemicals to evaluate in the risk assessment is intended to include all compounds whose concentrations are high enough that there may be concern for potential health hazards. The screening process included a background

comparison for inorganic analytes, a frequency test (analytes detected at less than 5 percent frequency were excluded as OU-wide contaminants because exposure potential is minimal), and concentration-toxicity screens that evaluate relative contribution to overall risk based on maximum detected concentrations. Concentration/toxicity screens have the potential for eliminating chemicals that could contribute significantly to overall risk if the relative magnitude of maximum concentrations differs from the relative magnitude of exposure concentrations (95% UCLs of the mean). However, the results of the risk assessment demonstrate that the selection process was sufficiently conservative so that potentially significant sources of health risk were not overlooked.

COCs in soil and groundwater were those identified in concentration/toxicity screens as contributing at least 1 percent of an overall "risk factor," based on maximum detected concentrations. Of the chemicals retained as COCs on the basis of the screen, only two or three COCs were found to contribute the majority of total estimated risk, and other COCs evaluated in the quantitative risk assessment contributed relatively insignificantly to total risk. Chemicals excluded by the screens would be expected to contribute even less to total risk. This is borne out by several examples, discussed below.

In surface soil in AOC No. 1, for example, Pu-239/240 contributed 97 percent and Am-241 contributed 3 percent of the estimated total RME cancer risk from exposure (ingestion and inhalation pathways) under the hypothetical residential scenario. Other COCs in surface soil (Aroclors, chromium, and BEHP) each contributed less than 0.6 percent of total risk from these two exposure routes. Compounds excluded by the screens were several uranium isotopes, radium-226, and strontium-89/90 (Table H3-6). Of these, U-238 had the highest combination of maximum concentration and toxicity. Even at the maximum concentration of 7.7 pCi/g, U-238 would result in a combined ingestion plus inhalation RME cancer risk of only 7E-07 (calculation not shown), compared to the total cancer risk from ingestion and inhalation of 3E-04 (Table H9-1). This shows that compounds excluded by the screen would have contributed insignificantly to the total estimated risk from exposure to surface soil.

Similarly, in groundwater in AOC No. 1, carbon tetrachloride contributed 86 percent, tetrachloroethene contributed 11 percent, and trichloroethene contributed 2 percent of the RME cancer risk of 6E-03 from ingestion of nonradionuclide carcinogens. (See chemical-

H3.) Other carcinogenic COCs each contributed less than 0.5 percent of cancer risk for this exposure pathway.

Chemical carcinogens excluded as COCs in groundwater by the concentration/toxicity screen were As, bromodichloromethane, benzene, BEHP, and Cd. Of these, As had the highest combination of maximum concentration and toxicity (Table H3-16). A discussion of risk levels associated with As and other selected metals in groundwater in OU-2 and in background is presented in Section H10.2 (background and site risks were of comparable magnitude). A 95% UCL concentration was not calculated for bromodichloromethane; it was detected in 6 percent of UHSU samples in concentrations ranging from 0.00015J mg/L to 0.19 mg/L, with an average concentration of 0.0015 mg/L. Using the average as a conservative estimate of exposure concentration (because the average does not include nondetect results), bromodichloromethane would result in a cancer risk of only 1E-06 (calculation not shown) for groundwater ingestion, or less than 0.02 percent of total risk from groundwater ingestion in AOC No. 1. Other carcinogens excluded as COCs by the screen would be expected to contribute even less to overall risk.

For noncarcinogenic effects of COCs in groundwater, carbon tetrachloride was associated with an RME HQ of 136 and tetrachloroethene with an HQ of 3. These two compounds contributed 99 percent of the total HI of 140 for groundwater ingestion. Other noncarcinogenic COCs had HQs ranging from 0.006 to 0.3 and contributed insignificantly to the total HI. Noncarcinogens excluded as COCs in groundwater by the concentration/toxicity screen were nitrate, 1,2-dichloroethene, Ba, and numerous other metals and organic contaminants (see Table H3-15). Nitrate had the highest combination of maximum concentration and toxicity. Using the maximum detected concentration of 0.444 mg/L as an exposure concentration would result in a HQ of 0.02 for residential groundwater ingestion. For 1,2-dichloroethene, a HQ of 0.0005 would be associated with the maximum detected concentration of 1.7 mg/L. Other chemicals excluded as COCs would have HQs equal to or less than 0.0005, even using maximum detected concentrations as exposure concentrations. These HQs are well below 1 and indicate that significant contributors to overall noncarcinogenic hazards from groundwater were not overlooked in the concentration/toxicity screen.

A similar demonstration could be provided for radionuclides in groundwater as well as for contaminants in subsurface soil. Therefore, it is concluded that potentially significant contributors to overall risk were adequately identified by the concentration/toxicity screens and that excluding some contaminants from quantitative evaluation on the basis of the screens does not result in an underestimate of site risk.

H10.1.2 Exposure Point Concentrations

The chief uncertainties in estimating exposure point concentrations of COCs lie in how the sample results are aggregated for risk assessment, in the numerical estimate of an average exposure concentration, and in the modeling assumptions used to estimate concentrations in air, surface water, and garden produce. The uncertainties can result in either an underestimate or overestimate of the concentration terms for risk assessment; however, conservative approaches were taken so as not to underestimate average exposure concentrations for the exposure scenarios and areas being evaluated in risk assessment.

Data Aggregation: In keeping with procedures agreed upon by CDPHE, EPA, and DOE, data were aggregated for risk assessment by large AOCs and by smaller maximum exposure areas of 10, 30, and 50 acres. All analytical data from sampling locations within the AOC or exposure area were pooled for risk assessment for that area. For example, results from both contaminated and uncontaminated wells were used to estimate groundwater exposure concentrations in some areas. Thus, the approach provides a reasonable estimate of exposure concentrations associated with predefined exposure areas. However, in areas evaluating maximum exposure to groundwater (10- and 30-acre areas), most wells were contaminated (e.g., wells in the 10-acre maximum exposure area had detectable levels of four or more contaminants).

Estimating the Concentration Term: Concentration terms were either the 95% UCL of the mean (normal or lognormal distribution) or the maximum detected concentration. The 95% UCL is used rather than the mean concentration to provide an additional level of conservatism in accounting for the uncertainties involved in estimating the true mean from a sample. Although small sample size, variability in sample results, extreme values, and accounting for negative or zero values add to the uncertainty in estimating the mean, these uncertainties usually result in a high, rather than a low, bias to the estimate. Therefore, the uncertainties

in the statistical evaluation of the data are not expected to result in an underestimation of exposure or risk. In some cases, the high bias appears to yield an overestimate of the exposure term and associated risk. A significant example that could result in an overestimate of risk is the concentration term for Pu in surface soil in AOC No. 1 and the 30-acre exposure area (see Sections H5.2 and H8.4.2).

Modeling Assumptions: Modeling was performed to estimate contaminant loads to Walnut and Woman creeks from groundwater and surface runoff, concentrations of COCs in creek water at Indiana Street, outdoor air concentrations of COCs associated with PM_{10}, and indoor air concentrations of VOCs from soil gas. A combination of average and reasonable maximum values for input parameters were used to produce conservative estimates of average exposure concentrations.

Some of the assumptions that produce conservative estimates of average exposure concentrations are listed below. Further detail is provided in the modeling appendixes (E, F, and G) attached to the RFI/RI Report.

- Contaminant loads in groundwater: No source decay was assumed in modeling migration of COCs in UHSU groundwater to discharge points (seeps). The maximum estimated concentrations at the discharge points were used as input to the OU-2 surface water model.

- Contaminant loads in surface runoff: Area-weighted average concentrations of COCs in surface soil were used as source concentrations for modeling mass flux in surface runoff. Thirty-six years of precipitation data were used to simulate annual loads to the creeks, using Monte Carlo techniques.

- Concentrations of COCs in Walnut and Woman creeks at Indiana Street: The results of the surface water modeling were 100 simulations of 30-year average concentrations of COCs. Either the maximum 30-year average (for VOCs) or the 90th percentile 30-year average (for radionuclides) was used as the concentration term for risk assessment. The model did not consider deposition of sediment or the effects of dams or other structures in the creeks.

- Outdoor air concentrations of COCs associated with PM_{10}: Source concentrations for air modeling were RME concentrations (95% UCLs) in surface soil. Five years of meteorological data were used to estimate onsite and offsite concentrations of PM_{10}, and the maximum of the five years was used as the exposure term in risk assessment. Other input parameters and assumptions included conservative estimates of mixing heights for onsite box models and of emission rates during construction and site-specific estimates of threshold wind speed.

- Indoor air concentrations of VOCs from soil gas: Maximum VOC concentrations in subsurface soil and groundwater and conservative estimates of transport through soil and through a porous building foundation yield conservative estimates of average "basement air" concentrations of VOCs.

- Indoor air concentrations of VOCs from domestic use of groundwater: The simplified model developed by Andelman (1990) was used to estimate VOC concentrations in indoor air. The model is not chemical-specific. A mean volatilization factor of 0.065 L/m^3 was used in combination with the RME source concentrations in groundwater to estimate average indoor air concentrations. This approach could underestimate or overestimate actual concentrations that would occur in a house from domestic use of groundwater. Uncertainties in estimating indoor VOC concentrations do not affect the conclusions of the risk assessment because where groundwater is contaminated, ingestion alone results in unacceptable levels of risk.

H10.1.3 Exposure Scenarios and Pathways

The chief uncertainty in the exposure assessment is future land use at RFETS. Residential development has been virtually eliminated as a potential future use by local planning and advisory bodies and regulatory agencies. Furthermore, use of UHSU groundwater at RFETS is not likely, due to limited yields and availability of public water. Therefore, the risk estimates for onsite residential exposure and groundwater use do not reflect risks reasonably expected in OU-2 and will not be used to derive cleanup goals for OU-2.

Because of the uncertainty in future land use, several possible scenarios were developed, ranging from commercial through open space use and construction worker exposure to subsurface soil. In addition, CT and RME exposure factors were developed for each scenario using EPA values and best estimates based on site-specific or local information. Therefore, the uncertainty in future land use and exposure conditions at RFETS is addressed by the range of scenarios evaluated.

Among the exposure scenarios that were considered possible at RFETS (i.e., nonresidential), the future industrial/office worker is the maximum exposed receptor and provides the reasonable maximum expected risk at the site. This receptor was evaluated for exposure to surface soil (ingestion and inhalation pathways), external irradiation from radionuclides in surface soil, and inhalation of VOCs migrating from subsurface soil and groundwater into a building.

Subsurface soil exposures: Risk from exposure to subsurface soil was evaluated for a construction worker scenario, assuming excavation in AOC No. 1 and in AOC No. 2. Chemical intake was estimated using an exposure duration of 30 days and ingestion rates of 95 mg/day (CT) or 480 mg/day (RME). Health risks for this exposure scenario were well below levels of potential concern. For example, the RME cancer risk estimate for this scenario was 4E-07 in AOC No. 1.

Longer exposure to subsurface soil in AOC No. 1 (for example, under an industrial exposure scenario if construction activities brought subsurface soil to the surface) would not be expected to result in unacceptable risk. RME cancer risk estimates for subsurface soil exposure could increase by roughly a factor of 100 for ingestion and inhalation, based on comparing RME intake factors for the construction worker and industrial/office worker. This would result in an estimated cancer risk of 100 x 4E-07 or 4E-05. The industrial worker intake factors assume an 8-hour/day exposure to outdoor air PM_{10}, 50 mg/day soil ingestion, and no landscaping or paving to reduce contact with soil. These are conservative assumptions that are likely to overestimate risk for an industrial/office worker.

H10.1.4 Toxicity Assessment

Toxicity values (RfDs and cancer SFs) derived by EPA are conservative upperbound estimates of potential toxicity or carcinogenicity of chemicals, and their use in risk assessment results in conservative estimates of risk. However, numerous compounds, primarily detected in groundwater (Table H3-1), do not have EPA-established toxicity factors. Therefore, they could not be evaluated in a quantitative risk assessment. Most of the compounds were detected at low frequency and at low concentrations (Table H3-1). The exclusion of infrequently detected compounds from risk assessment is not expected to contribute to an underestimation of risk because generally their concentrations and frequency of occurrence are trivial compared to concentrations of COCs.

Lead and copper in soil and groundwater and 1,1,1-trichloroethane (1,1,1-TCA) in groundwater were detected at relatively higher frequencies. EPA-established toxicity factors were not available for these analytes at this writing.

Lead in soil and groundwater: Potential risk from exposure to lead in soil and groundwater was addressed qualitatively in Section H8.8.

Copper in soil: Concentration distributions of copper in surface and subsurface soil were not significantly different than background distributions according to statistical background comparison. However, two sample results from subsurface soil exceeded the background $UTL_{95,95}$ of 49 mg/kg. The maximum site concentration was 132 mg/kg and the maximum background concentration was 123 mg/kg. Because copper levels in OU-2 subsurface soil are relatively low and appear generally to be within background range, and because copper is generally considered to have relatively low toxicity for humans, its exclusion from quantitative risk assessment would have no effect on the estimate of site risk.

Copper in groundwater: Copper concentration distributions were significantly different from background distributions in unfiltered groundwater samples but not in filtered groundwater samples. A summary of copper concentrations in OU-2 and background samples is shown below:

Concentrations of Copper in Groundwater, µg/L

Sample Type	Background Mean	Site Mean	Background Maximum	Site Maximum	$UTL_{99/99}$	No. > $UTL_{99/99}$
Unfiltered	11.4	55.3	105	1310	45.3	69
Filtered	10.7	9.8	175	20.9	53.8	0

Copper in unfiltered groundwater samples is not considered to be a site contaminant, but rather the result of high TSS in the samples. (Refer to discussion in TM No. 9, DOE 1994b).

1,1,1-TCA in groundwater: A provisional RfC for 1,1,1-TCA has been published by EPA but was not available at this writing. 1,1,1-TCA was detected in 25 percent of groundwater samples, ranging in concentration from 0.00018 mg/L to 1 mg/L (mean concentration of 0.026 mg/L). Because this concentration is relatively low compared to concentrations of carbon tetrachloride (3.5 mg/L) and tetrachloroethene (1.2 mg/L), which contribute 99 percent of the noncarcinogenic HI for groundwater ingestion, the exclusion of 1,1,1-TCA from the quantitative risk assessment will not result in an underestimate of risk.

H10.1.5 Toxicity Assessment - Dermal Toxicity Factors

EPA recommends using oral toxicity factors, adjusted, if possible by gastrointestinal absorption fraction, to evaluate toxic effects from dermal absorption of chemicals from contaminated media (EPA 1989a, 1992c). Unadjusted oral toxicity factors were used in the current assessment to estimate effects from dermal absorption of organic chemicals, an approach that may underestimate risk. Cancer risk from dermal exposure for the office worker in the 30-acre maximum exposure are in AOC No. 1 was 4E-06 and risks for other receptors were lower. Because these risk estimates for dermal exposure were within or below EPA's target risk range of 1E-06 to 1E-04 and represented only a small percentage of overall risk, it is unlikely that the use of adjusted oral toxicity factors to assess dermal exposure would have a significant impact on estimates of overall risk.

H10.2 EVALUATION OF RISK ASSOCIATED WITH SPECIAL-CASE COCs

Special-case COCs are (1) compounds that were infrequently detected (< 5 percent) but that exceeded 1000 times the RBC, and (2) compounds that are probably not environmental contaminants but were retained for separate consideration because of toxicity. A detailed discussion of the selection of special-case COCs is presented in the TM 9 (DOE 1994b). In addition, parties to the IAG agreed to evaluate hazard/risk for four metals (antimony, arsenic, beryllium, manganese) in groundwater that are probably not environmental contaminants, but may pose a health risk under long-term exposure to maximum detected concentrations (CDPHE 1994; EPA 1994b, DOE 1994d). Hazard/risk results for special-case COCs are summarized in Table H10-1 and detailed in Attachment H3.

H10.2.1 Metals in Groundwater in OU-2

Four metals were selected for separate evaluation of potential hazard/risk associated with hypothetical ingestion of groundwater: antimony, arsenic, beryllium, and manganese. None of these metals was identified as a COC in OU-2 groundwater, primarily because they do not appear to be contaminants but rather associated with high concentrations of TSS in unfiltered groundwater samples. However, their maximum concentrations exceeded RBCs for

groundwater ingestion (DOE 1994g). To address concerns that these metals could pose a health risk under long-term exposure to maximum detected concentrations, metals will be evaluated separately in the uncertainties section of the HHRA (CDPHE 1994; EPA 1994b; DOE 1994d).

Hazard/risk results for ingestion of these four metals in groundwater, assuming residential use, are shown in Table H10-1 and detailed in Attachment H3. Results from unfiltered samples were used in the risk evaluation.

Noncarcinogenic Hazard Index: The total HIs for noncarcinogenic health effects from exposure to these four metals in groundwater in AOC No. 1 are 2 and 14 for the average and RME conditions, respectively (Table H10-1). In AOC No. 2, the total hazard indexes are 1 for the average exposure condition and 8 for the RME condition. Manganese contributes most of the total HIs. HQs for the other metals were near or less than 1.

In the two AOCs, the HIs differ by approximately a factor of two, indicating that the concentrations of metals in groundwater in each AOC differ by only a factor of two. The small difference in metals concentrations in the two AOCs suggests that these metals are present in groundwater samples as a result of naturally occurring conditions, rather than from site-related activities. On the other hand, concentrations of COCs in groundwater (e.g., radionuclides and VOCs) are substantially higher near source areas (e.g., IHSSs in AOC No. 1) than they are distant from source areas (e.g., in AOC No. 2).

As stated above, the magnitude of the HIs are driven by manganese. However, the HIs may not be a sound guide to potential health hazards (assuming unfiltered UHSU groundwater is ingested chronically) because significant uncertainty exists with regard to the toxicity of manganese ingested in water. The toxicity value for manganese in water, represented by the RfD (0.005 mg/kg-day, EPA 1995b), is probably significantly overestimated. This RfD is 28-times smaller than the RfD for manganese in food (0.14 mg/kg-day, EPA 1995b); it is an order of magnitude less than the "Estimated Safe and Adequate Daily Dietary Intake" of 0.03 to 0.07 mg Mn/kg-day (manganese is an essential element) recommended by the National Research Council (NRC 1989); and it is well below the dose (0.129 mg/kg/day) considered by World Health Organization (WHO) to be "perfectly safe" (WHO 1973).

Manganese daily intake for RME conditions in AOC No. 1 (0.009 mg/kg-day; Attachment H3) is an order of magnitude less than the normal dietary intake of manganese for humans (0.07 to 0.14 mg/kg-day). There is EPA precedence for using the no-action alternative at Superfund sites when manganese is the only compound in groundwater with a hazard index that exceeds 1.0. At the Kenmark Textiles Printing site in Farmingdale, NY, the only chemical in groundwater with a HI greater than 1 was manganese (HI = 4). A no-action alternative was selected for the site because "the assessment was being driven by manganese, which were present at levels that are only a fraction of what the typical person consumes in his or her diet per day" (EPA 1995c). Because manganese in unfiltered groundwater samples at OU-2 is also present at levels that represent only a small fraction of what the typical person ingests in their diet each day, and probably results from naturally occurring sources, further evaluation or action in OU-2 related to manganese in groundwater is probably not warranted.

Carcinogenic Risk: The excess lifetime cancer risks for hypothetical onsite residents ingesting arsenic and beryllium in unfiltered groundwater are:

- AOC No. 1: 2E-05 (average) and 5E-04 (RME)
- AOC No. 2: 9E-06 (average) and 2E-04 (RME)

For the RME condition, cancer risks estimates in both AOCs exceeded the EPA target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000). Arsenic (cancer risk as large as 9E-05) and beryllium (cancer risk as large as 4E-04) each contributed significantly to the total cancer risk estimates. As for the metals evaluated for noncarcinogenic effects, because there is little difference in the risk estimates and groundwater concentrations of metals in the two AOCs, there is little evidence to suggest these metals are contaminants in groundwater. Instead, they are probably associated with high TSS in unfiltered samples.

H10.2.2 Risk at Background Levels of Metals in Groundwater

As a comparison to risk estimates for metals in unfiltered OU-2 groundwater samples and to help support the conclusion that metals in OU-2 groundwater are naturally occurring, hazard/risk levels were also estimated for background levels of arsenic, antimony, beryllium,

and manganese in groundwater using 95% UCLs of the background means as the exposure concentrations (Table H10-1). Sample results used in the calculation of the exposure terms are shown in Attachment H3.

Noncarcinogenic Hazard Index: The total HIs for noncarcinogenic health effects from ingestion of background levels of the four metals in groundwater are 0.4 and 3.0 for the average exposure and RME conditions, respectively (Table H10-1). HQs for antimony, arsenic, and beryllium are very similar to those in OU-2 AOCs. Only the HQ for manganese were lower in background samples, resulting in lower total HIs. As discussed in Appendix C of TM No. 9 (DOE 1994b), local geochemical characteristics are highly variable, and background wells were not located in areas of high manganese and iron whereas many of the OU-2 wells are located in areas characterized by elevated manganese and iron.

Carcinogenic Risk: The lifetime excess cancer risks associated with ingesting arsenic and beryllium in groundwater are 8E-06 (8 in 1 million) and 2E-04 (2 in 10,000) for the average exposure and RME conditions, respectively. Cancer risk from the RME condition for exposure to background levels of metals in groundwater slightly exceeds EPA's target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000). The risks at background levels are very similar to those in OU-2 AOCs.

The results indicate that hazard/cancer risk estimates from hypothetical residential exposure to naturally occurring metals in groundwater exceed generally accepted values for health hazard indexes and cancer risk. Cancer risk estimates for special-case metals in AOC No. 1 and 2 were similar to or less than cancer risk estimates for background levels, suggesting that special-case metals in groundwater samples in OU-2 are naturally occurring, and are not due to environmental contamination.

H10.2.3 Vinyl Chloride in Groundwater

Vinyl chloride was identified as a special-case COC based on low frequency of detection (3 percent) and high toxicity (the maximum concentration of 860 μg/L exceeded a screening level equivalent to 1,000 times the RBC of 0.028 μg/L for residential use). Risks associated with special-case COCs were evaluated for the residential ingestion pathway, even though residential development is not a reasonable future use scenario.

Vinyl chloride was detected in only five wells in AOC No. 1 in OU-2 in the following concentrations.

Vinyl Chloride in OU-2 Wells

Well No.	Detected Concentrations (mg/L)	Detection Frequency	Well Location
1391	0.001	1/3	West edge of Mound Area
3586	0.320 - 0.860	7/7	North edge of Mound Area upgradient of B-series ponds
7891	0.0001	1/4	Northeast Trenches
6691	0.034	1/3	903 Pad
7391	0.002 - 0.003	2/4	Southeast edge of 903 Lip

Because of the low detection frequency for vinyl chloride, it is not practical to calculate an area-wide exposure concentration. However, a range of cancer risk estimates was calculated using the range of detected concentrations and assuming long-term residential groundwater ingestion. The estimates were calculated using the intake factor for residential ingestion of carcinogens in groundwater (1.17 L/kg-day), the oral slope factor for vinyl chloride of 1.9 $(mg/kg\text{-}day)^{-1}$, and the minimum detected concentration (0.0001 mg/L in well 7891) and the arithmetic mean concentration from well 3586 (0.504 mg/L):

Estimated Cancer Risks from Direct Ingestion of Vinyl Chloride in Groundwater

Well	Concentration (mg/L)	RME Intake Factor (L/kg-day)	Slope Factor $(mg/kg\text{-}day)^{-1}$	Cancer Risk
7891	0.0001	1.17E-02	1.9	2E-06
3586	0.504 (average)	1.17E-02	1.9	1E-02

The cancer risk level for hypothetical residential ingestion of vinyl chloride in groundwater from the most contaminated well exceeds EPA's target risk range of 1E-06 to 1E-04 (EPA 1989a).

Vinyl chloride is one of several chlorinated solvents and related compounds detected in groundwater in AOC No. 1. The COCs carbon tetrachloride, chloroform, 1,1-DCE, methylene

chloride, tetrachloroethene, and trichloroethene were more widely detected in groundwater and resulted in excess lifetime cancer risk estimates in the range of 1E-03 to 1E-02. Incremental risk from vinyl chloride would not significantly affect the total cancer risk estimate for exposure to groundwater.

H10.2.4 PAHs in Surface Soil

As discussed in the COC TM for OU-2 (DOE 1994a), PAHs were retained for separate evaluation as special-case COCs because their presence in surface soil is more likely due to common sources such as vehicle emissions rather than waste releases at OU-2. PAHs are structurally similar compounds formed from burning coal, wood, tobacco, and petroleum based fuels. Different PAHs have the potential to produce similar toxic effects, although potency may vary widely. PAHs may be noncarcinogenic (anthracene), weakly carcinogenic (benz([k]fluoranthene), or strongly carcinogenic (benzo[a]pyrene). Adverse noncancer effects observed in test animals include inhibition of growth, and toxicity to the liver, kidney, and blood and immune systems. Noncancer effects are observed at exposure levels several orders of magnitude higher than those associated with unacceptable cancer risk. Hazard/risk results for exposure of hypothetical onsite residents to PAHs ingested in surface soil are summarized in Table H10-1 and detailed in Attachment H3. Calculations of the concentration terms are shown in Attachment H1.

Noncarcinogenic Hazard: The total HIs for onsite residential exposure to fluoranthene and pyrene in AOC No. 1 or AOC No. 2 via the soil ingestion pathway are 9E-05 or less for the average and RME exposure conditions. Because these HIs are well below 1, no adverse noncarcinogenic health effects are expected for onsite receptors from ingestion of PAHs in surface soil.

Carcinogenic Risk: The estimated lifetime excess cancer risks for onsite residential ingestion of the carcinogenic PAHs benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene,and indeno(1,2,3-cd)pyrene in AOC No. 1 and AOC No. 2 via the soil ingestion pathway is 3E-06 (3 in 1,000,000) or less for average and RME exposure conditions. Estimated risk under the industrial/office worker scenario would be approximately 5 times less (i.e., about6 E-07) and would not contribute significantly to overall risk from exposure to surface soils for this receptor.

TABLE H10-1
SUMMARY OF ESTIMATED HEALTH RISKS FOR SPECIAL-CASE CHEMICALS OF CONCERN

Exposure Pathway/Receptor	Average Exposure		Reasonable Maximum Exposure	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
Residential Ingestion of Metals in Groundwater				
AOC No. 1				
Antimony		2.4E-01		1.7E+00
Arsenic	2.9E-06	4.4E-02	6.8E-05	3.1E-01
Beryllium	1.8E-05	6.5E-03	4.2E-04	4.6E-02
Manganese		1.7E+00		1.2E+01
Total	2.1E-05	2.0E+00	4.9E-04	1.4E+01
AOC No. 2				
Antimony		3.6E-01		2.5E+00
Arsenic	3.7E-06	5.6E-02	8.8E-05	4.0E-01
Beryllium	5.1E-06	1.9E-03	1.2E-04	1.3E-02
Manganese		7.7E-01		5.5E+00
Total	8.8E-06	1.2E+00	2.1E-04	8.4E+00
Background				
Antimony		3.1E-01		2.2E+00
Arsenic	1.7E-06	2.6E-02	4.0E-05	1.8E-01
Beryllium	6.4E-06	2.3E-03	1.5E-04	1.6E-02
Manganese		8.2E-02		5.9E-01
Total	8.1E-06	4.2E-01	1.9E-04	3.0E+00
Residential Ingestion of PAHs in Surface Soil				
AOC No. 1				
Benzo(a)anthracene	1.5E-08		1.8E-07	
Benzo(a)pyrene	1.5E-07		1.8E-06	
Benzo(b)fluoranthene	1.7E-08		2.1E-07	
Benzo(k)fluoranthene	6.5E-10		7.9E-09	
Chrysene	1.6E-09		2.0E-08	
Indeno(1,2,3cd)pyrene	4.2E-09		5.1E-08	
Fluoranthene (Child)		9.6E-06		3.5E-05
Fluoranthene (Adult)		8.1E-07		3.8E-06
Pyrene (Child)		1.2E-05		4.2E-05
Pyrene (Adult)		9.7E-07		4.5E-06
Total	1.9E-07	2.3E-05	2.3E-06	8.6E-05
AOC No. 2				
Benzo(a)anthracene	1.2E-08		1.5E-07	
Benzo(a)pyrene	1.3E-07		1.6E-06	
Benzo(b)fluoranthene	1.9E-08		2.3E-07	
Benzo(k)fluoranthene	7.1E-10		8.7E-09	
Chrysene	1.3E-09		1.6E-08	
Indeno(1,2,3cd)pyrene	7.8E-09		9.5E-07	
Fluoranthene (Child)		8.5E-06		3.1E-05
Fluoranthene (Adult)		7.1E-07		3.3E-06
Pyrene (Child)		1.1E-05		4.0E-05
Pyrene (Adult)		9.1E-07		4.3E-06
Total	1.7E-07	2.1E-05	2.9E-06	7.8E-05

Note: Calculations are shown in Attachment H3.

H11.0
SUMMARY AND CONCLUSIONS

This section briefly summarizes the results of the HHRA for OU-2 and suggests conclusions that may be drawn from the assessment.

H11.1 SUMMARY

The HHRA for RFETS OU-2 estimated health risks and annual radiation doses for current and future onsite and offsite receptors who could be exposed directly or indirectly to COCs at or released from sources in OU-2. COCs were identified as the chemicals, metals, or radionuclides in soil or groundwater that were likely to contribute at least 1 percent of overall risk. The chief COCs were Am-241 and Pu-239/240 in surface soil, subsurface soil, and groundwater and chlorinated solvents in groundwater.

Exposure scenarios evaluated were a current worker (security patrol), a future industrial/office worker, a future ecological researcher, future open space use, a construction worker, and offsite residential exposures. In addition, a hypothetical onsite residential scenario was evaluated, even though future residential development will not occur, in order to provide an upperbound estimate of risk to support risk management decisions for low-hazard areas in OU-2.

Exposure media evaluated were surface soil, subsurface soil (construction worker only), outdoor and indoor air, surface water/sediment, and groundwater (residential only).

Risks were estimated for two AOCs in OU-2. AOC No. 1 contains all of the IHSSs within the OU and includes the extent of contiguous groundwater contaminant plumes in OU-2. AOC No. 2 is east of the IHSSs and extends to Indiana Street. In addition, risks were evaluated in three maximum exposure areas: a 10-acre area at the 903 Pad Area (hypothetical resident), a 30-acre area including the 903 Pad Area (industrial/office worker scenario), and a 50-acre ecological study area including the 903 Pad Area. Annual radiation doses in terms of mrem/year were also estimated for comparison to national radiation standards.

The risk characterization process combines average and reasonable maximum estimates of exposure with upperbound estimates of toxicity to yield conservative (protective) estimates of health risk. Estimates of health risk for CT and RME conditions are provided so that risk management decisions can be based on a range of potential risk for different exposure scenarios.

Results of the risk assessment for each exposure area are summarized in Table H11-1 and described briefly below.

AOC No. 1: HIs and cancer risk estimates were below levels of concern for all current and possible future land use scenarios in AOC No. 1; those for the hypothetical resident exceeded levels of concern. These results are described below.

- The future industrial/office worker is the maximum exposed individual under current and possible future land use scenarios in AOC No. 1. Pathways evaluated were exposure to surface soil, airborne PM_{10}, and indoor VOCs from soil gas. Cumulative HIs were below 1, indicating no threat of adverse noncarcinogenic effects. RME (8E-05) and CT (3E-06) cancer risk estimates for this receptor in AOC No. 1 are within EPA's target cancer risk range of 1E-06 to 1E-04. Ingestion of Pu-239/240 in surface soil was the greatest contributor to overall risk (Attachment H3).

- Cumulative HIs were below 1 for current workers and for future ecological workers, open space users, and construction workers in AOC No. 1 indicating that no adverse noncarcinogenic health hazards are expected for these nonresidential exposure scenarios. RME cancer risk estimates for these receptors ranged from 3E-07 to 1E-05. These values are within or below EPA's target cancer risk range of 1E-06 to 1E-04. The contaminants that contributed most to estimated health risk for nonresidential onsite receptors are Pu-239/240 and Am-241 in surface soil.

- Chlorinated solvents in groundwater in AOC No. 1 would pose unacceptable risk if directly ingested (hypothetical onsite residential scenario). However,

drinking water for current onsite workers is provided by a municipal water supply, and it is expected that drinking water for future onsite receptors will also be provided from a public water supply. Therefore, ingestion of UHSU groundwater is an incomplete pathway for all current and possible future receptors in OU-2. Additionally, migration of groundwater via surface water to offsite locations is not significant, even using conservative modeling assumptions.

Maximum Exposure Areas: HIs were below levels of concern and cancer risk estimates were at or below levels of concern for future industrial/office workers and ecological researchers in 30- and 50-acre maximum exposure areas. Hazard/risk estimates for hypothetical onsite residents in a 10-acre maximum exposure area exceeded levels of concern. These results are described below.

- Chlorinated solvents in groundwater in the 10-acre maximum exposure area in AOC No.1 would pose an unacceptable risk if directly ingested (hypothetical onsite residential scenario). However, groundwater ingestion is an incomplete pathway for all current and possible future receptors in OU-2.

- Cumulative HIs were below 1 for the future industrial/office worker in the 30-acre maximum exposure area, indicating no threat of adverse noncarcinogenic effects. The CT cancer risk estimate for this receptor is within EPA's target risk range of 1E-06 to 1E-04, whereas the RME cancer risk estimate (2E-04) exceeds this range. RME cancer risk estimates for this receptor are likely to significantly overestimate actual risk because overly conservative assumptions resulted in overestimation of intake values for ingestion and inhalation of soil. Ingestion of Pu-239/240 in surface soil was the greatest contributor to overall risk (see Attachment 3). However, the concentration term for Pu-239/240 in surface soil in the 30-acre maximum exposure area was biased by an extreme value in one sample and other samples in the data set had significantly lower concentrations.

- Cumulative HIs were below 1 and cancer risk estimates were within EPA's target risk range of 1E-06 to 1E-04 for the future ecological worker in the 50-acre maximum exposure area.

AOC No. 2: Cumulative HIs were below 1 and cancer risk estimates were equal to or below 1E-06 for onsite receptors in AOC No. 2 (including the hypothetical onsite resident).

Offsite Receptors: HIs and cancer risk estimates for offsite residential receptors were negligible.

H11.2 CONCLUSIONS

The industrial/office worker is the maximum exposed individual under possible future land use scenarios at RFETS. The maximum RME cancer risk estimate for this receptor was 2E-04 (30-acre maximum exposure area). This level exceeds EPA's target cancer risk range of 1E-06 to 1E-04. This estimate of RME cancer risk very likely overestimates potential risk in the 30-acre maximum exposure area because of the overly conservative exposure assumptions (e.g., daily contact with surface soil for 25 years, with no paving, grading, or indoor work to reduce exposure).

RME cancer risk estimates for the future industrial/office worker in AOC No. 1, AOC No. 2, and for all other nonresidential receptors were within or below EPA's target cancer risk range. HIs were also below 1, indicating no adverse noncarcinogenic health effects are expected.

HIs and cancer risk estimates for offsite residents were negligible.

Concentrations of chlorinated solvents in UHSU groundwater in AOC No. 1 would pose an unacceptable risk if directly ingested. However, direct ingestion of groundwater is an incomplete exposure pathway for all current and possible future receptors in OU-2. Therefore, chemicals in groundwater do not pose a risk to human health under current and possible future land use scenarios.

TABLE H11-1*
SUMMARY OF ESTIMATED HEALTH RISKS

	Average Exposure (CT)		Reasonable Maximum Exposure (RME)	
	Carcinogenic Risk	Hazard Index	Carcinogenic Risk	Hazard Index
AOC No. 1**				
Current Worker	7E-07	2E-03	1E-05	1E-02
Future Industrial/Officer Worker	3E-06	6E-03	8E-05	4E-02
Future Ecological Worker	1E-06	5E-03	4E-06	2E-02
Future Open Space Use	2E-07	5E-04	1E-05	1E-02
Future Construction Worker	2E-07	4E-03	3E-07	2E-02
Hypothetical Resident	4E-04	2E+01	8E-03	1E+02
Maximum Exposure Areas				
Hypothetical Resident (10 Acres)	1E-03	2E+01	2E-02	2E+02
Future Industrial/Officer Worker (30 Acres)	5E-06	1E-02	2E-04	8E-02
Future Ecological Worker (50 Acres)	2E-06	8E-03	7E-06	4E-02
AOC No. 2**				
Current Worker	1E-08	3E-07	2E-07	2E-06
Future Industrial/Officer Worker	4E-08	9E-07	1E-06	1E-05
Future Ecological Worker	2E-08	2E-04	7E-08	3E-04
Future Open Space Use	6E-09	3E-05	3E-07	4E-04
Future Construction Worker	3E-08	3E-03	1E-07	2E-02
Hypothetical Resident	8E-07	1E-03	1E-05	6E-03
Offsite Receptors***				
Current Resident, Southeast	1E-09	0	2E-08	0
Current Resident, Indiana South	9E-13	0	9E-12	0
Future Resident, Walnut Cr./Indiana	8E-09	9E-05	2E-07	6E-04
Future Resident, Woman Cr./Indiana	2E-09	3E-05	6E-08	2E-04

Note:

* Same as Table H.ES-1.

** Area of concern boundaries are illustrated in Figure H2-1.

*** Results shown correspond to the higher of estimated air impacts from AOC No. 1 and AOC No. 2.

CT = Central Tendency

RME = Reasonable Maximum Exposure

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