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U-007-301.4

URANIUM SOILS INTEGRATED DEMONSTRATION TREATABILITY SAMPLING PLAN AUGUST 1991

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URANIUM SOILS INTEGRATED DEMONSTRATION TREATABILITY SAMPLING PLAN

2255

Fernald Environmental Management Project
Fernald, Ohio

August 1991

U. S. Department of Energy
Office of Technology Development
Fernald Site Office

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ACRONYMS

AEC	Atomic Energy Commission
ARAR	Applicable or Relevant and Appropriate Requirement
CAA	Clean Air Act
CBD	Commerce Business Daily
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	Department of Energy
EPA	Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FFCA	Federal Facilities Compliance Agreement
FMPC	Feed Material Production Center
FSO	Fernald Site Office
IDC	Integrated Demonstration Coordinator
ID	Integrated Demonstration
mtu	metric tons of uranium
NEPA	National Environmental Policy Act
NPL	National Priorities List
OR	Oak Ridge
OTD	Office of Technology Development
OU	Operable Unit
ppm	parts per million
pCi/g	picoCuries per gram
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RFP	Request For Proposal
RI/FS	Remedial Investigation and Feasibility Study
SARA	Superfund Amendments and Reauthorization Act
TPM	Technical Program Manager
TPO	Technical Program Officer
WBS	Work Breakdown Structure
WEMCO	Westinghouse Environmental Management Company of Ohio

1.0 Project Description

The Fernald Environmental Management Project (FEMP), previously known as the Feed Materials Production Center (FMPC), is a contractor-operated federal facility for the remediation of a site which produced high purity uranium metal for the U.S. Department of Energy (DOE). The FEMP is located on 1050 acres in a rural area approximately 18 miles northwest of downtown Cincinnati,Ohio. On July 18, 1986, a Federal Facilities Compliance Agreement (FFCA) was jointly signed by the U.S. Environmental Protection Agency (U.S. EPA) and DOE to ensure that human health and environmental impacts associated with past and present activities at the FEMP are thoroughly investigated so that appropriate remedial actions can be assessed and implemented. A Remedial Investigation/Feasibility Study (RI/FS) has been initiated to develop these remedial actions.

In order to help meet the cleanup goals of the DOE's nuclear waste sites such as the FEMP, the Director of Environmental Restoration and Waste Management for the DOE initiated the Office of Technology Development (OTD). One program initiated by OTD is the Integrated Demonstration (ID) program. The ID program focuses on improving/validating technologies by demonstrating effectiveness, cost savings, risk reduction potential, site applicability, and regulatory and public acceptance.

The objective of this sampling plan is to collect and analyze treatability samples to be utilized in the determination of the effectiveness of various technologies. The technologies will be assessed/compared under the ID program being hosted at the FEMP for the remediation of uranium contaminated soils (Uranium Soils ID).

1.1 Purpose

The purpose of this sampling plan is to describe the objectives, approach, data quality, and health and safety aspects for the treatability sampling to be conducted under the Uranium Soils ID.

The samples are to be collected under the direction of the Uranium Soils ID described in Section 1.2.1. The samples collected will be used throughout the ID for use in laboratory and bench-scale treatability tests. All data obtained under the ID will be available to the RI/FS being conducted at the FEMP and any derived benefits transferred to other DOE sites to the degree possible.

1.2 Background Information

1.2.1 Uranium Soils ID Description

IDs are being funded through the DOE OTD. The objectives of the IDs are to improve/validate remediation technologies components and systems in terms of risk-reduction, effectiveness, cost savings, regulatory, and public acceptability, and duration. The results of the ID will be transferred for implementation throughout the DOE and the Private sector. Technology transfer involves the transfer of technological information outside the Department of Energy (DOE) system (ie: the private sector, EPA, DOD, etc.). The DOE strategy for technology transfer, as noted in SEN-30-91, is to increase DOE and industrial participation in an accelerated process. OTD headquarters (EM-55) will administer directives to ensure that technological data, reported in weekly and monthly internal reports, is distributed and disseminated outside the DOE system. Vehicles for the transfer of information include, but are not limited to, publications, presentations, and information exchange conferences.

The FEMP will host an ID for the remediation of uranium contaminated soil. The ID will address the issues from "cradle to grave" surrounding the remediation of uranium contaminated soils, specifically soils of a high clay/silt content. Reduction of contaminated soil quantity, through the coupling of real time analysis and precise excavation, along with decontamination techniques applicable in high clay/silt soils will be the major technology areas. Secondary waste generation reduction, waste stabilization, cost optimization, risk reduction, and user applicability are important elements in this ID.

Innovative technologies applicable to remediation of uranium contaminated soils will be investigated throughout the DOE National Laboratory network, private industry, and universities. The ID is expected to be conducted throughout approximately three years with results feeding directly into the FEMP remediation program.

The ID has been broken into six principal tasks. These task are characterization, excavation, soil decontamination, secondary waste stream treatment/disposal, regulations, and performance assessment. Teams comprised of experts from multiple DOE sites have been formed to address each of the tasks. Representation from multiple sites provides a broader picture of soil remediation obstacles faced by DOE, a larger realm of technical inputs, and a greater potential that treatment technologies demonstrated will be adaptable to other sites.

A conceptual organizational chart for the ID is shown in Figure 1. The principal parties include: DOE-Headquarters, DOE-Oak Ridge Technical Program Officer (TPO), DOE-Fernald Site Office (FSO), Planning Review Group, FEMP Technical Program Manager (TPM), Integrated Demonstration Coordinator (IDC), and Core Group.

The Planning Review Group will be comprised of the DOE Oak Ridge TPO, DOE Fernald Site Office (FSO) representative, DOE Headquarters EM-55 representative, DOE Headquarters EM-54 representative, DOE Headquarters EM-40 representative and a representative from EPA Risk Reduction Engineering Laboratory.

The Core Group will be chaired by the Uranium Soils IDC. The leader of each task team will be a member of the Core Group representing the interest of their task. A representative from HAZWRAP, and a representative from FEMP ER program will also participate on the group.

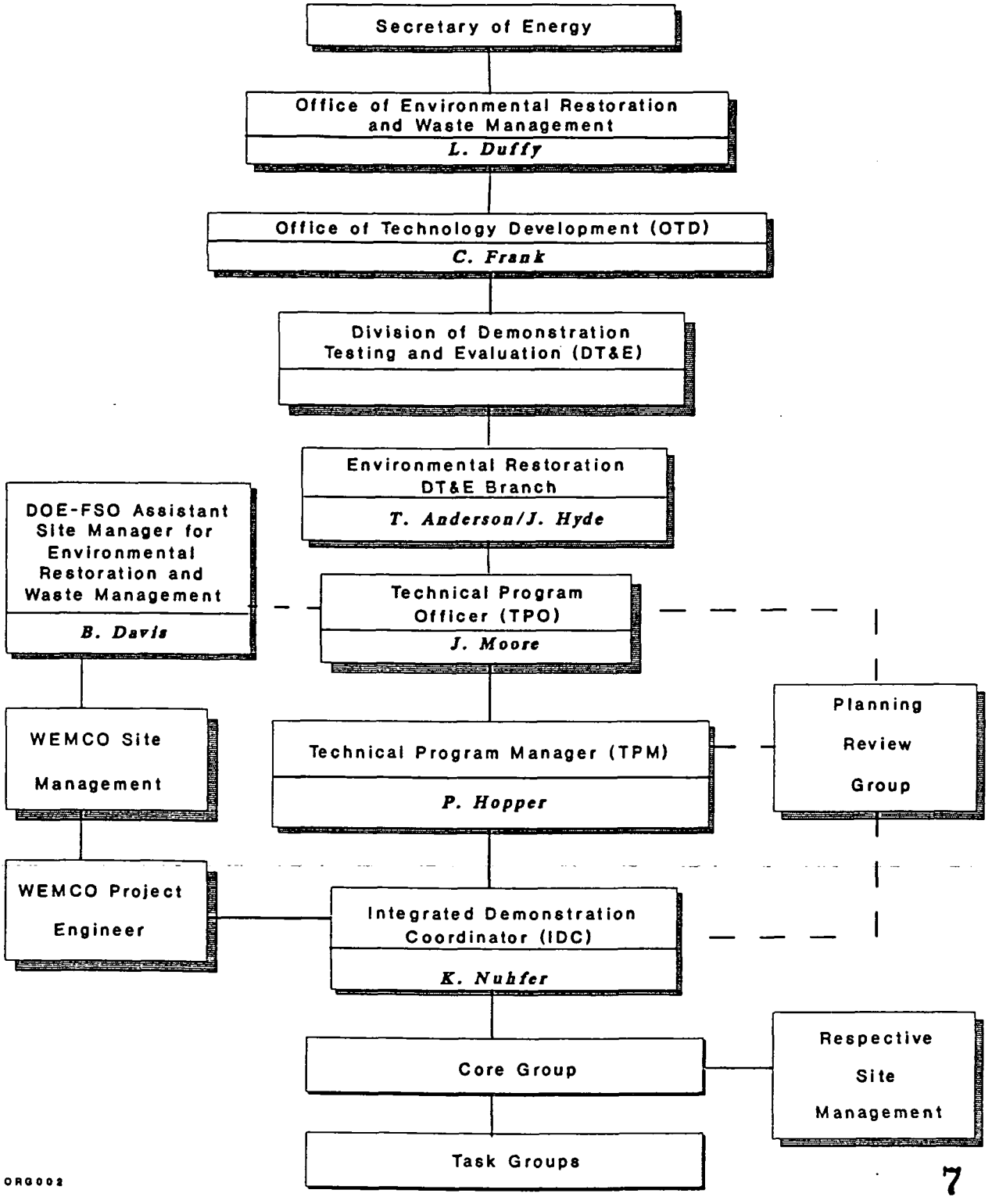
1.2.2 Site Description

The Atomic Energy Commission (AEC), predecessor to the U.S. DOE, established a production complex in the early 1950's for processing uranium and its compounds from natural uranium ore concentrates. This complex, known as the Fernald Environmental Management Project (FEMP), is located on 1050 acres in a rural area approximately 18 miles northwest of downtown Cincinnati, Ohio. The villages of Fernald, New Baltimore, Ross, Shandon, and New Haven are all located within a few miles of the plant.

The production area covers approximately 136 acres near the center of the FEMP. The production area consists of several processing plants and waste storage areas. The Pilot Plant was completed in 1951 and was the first operational facility at the FMPC. The Pilot Plant was utilized to house many different processes including thorium metal production, uranium metal production, and uranium hexafluoride reduction. Following the completion of the Pilot Plant the metals fabrication plant, Plant 6, began operations in 1952. The metal production plant, Plant 5; the greensalt plant, Plant 4; the recovery plant, Plant 8; the sampling plant, Plant 1; and the refinery (Plant 2/3) began operation in 1953. A uranium hexafluoride reduction plant, Plant 7 and the special products plant, Plant 9 were operational in 1954.

Production peaked in 1960 at approximately 10,000 metric tons of uranium (mtu) per year. A product decline began in 1964, to a low in 1975 of about 1230 mtu. During the 1970's consideration was given to closing the FEMP, therefore capital improvements and staffing were minimized. In 1981, the FEMP began to accommodate increased production requirements.

FEMP INTEGRATED TECHNOLOGY DEMONSTRATION ORGANIZATION



Production levels significantly increased and there was a rapid staff buildup for several years. Implementation of a major facilities restoration program followed. Production ceased in the summer of 1989 to focus plant resources on the environmental restoration program.

On July 18, 1986, a FFCA pertaining to environmental impacts associated with operation of the FEMP was jointly signed by DOE and the U.S. EPA. The FFCA was entered into pursuant to Executive Order 12088 (43CFR47707) to ensure compliance with existing environmental Statutes and implementing regulations such as the Clean Air Act (CAA); Resource Conservation and Recovery Act (RCRA); and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In particular, the FFCA was intended to ensure that environmental impacts associated with past and present activities at the FEMP are thoroughly and adequately investigated so that appropriate remedial response actions can be formulated, assessed, and implemented. The 1986 FFCA was amended by a Consent Agreement under section 120 and 106(a) of CERCLA. The Consent Agreement became effective on June 29, 1990 and is currently being renegotiated.

In response to the FFCA, a RI/FS is in progress pursuant to CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA). The technical strategy adopted by the CERCLA program is to divide the site into 5 distinct operable units. The components of the operable units (OU's) are:

- OU 1 - Waste Pits 1-6, Clearwell, and Burn Pit
- OU 2 - Other Waste Units (fly ash pile and Solid waste landfill)
- OU 3 - Production Area
- OU 4 - Silos 1, 2, 3, and 4
- OU 5 - Environmental Media

Contaminated soil is exist to some degree in the majority of the Operable Units. Operable Unit 1 has contaminated soil surrounding the pits as well as lining the pit and Operable Unit 4 has contaminated soil surrounding the silos. Operable Unit 2 has contaminated soil surrounding the fly ash pile and solid waste landfill. The bulk of the contaminated soil is located in the production area, Operable Unit 3. Although contaminated soil is present in all the Operable Units, all contaminated soil is being managed under Operable Unit 5.

Soils in the region of the FEMP were formed from source materials that were deposited by the action of Wisconsin and Illinoisan glaciers. These materials consist mainly of glacial till but include sand, gravel, glacial lake clays and silt clays.

Uranium is the principle contaminant of concern at the FEMP. The acceptable concentration level for uranium in soils has not been established. For planning purposes, the preliminary remedial action objective adopted under the FEMP RI/FS, 35 pCi/g, will be utilized. The majority of soils containing uranium exceeding 35 pCi/g are located in the top 1.5 feet of surficial material. With respect to surface area, approximately 50 percent of the production area soils contain contamination exceeding 35 pCi/g.

2.0 Sampling

2.1 Sampling Location and Quantity

The applicable/potential technologies for removing the uranium from the soil will depend on the current physical/chemical form of the uranium in the soil. The wide variety of uranium compounds utilized at the FEMP gives rise to a number of potential sources which may generate unique uranium waste forms in the environment. Three characteristic waste forms have been identified for use in this sampling:

- aqueous uranium waste (solubilized and absorbed)
- solid uranium product particulate (as released through spills), and
- air borne uranium waste particulate (dust, aerosols).

Five locations representing the three characteristic waste forms were selected based on information obtained from the Draft Remedial Investigation Report for Operable Unit 3 and FMPC-2082, History of FMPC Radionuclide Discharges. The five locations selected were:

1. Plant 2/3 Area
2. Plant 1 Storage Pad Area
3. Decontamination Pad/Drum Bailing Area
4. Plant 6 Area
5. Old Incinerator Area

The locations are depicted on Figure 2 and Figure 3. (Note: A removal action will soon be initiated at the Plant 1 Storage Pad Area. Depending on the status of the removal action, this area may no longer be available as a sampling location.)

In June 1991, screening samples were obtained from these five locations in accordance with the RI/FS Revised Quality Assurance Project Plan (QAPP). The objective was to determine some specific chemical physical data on the soil and uranium waste forms. A listing of the analysis, currently being completed on the screening samples at Oak Ridge National Laboratory, and the informational needs being addressed is provided in Table 1. Preliminary screening data will be

TABLE 1 Informational Needs

ANALYSIS	DATA TYPE
1) Soil pH	General soil characteristic
2) Soil color	General soil characteristic
3) Cation exchange capacity	General soil characteristic
4) Particle density	General soil characteristic
5) Bulk density	General soil characteristic
6) Extractable iron, aluminum, and manganese	General soil characteristic
7) Particle size distribution	General soil characteristic
8) Soil dispersion test	General soil characteristic
9) Soil mineralogy	General soil characteristic
10) Total uranium analysis (bulk sample)	Bulk uranium content in sample
11) Total uranium analysis (fractionated sample)	Uranium distribution by particle size
12) Magnetic separation test	Association of uranium with magnetic fraction
13) Microscopic analysis	Waste form character (adsorbed, particulate)
14) Selective dissolution test	Uranium leachability

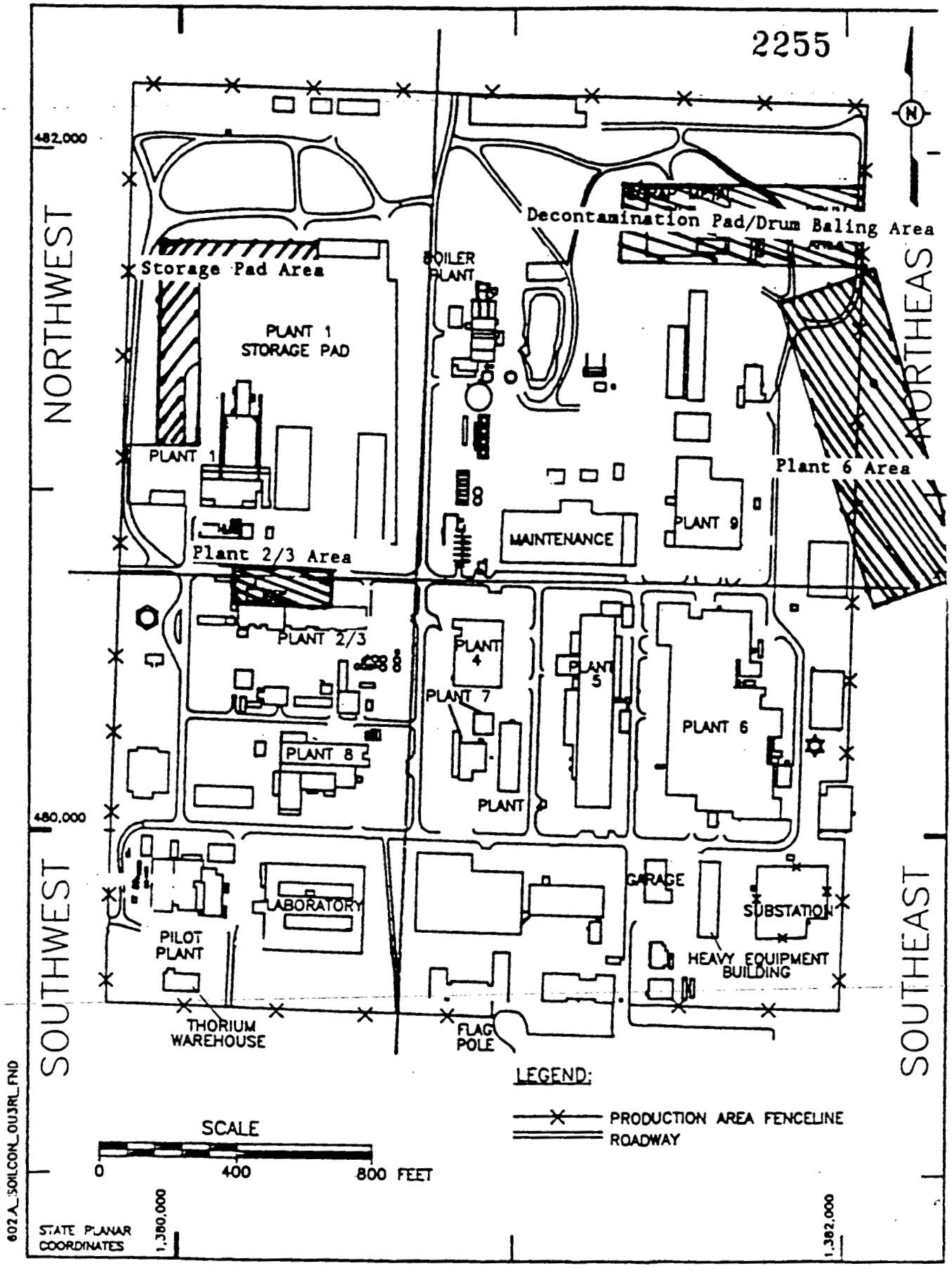


FIGURE 2 Source Areas

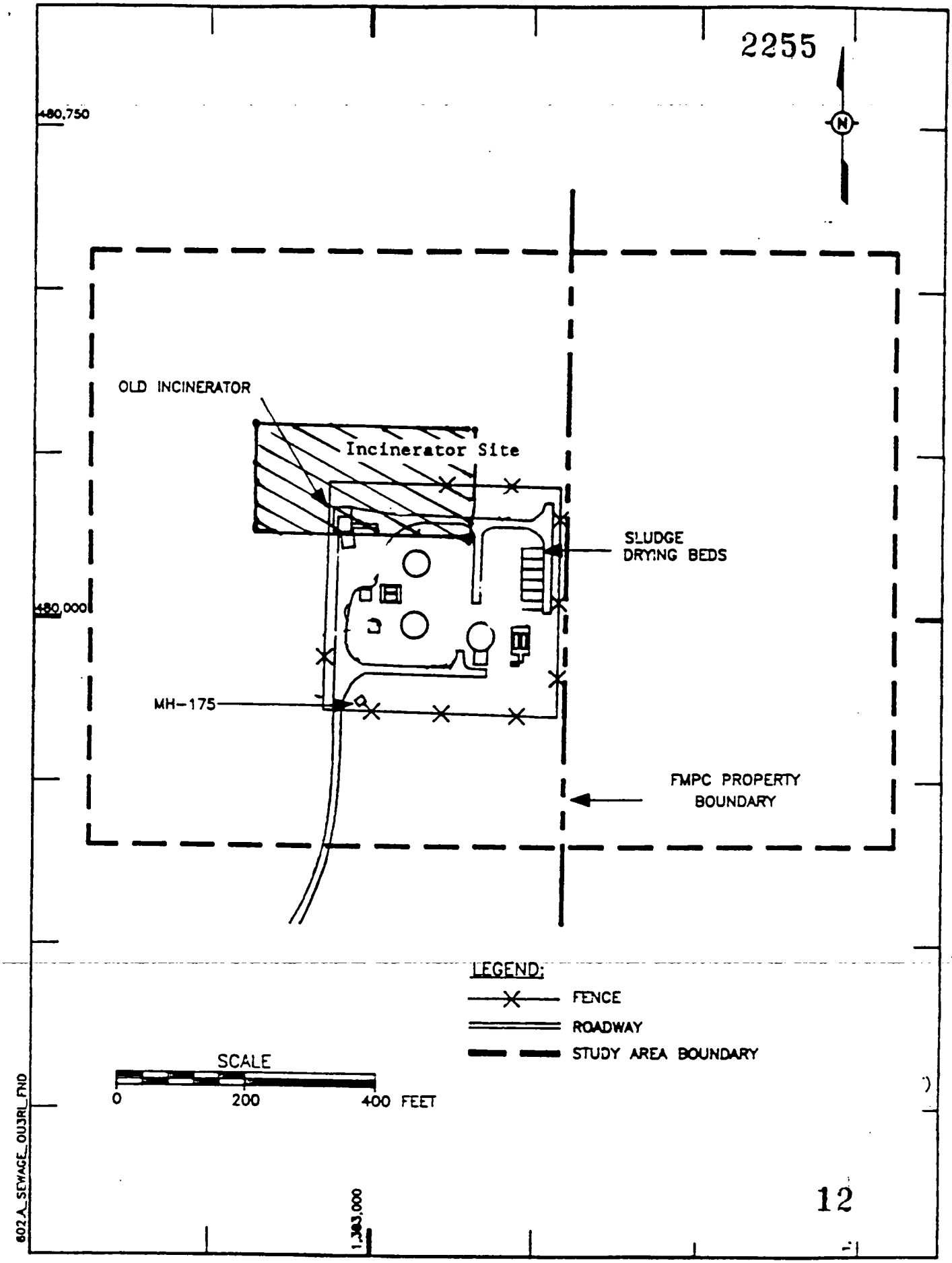


FIGURE 3 Incinerator Area

available in early September with the total analysis and report to be completed by late September. As additional information, the screening sampling plan, Phase I Sampling Plan, has been provided as Attachment 1.

The ID treatability samples will be obtained from two or more of the five sample locations on which screening data was collected. The areas selected will be based on the characterization results from the previous screening sampling and the RCRA determination completed for the potential locations. The locations selected must be classified as non-RCRA areas.

The goal is to obtain a specific quantity of material from an aqueous waste area and a particulate waste area. After the characterization results have been reviewed and the treatability sample locations have been selected, a letter will be issued stating the sampling locations and the basis for their selection. The letter will be filed as an addendum to this sampling plan. A sodium iodide detector will be utilized to focus in on uranium contaminated spots within the selected areas.

A sufficient amount of material must be collected at each area to conduct treatability tests on multiple technologies throughout the ID. It is important that the same material be used for all treatability tests so that the results will be comparable. The quantity of soil obtained at each area will be sufficient enough to fill approximately twelve 55 gal drums. The twelve drums from each area will be blended to obtain twelve "equal" homogeneous samples from each location.

2.2 Sample Equipment and Procedure

Collection of soil samples for ID treatability tests will be performed according to the revised RI/FS QAAP and the Project Specific Health and Safety Plan.

All samples will be obtained through the use of mechanical equipment such as graders or manual equipment such as shovels. A radiological survey utilizing sodium iodide detectors will be conducted in conjunction with media removal to ensure that material being removed exceeds the action level of 35 pCi/gm. The soil will then be screened to remove oversized material such as gravel and sod. The screen size to be utilized is 3/4 inch mesh. The oversize material will be segregated and stored for future analysis. After screening, the material will be blended to obtain "equal" homogenous samples representing each area.

Blending of soil (that passes through a 3/4 inch screen) will be conducted using a redi-mix cement truck or other dry

blending equipment which has been properly cleaned to assure that no debris from past operations remains. After initial blending, a screening test will be completed to estimate homogeneity among drums in order to determine if additional blending may be required.

Samples will be taken from the drums using a coring device to assure that the sample is representative over the depth. Air-dried soil samples from selected drums will be sieved using ASTM method D-2487 to classify homogeneity of sampling into three particle ranges (>2, 2-0.075, and <0.075 mm in diameter). A statistical sampling design is being prepared that outlines the number of samples required within, as well as, among drums to estimate sampling error and to determine expected homogeneity confidence levels. If the sieve analysis among soil samples taken from the drums does not meet the predetermined criteria, then the soil from the 12 drums will again be blended and the homogeneity test reapplied until the homogeneity criteria are met. Total uranium activity (by a direct counting method) will also be conducted on each sample and also particulate fraction to test for homogeneity at a predetermined confidence level.

Once the soil meets the blending criteria, each of the drums will be sampled and shipped to an RI/FS approved lab for the following analysis:

- moisture content,
- pH,
- % organic carbon,
- total uranium,
- chemical analysis for RCRA constituents (TCLP, Trichloroethane, Trichloroethylene, 2-Butanone, and Tetrachloroethylene), and
- particle-size characteristics using ASTM D-2487-90.

Depending on the technologies being evaluated, additional analysis may be conducted on the samples prior to conducting treatability test to meet the evaluation requirements. Tables 2, 3, and 4 will be used as a guide to determine analysis requirements of the specific technologies.

2.3 Sample Handling and Labeling

As each sample is collected in the field it will receive a unique five digit designator in an effort to maintain integrity between the sample and the location from which it was collected. The First designator will be T for treatability samples. The following designator will be related to the source area according to the following convention:

1 - Plant 2/3 Area
2 - Plant Storage Pad Area
3 - Decontamination Pad/Drum Baling Area

TABLE 2

CHARACTERIZATION PARAMETERS FOR BIOLOGICAL TREATMENT

Treatment technology	Matrix	Parameter	Purpose and comments
General	Soils/sludges	Physical:	
		Moisture content Field capacity pH Temperature Oxygen availability	To determine the treatability of the material and the treatment process of choice.
		Chemical:	
		Total organic carbon (TOC) Redox potential	To determine the treatability of the material and the treatment process of choice.
		Carbon:nitrogen:phosphorus ratio	To determine mineral nutrient requirements.
		Biological:	
		Soil biometer tests	To determine biodegradation potentials and to quantify biodegradation rates of contaminants.
		Electrolytic respirometer tests	This is an enrichment procedure used to measure oxygen uptake and biodegradation.
		Culture studies	To determine the indigenous microflora or specifically adapted microflora to be used in the inoculum during the enrichment procedure.
		Bacterial enumeration tests (e.g., spread-plate techniques)	To determine the bacterial population density in the inoculum.
		Microbial toxicity/growth inhibition tests	To determine biological activity in the laboratory.
	Liquids	Chemical:	
		pH Dissolved oxygen (DO) Chemical oxygen demand (COD)	To determine the treatability of the material and the treatment process of choice.
		Biological:	
		Biological oxygen demand (BOD)	To determine the treatability of the material and the treatment process of choice.
		Culture studies	To determine the indigenous microflora.
		Microbial toxicity/growth inhibition tests	To determine biological activity in the laboratory.

TABLE 3

CHARACTERIZATION PARAMETERS FOR PHYSICAL/CHEMICAL TREATMENT

Treatment technology	Matrix	Parameter	Purpose and comments
General	Soils/sludges	Physical:	
		Type, size of debris	To determine need for pretreatment.
		Dioxins/furans, radionuclides, asbestos	To determine special waste-handling procedures.
Extraction - Aqueous - Solvent - Critical fluid - Air/steam	Soils/sludges	Physical:	
		Particle-size distribution	To determine volume reduction potential, pretreatment needs, solid/liquid separability.
		Clay content	To determine adsorption characteristics of soil.
		Moisture content	To determine conductivity of air through soil.
		Chemical:	
		Organics	To determine concentration of target or interfering constituents, pretreatment needs, extraction medium.
		Metals (total)	To determine concentration of target or interfering constituents, pretreatment needs, extraction medium.
		Metals (leachable)	To determine mobility of target constituents, posttreatment needs.
		Contaminant characteristics: • Vapor pressure • Solubility • Henry's Law constant • Partition coefficient • Boiling point • Specific gravity	To aid in selection of extraction medium.
		Total organic carbon (TOC), humic acid	To determine presence of organic matter, adsorption characteristics of soil.
		Cation exchange capacity (CEC)	To determine adsorption characteristics of soil.
		pH	To determine pretreatment needs, extraction medium.
		Cyanides, sulfides, fluorides	To determine potential for generating toxic fumes at low pH.
Chemical dehalogenation	Soils/sludges	Physical:	
		Moisture content	To determine reagent requirements.
		Chemical:	
		Aromatic halides	To determine concentration of target constituents, reagent requirements.
		Metals	To determine concentration of other alkaline-reactive constituents, reagent requirements.
		pH	To determine reagent requirements.
	Liquids	Chemical:	
		Aromatic halides	To determine concentration of target constituents, reagent requirements.

(continued)

TABLE 3 (continued)

Treatment technology	Matrix	Parameter	Purpose and comments
Oxidation/ reduction	Soils/sludges	Physical:	
		Total suspended solids	To determine the need for slurrying to aid mixing.
		Chemical:	
		Chemical oxygen demand (COD)	To determine the presence of oxidizable organic matter, reagent requirements.
		Metals (Cr^{+3}, Hg, Pb, Ag)	To determine the presence of constituents that could be oxidized to more toxic or mobile forms.
		pH	To determine potential chemical interferences.
Flocculation/ sedimentation	Liquids	Physical:	
		Total suspended solids	To determine reagent requirements.
		Specific gravity of suspended solids	To determine settling velocity of suspended solids.
		Viscosity of liquid	To determine settling velocity of suspended solids.
		Chemical:	
		pH	To aid in selection of flocculating agent.
		Oil and grease	To determine need for demulsifying agents, oil/water separation.
Carbon adsorption	Liquids	Physical:	
		Total suspended solids	To determine need for pretreatment to prevent clogging.
		Chemical:	
		Organics	To determine concentration of target constituents, carbon loading rate.
		Oil and grease	To determine need for pretreatment to prevent clogging.
		Biological:	
		Microbial plate count	To determine potential for biodegradation of adsorbed organics and/or problems due to clogging or odor generation.
	Gases	Physical:	
		Particulates	To determine need for pretreatment to prevent clogging.
		Chemical:	
		Volatile organic compounds (VOCs), sulfur compounds, mercury	To determine concentration of target constituents, carbon loading rate.
Ion exchange	Liquids	Physical:	
		Total dissolved solids	To determine exhaustion rate of ion exchange resin.
		Total suspended solids	To determine need for pretreatment to prevent clogging.
		Chemical:	
		Inorganic cations and anions, phenols	To determine concentration of target constituents.
		Oil and grease	To determine need for pretreatment to prevent clogging.

(continued)

TABLE 4

CHARACTERIZATION PARAMETERS FOR IN SITU TREATMENT

Treatment technology	Matrix	Parameter	Purpose and comments
Vapor extraction - Vacuum extraction - Steam-enhanced - Hot-air-enhanced	Soils/sludges	Physical: Vapor pressure of contaminants	To estimate ease of volatilization.
		Soil permeability, porosity, particle-size distribution	To determine if the soil matrix will allow adequate air and fluid movement.
		Depth of contamination and to water table	To determine relative distance; technology applicable in vadose zone.
Solidification/stabilization (undisturbed) - Pozzolanic - Polymerization - Precipitation	Soils/sludges	Physical: Presence of subsurface barriers (e.g., drums, large objects, debris, geologic formations	To assess the feasibility of adequately delivering and mixing the S/S agents.
		Depth to first confining layer	To determine required depth of treatment.
Soil flushing - Steam/hot water - Surfactant - Solvent	Soils/sludges	Physical: Presence of subsurface barriers (e.g., drums, large objects, debris, geologic formations)	To assess the feasibility of adequately delivering the flushing solution.
		Hydraulic conductivity	To assess permeability of the soils.
		Moisture content (for vadose zone)	To calculate pore volume to determine rate of treatment.
		Soil/water partition coefficient	To assess removal efficiency and to correlate between field and theoretical calculations.
		Octanol/water partition coeffcient	To assess removal efficiency and to correlate between field and theoretical calculations.
		CEC	To evaluate potential for contaminant flushing.
		Alkalinity of soil	To estimate the likelihood of precipitation.
		Chemical: Major cation/anions present in soil	To estimate the likelihood of precipitation; to estimate potential for plugging of pore volumes.
Vitrification	Soils/sludges	Physical: Depth of contamination and water table	Technology is only applied in the unsaturated zone.
Radio-frequency heating and direct-current heating	Soils/sludges	Physical: Depth of contamination and water table	Technology is only applied in the unsaturated zone.
		Presence of metal objects	Presence of metal objects precludes application.
Electrokinetics	Soils/sludges	Physical: Hydraulic conductivity	Technology applicable in zones of low hydraulic conductivity.
		Depth to water table	Technology applicable in saturated soils.
		Chemical: Presence of soluble metal contaminants	Technology applicable to soluble metals, but not organics and insoluble metals.

(continued)

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TABLE 4 (continued)

Treatment technology	Matrix	Parameter	Purpose and comments
Microbial degradation - Aerobic	Soils/sludges	Physical: Permeability of soil	To determine ability to deliver nutrients or oxygen to matrix and to allow movement of microbes.
		Chemical/biological: Contaminant concentration and toxicity	To determine viability of microbial population in the contaminated zone.
- Anaerobic	Soils/sludges	Chemical/biological: Contaminant concentration and toxicity	To determine viability of microbial population in the contaminated zone.
Adsorption (trench)	Soils/sludges	Physical: Depth of contamination and water table	Technology applicable in saturated zone.
		Horizontal hydraulic flow rate	To determine if ground water will come into contact with adsorbent.

4 - Plant 6 Area
5 - Incinerator Site

The following two digit designator will define the drum number (01-12). The final two digit designator will be sequential for samples obtained from specific drums (1-99). An example is:

T-10203 - the third sample to be collected from the second drum of material collected from plant 2/3 area.

The drums will then be stored in a controlled area until needed for treatability tests. The controlled area will be roped off and posted indicating that material is only to be removed under direction of IDC. The drums may later be split into smaller quantities to meet the quantity needs for a particular test.

3.0 Treatability Studies

One goal of the ID is to evaluate uranium/soil separation technologies for use in the FEMP remediation as well as other DOE sites. This goal can best be achieved through the conductance of treatability test. There are three tiers of treatability test: Laboratory, bench scale, and pilot scale. The level of treatability is dependent on the development level of the technology for the particular application. Technologies which are fully developed and have been applied in equal situations may only require pilot testing to obtain full scale design information. Innovative/new technologies will require the application of all three tiers with decision points upon completion of each tier.

The soil collected under this sampling plan will be utilized throughout the ID for laboratory and bench-scale treatability tests. Some potential technologies to be evaluated through treatability test include, physical size fraction separation, chemical extraction/leaching, application of chelators, and electrokinetics. As potential technologies are identified and the treatability test needs determined, the scope of work and performance criteria will be defined and documented.

ID treatability test will be conducted on AWC/Lockeed's physical size fraction seperation process. A pilot unit is available at the DOE facility in Nevada. A work plan describing the scope of the work and performance criteria is being prepared.

4.0 Data Quality

In order to validate the technology for use in the remediation of the FEMP as well as other DOE sites, the data quality objectives currently in use in the FEMP CERCLA program will be utilized. All data will be written into standard laboratory notebooks or on to standard formatted data entry sheets. All record management and reporting will follow standard QA/QC protocol.

5.0 Health and Safety

The requirement for Health and Safety plans is dictated by OSHA Regulations (CFR 1910.120). The FEMP Site Health and Safety Plan defines the physical facilities and operations, their associated risks and required control measures. The purpose of the Health and Safety Plan is to provide the mechanisms to minimize the risk of exposure of employees to both hazardous substances and unsafe conditions.

This plan summarizes the requirements for protecting the health and safety of employees during hazardous waste operations and during hazardous substance clean-up related activities conducted at the FEMP. The requirements, designated protocols and procedures defined or referenced in this plan shall be followed by all personnel working at the FEMP where work involves clean-up and potential exposure to hazardous substances. This document is applicable to all FEMP employees, visitors, contractors, and subcontractors.

A Project/Task Specific Health and Safety plan is a complementary program element that aids in the effective control of anticipated health and safety hazards. A Project/Task Specific Health and Safety Plan will be completed and approved prior to initiating sampling activities.

6.0 Residuals Management

Residuals from ID treatability test will be returned to the FEMP along with a complete characterization. The exception will be with ID treatability tests conducted at the other DOE National Laboratories. In some cases characterization will be completed and then the waste will remain at the DOE treatability site for disposal.

7.0 Community Relations

Community relations activities shall be conducted as part of the ID in conjunction with the community relation activities

currently ongoing under the FEMP CERCLA program. Information on treatability studies conducted within the ID will be conveyed to the public through community meetings and publications. All final documents in regards to the ID treatability test will be submitted to the Administrative Record of File.

8.0 Reports

A draft report on each treatability test will be issued upon completion of that test. The final report will be completed upon the completion of test under the ID. The final report will evaluate and compare all technologies investigated.

Attachment

2255

INTEGRATED TECHNOLOGY DEMONSTRATION

REMOVAL OF URANIUM SUBSTANCES FROM SOILS

PHASE I SAMPLING PLAN

June 1991

U.S. Department of Energy
Office of Technology Development

LIST OF ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
ITD	Integrated Technology Demonstration
RI/FS	Remedial Investigation/Feasibility Study
WMCO	Westinghouse Material Company of Ohio

1.0 INTRODUCTION

1.1 Problem Statement
1.2 Objectives
1.3 Schedule

2.0 Source Areas

2.1 Sites Representative of Aqueous Releases
2.2 Sites Representative of Product Spills
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1.0 INTRODUCTION

The Fernald Site, located approximately 18 miles northwest of Cincinnati, Ohio, is a uranium production facility owned by the U.S. Department of Energy (DOE) and managed by Westinghouse Materials Company of Ohio (WMCO) under a prime contract. The Atomic Energy Commission, predecessor to the DOE, established this production complex in the early 1950's for processing uranium and its compounds from natural uranium ore concentrates. In 1989 production activities at Fernald Site were suspended and efforts concentrated on addressing environmental concerns.

In 1986 a Remedial Investigation and Feasibility Study (RI/FS) was initiated pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The goal of the RI/FS is to ensure that human health and environmental impacts associated with past releases and present activities at the Fernald Site are thoroughly and adequately investigated so that appropriate remedial response actions can be formulated, assessed, and implemented. Predicated on the Fernald Site's former mission, uranium has been identified as the contaminant of greatest concern. Releases to the air, waters, and soils surrounding the plant are known to have occurred.

In support of this RI/FS program as well as other sites faced with uranium contaminated soils remediation, an Integrated Technology Demonstration (ITD) Program has been established by the DOE Headquarters Office of Technology Development. The principal objective of this ITD is to evaluate and compare the versatility, efficiency, and economics of various technologies that may be combined into systems for the removal of uranium substances from soils (DOE 1991). Once viable remedial technologies have been demonstrated efforts will be made to transfer these technologies to the private sector as well as integrate the new technologies into the DOE system.

Because the scope of the ITD program is to address remedial alternatives for uranium contaminated soils, the Fernald Site was selected as the DOE facility for hosting the field demonstration. With the majority of uranium contaminated soils at the Fernald Site being located within Operable Unit 3 (DOE 1990) the selection of a suitable field demonstration site will focus on this Operable Unit.

1.1 PROBLEM STATEMENT

A need for basic information relative to soil properties and the nature of the uranium waste forms that are present in the soils at the Fernald Site has been identified. Such information is of need for:

- the selection of a field demonstration site or sites within Operable Unit 3,
- the preliminary screening of integrated technologies, and
- the selection of soils for use in treatability studies.

A list of the information needs may be found in Table 1.1.

TABLE 1.1: Informational Needs

ANALYSIS	DATA TYPE
1) Soil pH	General soil characteristic
2) Soil color	General soil characteristic
3) Cation exchange capacity	General soil characteristic
4) Particle density	General soil characteristic
5) Bulk density	General soil characteristic
6) Extractable iron, aluminum, and manganese	General soil characteristic
7) Particle size distribution	General soil characteristic
8) Soil dispersion test	General soil characteristic
9) Soil mineralogy	General soil characteristic
10) Total uranium analysis (bulk sample)	Bulk uranium content in sample
11) Total uranium analysis (fractionated sample)	Uranium distribution by particle size
12) Magnetic separation test	Association of uranium with magnetic fraction
13) Microscopic analysis	Waste form character (adsorbed, particulate)
14) Selective dissolution test	Uranium leachability

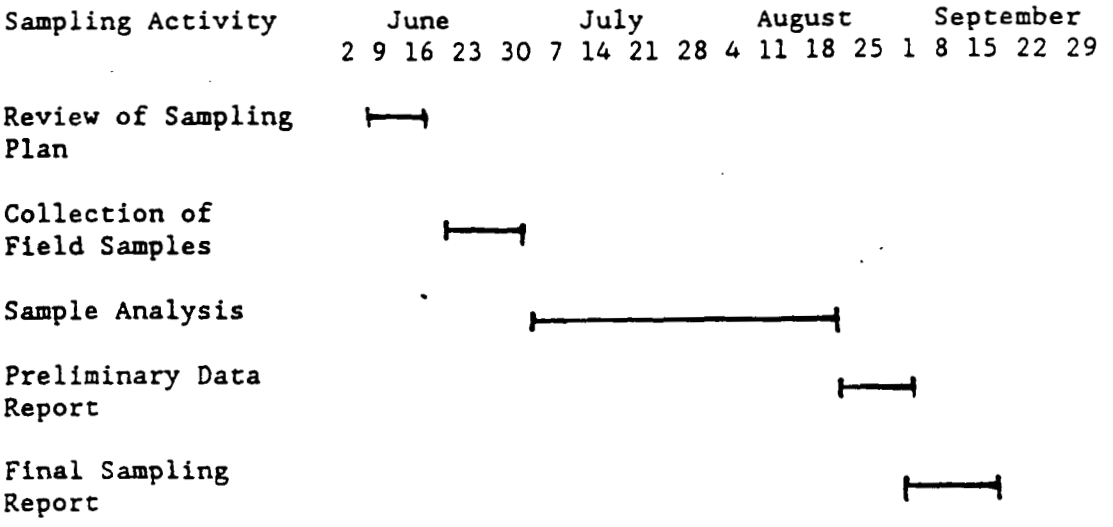
1.2 OBJECTIVES

The primary objective of the Phase I Sampling Program is to satisfy the information needs identified in Table 1.1. Because the nature of the uranium waste form is expected to vary according to the source, the identified information needs must be addressed on a "by-source" basis. For this reason source terms which have the potential to give rise to uranium waste forms of unique character must be identified. It will then be necessary to characterize each unique waste form through the collection of a minimal number of samples. It should be noted that the program is constrained to complete sampling and analysis within a two-and-a-half month period.

1.3 SCHEDULE

Activities relative to the Phase I Sampling Program will be conducted according to the schedule given in Table 1.3.

TABLE 1.3: Sampling Plan Schedule



2.0 SOURCE AREAS

A variety of chemical and metallurgical processes were utilized at the Fernald Site for the manufacture of uranium products. During the manufacturing process, high quality uranium compounds were introduced in the Fernald Site processes at several points. Impure starting materials were dissolved in nitric acid and the uranium was purified through solvent extraction using kerosene-tributyl phosphate to yield a solution of uranyl nitrate. Evaporation and heating converted the nitrate solution to uranium trioxide (UO_3) powder. This compound was reduced with hydrogen to uranium dioxide (UO_2) and then converted to uranium tetrafluoride (UF_4) by reaction with anhydrous hydrogen fluoride. Uranium metal was produced by reacting UF_4 and magnesium metal in a refractory-lined vessel. The uranium metal was then remelted with scrap uranium metal to yield a purified uranium ingot. Various uranium metalworking processes were also housed on the Fernald Site.

The wide variety of uranium compounds utilized at the Fernald Site gives rise to a number of potential sources which may generate unique uranium waste forms in the environment. Ideally, one would like to delineate potential source terms according to the various species of uranium released to the environment; however, the analysis of the uranium waste forms according to distinct species requires very complex analytical techniques which are well beyond the scope of this sampling exercise. For this reason source identification efforts for this phase of sampling will be accomplished according to the nature of the uranium waste as it was introduced into the environment. Three characteristic waste forms have been identified for use in this phase of sampling:

- aqueous uranium wastes,
- solid uranium product (as released through spills), and
- air borne uranium wastes (dust, aerosols).

Criteria for selecting sites for inclusion in the Phase 1 Sampling Program include, 1) the sites are located in Operable Unit 3, 2) soil contamination is believed to be representative of one of the three source terms given above, and 3) relatively high levels of contamination are present. Site selection relied heavily on information provided in the RI/FS Report for Operable Unit 3 (DOE 1990). Information of particular interest consisted of total uranium content of soils and perched groundwaters, and background information on past facility operations. This information allowed inferences to be drawn concerning relationships between potential source terms and areas of known soils contamination.

2.1 SITES REPRESENTATIVE OF AQUEOUS RELEASES

Two sites have been selected which are believed to be representative of soils contaminated by aqueous uranium wastes (Figure 2.1). One site is located north of Plant 2/3 while the other site is associated with the Decontamination Pad/Drum Baling area.

Plant 2/3, the refinery, is a large-scale chemical operations plant in which the following processes occurred: digestion of enriched uranium scrap residues in nitric acid to produce a uranyl nitrate feed solution, solvent extraction and purification using kerosene-tributyl phosphate, concentration of the purified

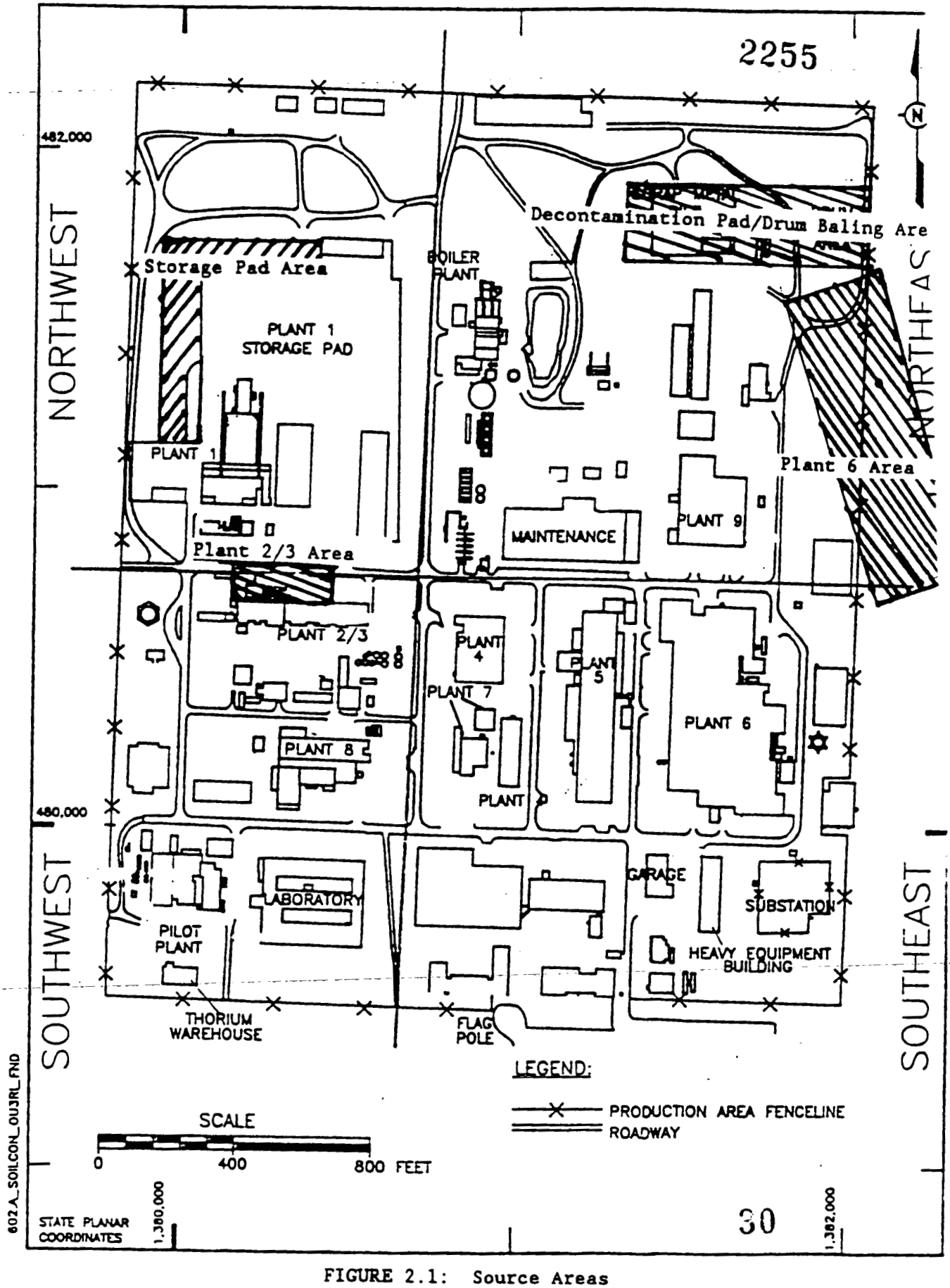


FIGURE 2.1: Source Areas

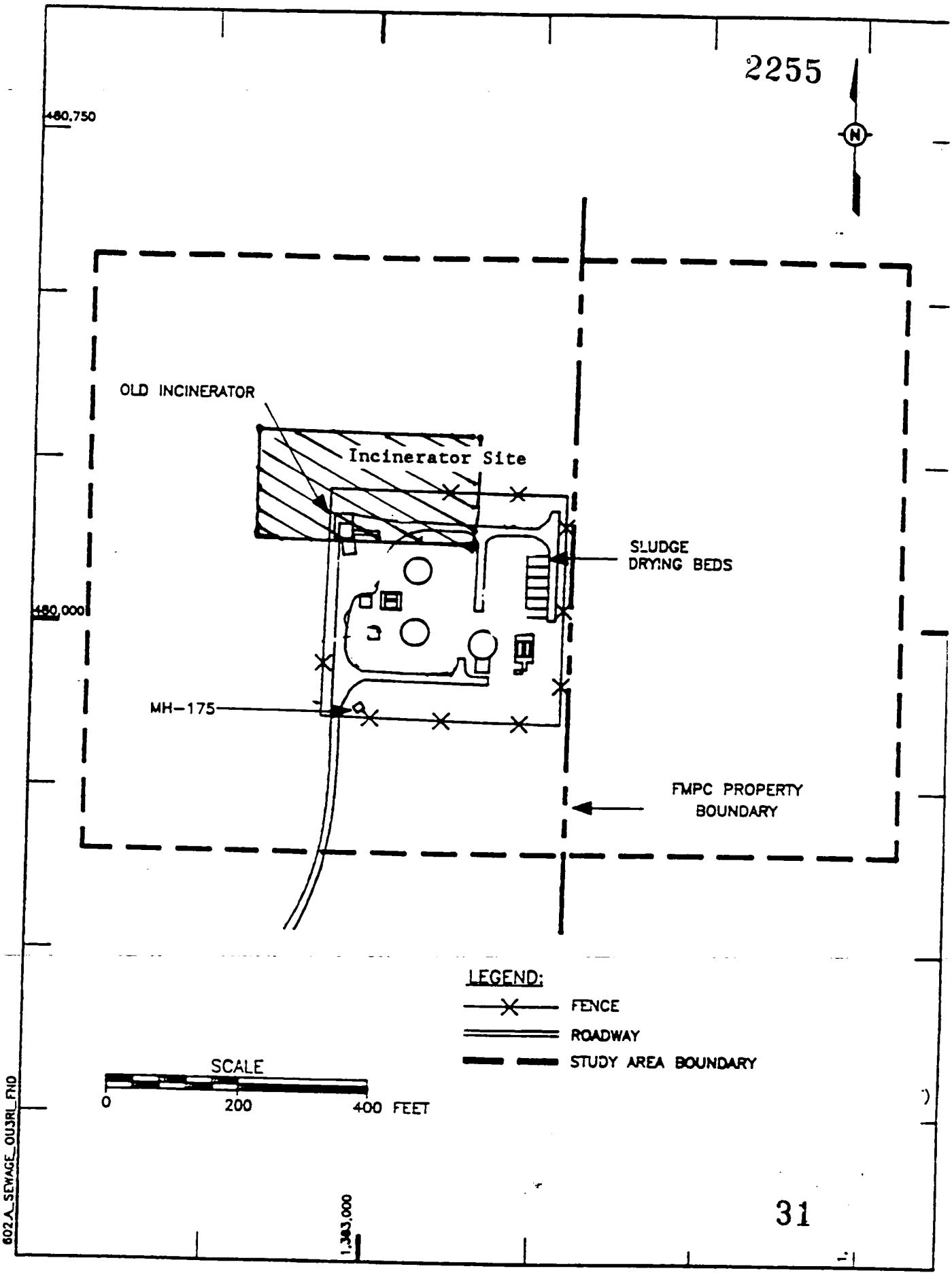


FIGURE 2.2: Incinerator Area

uranyl nitrate solution by evaporation, and thermal denitration to uranium trioxide. This information concerning the uranium processing conducted at Plant 2/3 suggests that large quantities of uranium in the aqueous phase were present at this site.

Based on sampling conducted as part of the RI/FS, soils and perched waters in the vicinity of the plant yielded elevated levels of uranium. In the area surrounding the metals dissolver, concentrations of total uranium in the soil exceed 3,000 micrograms/gram while perched water concentrations exceed 10,000 micrograms/liter (DOE 1990).

The decontamination and decommissioning building and pad areas were used primarily for decontamination and disposal activities. Materials were cleaned and reused, salvaged if possible, or placed on the metal scrap pile. Within the drum baling area are various discarded scraps and materials, and abandoned vehicles and equipment. In this area samples collected during the RI/FS suggested uranium concentrations above 240 micrograms/gram in the soils and above 100 micrograms/liter in the perched water.

This area is of particular interest because of the of the nature of the aqueous waste generated at the site and because of the potential for the mixing of uranium wastes originating from air borne and aqueous releases. Aqueous wastes generated at Plant 2/3 are predominately of a uranyl nitrate form whereas wastes generated at this site are more likely uranium oxides or hydroxides dissolved in wash-water from the decontamination of production materials.

2.2 SITES REPRESENTATIVE OF PRODUCT SPILLS

A single site has been selected for the characterization of soils contaminated by uranium product spills (Figure 2.1). The site selected is associated with the Plant 1 Drum Storage Pad. Activities that were conducted at Plant 1 and the storage pad included:

- shipping, receiving, storing, milling, and classifying depleted, normal, and enriched uranium materials, and
- the sampling and analysis of incoming materials and the storage of residues and other materials awaiting off-site shipment.

Sampling results from the RI/FS indicate uranium concentrations at levels as high as 459 micrograms/gram in perimeter soils of the storage pad and perched water concentrations on the order of 10 to 100 micrograms/liter (DOE 1990).

2.3 SITES REPRESENTATIVE OF AIR BORNE RELEASES

For the preliminary characterization of soils contaminated by uranium dusts released from plant processing and waste disposal practices, two sites have been selected; one located northeast of Plant 6 (Figure 2.1) and the other near the Incinerator Site (Figure 2.2). Surface soil contamination northeast of Plant 6 has been identified at levels exceeding 150 micrograms/gram while uranium concentrations in the incinerator area exceed 5000 micrograms/gram. Uranium concentrations in perched waters associated with each site are relatively low (10 to 100 micrograms/liter) in relation to other areas at the plant (DOE 1990).

The most probable source for the soils contamination in these areas is air borne releases from Plants 5 and 6, and the Incinerator Site. These plants housed the uranium milling and machining operations for the Fernald Site while the incinerator was used to dispose of combustible materials contaminated with uranium. Furthermore, meteorological data contained in the RI/FS Report (DOE 1990) suggest that the prevailing winds are from the southwest and west-southwest. This information coupled with a lack of significant perched water contamination suggest that uranium contamination in the soils is the result of airborne deposition.

2.4 SITES REPRESENTATIVE OF BACKGROUND CONDITIONS

In order to better interpret results gained from the Phase I sampling effort, information concerning the physical characteristics of naturally occurring uranium is needed. Although background uranium concentrations have been measured in the soils of the Greater Cincinnati Area (DOE 1989) these data provide information only on total uranium concentrations and not of the physical characteristics which is of need. Such information will allow the identification of the impact of the Fernald Site on the surface soils in the vicinity of the plant. As a preliminary step toward this goal, background soil samples will be collected and analyzed. These samples will be collected off-site in areas characterized by the same soil series and geomorphological setting as that found at the Fernald Site. Two such soil series have be selected for characterization; one of a lacustrine origin and the other of a glacial till. To aid in locating off-site soils of the desired series, the local Soil Conservation Service will be consulted.

3.0 SAMPLING PLAN

With source areas of interest defined, questions concerning the selection of sampling sites and sample analyses must be addressed. In the following sections the rationale that will be used in selecting the number of samples to be collected at each source area and their locations is given. This is followed by a description of the types of analyses that will be performed on each sample and the reasons for conducting such analyses.

3.1 SAMPLING RATIONALE

The sampling rationale for the Phase I Sampling Program is formulated according to the goals and constrains placed on the program. The primary goal of the program is to acquire basic information relative to soil properties and the nature of the uranium waste forms that are present in the soils at the Fernald Site. Such information is of need for:

- the selection of a field demonstration site or sites within Operable Unit 3,
- the preliminary screening of integrated technologies, and
- the selection of soils for use in treatability studies.

The program is constrained by the need for this information within a two-and-a-half month period. Because of this constraint the number of samples that may be collected and analyzed is limited. Correspondence with the laboratory indicate that a maximum of 8 to 12 samples may be processed within this time frame. This implies that a maximum of 2 samples may be collected at each source area with background samples being of low priority.

In order to assure that the uranium waste form associated with each of these source areas is successfully characterized, a biased sampling approach has been adopted. Sampling will be biased according to the identification of "hot spots" in the designated source areas and site-specific information needs. By sampling the "hot spots" activity levels will be of a sufficient nature to allow analyses to be performed for addressing each of the information needs identified in Table 1.1.

3.2 SELECTION OF SAMPLE LOCATIONS

A host of sources will be utilized in the biased selection of field sampling sites. These include:

- RI/FS data,
- communication with personnel knowledgeable about the Fernald Site,
- field inspection, and
- the use of real-time activity monitoring instruments.

The site selection process will begin with a survey of the identified source area. This will include locating RI/FS sampling points and borings. This will be accompanied by an effort to identify potential site specific sources such as corroded pipes or tanks, stained soil, as well as concentration points such as shallow depressions within storm water gullies. Fernald Site employees as well as RI/FS personnel will also be questioned to gain insight on past activities conducted at the site and to learn of experience gained as a result of RI/FS

field investigations. With information from the field survey and data from the RI/FS investigations, sample selection efforts will be focused onto smaller more manageable sites within the source area. Final site selection will then be accomplished by conducting a survey of these sites using a sodium-iodide scintillation detector. The sodium-iodide detector was selected because of its ability to detect low energy gamma radiation (primarily Pa-234 a decay product of U-234 and U-238) with a high degree of sensitivity.

One other criteria, site-specific information needs, was used to select sampling locations. For example, the leachability of uranium wastes originating from aqueous releases may vary considerably with depth; however, uranium contamination derived from air borne releases are expected to be concentrated in the upper horizons of the soil column. Because these concerns suggest variability in important waste form characteristics, the sampling strategy must be developed in a manner to address site-specific information needs.

Based on these two criteria soil sampling strategy will vary according to the source area. For the case of sites associated with aqueous releases (Plant 2/3 area and the Decontamination Pad/Drum Baling area) a single sampling location will be identified within the boundaries of each site. Two samples will then be collected, one from a depth of 0.0-1.5 feet and the other 1.5-3.0 feet. The sample interval is predicated on the amount of soil necessary for sample analysis and on enhancing comparison with RI/FS data. Relative to the product spill source area, two sampling locations will be identified along the northwest perimeter of the Plant 1 Storage Pad. Again each sample will be collected from an interval of 0.0-1.5 feet below ground surface. Because uranium contamination resulting from air borne releases will be concentrated in the upper few inches of the soil, samples associated with both source areas (northeast of Plant 6 and the Incinerator Site) will be collected from a depth of 0.0-0.5 feet. Within each source area two sampling locations will be selected. At each location three samples will be collected and composited to obtain the necessary quantity of soil for analysis.

3.3 SAMPLE ANALYSIS

To meet the information needs identified in Table 1.1 the following analyses will be performed. General soil characteristics such as color, pH, bulk and particle density, cation exchange capacity, and extractable iron, manganese, aluminum, and particle size distribution will be determined by standard soil analysis methods (Black et al, 1969).

To characterize the binding nature of uranium on soil particles, samples will be leached with tap water, dilute ammonium acetate and sodium carbonate solution, sodium dithionite-citrate-bicarbonate, hydroxylamine hydrochloride, dilute sodium hypochlorite, and dilute nitric acid (Jackson, 1975). Dispersivity of the soils will be tested by varying soil to solution ratio and changing solution pH.

After separation of the soils into five size fractions (> 2 mm, 2 to 0.1 mm, 0.1 to 0.05 mm, 0.05 to 0.002 mm, and < 0.002 mm), uranium activities for each fraction will be determined for establishing the uranium distribution pattern. The elemental mineralogical composition of each size fraction will be determined by inductively coupled plasma spectroscopy and x-ray diffraction analysis. Uranium and other radionuclides in the bulk soils and each size fraction will be

determined by alpha and gamma spectroscopy. For x-ray diffraction analysis, the < 0.002 mm (clay) fraction will be saturated with magnesium, potassium, and solvated glycerol, and heated to 550 degree Celsius.

The microscopic association of uranium with the soil matrix will be examined by scanning electron microscopy. Semiquantitative chemical compositions of the surface and the polished cross-sectional surfaces of the soil block will be determined by an energy dispersive x-ray analyzer attached to the scanning electron microscope. If a major portion of uranium is associated with the clay fraction, a JOEL transmission electron microscope will be utilized to determine the nature of the association (Lee, Hayden, and Alley, 1991). If uranium appears in a particulate form in the soils, the uranium particle will be isolated by the heavy liquid separation technique and then examined by scanning electron microscopy and energy dispersive x-ray spectroscopy.

4.0 PROCEDURES

In the following sections an outline of the approach to sample collection and analysis is given. Procedures relative to the collection, handling, shipping, etc., of samples for the Phase I Sampling Program will follow those procedures adopted by the RI/FS for Operable Unit 3. Sample analysis procedures, on the other hand, will follow standard analytical techniques since such analyses were not conducted as part of the RI/FS effort and thus program-specific procedures are not available.

4.1 SAMPLE COLLECTION

Collection of soil samples for the Phase I Sampling Program will be performed according to the protocols and procedures established for the RI/FS Operable Unit 3 Program, the RI/FS Quality Assurance Project Plan and the Project Specific Health and Safety Plan. The following is a brief outline of the steps that will be taken during soil sampling.

1). Locate source area as designated on Figure 2.1.
2). Perform site survey with aid of Fernald employee and personnel associated with the RI/FS effort.
3). With information gained from site survey and RI/FS Report (DOE 1990) delineate sites for sodium-iodide detector scan.
4). With aid of sodium-iodide detector make final decisions on sample locations.
5). Remove gravel or grass/organic matter from sample area.
6). Collect sample with hand driven auger. Soil sampling will be conducted in accordance with EM-EXM-90-001, Rev. 2, "Environmental Media Sampling Extraction Methodology for Using a Stainless Steel Auger and Stainless Steel Scoop."
7). The auger will be fitted with a 2 inch I.D. polybutyrate sleeve for sample collection.
8). Once sample is collected the sleeve will be cut to length of core, capped, sealed, and numbered.
9). A field description of the soil will be made and recorded in the log book along with sample location and other pertinent data.
10). The sampling location will be staked for future surveying.
11). Once sampling is complete, all samples will be packed in a cooler and shipped overnight to Oak Ridge National Laboratory for analysis.
12). Photographs will be taken during the sampling process to aid in the documentation of sampling techniques, field characteristics of the core, and the location from which it was taken.

4.2 SAMPLE ANALYSIS

Sample analysis will be conducted under the supervision of Dr. S.Y. Lee at the Oak Ridge National Laboratory. References for the analytical procedures to be utilized by the Phase I site characterization effort are given in Section 3.3. A logbook will be kept at the laboratory to record information pertinent to sample analysis as well as any deviations from standard analytical procedures.

4.3 DATA MANAGEMENT

Management of the data generated as a result of the sampling exercise will be conducted in accordance to procedures given in the Quality Assurance Project Pla for Operable Unit 3. At a minimum this will involve maintaining a complete and accurate account of all field activities in a bound notebook and submitting a complete copy of all raw and reduced data generated by this program to the Fernald Site Data Management Center.

As each sample is collected in the field it will receive a unique five digit designator in an effort to maintain integrity between the sample and the locatio from which it was collected. The first designator will be related to the source area according to the following convention:

1 - Plant 2/3 Area
2 - Storage Pad Area
3 - Decontamination Pad/Drum Baling Area
4 - Plant 6 Area
5 - Incinerator Site

The following two designators will define the sample number (sequential number from 1 to 99). The final two designators will relate to the depth of the sample interval below ground surface (as measured from the top of the interval in feet). An example is:

10200 - the second sample to be collected from the Plant 2/3 area; the sample interval is initiated at 0.0 feet below ground surface.

5.0 Summary

A Phase I Sampling Plan for the ITD Removal of Uranium Substances from Soils has been developed. The goal of the effort is to collect basic information on soil properties and uranium waste form characteristics to aid in the scoping of ITD program activities. Table 5.1 provides basic information on the number and location of the soil samples to be collected.

TABLE 5.1: SAMPLING PLAN SUMMARY

SOURCE AREA	# OF SAMPLES	DEPTH OF SAMPLES (ft)
Plant 2/3	2	0.0-1.5, 1.5-3.0
Storage Pad	2	0.0-1.5, 0.0-1.5
Decon. Pad/Drum Baling	2	0.0-1.5, 1.5-3.0
Plant 6 Area	2	0.0-0.5, 0.0-0.5
Incinerator Site	2	0.0-0.5, 0.0-0.5
Lacustrine Background	2	0.0-1.5, 1.5-3.0
Glacial Till Background	2	0.0-1.5, 1.5-3.0
Total	14	

6.0 REFERENCES

Black, C.A. et al, 1969, Methods of Soil Analysis, Agronomy No. 9, American Society of Agronomy, Madison, Wisconsin.

DOE, 1991, "Integrated Technology Demonstration; Removal of Uranium Substances from Soils Management Plan," Prepared by Westinghouse Materials Company of Ohio for the U.S. Department of Energy, March 1991, DRAFT.

DOE, 1990, "Remedial Investigation Report for Operable Unit 3," Task 6 Report, Feed Materials Production Center Fernald, Ohio, U.S. Department of Energy Oak Ridge Operations Office, December 1990, DRAFT.

DOE, 1989, Annual Environmental Report for Calender Year 1989: Feed Materials Production Center, DE-AC05-860r21600.

Jackson, M.L., 1975, Soil chemical Analysis-Advanced Course, 2nd Edition, Depart of Wisconsin, Madison, Wisconsin.

Lee, S.Y., Hayden, L.K., and Alley, P.D., 1991, "Microstructural and Mineralogical Characterization of Selected Shales in support of Nuclear Waste Repository Studies," In Microstructure of Fine-Grained Sediments, Bennet, R.H. et al (eds), Springer-Verlag, New York.