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April 17, 1995

95-RF-03469

Norma I Castaneda
Environmental Restoration Division
DOE/RFFO

TRANSMITTAL OF FINAL REMOVAL OF ACTINIDES FROM SOIL TREATABILITY
STUDY REPORT - ALP-027-95

Action None required

Enclosed is a copy of the report titled, "Final Removal of Actinides From Soil Treatability Study Report" All comments from the Department of Energy/Rocky Flats Field Office from the April 6, 1995 release of the draft report have been incorporated This is the final deliverable which marks completion of the Soil Washing Treatability Study project

If you have any questions regarding this document or the Soil Washing Treatability Study project, do not hesitate to contact Robert Brown at extension 6912

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**Removal of Actinides from Soil
Treatability Study Report**

Final Report

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

ENVIRONMENTAL RESTORATION PROGRAM DIVISION

April 1995

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ACRONYMS

Am - Americium

AEC - United States Atomic Energy Commission

Al - Aluminum

ASTM - American Society of Testing and Materials

ASME - American Society of Mechanical Engineers

ARARs - Applicable or Relevant and Appropriate Requirements

Ca - Calcium

CDPHE - Colorado Department of Public Health and Environment

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act of 1980

CESS - Chemically Enhanced Steam Stripping

Ci - Curies

cm - centimeter

COC - Chemical of Concern

cpm - counts per minute

DOE - United States Department of Energy

DOE/RFFO - Department of Energy/Rocky Flats Operations Office

dpm/g - disintegrations per minute per gram

DQO - Data Quality Objective

EA - Environmental Assessment

EE&T - Environmental Engineering and Technology

EPA - United States Environmental Protection Agency

ERM - Environmental Restoration Management

ET - Environmental Technology

FS - Feasibility Study

FSP - Field Sampling Plan

g - gram

g/l - grams per liter

GRRASP - General Radiochemistry and Routine Analytical Services Protocol

HMP - Hexametaphosphate

H&SP - Health and Safety Plan

HCl - Hydrochloric Acid

IAG - Interagency Agreement

IHSS - Individual Hazardous Substance Site

IM/IRA - Interim Measures/Interim Remedial Action

K - Potassium

kg - kilograms

l - liter

LANL - Los Alamos National Laboratory

m - meter

M - Molar

MDA - Minimum Detectable Activity

Mg - Magnesium

mg - milligrams

mg/l - milligrams per liter

ml - milliliters

mm - millimeters

mM - Millimoles

Na - Sodium

NaOH - Sodium Hydroxide

(NaPO₃)₆ - Sodium Hexametaphosphate

NEPA - National Environmental Policy Act

NH₄ - Ammonium

NRT - National Response Team

NQA 1 - Nuclear Quality Assurance, Level 1

OU - Operable Unit

pCi/g - picoCuries per gram

pCi/l - picoCuries per liter

pH - Negative log of the hydrogen ion concentration

PSZ - Perimeter Security Zone

Pu - Plutonium

QA - Quality Assurance

QAA - Quality Assurance Addenda

QA/QC - Quality Assurance/Quality Control

RCRA - Resource Conservation and Recovery Act of 1976

RFETS - Rocky Flats Environmental Technology Site

RFI/RI - RCRA Facility Investigation/Remedial Investigation

RF - Rocky Flats

TBD - To be determined

TDS - Total Dissolved Solids

TSS - Total Suspended Solids

TSWP - Treatability Study Work Plan

U - Uranium

μCi - microcuries

$\mu\text{Ci/l}$ - microcuries per liter

$\mu\text{g/l}$ - micrograms per liter

μm - micrometer

WSRIC - Waste Stream and Residue Identification and Characterization Program

1.0 INTRODUCTION

Rocky Flats Environmental Technology Site (RFETS) remediation programs are addressing the cleanup of contaminated areas for the purpose of reducing their associated risks. As a part of the process to screen and select remedial options for Operable Unit 2 (OU2) at RFETS, this treatability study was performed to evaluate a series of soil decontamination techniques and will be referred to as the "soils washing" treatability study. The soils washing study assessed the technological capability of physical separation processes to decontaminate the soil media of its actinide [plutonium (Pu) and americium (Am)] constituents. Removal of uranium, if present, was not specifically evaluated in this study. Information on the effectiveness of the processes studied, individually and in series, will be used for comparison with soil cleanup standards derived from risk reduction calculations or potential Applicable or Relevant and Appropriate Requirements (ARAR). Although the treatability study was performed to supply data for the OU2 feasibility study, the results of this effort are pertinent to soil remediation at other locations contaminated with transuranic constituents.

1.1 SITE DESCRIPTION

1.1.1 Site Name and Description

RFETS, owned by the U S Department of Energy (DOE) and operated by EG&G Rocky Flats, Inc, is located on approximately 6,550 acres in Northern Jefferson County. The facility is approximately 16 miles northwest of downtown Denver. The adjacent land use is a mixture of agriculture, open space, industry, and low density residential housing ¹

RFETS climate is semiarid with an annual precipitation of 16 inches with more than 40 percent occurring between the months of April through June ². Winds are predominately north-westerly.

RFETS is located on a alluvium with thicknesses varying between approximately 103 feet to less than 10 feet. The underlying bedrock primarily consists of claystone with some siltstones. Seismic activity for the area is low, and the potential for landslide is also low ². The surface waters of RFETS typically flow from west to east. Most of the surface waters are diverted from entering the Great Western Reservoir by pipe into the Broomfield Diversion Ditch ¹. The subsurface flow is primarily controlled by a shallow unconfined system in the alluvium. The direction of subsurface flow is controlled by topography and subcropping sandstone channels ¹. The topography slopes gradually at an average down gradient of 95 feet per mile in

an easterly direction. Approximately 20 miles to the west, the continental divide rises to an elevation exceeding 14,000 feet ¹

OU2 is located on the southeastern edge of the Rocky Flats (RF) protected security zone (PSZ). The Individual Hazardous Substance Sites (IHSSs) of OU2 are located on a relatively flat ridge between Woman Creek on the south and South Walnut Creek to the north (See Appendix A). OU2 elevations range from 5,920 feet above sea level on the southeast side of the 903 Pad Area to 5,980 feet along the top of a ridge west of the OU2 site. Drainage from OU2 is both to the south, to the South Interceptor Ditch and Woman Creek, and to the north, to South Walnut Creek ³. Currently the Resource Conservation and Recovery Act (RCRA) Facility Investigation/Remedial Investigation (RFI/RI) is being developed to investigate the nature, extent, characterization, and rate of migration of contamination from identified releases in OU2.

1.1.2 History of Operations

Construction of the Rocky Flats facility began in 1952 with a mission from the United States Atomic Energy Commission (AEC), the early predecessor to the DOE, to produce components for nuclear weapons from materials such as plutonium, uranium, beryllium, and various alloys of stainless steel. The first components were completed and shipped offsite in 1953. Processes involved in manufacturing these components were fabrication, assembly, chemical recovery and purification of transuranics from production byproducts or waste streams.

Dow Chemical Company was the first prime contractor for operations at the facility. Rockwell International replaced Dow in 1975 and operated the plant through 1989. EG&G is the current prime contractor, assuming operations in 1990 ¹.

The plant's production mission was changed in 1992 with the end of the cold war, and was renamed RFETS in 1994. Now the mission of RFETS primarily focuses on environmental restoration, waste management, and decommission and decontamination of facilities. Remedial actions principally involve the cleanup of soil and ground water, conducted according to the requirements of the Interagency Agreement between DOE, EPA and the State of Colorado, as well as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the RCRA.

Measured contamination levels of Pu and Am in soil near the 903 Pad area is the primary focus of this treatability study. Within OU2, past operations contributed to the identified contamination at the 903 Pad, Mound areas, and East Trenches. During the 1950s and 1960s, stored drums containing waste corroded over time,

allowing hazardous and radioactive material to leak into the surrounding soil. Additional dispersion has been caused by wind during removal of drums and contaminated soil.

1.1.3 Prior Removal and Remediation Activities

Drums of process waste and surface soils located in IHSS 112 (See Appendix A) have been removed to eliminate the source of contamination. The area has been excavated and capped with asphalt to prevent further migration of contaminants. This area is known as the 903 Pad. This area is restricted to prevent further migration of contaminants.

OU2's Interim Measures/Interim Remedial Action (IM/IRA) collects seep and surface water contamination sources, then treats and discharges the effluent to the surface water drainage. Operation of the field-scale treatability unit for the South Walnut Creek drainage began in May 1991. The effectiveness of the treatment process was evaluated at three locations: the influent to the treatment facility, several points within the facility, and the discharge point. Approval was granted to discontinue collection of two of the three sources due to the small amount of contamination.

A second IM/IRA was established in late 1991. This Subsurface IM/IRA Plan/Environmental Assessment encompasses the 903 Pad, the Mound Area, and the East Trenches Area of OU 2. This IM/IRA describes the process to evaluate a remediation technology for removal of residual free-phase volatile organic compound contamination at OU 2. The volatile organic compound removal actions involve an in-situ vacuum-enhanced vapor extraction technology. The interim remedial action will provide information to aid in the selection and design of final remedial actions that address subsurface, residual free-phase volatile organic compound contamination at OU 2.

1.2 Waste Stream Description

1.2.1 Waste Matrices

Treatability testing was conducted using soils collected from Plot 28 in IHSS 155. IHSS 155 is a recognized source of actinide contamination in OU2, which will make the soil sample representative of the contamination levels to be encountered during remediation and the soil composition characteristic of the area (See Table 1.2 1-1). The plot is located directly east of the 903 Pad (See Appendix A). The sampling event was conducted under the "Field Sampling Procedure for

Sampling Plutonium-Contaminated Soils to Support Treatability Tests at NRT and LANL"

Table 1.2.1-1 Composition of Soil on the East Side of the 903 Pad

Data	Sample Number	
	5-1001	5-1002
pH	7.1	7.2
Calcium	1000 µg/g	1100 µg/g
Sulfate	<500 µg/g	<500 µg/g
Specific Gravity	2.6	2.5
Total OC*	0.52	0.8
Am-241	76 pCi/g	140 pCi/g
Pu-238	3.4 pCi/g	4 pCi/g
Pu-239+240	310 pCi/g	690 pCi/g
U-233+234	0 pCi/g	1.1 pCi/g
U-235	0 pCi/g	0.1 pCi/g
U-238	2.2 pCi/g	3.2 pCi/g

* Organic carbon reported as percent carbon

Leaking drums, containing solvents, cutting oils and lathe coolants from plutonium component manufacturing, contaminated the environment at IHSS 112. The original form of the plutonium in the machine oil-carbon tetrachloride was elemental, with storage, hydrochloric acid was likely generated from the hydrolysis of carbon tetrachloride and it could have dissolved some or all of the plutonium metal. The resulting plutonium chloride could have been converted to carbonates, hydroxides, oxides, polymers, etc. The plutonium metal could also have been converted directly to one or more of these compounds via other mechanisms.

1.2.2 Pollutants/Chemicals

Several locations of known soil contamination exist at RFETS. One type of soil contamination of concern at RFETS is the incidence of radionuclide activity above natural levels. The major contributors to elevated radionuclide concentrations measured in the environment at RFETS are the actinides, Pu, Am, and U. Various transport mechanisms acting upon identified sources of actinide contamination have sometimes resulted in the migration and dispersion of that contamination. Plutonium has become a widespread contaminant in soils at RFETS and is a significant contributor to the human health risk and environmental impact estimated for the OU2 area.

1.3 Treatment Technology Description

1.3.1 Treatment Process and Scale

The soil washing treatability study involved testing a series of physical and chemical soil treatment processes to attempt complete removal of Pu and Am contaminants from the soil matrix. The physical processes, selected on the basis of capability as well as implementability, include wet sieving and attrition scrubbing. Rotary scrubbing was reexamined using residence times closer to the recommended contact time for this technology, rather than the originally studied six minute duration which resulted in unfavorable results. The use of chemical dispersants were evaluated in conjunction with the physical processes for their ability to improve the efficiency of the physical separation of the < 2-mm colloidal clay particles, referred to as micelles (microcells), from the remainder of the soil media. This effect is significant because the Pu and Am cationic complexes are attracted to the negatively charged micelles and will therefore follow them through the separation process. The intent of the physical separation procedure was to achieve a volume reduction of the contaminated media, and it was anticipated that the fine particle size soil fractions will contain the majority of the Pu and Am contamination. Chemical leaching and magnetic separation (Mag*Met) are two alternative separation processes evaluated for reducing the concentration of Pu and Am in the soil fines which were previously physically separated from the larger particle size soil fractions. Figure 1.3.1-1 graphically illustrates the experimental task plan for the Removal of Actinides from Soil Treatability Study.

The first series of soil decontamination tests consisted of wet sieving the soil into fractions representing different particle size ranges. Several combinations of wash solutions comprised of water and chemical dispersants were used during the sieving operation. Aqueous solutions of sodium hydroxide and sodium hexametaphosphate dispersants were evaluated alone and in combination. Plain water was also evaluated as a baseline for comparison purposes. Sodium ions disperse clays in water while hydroxide ions increase the negative charge exhibited by clay particles to enhance dispersion. The dispersion and swelling of clays are also affected by the type of adsorbed cations. The order of strength of dispersion is $\text{Na}^+ > \text{NH}_4^+ = \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{Al}^{3+}$, which indicates that sodium has the most pronounced effect on the swelling and/or dispersion of soil colloids.⁴ Studies have shown that calcium sulfate (>3 %) inhibits the dispersion of clay particles in soil.⁶ The soil used in this experiment was calculated to be less than 3% CaSO_4 .

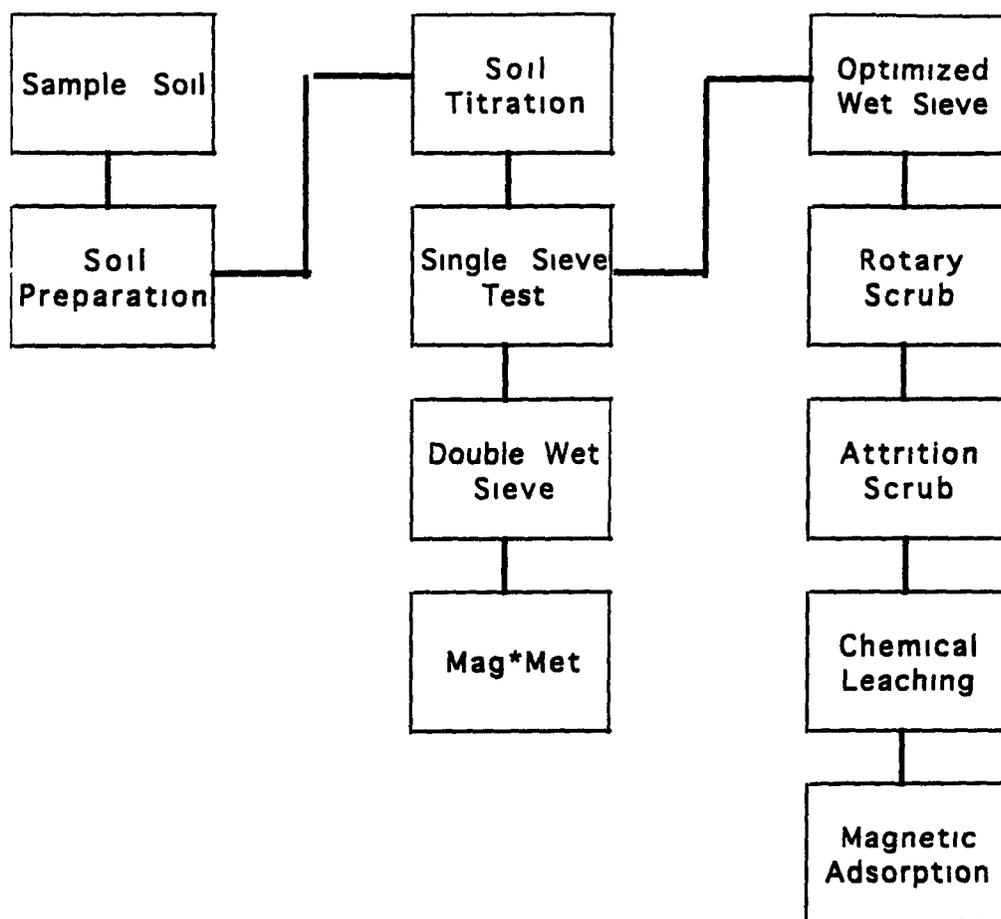


Figure 1 3.1-1 Experimental Task Plan

The soil fractions physically separated by the wet sieving operation were analyzed to determine the mass of soil distributing into each fraction as well as the partitioning of Pu and Am activity into each size fraction. The results anticipated are that some of the larger particle size fractions will yield "decontaminated" soil. Based on the lowest amount of actinide activity in these larger particle fractions, the most effective wash solution was chosen from those selected for evaluation. The remaining soil treatment processes were conducted using only the most effective wash solution identified. Wash solutions generated by the experiments were analyzed for Pu and Am content.

An additional wet sieving operation was performed to gauge the effectiveness of supplemental washing and mechanical sieving action. Data from this double wet sieving treatment process were used for comparison with the rotary and attrition scrubbing soil treatment processes, as they involved a second wet sieving procedure. Measurements of the physically separated soil fractions were repeated to determine the mass of soil distributing into each of these fractions as well as the partitioning of

the Pu and Am contaminants into each size fraction. Wash solutions were evaluated as well.

The third series of soil decontamination tests evaluated rotary scrubbing. After an initial wet sieving wash, the soil fractions were recombined and rotary-scrubbed with fresh wash solution. The purpose of recombining the soil fractions >0.063mm was to provide enhanced scrubbing action of the fine soil particles by the coarse soil particles. The rotary scrubbing experiment was performed using 8 and 18 hour residence times. Studies have shown that a minimum of eight hours mixing is recommended for the complete dispersion of clay particles in soil⁶. The 18 hour time interval was selected to encourage maximum dispersion of the clay particles in soil. In addition, the 18 hour time interval was convenient because the scrubbing could be performed overnight. The soil slurry was wet sieved after rotary scrubbing using fresh wash solution. Soil fractions and solutions were then analyzed for Pu and Am content.

A fourth series of soil treatment experiments involved attrition scrubbing. Previous soil studies at RFP showed that attrition scrubbing releases actinides most effectively from the <4.0- to 0.5-mm soil particles⁷. The soil fractions larger than 4.0-mm were not attrition-scrubbed due to the potential for damage to the scrubbing impeller. Therefore, the recombined fine soil fractions between 0.5-mm and 4.0-mm that were previously wet sieved and rotary scrubbed were then attrition scrubbed with fresh wash solution for 10 minutes at 1,000 rpm. This soil slurry was then wet sieved using fresh wash solution. Soil fractions and solutions were then analyzed for Pu and Am content.

The fifth decontamination series evaluated the "optimum" ambient chemical extractant reagent identified in the Chemically Enhanced Steam Stripping (CESS) Treatability Study in combination with rotary scrubbing for their combined ability to partition Pu and Am from the fine soil fractions, sodium citrate and sodium dithionite were identified in the CESS Treatability Study to remove 62% of Pu at ambient conditions⁸.

The soil treatment process evaluated for the sixth series of tests involved a newly developed magnetic separation procedure, the Mag*Met process for treating the fine clay particles⁹. The smaller than 0.063-mm particle size soil fraction used in the evaluation was obtained from the double wet sieve process. The size fraction was stirred for 10 minutes with a small amount of activated magnetite and magnetic iron, after which the magnetite containing the contaminants were then magnetically separated from the soil.

A separate magnetic separation process evaluated removing actinide ions from the wash solutions generated by the soil decontamination tests. In this process, the

spent wash solution was pumped through a column of magnetic adsorbent surrounded by a magnetic field ¹⁰

1.3.2 Operating Features

Figure 1 3 2-1 represents the single wet sieve bench experiment for this treatability study. Experimental trial soils were processed through this layout using various wash solutions. The bench scale process was designed to collect effluent wash solution and the partitioned soil fractions. The sized soil fractions were removed by unstacking the sieves.

A washing experiment began by placing pre-processed soil in the top sieve (after vegetation removal, homogenizing, splitting, and/or pre-scrubbing of the soil). The screen mesh number increases downward on the stack of sieves. The trial wash solution was then added into the influent container. The pump, vibrating sieve table, and timer were activated approximately the same time. The influent wash solution flow rate was maintained about 1200 ml/min. Each run was completed when the effluent discharge stopped, which took approximately 4.5 min.

After the test run was completed, the sieves were separated, and the soil fractions were removed, dried and weighed. Soil samples were taken from each size fraction. Both the soil size fractions and effluent discharge were analyzed in the inhouse laboratory. Duplicate samples were labeled and packaged for independent off-site laboratory analysis.

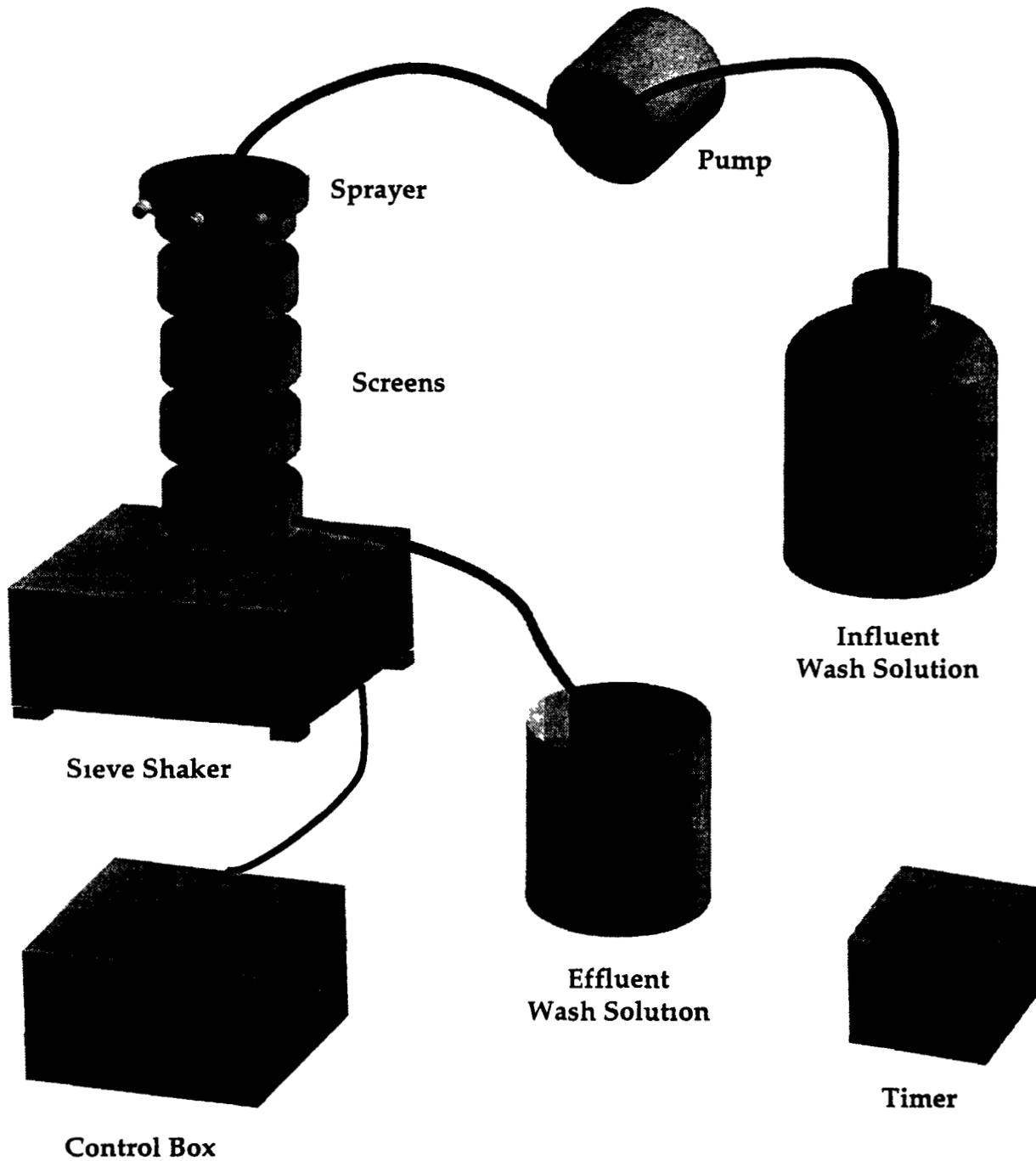


Figure 1.3.2-1 Schematic of The Wet Sieve Experiment

1.4 PREVIOUS TREATABILITY STUDIES AT THE SITE

Extensive soil decontamination studies were conducted at Rocky Flats. These studies evaluated wet and dry sieving, attrition scrubbing, rotary scrubbing, ultrasonic scrubbing, vibratory grinding, calcination, vitrification, flotation, acid leaching, hydraulic classification, and mineral jiggling^{5,7,11-16}. Various dispersants, surfactants, complexing agents, and adsorbents were incorporated into these evaluations. The most promising technologies tested were wet sieving, attrition scrubbing, vibratory grinding, hydraulic classifying, acid leaching, and the use of dispersants.

Results showed that wet sieving was effective in removing plutonium and americium from the larger soil particles, thereby concentrating the activity in the fine clay and silt fraction^{5,15,16}. Vibratory grinding was more effective at physically decontaminating Rocky Flats soil than rotary scrubbing, and sodium hydroxide solution at pH 12.5 was the best washing solution to lower actinide concentrations in RF soils¹². Recent work with wet sieving, scrubbing and a gravimetric separator (mineral jig) showed that, (1) sieving removed >98% of the activity in the <50 to 40 μ m soil fraction, representing >50wt% of the soil (2) and attrition scrubbing was better than wet sieving and rotary scrubbing in removing activity from the <40 to 0.42mm fraction. The mineral jig was effective in removing actinide-containing clays from the <0.42mm fraction¹⁴.

2 0 CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

Titration curves between pH of 8 to 12.5 showed that significant buffering regions were not present in the RF soil. Since the consumption of NaOH started to increase above pH 11, this was chosen as an intermittent pH to utilize in the washing solution evaluation, especially since it was between the starting pH of the water-soil mixture (pH 8) and the desired upper pH limit of 12.5 (RCRA limitations).

The different types of wash solutions made little difference in the amount of soil reporting to each of the size fractions. 34, 10, 24, 25, and 6 wt % reported to the <50 - 12.5, <12.5 - 4.0, <4.0 - 0.5, <0.5 - 0.063 and <0.063 mm fractions, respectively. These results are not surprising since the wash solutions used were not expected to dissolve significant amounts of soil, however, greater dispersion of the smaller particles from the larger particles could have been attributed to some properties of certain wash solutions. Actinide amounts remaining in all the fractions above 4.0 mm (except water) were within the same range (1-3 pCi/g Am and 2-11 pCi/g Pu). Therefore, hot water works about as well to decontaminate the > 4.0 mm soil size fractions as wash solutions containing phosphate and/or hydroxide ions. However, for the smallest size fraction (<0.063 mm), a 0.1 M solution of sodium hexametaphosphate (HMP) at pH of 6.5 consistently gave the lowest actinide measurements, the wash solution also contained significant amounts of activity, showing that plutonium and americium were transferred from the soil to the solution phase.

The most favorable decontamination conditions found in this study were a preliminary wet sieving with a sodium citrate/sodium dithionite solution followed by a five hour rotary scrub and a second wet screening using citrate/dithionite wash solution, these conditions decontaminated about 87 wt % of the soil to <2.4 pCi/g Pu activity and outperformed a double HMP wet sieving and a single wet sieving followed by either attrition or rotary scrubbing and a second wet sieving using HMP. The magnetic adsorption process shows promise to remove actinides from the spent wash solutions to permit recycle.

Figure 2.1-1 shows the potential removal efficiencies for a practical process flow. For the larger size fractions (>4.0 mm size fraction), HMP wet sieve process was almost as efficient in the removal of Pu and Am from the soil matrix as the citrate/dithionite rotary scrub process. The unit operations presented here are more efficient because of reagent cost and energy savings. A potential of 88% of feed had an average of 4.6 pCi/g Pu utilizing these unit operations.

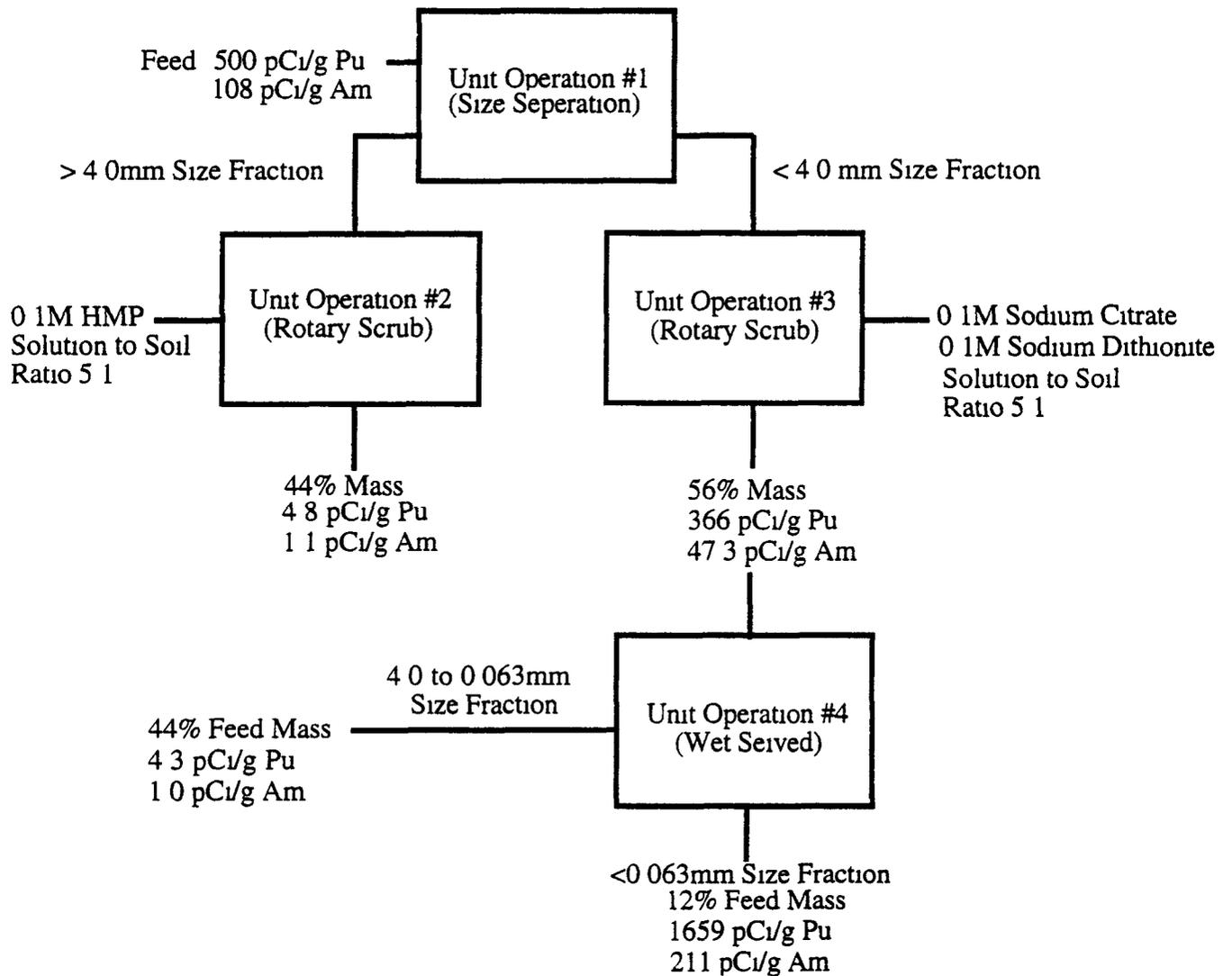


Figure 2.1-1 Conceptual Unit Operations

2.2 RECOMMENDATIONS

To simplify wash solution recycle operations and reduce waste generation, hot water rotary scrubbing followed by wet screening with hot water may be sufficient to decontaminate the >0.5 mm soil particles, further decontamination of a smaller soil fraction may require chemical processing with HMP or citrate/dithionite.

Demonstration of rotary scrubbing-wet sieving should be performed on a pilot-plant scale to evaluate performance. Decontamination of the particles between 0.5 and 0.063 mm (or smaller) needs evaluation on a pilot scale to better evaluate economics, solid-liquid separation problems and wash solution recycle. The ability of the process to treat vegetation and > 50 mm rocks, and disposition of the fine (<0.5 mm) contaminated fractions, needs to be studied as well.

Research is needed to evaluate the physical nature of actinides in RF soil to help further identify "clean" soil size fractions, since most of the activity is grouped in the less than 0.063 mm size fraction. This could be accomplished by examining colloidal particles under a high power microscope or wet sieving the soil into finer particle size discriminations.

An evaluation of actinides species before and after treatment would help identify treatment potentials for different feed stocks, since the species of actinides is the primary factor for dissolution. This would also help in relating the "Soils Washing" Treatability Study to other treatment potentials outlined in other treatability studies.

3.0 TREATABILITY STUDY APPROACH

3.1 TEST OBJECTIVES

The experimental program was designed to

- 1) Determine which of the wash solutions under evaluation was most effective for separating Pu and Am constituents from the contaminated soil matrix,
- 2) Evaluate the effectiveness of wet sieving for separating Pu and Am from the remainder of the soil matrix,
- 3) Evaluate the effect of rotary scrub operations on the separation of Pu and Am from soil media,
- 4) Evaluate the effectiveness of attrition scrubbing for removing Pu and Am from the 40- to 0.5-mm soil fraction,
- 5) Evaluate the effectiveness of chemical leaching agents to solubilize Pu and Am from the <40-mm soil fraction,
- 6) Evaluate the effectiveness of magnetic adsorbents for removing Pu and Am from the <0.063-mm soil fraction and the wash solution used,
- 7) Evaluate the effectiveness of magnetic adsorbents for removing Pu and Am from a selected spent aqueous solution generated by soil washing,
- 8) Optimize soil treatment processes and conditions in anticipation of scaling-up activities for a soil remediation pilot plant operation, and,
- 9) Determine the reduction levels of Pu and Am activity that can be reached utilizing chemical and physical separation technologies

3.2 EXPERIMENTAL DESIGN AND PROCEDURES

3.2.1 Soil Preparation

Approximately 25 kg of soil (<50 0-mm) for the experimental program was supplied through the Sitewide Treatability Studies Soil Sampling Program. The soil sample was spread out to dry for several days at ambient room temperature (22-24 °C) to its approximate surface-dry condition. The dried soil sample was dry sieved into two fractions (<50 0- to 12 5-mm and <12 5-mm) and weighed to determine the weight percent of total mass contained in each fraction. The <50 0- to 12 5-mm soil was then coned and quartered and the <12 5-mm soil was split with a riffle splitter. Proportional amounts of both the cone/quartered and riffle split soil fractions were then recombined for use in the soil decontamination tests.

3.2.2 Soil Characterization

3.2.2.1 Soil Analysis

A sample of the prepared soil was sent to an off-site laboratory for an initial soil characterization analyses including plutonium, americium, and uranium, as well as specific gravity, pH, total organic carbon, and calcium sulfate.

3.2.2.2 Soil pH Titrations

Soil pH titrations were performed to determine the buffering capacity of the soil, or the resistance of the soil pH to change. This information was used to estimate the amount of 1.0M NaOH required to produce a change in soil pH during processing. The tests were used to develop a curve which graphically describes the buffering capacity behavior of the soil and to determine the upper and lower pH values which define the limits of the region of maximum soil buffering capacity on the curve. This was accomplished by titrating 10 grams of soil (<4.0-mm) at a soil-to-solution mass ratio of 1:4 (with stirring) with 1.0 M NaOH solution and monitoring the pH. The titration procedure was repeated using 1.0M NaOH plus 0.1M HMP solution.

3.2.3 Soil Decontamination Tests

3.2.3.1 Wet Sieve Tests

Each wet sieve test was performed with a Tyler Model RX-24 sieve shaker and U S Standard sieves (20-cm diameter) A sieve lid (with spray head) and bottom pan (with drain tube) were used in conjunction with the sieves In addition, a Masterflex peristaltic pump as well as a supply reservoir and receiving vessel (4-liter containers) completed the wet sieving system

Four wet sieve tests were conducted, each using 500 grams of soil with 2.5 liters of wash solution The wash solutions evaluated were

- 1 Water both room (22-24°C) and elevated (60-80°C) temperatures,
- 2 0.1M sodium hexametaphosphate (NaPO_3)₆ solution,
- 3 Sodium hydroxide (NaOH) solution Two tests one at the upper pH limit and one at the lower pH limit identified during titration tests, and,
- 4 NaOH - 0.1M (NaPO_3)₆ solution Two tests upper and lower pH limits,

The soil was wet sieved into five fractions (<50 to 12.5 mm, <12.5 to 4.0 mm, <4.0 to 0.5 mm, <0.5 to 0.063 mm, and <0.063 mm) Each of the soil fractions were dried at ambient temperature and weighed Samples of the soil fractions was collected and sent to the independent laboratory for Pu^{239,240} and Am²⁴¹ analysis Samples were analyzed in-house for Am

The spent wash solutions from the wet sieve operations were filtered through coarse (Whatman No. 41 or 20-25 μm) and fine (Whatman No. 42 or 2.5 μm) paper A portion of these wash solutions was syringe filtered through a 0.2 μm membrane, and samples of the collected wash solution were sent to the offsite laboratory for Pu^{239,240} and Am²⁴¹ analysis Samples were analyzed in-house for Am

3.2.3.2 Double Wet Sieve Tests

A subsequent wet sieve test was performed using 500 grams of soil (from the recombined fractions of the previous sieving process, which identified the most effective wash solution) and an additional 2.5 liters of the fresh wash solution The second sieving operation separated the soil into five particle size fractions (<50 to 12.5-mm, <12.5- to 4.0-mm, <4.0- to 0.5-mm, <0.5- to 0.063-mm, and <0.063-mm) Each of these fractions were dried and weighed Samples of the soil fractions and

long), packed with a 10 cm plug of fine No 431 stainless steel wool, was placed between the pole faces of an electromagnet, with the bottom portion of the stainless steel wool plug aligned with the electromagnet. The bottom of the column had a Teflon stopcock (2 mm bore) and was secured at the top with a one hole (6 mm i d) rubber stopper, fitted with a glass tube (6 mm o d x 5 cm). Tygon tubing (6 mm i d) was attached to both ends of the column.

The magnetic adsorbent (200 g) was activated by stirring the adsorbent with 200 ml of sodium hydroxide (pH 12.0) solution for 10 minutes at 200 rpm. The adsorbent slurry was pumped up-flow at 10 ml per minute by a peristaltic pump into the glass column while a field strength of 0.3 Tesla (3,000 Gauss) was applied to the electromagnet. The pH of the spent wash solution was adjusted to 10-12. The spent wash solution was then pumped through the column up-flow at 10 ml per minute while a field strength of 0.3 Tesla was applied to the electromagnet. A quantity of effluent equal to the system volume was collected and discarded prior to collecting the first sample. The column effluent was then collected and sent to the laboratory for Pu^{239,240} and Am²⁴¹ analysis. Solutions generated during the experiment were filtered and sampled as described in Section 3.2.3.1.

3.3 EQUIPMENT AND REAGENTS

3.3.1 Equipment

- a U S standard sieves (20-cm diameter) in the following sieve sizes 50 0-mm, 12 5-mm, 4 0-mm, 0 5-mm, and 0 063-mm,
- b Sieve lid with spray head and bottom pan with drain tube,
- c Tyler Model RX-24 sieve shaker,
- d Masterflex peristaltic pumps,
- e P K "Yoke" Twin Shell® blender, Model LB-4229,
- f U S Stoneware rotary jar mill,
- g Tube rotator, Glas-Col, RD-250;
- h Denver Model D-12 attrition scrubber,
- i ANAC Model 3470 laboratory electromagnet and power supply,

-
- j Top loading balance, Mettler PC440,
 - k Nuclear Measurements Corporation PC-5 proportional alpha counter,
 - l Canberra Series 80 multichannel analyzer in conjunction with a Phoswich-type (NaI) detector,
 - m Canberra Series 100 multichannel analyzer in conjunction with a Phoswich-type (NaI) detector,
 - n Damon model HT centrifuge,
 - o Thermolyne type 1400 drying oven,
 - p Sample splitter, Humboldt Splitter, model # H-3971, H-3962, and H-3987,
 - q Corning Model 7 pH meter,
 - r pH probe, Ag/AgCl, Single function with standard connector,
 - s Balance, Dial-O-Gram Model H-4835, and,
 - t Glass and plastic ware (e g , beakers, cylinders, and pipette tips)

3.3.2 Reagents

- a Sodium hydroxide, Baker Analyzed, Reagent Grade,
- b Sodium hexametaphosphate, Baker Analyzed, Reagent Grade,
- c Sodium citrate, Mallinckrodt, Reagent Grade,
- d Sodium dithionite, Baker Analyzed, Reagent Grade,
- e Ascorbic acid, Mereck, U S P
- f Magnetite, Write Industries Inc , Type 012672,
- g Magnetic resin, Synthesized by R L Kochen,
- h Nitric acid, Mallinckrodt, Reagent Grade, and,
- i Powdered iron, Baker Analyzed, Reagent Grade

3.4 SAMPLING AND ANALYSIS

The initial soil supply and the treated soils were sampled for analysis by the cone/quarterming and/or riffle splitting methods as appropriate for the particle size fraction samples collected. Soil sampling techniques were performed in accordance with ASTM Designation C 702-87 specifications. Sampling activities were performed by EG&G RF personnel using EG&G Standard Operating Procedures (Appendix A, OSA 779 066) for sample designation, handling, shipping, and documentation requirements. A chain of custody form was utilized in transferring samples from RF to the analytical lab.

The soil fractions and solution samples were screened for Am²⁴¹ using a Canberra multichannel analyzer and Pu²³⁹ using a proportional alpha counter within Room 139 of Building 779 by EG&G RF personnel prior to packaging and shipment to the analytical laboratory for analysis. This provided a guideline for the number and size of samples that can be sent at one time to the analytical laboratory for actinide analyses. In addition, the liquid samples were stabilized prior to packaging with nitric acid to a pH of 2.

Soil and solution sample analyses were performed by Accu-Lab® Research, Inc. The analytical laboratory followed the General Radiochemistry and Routine Analytical Services Protocol and used EPA approved methods.

3.4.1 Waste Streams

All excess soil and wash solutions were disposed of as specified in the Waste Stream and Residue Identification and Characterization Program (WSRIC) documentation. This process is described in the Building 779 WSRIC manual. The soil and solution samples sent off-site for analysis were properly disposed of by the contract analytical laboratory. None of the solids or solutions are RCRA regulated. Ultimately, there was 25 kg of soil and 150 liters of solution requiring disposal. The other waste generated (e.g., dry combustibles, glass, plastic) occupied less than a 55-gallon drum. The waste generators are responsible for disposal of the solid and aqueous wastes generated. All sludge and residual waste shipments complied with the provisions of the Federal Treatability Study Exemption Rule (see Section 3.9 to "Guide for Conducting Treatability Studies Under CERCLA"). Disposal of materials at the source site was in accordance with the requirements of CERCLA, RCRA, federal, state and RFETS waste management practices.

All efforts were taken to minimize the quantity of contaminated or potentially contaminated debris. Efforts included minimizing the use of disposable materials.

Glassware, which can normally be decontaminated and reused for other treatability studies, were used for bench-scale testing. Porous media such as clothing and paper towels were evaluated for disposal as low level radioactive waste.

3.4.2 Treatment Process

The experimental program was designed to determine which of the wash solutions under evaluation was most effective for separating Pu and Am constituents from the contaminated soil matrix, evaluate the effectiveness of wet sieving for separating Pu and Am from the remainder of the soil matrix, evaluate the rotary scrub operation on separation of Pu and Am from soil media, evaluate the effectiveness of attrition scrubbing for removing Pu and Am from the 40- to 0.5-mm soil fraction, evaluate the effectiveness of a chemical leaching agent in combination with rotary scrub processing for their ability to desorb Pu and Am from <40-mm soil fraction, evaluate the effectiveness of a magnetic process for removing Pu and Am from the <0.063-mm soil fraction, evaluate the effectiveness of magnetic adsorbents for removing Pu and Am from spent aqueous solutions generated by soil washing, and, determine the levels of Pu and Am activity to which the soil treatment processes tested are technologically capable of reducing contamination in RF soil.

The Treatment process is outlined in Section 1.3.1.

3.5 DATA MANAGEMENT

All procedures used in the treatability study were documented in project data book 2419. Observations made during the study were recorded in a bound laboratory notebook. The project and laboratory notebooks for this study were specific to this project. The treatability study logbooks documented the following at a level of detail sufficient to allow another qualified researcher to retrace the investigation and confirm the results:

- Testing procedures,
- Departure from protocols, and the reasons for departures,
- Instrument calibrations,
- Sampling methods,
- Chemical additions, and,
- Test observations

All samples received and generated during this study were labeled with unique sample identification numbers. In addition to the unique sample numbers, the

source of each sample was documented. A complete history of all samples from collection through transportation to receipt, testing or analysis, and disposition at the laboratory recorded in the project book. Each experimental soil sample was accompanied by documentation on the sample transmittal form describing the sample collection location and method, pertinent observations, personnel involved, date of collection, any sample preservation performed, containers used, etc.

3.6 DEVIATIONS FROM WORK PLAN

There were several deviations from the original Work Plan since the commencement of this treatability study. These rational deviations were required to allow the study to progress logically forward. After deliberation with the Removal of Actinides From Soil Treatability Study Team, it was determined that all test objectives would still be met.

The first deviation from the Work Plan was to reduce the soil test size from 1000 grams to about 500 grams. This was necessary because of the reduced soil sample size from the first soil sampling event. The soil sample size was reduced when all of the vegetation was eliminated from the soil sample. Reducing the sample size does not influence the partitioning of the soil during wet sieving operations. To maintain consistency, all test runs used this reduced sample size.

The second deviation from the Work Plan was the introduction of a flocculent (Purifloc). After filtering the wash solution through Whatman #42 filter paper, the researcher noticed the presence of suspended solids remaining in the filtrate. Flocculent was added to enhance the separation of these suspended soils from solution. The flocculent was added to the solution at 2 ppb. The flocculent and flocculated dissolved soils did not add significantly to the weight for the less than 0.063 mm soil fraction size.

The chemical leaching experiments were changed to avoid a duplication of work from the CESS Treatability Study, which also evaluated leaching reagents. The chemical leaching experiment was combined both with wet sieve and rotary scrub processing to evaluate both physical and chemical separation processes in series. The scrub solution utilized the most attractive reagent(s) identified during the CESS Treatability Study.⁸

Finally, an additional experimental run was performed that was not part of the original Work Plan. This test run was performed with water wash at an elevated temperature (60 to 80 °C). This experimental run gave more insight into the effects of elevated temperatures which could be encountered during field operations.

4.0 RESULTS AND DISCUSSIONS

4.1 DATA ANALYSIS AND INTERPRETATION

Data presented herein were interpreted in accordance with Section 3.11 of The Guidance for Conducting Treatability Studies under CERCLA (EPA 1992)

4.1.1 pH Titration Curves

Soil pH titration curves were established by adding NaOH solutions to beakers containing 40 ml of de-ionized water and 20 grams of RF soil. The pH changes were then monitored. The data obtained were then used to construct pH titration curves, i.e., pH versus volume of sodium hydroxide added. Figures 4.1.1-1 and 4.1.1-2 show representative pH titration curves using 1.0 M NaOH and 1.0 M NaOH-0.1 M sodium hexametaphosphate solutions, respectively.

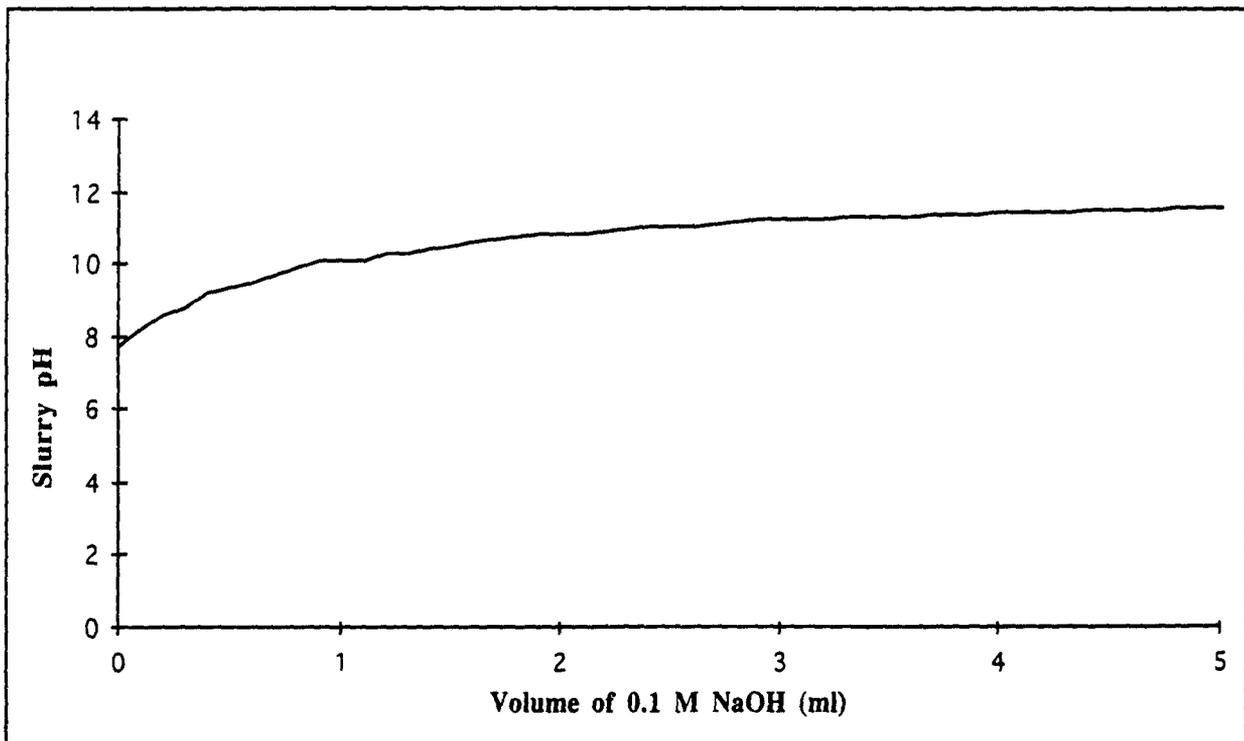


Figure 4.1.1-1 Soil Titration Curve (1.0 M NaOH)

The purpose of constructing the curves was to explore if there was a region between pH of 8 to 12.5 where there would be little change in pH with sodium hydroxide addition, i.e., a buffering region. The data shown in the figures, of which duplicate experiments were in excellent agreement, show that buffering regions were not present. Figure 4.1.1-1 shows that only 0.2 millimoles of sodium hydroxide (0.2 ml NaOH multiplied times 1.0 M NaOH) was required to reach a pH of 11.0, but 2.0 millimoles of NaOH were needed to reach a pH of 12.5.

Since the consumption of NaOH started to increase above pH 11, this was chosen as an intermittent pH to utilize in a washing solution, especially since it was between the starting pH of the water-soil mixture (pH 8) and the desired upper limit (pH of 12.5). The pH of 0.1 M HMP was about six and considered a lower operating limit to avoid excess dissolution of soil constituents such as aluminum, calcium, iron, etc.

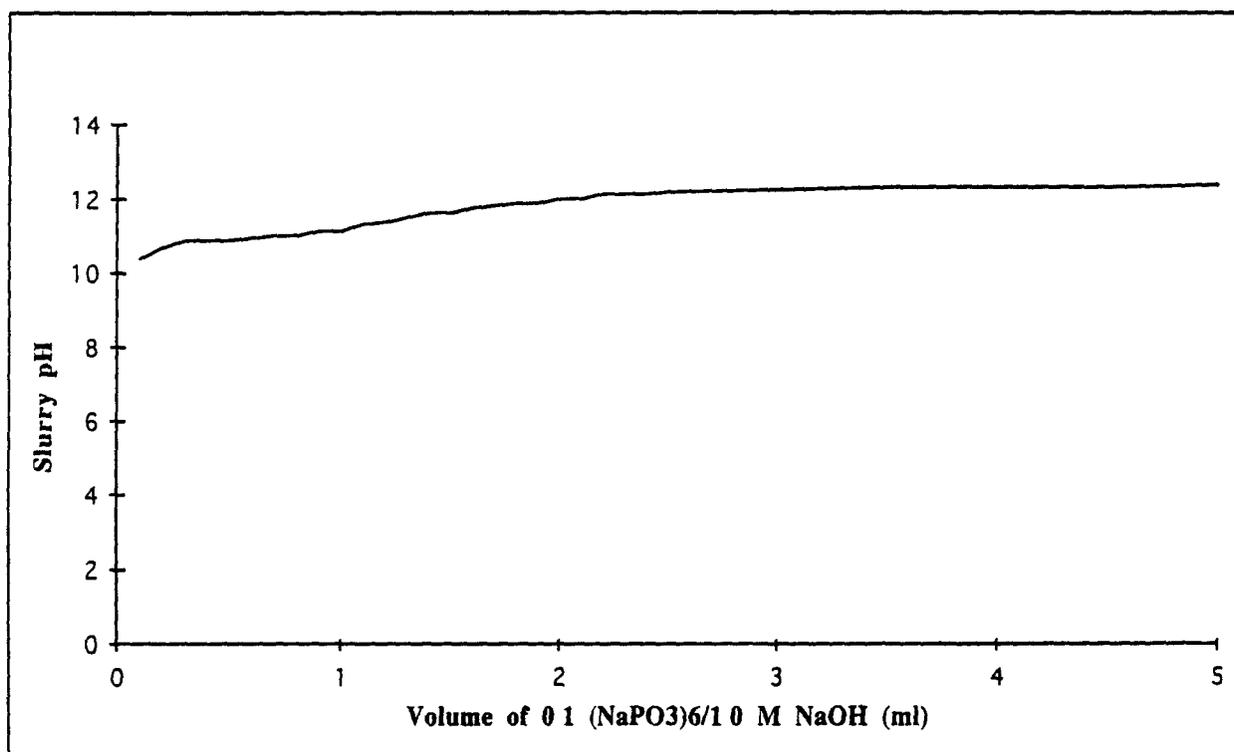


Figure 4.1.1-2 Soil Titration Curve ((NaPO₃)₆-1.0 M NaOH)

4.1.2 Evaluation of Wash Solutions

The data presented in Figure 4.1.2-1 show that the different wash solutions tried, made little difference in the percent soil reporting to each of the size fractions. As expected, there was no significant soil dissolution or dispersion between the wash

solutions However, greater dispersion of the smaller particles from the larger particles could have been attributed to the characteristics of some of the reagents Essentially 33-34 wt % of the soil reported to the <50 to 12.5 mm fraction, 9-11% to the <12.5 to 4.0 mm fraction, 24-25% to the <4.0 to 0.5 mm fraction, 23-27% to the <0.5 to 0.063 mm fraction, and 5-8% to the 0.063 mm fraction These data are in good agreement with previous washing studies of RF soil ⁵

HMP has excellent soil dispersion and deflocculation properties and keeps calcium, magnesium, and iron salts including, CaCO₃ and CaCO₄, from interfering with the wet sieving process

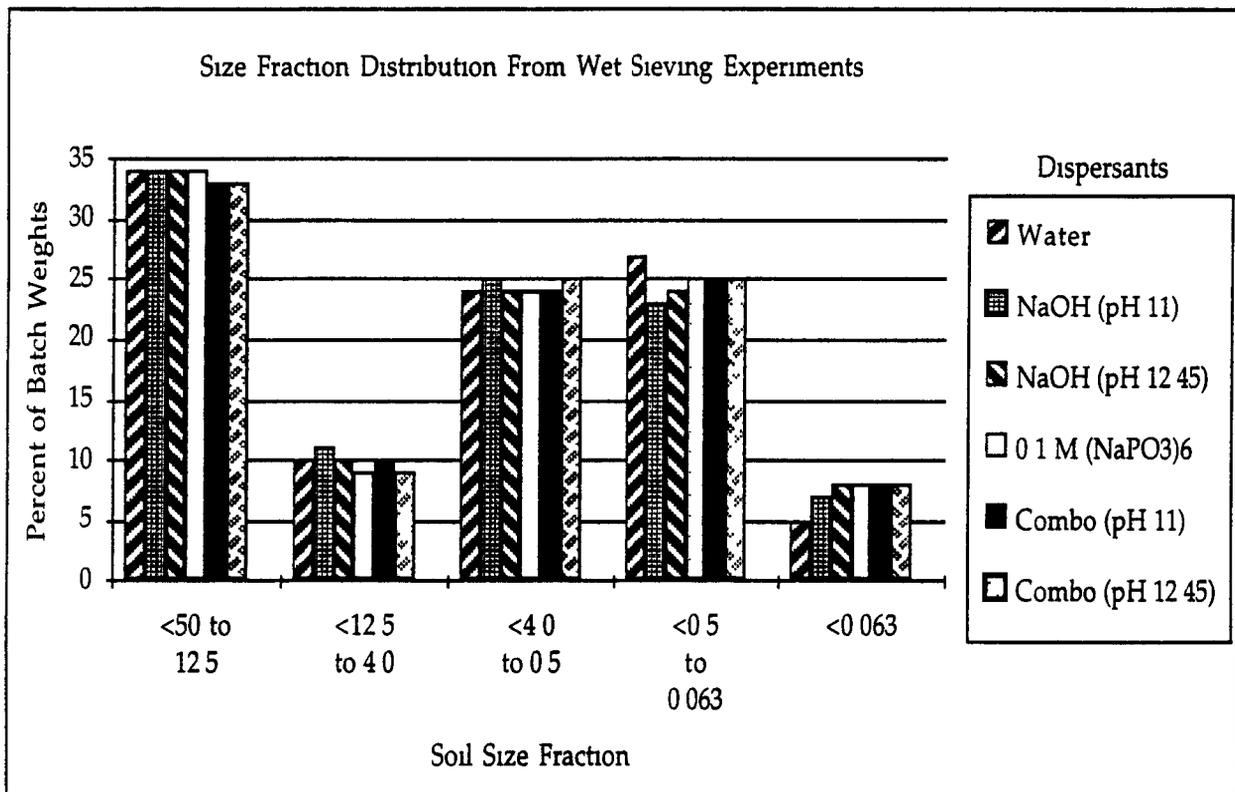


Figure 4.1.2-1 Size Fraction Distribution From Wet Sieve Experiments

Figures 4.1.2-2 and 4.1.2-3 show the actinide results of the soil fractions treated with various wash solutions Generally the actinide concentrations remaining in all the fractions above 4.0 mm were within the same range (1-3 pCi/g Am and 2-11 pCi/g Pu) except water washed soil, thus hot water works about as well as wash solutions containing phosphate and/or hydroxide ions However, for the next smaller size soil fraction (<4 to 0.5 mm), a 0.1 M solution of HMP at pH of 11 and hot water gave the lowest actinide results The actinide concentration only varied between 1 and 4 pCi/g The <0.5 to 0.06 mm fraction contained high concentrations of Am and Pu

with the lowest amount after HMP washing. The HMP solution also decontaminated the <0.063 mm fraction and transferred some of the contamination to the liquid phase.

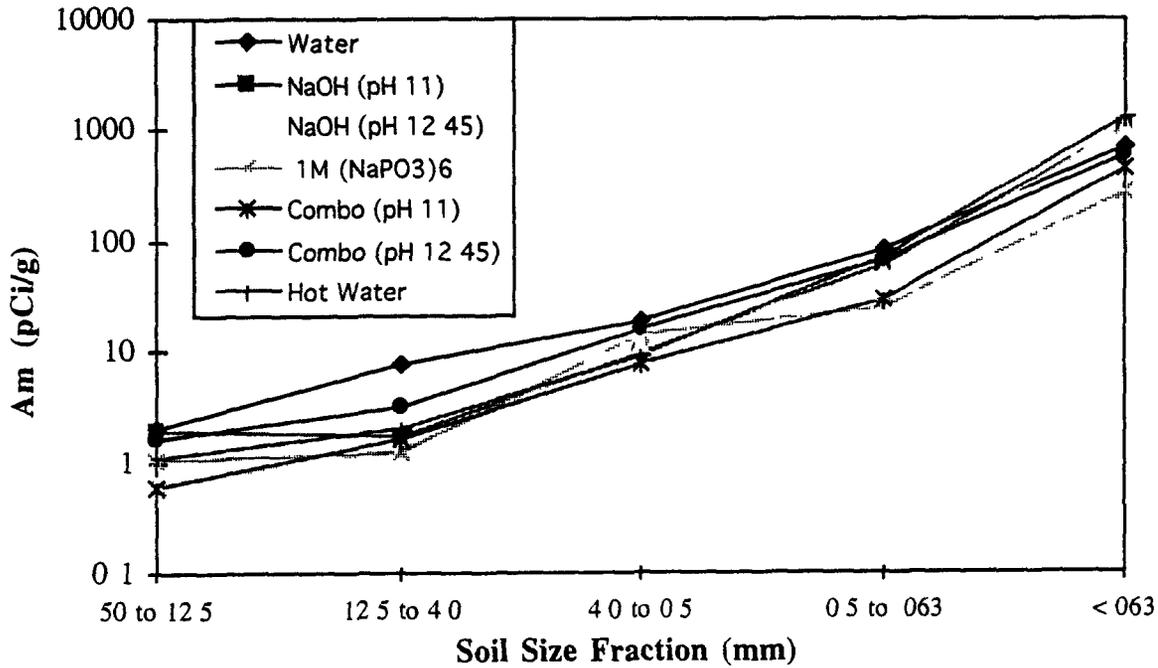


Figure 4.1 2-2 Activity of Am in Soil Size Fractions

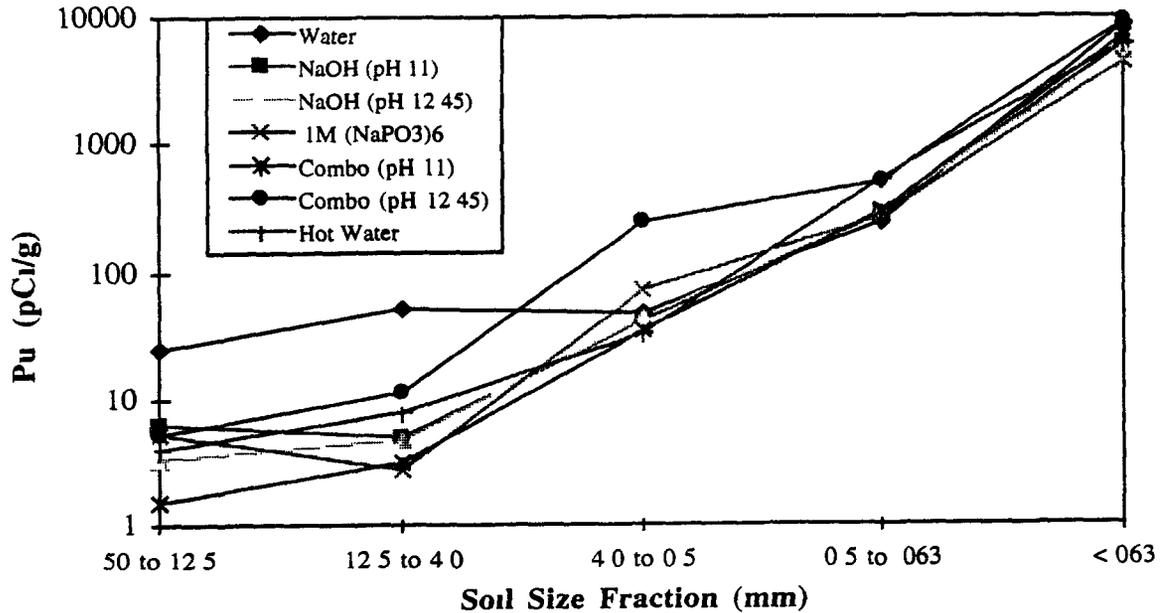


Figure 4.1 2-3 Activity of Pu in Soil Size Fractions

The actinide activity in the spent wash solutions is shown in Table 4.1.2-1. These results indicate that indeed HMP treatment partitioned more activity into solution than did other wash solutions. These results are in good agreement with the amount of activity remaining in the soil size fractions (see mass balances in Appendix D).

An additional wet sieving operation with fresh wash (HMP) solution was performed during the second soil decontamination test to gauge if improvement in the effectiveness of the separation resulted from the supplemental washing and mechanical sieving action contact time. Data from this double wet sieving treatment process was used for comparison with the rotary and attrition scrubbing soil treatment processes, as they involved a secondary wet sieving procedure. Additionally, the second wet sieving operation separated the recombined fractions from the initial wet sieving operation into fractions of even finer particle size discrimination. Measurements of the physically separated soil fractions were repeated to determine the mass of soil distributing into each of these fractions as well as the partitioning of the Pu and Am contaminants into each mass fraction. The results are shown in Figures 4.1.2-4 and 4.1.2-5. Wash solutions were evaluated as well, and the data are presented in Appendix B.

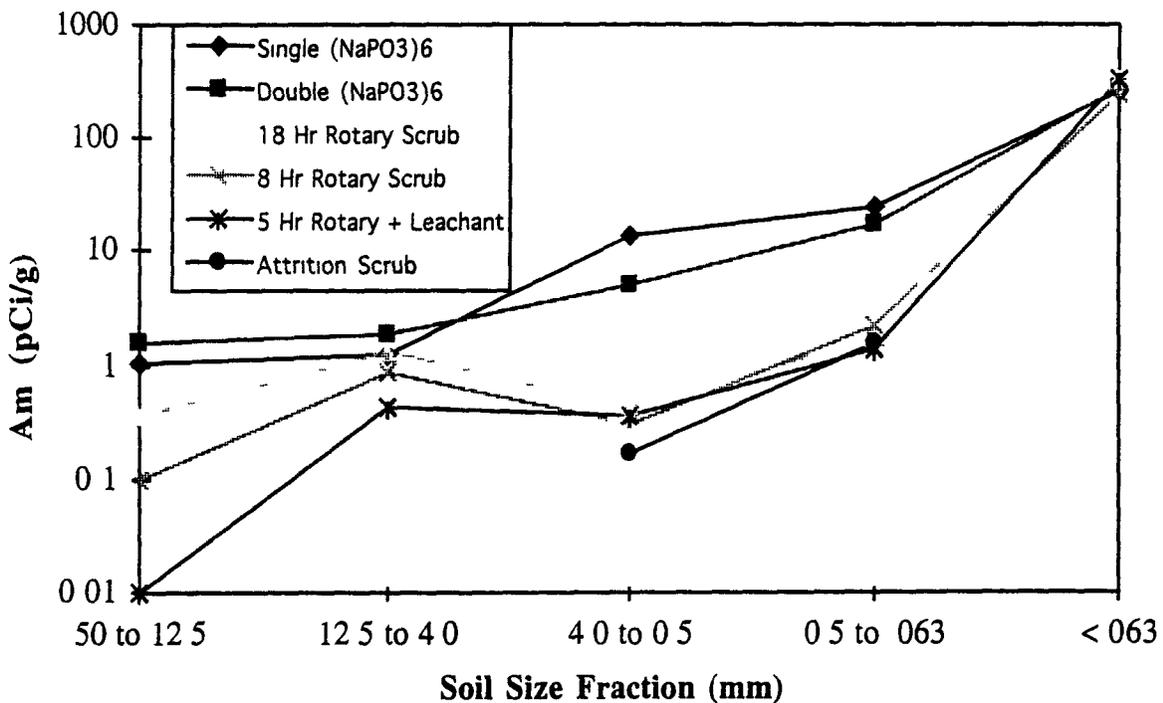


Figure 4.1.2-4 Activity of Am From Process Trials

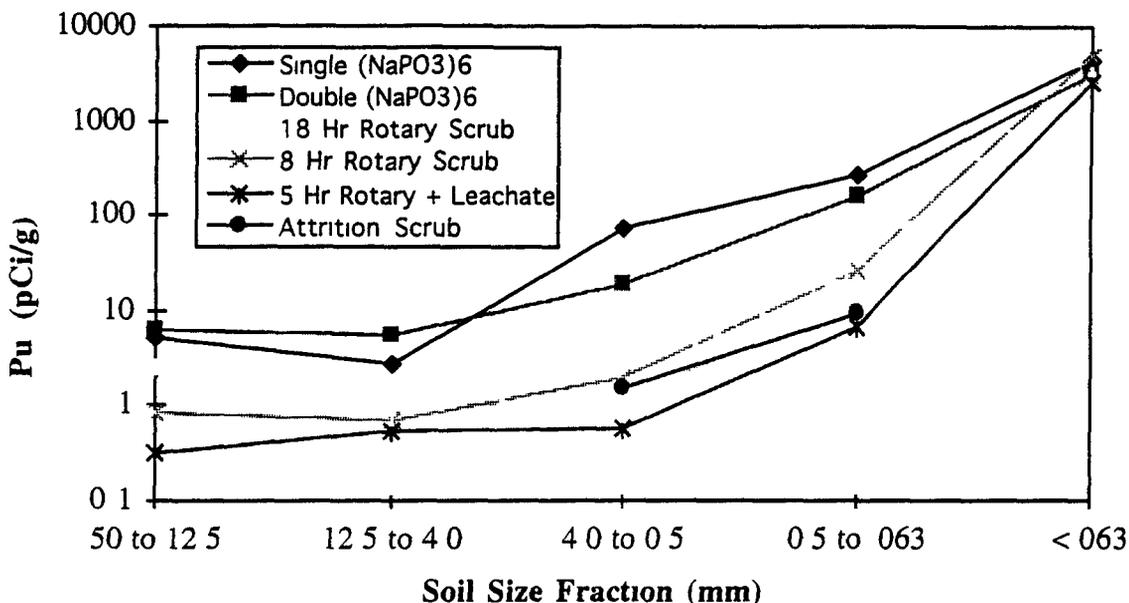


Figure 4.1 2-4 Activity of Pu From Process Trials

The double wet sieving showed slightly improved decontamination compared to a single wet sieving operation. The comparisons with rotary and attrition scrubbing are described in the next section.

Table 4.1 2-1 Wash Solution Analysis

	Wash Solution analysis (pCi/L)				
	DI Wash	Hot DI Wash	NaOH (pH12.5)	(NaPO3)6	Combination
Americium	19	470	85	13700	230
Plutonium	52	770	750	77500	7960

4.1.3 Evaluation of Rotary and Attrition Scrubbing

After an initial wet sieving wash with HMP, the soil fractions >0.063mm were recombined and rotary-scrubbed for 8 and 18 hours with fresh HMP wash solution. The purpose of recombining the soil fractions was to provide enhanced scrubbing action of the fine soil particles by the coarse soil particles. The 18-hour time interval was selected to encourage maximum dispersion of the clay particles in soil. Each soil slurry was wet sieved after rotary scrubbing using fresh HMP wash solution. Soil fractions and solutions were then analyzed for Pu and Am content, and the results are shown in Figures 4.1 2-3 and 4.1 2-4. The rotary scrub promoted further decontamination of the larger fractions compared to wet sieving, and the eight-hour period provided approximately the same result as 18 hours, showing that 8 hours or

less is a sufficient rotational time

The recombined soil fractions between 0.5-mm and 4.0-mm that were previously wet sieved and rotary scrubbed were attrition scrubbed with fresh HMP wash solution for 10 minutes at 1,000 rpm. This soil slurry was then wet sieved using fresh wash solution. Soil fractions and solutions were analyzed for Pu and Am content and the results are shown in Appendix B. Additional activity was removed from the <0.5 to 0.063 fraction with attrition scrubbing, but the small decrease would probably not warrant its use in a process.

4.1.4 Evaluation of Chemical Leaching

A chemical leaching solution (sodium dithionite and sodium citrate) was tested with wet sieving and rotary scrubbing because of its ability to desorb Pu and Am from the fine soil fractions by leaching the actinides into the aqueous phase (based on favorable results from another experimental investigation)⁸. The results show that these conditions were the best for decontamination of soils >0.063 mm (see Figures 4.1.2-3 and 4.1.2-4). The dithionite-citrate mixture also leached more actinide from the clay-silt fraction into solution than HMP.

4.1.5 Evaluation of The Mag*Met Process

A newly developed magnetic separation procedure from Rust Federal Services was tested for decontamination of the fine clay particles. The less than 0.063-mm particle size soil fraction used in this evaluation was obtained from the double wet sieve process. The soil fines were stirred for 10 minutes with a magnetic sorbent followed by a magnetic separation step. A comparison experiment, where no magnetic sorbent was added, gave the same result, showing that the Mag*Met process was not applicable for the decontamination of these type of soils.

4.1.6 Evaluation of Magnetic Adsorption Process

A different magnetic separation process was evaluated for removing actinide ions from the wash solutions generated by the soil decontamination tests. In this process, the spent wash solution was pumped through a column of magnetic adsorbent in the presence of a magnetic field. As shown in previous studies¹⁰, the process will effectively remove plutonium and americium from HMP solutions, as long as the pH is above nine. It was shown that complexing agents, such as EDTA, interfere with the magnetic resin process. Recent results are summarized elsewhere¹⁸.

4.1.7 Comparison to Test Objectives

All of the test objectives were met. HMP and citrate-dithionate were found to be the most effective wash solutions for separating Pu and Am constituents from the contaminated soil matrix. The effect of dissolving calcium sulfate from the soil to promote clay particle dispersion was not necessary because its concentration was below reported limits of interference. Wet sieving was very effective for separating Pu and Am from the >0.5 mm soil fractions. The residence times for the rotary scrub operation on separation of Pu and Am from soil media were determined to be less than 8 hours, and attrition scrubbing was not as effective. A chemical leaching agent was effective for desorbing Pu and Am from the <4.0-mm soil fraction. Magnetic sorbents were not effective in removing Pu and Am from the <0.063-mm soil fraction, but are practical for treating wash solutions. The data produced from this study could be utilized to develop a remedial design/remedial action treatability study for the soil washing technologies. Levels of Pu and Am decontamination were determined.

4.2 QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance issues pertaining to this project are addressed in a Quality Assurance Addendum for the Removal of Actinides From Soil Treatability Study Work Plan. The content of the QAPjP was driven by DOE Order 5700.6C, which required the QA/QC program to be based on American Society of Mechanical Engineers NQA-1. The Quality Assurance Addendum outlines an 18 element format some of which are Training, Data Quality Objectives, Analytical Procedures, Sampling Procedures, and Quality Assurance.¹⁷

4.4 KEY CONTACTS

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Appendix A

Operable Unit 2 IHSS Map

A-1

U.S. Department of Energy
Rocky Flats Plant

Paved roads

Fences

Streams, ditches and
other drainage facilities

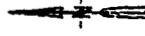
Ponds/Leads

Individual Hazardous
Substance Sites (H.S.)

Buildings per 1/2, 1, 4, 8

AS 27 3111

Individual Hazardous Substance Sites - General Release Dept

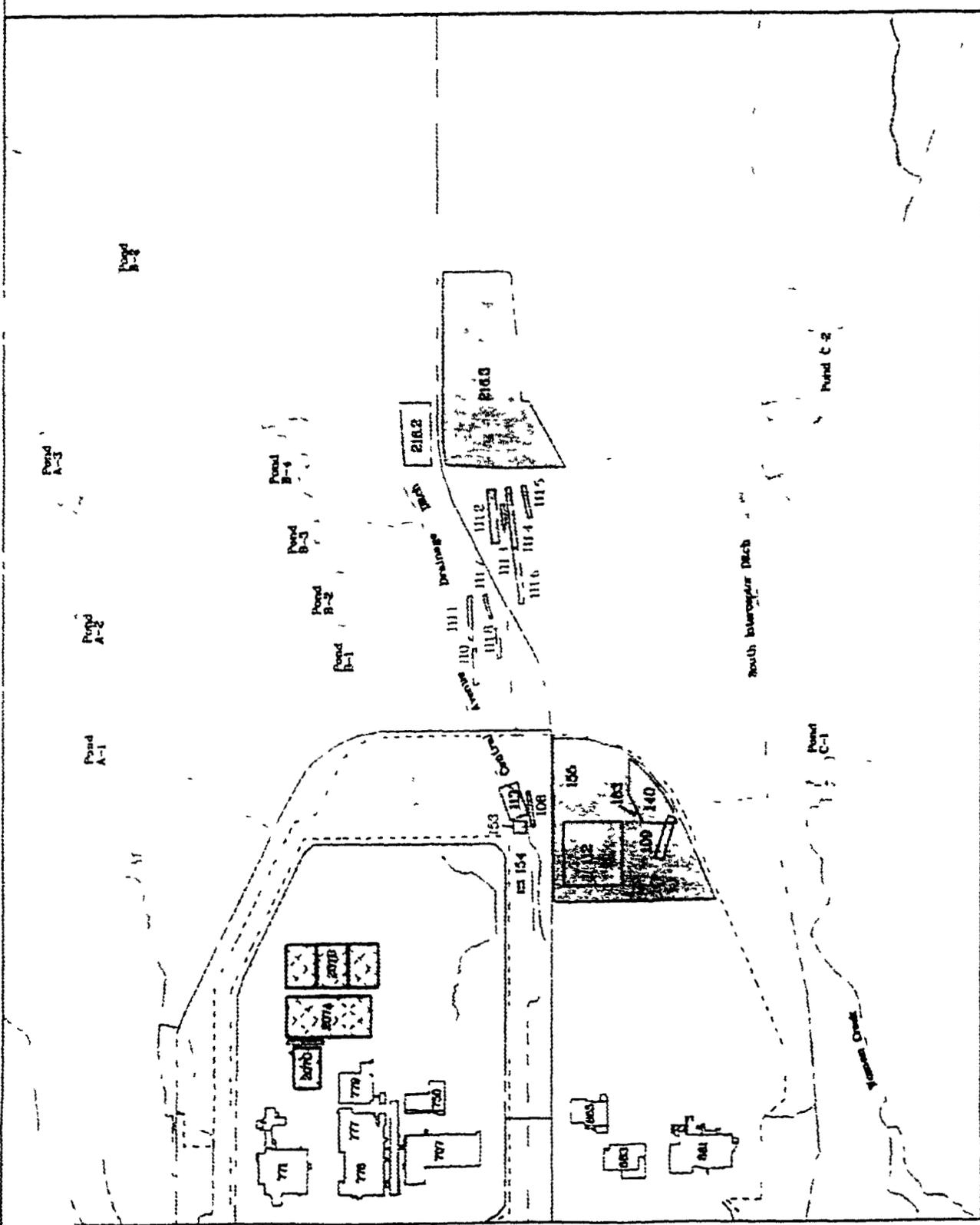


0 feet 500 1000

Scale bar with units: 0, 500, 1000 feet

Environmental Restoration
Technical Support Document

Operable Unit 2
903 Pad, Round
East Tranches



Appendix B

Accu-Labs Research Sample Analysis

B-1

Water Sieve (Table 4 1 2 3 1)

Table 4 1 2 3-1 Dionized Water Wet Sieve		Acculab's Data					
Size Fraction (mm)	Weight (g)	Weight %	Am-241 pCi/g (Ave)	Am-241 Error*	Pu-239+240 pCi/g (Ave)	Pu-239+240 Error*	Weight g
<50 to 125	163 82	33 39	3 5	0 7	25	2 1	4 73
<125 to 40	49 46	10 08	11	2 1	52	5 3	1 16
<40 to 0 5	113 08	23 05	13	3 5	46	6 5	0 68
<0 5 to 0 063	127 53	25 99	53	10	250	16	0 9
<0 063	36 8	7 50	1200	97	8800	210	0 5
Totals	490 69	100 00					

* 95% confidence level for analytical counting error

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Hot Water Wet Sieve

Table Hot Water Wet Sieve		Weight		Am-241		Pu-239+240		Weight	
Size Fraction (mm)	Weight (g)	pCi/g	Error*	pCi/g	Error*	pCi/g	Error*	g	g
<50 to 12.5	165.28	1.1	0.7	3.9	1	3.77			
<12.5 to 4.0	48.41	2	0.7	7.7	1.4	1.68			
<4.0 to 0.5	119.5	9.1	1.4	3.2	3.2	0.47			
<0.5 to 0.063	130.04	6.9	5.4	5.30	18	0.44			
<0.063	38.61	1300	5.4	16000	160	0.42			
Totals	501.84								

* 95% confidence level for analytical counting error

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NaOH (pH 11) Sieve (4 1 2 3-2)

Table 4 1 2 3-2 NaOH (pH 11) Wet Seive		Acculab's Data					
Size Fraction (mm)	Weight (g)	Weight %	Am-241 pCi/g (Ave)	Am-241 Error*	Pu-239+240 pCi/g (Ave)	Pu-239+240 Error*	Weight g
<50 to 12.5	337.03	34	1.9	1.1	6.3	1.9	8.96
<12.5 to 4.0	108.5	11	1.69	0.7	4.95	1.1	2.28
<4.0 to 0.5	241.44	25	9.7	2.1	41.5	4.5	1.5
<0.5 to 0.063	227.91	23	5.9	12.9	28.0	27.5	1.25
<0.063	71.13	7	7.10	9.7	59.50	2.00	0.84
Totals	986.01	100					
* 95% confidence level for analytical counting error							

Table 4 1 2 3-3 NaOH (pH 12.45) Wet Sieve

Size Fraction (mm)	Weight (g)	Weight %	Acculab's Data					
			Am-241			Pu-239+240		
			pCi/g (Ave)	Error*	pCi/g (Ave)	Error*	Weight g	
<50 to 125	340.98	34	0.63	0.5	3.3	0.8	9.45	
<125 to 40	95.22	10	1.32	0.6	4.75	1	2.28	
<40 to 0.5	237.86	24	11	2	42	7.3	1.85	
<0.5 to 0.063	246.52	24	51	6.3	300	12.5	1.21	
<0.063	77.11	8	1000	63	5200	110	1.01	
Totals	997.69	100						

* 95% confidence level for analytical counting error

(NaPO3)6 Sieve (4 1 2 3-4)

Table 4 1 2 3-4 0 1M (NaPO3)6										
Size Fraction (mm)	Weight (g)	Weight %	Am-241				Pu-239+240			Weight g
			pCi/g (Ave)	Error*	pCi/g (Ave)	Error*	pCi/g (Ave)	Error*		
<50 to 125	339 54	34	1 06	0 5	5 3	1 1	7 81			
<125 to 40	88 77	9	1 25	0 5	2 7	0 9	2 18			
<40 to 0 5	245 41	24	14	3 8	71 5	5 4	1 24			
<0 5 to 0 063	256 78	25	25	3 3	270	12	1 04			
<0 063	81 62	8	265	12 5	4400	105	0 89			
Totals	1012 12	100								

* 95% confidence level for analytical counting error

(NaPO3)6 Double Wet Sieve

Table (NaPO3)6 Double Wet Sieve		Acculab's Data					
Size Fraction (mm)	Weight (g)	Weight %	Am-241		Pu-239+240		Weight g
			pCi/g (Ave)	Error*	pCi/g (Ave)	Error*	
<50 to 125	335.3	33	1.6	0.5	6.25	1	7.76
<125 to 40	96.27	9.5	1.82	0.6	5.65	1	3.56
<40 to 0.5	234.63	23	5	0.9	19.1	1.7	1.21
<0.5 to 0.063	258.9	25.5	17	2.3	160.5	9.3	0.97
<0.063	91.72	9	275	15.5	3150	54.5	0.75
Totals	1016.82	100					

* 95% confidence level for analytical counting error

Attrition Scrub Test

Table Attrition Scrub Test (0.5 Hour) (NaPO ₃) ₆					
Size Fraction (mm)	Weight (g)	Weight %	Acculab's Data		
			Am-241 pCi/g (Ave)	Pu-239+240 pCi/g (Ave)	Weight g
<4.0 to 0.5	233.4	98.18	0.165	1.5	1.34
<0.5 to 0.063	3.53	1.48	1.6	9.5	1.11
<0.063	0.79	0.33	NA	NA	NA
Totals	237.72	100.00			

Table 4 1 2 3-6) 1M NaPO3)6/NaOH (pH 11)

Size Fraction (mm)	Weight (g)	Weight %	Acculab's Data					
			Am-241		Pu-239+240		Weight g	
			pCi/g (Ave)	Error*	pCi/g (Ave)	Error*		
<50 to 12.5	337.4	33	0.6	0.4	1.5	0.5	10.6	
<12.5 to 4.0	96.61	10	1.63	0.6	3.15	0.9	2.17	
<4.0 to 0.5	241.75	24	7.6	1.4	33.5	2.6	1.22	
<0.5 to 0.063	253.93	25	28.5	3.2	295	12	1.06	
<0.063	79.42	8	445	23	7000	125	1.04	
Totals	1009.11	100						

* 95% confidence level for analytical counting error

Combo (pH 12.45) (4 1 2 3-5)

Table 4 1 2 3-5) 1M NaPO3)6/NaOH (pH 12.45)										
Size Fraction (mm)	Weight (g)	Weight %	Am-241				Pu-239+240			Weight g
			pCi/g (Ave)	Error*	pCi/g (Ave)	Error*	pCi/g (Ave)	Error*		
<50 to 12.5	332.43	33	158	05	515	08			869	
<12.5 to 4.0	92.28	9	315	08	111	1			228	
<4.0 to 0.5	245.14	25	16	24	239	73			103	
<0.5 to 0.063	245.04	25	68	47	500	125			097	
<0.063	75.49	8	575	145	9300	110			081	
Totals	999.38	100								

* 95% confidence level for analytical counting error

Rotary Scrub Test 18 Hour (PO3)

Table Rotary Scrub Test (18 Hour) (NaPO3)6									
Size Fraction (mm)	Weight (g)	Weight %	Am-241			Pu-239+240			Weight g
			pCi/g (Ave)	Error*	pCi/g (Ave)	Error*			
<50 to 12.5	635.83	31.43	0.35	0.3	2.5	0.8	6.63		
<12.5 to 4.0	195.13	9.65	1.33	0.7	0.935	0.6	2.53		
<4.0 to 0.5	257.1	12.71	0.43	0.4	1.16	0.7	1.44		
<0.5 to 0.063	521.55	25.78	1.8	0.8	13.5	2	0.97		
<0.063 #1	167.77	8.29	335	21	3050	62	1.19		
<0.063 #2	245.32	12.13	30	3.1	340	14	1.09		
Totals	2022.7	100.00							

* 95% confidence level for analytical counting error

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Rot Scrub Test 8 hr (NaPO3)6

Table Rotary Scrub Test (8 Hour) (NaPO3)6									
Size Fraction (mm)	Weight (g)	Weight %	Am-241			Pu-239+240			Weight g
			pCi/g (Ave)	Error*	pCi/g (Ave)	Error*			
<50 to 12.5	322.35	31.60	0.1	0.1	0.84	0.4	4		
<12.5 to 4.0	89.71	8.79	0.87	0.2	0.7	0.2	1.57		
<4.0 to 0.5	159.17	15.60	0.3	0.2	2	0.5	0.95		
<0.5 to 0.063	284.87	27.93	2.2	0.6	26	2	0.61		
<0.063 #1	104.44	10.24	250	20	4800	120	0.58		
<0.063 #2	59.5	5.83	31	3.5	430	15	0.51		
Totals	1020.04	100.00							
* 95% confidence level for analytical counting error									

Rotary Scrub Test 5 Hour Cit

Table Rotary Scrub Test (5 Hour) Dithionite/Citrate		Am-241		Pu-239+240		Weight g	
Size Fraction (mm)	Weight (g)	Weight %	pCi/g (Ave)	Error*	pCi/g (Ave)		Error*
<50 to 12.5	322.55	32.71	0.01	0.06	0.33	0.2	4.61
<12.5 to 4.0	94.84	9.62	0.42	0.2	0.55	0.3	1.07
<4.0 to 0.5	184.59	18.72	0.36	0.2	0.59	0.2	.97
<0.5 to 0.063	259.27	26.29	1.4	0.3	6.9	0.8	0.9
<0.063 #1	77.48	7.86	320	0.5	2500	47	0.58
<0.063 #2	47.5	4.82	35	3.9	290	12	0.61
Totals	986.23	100.00					
* 95% confidence level for analytical counting error							

Magnetic Adsorption

Table Magnetic Adsorption Process					
<0.063 mm Soil Fractions					
Test #	Accu-labs Am 241		Accu-labs Pu-239+240		
	Feed pCi/L	Eluate pCi/L	Feed pCi/L	Eluate pCi/L	
1 (pH 12.45)	110	60.00	430	390	
2 (pH 12.45)	80	39.00	380	460	
3 (pH 12.00)	4400	1500.00	33000	7200	
4 (pH 12.00)	4500	1200.00	30000	7100	

MAG*MET

Table MAG*MET Process <0.063 mm Soil Fractions										Activity Prior to Process In-house	
Test #	Non-Magnetic Weight from 30 (g)	Weight %	Ave counts	Am-241 a(In-House)		Pu 239 b pCi/g	Am-241 a pCi/g	Pu-239 b pCi/g			
				Less Background (varied)	pCi/g						
1	24.97	83.23	NA	Not Taken	Not Taken	Not Taken	155	1194			
2	26.02	86.73	NA	Not Taken	Not Taken	Not Taken	159	1224			
3	21.49	71.63	8337	8061	156	1201	157	1209			
4	21.2	70.67	8758	8477	159	1224	154	1186			
5	19.708	65.69	8050	7762	153	1178	153	1178			
Footnotes											
a 60 keV Radiation											
b Implies total TRU alpha activity less Am-241											

Appendix C

Mass Balance

C-1

Note The field sampling event provided soil ranging from 500 pCi/g to 2,000 pCi/g
 The soil is considered heterogeneous with respect to hot spots

R S = Rotary Scrub processed

The feed material came from the rotary scrub operations, 4 0 to 0 5mm size fraction
 * 100g basis, ** Activity is measured in pCi/l units

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	34.15	0.48	6.3	16	215
12.5 to 4.0	10.49	3.9	8.5	41	89
4.0 to 0.5	24.55	2.5	120	614	2946
0.5 to 0.063	28.97	1.10	1600	3187	46352
<0.063	1.84	1.90	5100	350	9384
Effluent **	2.5(l)	10	37	25	93
Totals	100.00			4232	59079

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.38	3.5	25	117	835
12.5 to 4.0	10.08	1.1	52	111	524
4.0 to 0.5	23.05	1.3	46	300	1060
0.5 to 0.063	25.99	5.3	250	1377	6498
<0.063	7.50	1200	8800	9000	66000
Effluent **	2.5(l)	28	66	70	165
Totals	100.00			10975	75081

Trial Run NaOH pH 11 #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	34.64	2.4	9	83	312
12.5 to 4.0	12.80	2.4	6.2	31	79
4.0 to 0.5	23.54	1.2	41	282	965
0.5 to 0.063	22.03	7.3	290	1608	6389
<0.063	6.99	1000	6800	6990	47532
Effluent **	2.5(l)	26	110	65	275
Totals	100.00			9060	55552

Trial Run NaOH pH 11 #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.71	1.4	3.6	47	121
12.5 to 4.0	9.17	0.98	3.7	9	34
4.0 to 0.5	25.45	7.4	42	188	1069
0.5 to 0.063	24.22	4.5	270	1090	6539
<0.063	7.44	420	5100	3125	37944
Effluent **	2.5(l)	170	1100	425	2750
Totals	99.99			4884	48458

Trial Run NaOH pH 12.45 #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	34.64	0.77	4.3	27	149
12.5 to 4.0	9.99	0.83	4.8	8	48
4.0 to 0.5	23.14	1.4	55	324	1273
0.5 to 0.063	24.37	4.9	180	1194	4387
<0.063	7.86	1200	9100	9432	71526
Effluent **	2.5(l)	88	850	220	2125
Totals	100.00			11205	79507

Trial Run NaOH pH 12.45 #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.71	0.49	2.3	17	78
12.5 to 4.0	9.10	1.8	4.7	16	43
4.0 to 0.5	24.54	7.9	29	194	712
0.5 to 0.063	25.05	5.3	420	1328	10521
<0.063	7.60	800	13000	6080	98800
Effluent **	2.5(l)	81	650	203	1625
Totals	100.00			7837	111778

Trial Run (NaPO3)6 #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.55	0.41	4.5	14	151
12.5 to 4.0	8.52	1.3	2.3	11	20
4.0 to 0.5	24.66	14	7.8	345	1923
0.5 to 0.063	25.14	20	330	503	8296
<0.063	8.12	330	4300	2680	34916
Effluent **	2.5(l)	24000	60000	60000	150000
Totals	99.99	63552	195306		

Trial Run (NaPO3)6 #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.58	1.7	6.1	57	205
12.5 to 4.0	9.02	1.2	3.1	11	28
4.0 to 0.5	23.85	14	65	334	1550
0.5 to 0.063	25.22	30	210	757	5296
<0.063	8.33	200	4500	1666	37485
Effluent **	2.5(l)	3400	95000	8500	237500
Totals	100.00	11324	282064		

Trial Run Combo, pH12.45 #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.09	2.4	6.7	79	222
12.5 to 4.0	8.64	3.6	15	31	130
4.0 to 0.5	25.28	15	7.8	379	1972
0.5 to 0.063	25.87	79	700	2044	18109
<0.063	7.12	690	10000	4913	71200
Effluent **	2.5(l)	350	25000	875	62500
Totals	100.00	8321	154132		

Trial Run Combo, pH12.45 #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.44	0.76	3.6	25	120
12.5 to 4.0	9.86	2.7	7.2	27	71
4.0 to 0.5	23.74	17	400	404	9496
0.5 to 0.063	24.95	57	300	1422	7485
<0.063	8.01	460	8600	3685	68886
Effluent **	2.5(l)	110	920	275	2300
Totals	100.00	5837	88358		

Trial Run Combo, pH11.1 #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.36	0.84	1.4	28	47
12.5 to 4.0	10.92	0.86	1.3	9	14
4.0 to 0.5	23.69	7.6	4.1	180	971
0.5 to 0.063	24.17	35	250	846	6043
<0.063	7.86	350	5600	2751	44016
Effluent **	2.5(l)	4600	43000	11500	107500
Totals	100.00	15314	158591		

Trial Run Combo, pH11.1 #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.52	0.36	1.6	12	54
12.5 to 4.0	8.21	2.4	5	20	41
4.0 to 0.5	24.22	7.6	26	184	630
0.5 to 0.063	26.17	22	340	576	8898
<0.063	7.88	540	8400	4255	66192
Effluent **	2.5(l)	6100	10000	15250	25000
Totals	100.00	20297	100814		

Trial Run (NaPO3)6, Double #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	33.28	0.47	1.5	16	50
12.5 to 4.0	11.62	0.94	4.6	11	53
4.0 to 0.5	22.13	4.3	9.2	95	204
0.5 to 0.063	24.10	12	71	289	1711
<0.063	8.87	300	3500	2661	31045
Effluent **	5.0(1)	1800	32000	9000	160000
Totals	100.00			12072	193063

Trial Run (NaPO3)6, Double #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	32.73	2.8	11	92	360
12.5 to 4.0	7.33	2.7	6.7	20	49
4.0 to 0.5	24.06	5.7	29	137	698
0.5 to 0.063	26.87	22	250	591	6718
<0.063	9.01	250	2800	2253	25228
Effluent **	5.0(1)	1900	34000	9500	170000
Totals	100.00			12592	203052

Trial Run Hot Water #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	32.93	1.1	3.9	36	128
12.5 to 4.0	9.65	2	7.7	19	74
4.0 to 0.5	23.82	9.1	32	217	762
0.5 to 0.063	25.91	69	530	1788	13732
<0.063	7.69	1300	16000	9997	123040
Effluent **	2.5(1)	470	770	1175	1925
Totals	100.00			13232	139662

Trial Run 18Hr Rotary Scrub #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	32.01	0.53	3.9	17	125
12.5 to 4.0	7.94	0.46	1	4	8
4.0 to 0.5	13.14	0.4	1.4	5	18
0.5 to 0.063	26.64	1.4	11	37	293
<0.063	8.34	370	4100	3086	34194
<0.063 + R S	11.93	32	420	382	5011
Effluent **	5.0(1)	86	640	215	1600
Totals	100.00			3746	41249

Trial Run 181Hr Rotary Scrub #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	30.86	0.17	1.1	5	34
12.5 to 4.0	11.35	2.2	0.87	25	10
4.0 to 0.5	12.28	0.46	0.91	6	11
0.5 to 0.063	24.93	2.2	16	55	399
<0.063	8.25	300	2000	2475	16500
<0.063 + R S	12.33	28	260	345	3206
Effluent **	5.0(1)	980	6500	2450	16250
Totals	100.00			5361	36410

Initial Run Rotary Scrub, 8Hr

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	31.60	0.1	0.84	3	27
12.5 to 4.0	8.80	0.87	0.7	8	6
4.0 to 0.5	15.60	0.3	2	5	31
0.5 to 0.063	27.93	2.2	2.6	61	726
<0.063	10.24	250	4800	2560	49152
<0.063 + R S	5.83	31	430	181	2507
Effluent **	5.0(1)	33	290	83	725
Totals	100.00			2900	53174

Total Run Rotary Scrub, 5Hr, Leachant Reagent

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	32.70	0.01	0.33	0	11
12.5 to 4.0	9.62	0.42	0.55	4	5
4.0 to 0.5	18.72	0.36	0.59	7	11
0.5 to 0.063	26.29	1.4	6.9	37	181
<0.063	7.86	320	2500	2515	19650
<0.063 + R S	4.82	35	290	169	1398
Effluent **	5.0(1)	990.00	6700.00	2475	16750
Totals	100.01			5207	38006

Trial Run Attrition Scrub, #1

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	0.00			0	0
12.5 to 4.0	0.00			0	0
4.0 to 0.5	98.67	0.21	1.90	21	187
0.5 to 0.063	1.02	1.90	13.00	2	13
<0.063	0.31	†	†	†	†
Effluent **	5.0(1)	0	130	0	325
Totals	100.00			23	526 v +

Trial Run Attrition Scrub, #2

Size Fraction (mm)	Percent	Am (pCi/g)	Pu (pCi/g)	Am (pCi)*	Pu (pCi)*
50 to 12.5	0.00			0	0
12.5 to 4.0	0.00			0	0
4.0 to 0.5	97.69	0.12	1.10	12	107
0.5 to 0.063	1.96	1.30	6.00	3	12
<0.063	0.00	†	†	†	†
Effluent **	5.0(1)	0	80	0	200
Totals	99.65			14	319 v +

† Insufficient material for analysis