Soil Washing: A Preliminary Assessment of Its Applicability to Hanford

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September 1991

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SUMMARY

Soil washing is being considered for treating soils at the U.S. Department of Energy's (DOE) Hanford Site. As a result of over 50 years of operations to produce plutonium for the U.S. Department of Defense and research for DOE, soils in areas within the Site are contaminated with hazardous wastes and radionuclides. The purpose of this study was to assess the applicability of the soil washing process to Hanford soils.

In the soil washing process, contaminated soil is mixed with a liquid and then physically and/or chemically treated to dissolve the contaminants into solution and/or concentrate them in a small fraction of the soil. The purpose of this procedure is to separate the contaminants from the bulk of the soil. The key to successful application is to match the types of contaminants and soil characteristics with physical-chemical methods that perform well under the existing conditions. Several companies in the U.S. and other countries have conducted research and development studies on the soil washing technology. Some commercial systems are in operation outside the U.S. Information from these studies was used to determine the state-of-the-art of the technology.

The applicability of soil washing to Hanford Site contaminated soils must take into account both the characteristics of the soil and the type of contamination. Hanford soils typically contain up to 90% sand, gravel, and cobbles, which generally are favorable characteristics for soil washing. For example, in soil samples from the north pond in the 300 Area, 80% to 90% of the soil particles were larger than 250 μm . The principal contaminants in the soil are radionuclides, heavy metals, and nitrate and sulfate salts. For most of the sites, organic contaminants are either not present or are found in very low concentrations.

Previous studies on heavy metals and radionuclides using soils from other sites as well as Hanford suggest that it is possible to achieve a high degree of decontamination of the coarse fractions of the soil. However, there are significant variations in the partitioning of different heavy metals and

radionuclides between the coarse and fine soil fractions at any one site, as well as variations among different sites.

The results of a limited number of bench-scale soil washing experiments conducted in this study confirmed similar trends for soil samples obtained from different locations in the north pond of the 300 Area at the Site. In general the contaminants in the 300 Area pond soils partitioned preferentially to the fine fraction of the soil ($<250\ \mu\text{m}$); however, the sand fraction ($-2\text{mm} + 250\ \mu\text{m}$) still contained significant contamination. These tests also showed that the contaminants would not dissolve in the wash water, which will reduce water treatment requirements. Further testing is necessary to evaluate a number of treatment options, such as attrition scrubbing and chemical extraction, to further reduce contamination in the sand fraction.

CONTENTS

SUMMARY	iii
1.0 INTRODUCTION	1.1
2.0 PRINCIPLES OF SOIL WASHING	2.1
2.1 FACTORS AFFECTING SOIL CONTAMINATION	2.1
2.1.1 Soil Chemical Properties	2.1
2.1.2 Soil Physical Properties	2.3
2.1.3 Waste Properties	2.4
2.2 SOIL WASHING TECHNIQUES	2.5
2.2.1 Physical Separation	2.5
2.2.2 Chemical Separation	2.6
3.0 STATE OF THE ART FOR SOIL WASHING	3.1
3.1 LABORATORY AND BENCH-SCALE RESEARCH	3.1
3.1.1 Hazardous Wastes	3.1
3.1.2 Radionuclides	3.4
3.2 COMMERCIAL AND DEMONSTRATION SCALE PROCESS EXPERIENCE . .	3.4
3.3 COST OF SOIL WASHING	3.8
4.0 ASSESSMENT OF SOIL WASHING TECHNOLOGY AT HANFORD SITE	4.1
4.1 APPLICABILITY TO THE HANFORD SITE CONDITIONS	4.1
4.1.1 Soil Characteristics	4.1
4.1.2 Soil Contamination	4.3
4.2 RESULTS OF BENCH-SCALE SOIL WASHING TESTS AT HANFORD . .	4.4
4.2.1 Samples Tested	4.8
4.2.2 Bench-Scale Experimental System and Procedures . .	4.11
4.2.3 Experimental Results	4.12

4.3 OTHER TESTS WITH HANFORD SOILS	4.17
5.0 CONCLUSIONS AND RECOMMENDATIONS	5.1
6.0 REFERENCES	6.1
APPENDIX A - SUMMARY OF BENCH-SCALE TESTS ON SOIL WASHING APPLICABILITY TO RADIONUCLIDE REMOVAL	A.1
APPENDIX B - DESCRIPTION OF COMMERCIAL AND DEMONSTRATION SCALE SOIL WASHING SYSTEMS	B.1
APPENDIX C - DESCRIPTION OF ENGINEERED FACILITIES FOR LIQUID WASTE DISPOSAL	C.1

FIGURES

4.1	Map of Hanford Site	4.2
4.2	Diagram of 300 Area North Pond	4.7
4.3	Particle Size Distribution	4.10
4.4	Procedure Flow Diagram of Bench-Scale Soil Washing	4.11
4.5	Contaminant Partitioning	4.14

TABLES

3.1	Summary of Hazardous Waste Soil Washing Laboratory and Bench-Scale Studies	3.2
3.2	Summary of Radionuclide Soil Washing Laboratory and Bench-Scale Studies	3.5
3.3	Typical Performance of Large-Scale Soil Washing Systems	3.6
3.4	Capital and Operating Cost Estimates for Soil Washing	3.9
4.1	Summary of Selected Contaminated Sites at Hanford	4.5
4.2	Estimated Nonradiological Chemical Waste Inventory for the North Process Pond	4.8
4.3	North Pond Soil Sample Composition	4.9
4.4	Soil Washing Results for A03 Soil Sample Obtained from North Pond	4.13
4.5	Comparison of Soil Washing for Soil Samples Obtained From Four Different Locations in the North Pond	4.16
4.6	Percent of Total Soil Remaining in Soil Fraction After Tests	4.18

1.0 INTRODUCTION

Soil washing is being considered for remediating soils located at the U.S. Department of Energy's (DOE's) Hanford Site. The Hanford Site encompasses approximately 560 square miles of semiarid desert in south central Washington and lies in a structural and topographic basin of eastern Washington within the Columbia Plateau. The site is bordered to the north and east by the Columbia River and is adjacent to the northern boundary of the City of Richland, Washington. Over the past 50 years a number of government facilities have been operated to produce plutonium for the U.S. Department of Defense and for DOE-sponsored nuclear research. As a result of these operations, over 1000 inactive waste disposal and unplanned release sites were generated ranging in size from minor spills to burial grounds up to 100 acres. The soils at these sites are contaminated with both hazardous wastes and radionuclides. Estimates of the total extent of contaminated soil at Hanford exceed a billion cubic yards (Day and Pimental 1989).

Soil washing is a process in which contaminated soil is mixed with a fluid, such as water, in a vessel and then physically and/or chemical treated to separate the contaminants from the bulk of the soil. In a total system the following steps are used:

- excavation of the soil-waste matrix
- rough screening of the soil to remove large objects
- intimately contacting the soil with a solvent, usually water, and chemical additives to break up the soil matrix and dissolve or disperse chemicals into the solvent
- physical separation of the resulting spent solvent, contaminated solids, and cleaned soil
- treatment/disposal of the spent solvent and the contaminated solids
- returning the cleaned soil to the site.

Soil washing has been shown to be effective in removing certain chemicals from coarse particles such as sand, but it is not as effective for fine particles such as silt and clay. As it is currently practiced, the process

results in a volume reduction primarily through separation of soil fractions. In other words, the clean coarse fraction of the soil is separated from the contaminated fine fraction.

Ideally, the cleaned coarse fraction would be returned to the site. The fine fraction, which is usually in the form of a sludge, requires further treatment or offsite disposal. Some chemicals are solubilized or dispersed in the water phase, and others are stripped into the off-gas during washing. Depending on the nature of the chemicals, treatment of the off-gas and wash water may also be required.

Soil washing has been the subject of a U.S. Environmental Protection Agency (EPA) research program since 1982 and has been used commercially at several sites in the Netherlands and Germany. In the U.S., companies are marketing the process, but to date there have been no commercial operations.

The physical and chemical properties of the soil to be treated and the chemicals to be removed have a very significant impact on the effectiveness of soil washing procedures. The purpose of this document is to provide an overview of the technology and an assessment of its potential application at the Hanford Site. This report briefly describes the general principles behind soil washing (Section 2.0) and reviews the state of the art based on a literature review of laboratory research and commercial-scale plant operations (Section 3.0). A general description of the type of soil and contamination present at Hanford is given in Section 4.0, as well as a summary of the results of a limited number of bench-scale soil washing tests using contaminated soil obtained from Hanford. Section 5.0 provides conclusions and recommendations regarding the application of the technology and further information needed to fully assess its potential. The appendices contain a summary of bench-scale research in radionuclide removal, a description of commercial and demonstration scale systems, and a description of engineered facilities for liquid waste disposal.

2.0 PRINCIPLES OF SOIL WASHING

Soil washing is a combination of physical and chemical treatments performed on soil in an aqueous solution, which cause contaminants to be dissolved into solution and/or concentrated in a small fraction of the soil. The purpose of this treatment is to separate the contaminants from the bulk of the soil. Successful application of soil washing largely depends on matching the type of contamination and soil characteristics to specific operations that can perform well under the particular conditions. This section summarizes some of the key factors affecting soil contamination and describes the physical-chemical techniques used to treat the soil.

2.1 FACTORS AFFECTING SOIL CONTAMINATION

There are three main types of soil contamination: contaminants dissolved in the water in the soil, contaminants chemically fixed as solid compounds, and contaminants adsorbed onto the surfaces of the various solids in the soil. A number of factors also influence the type of contamination occurring in the soil. These factors can generally be grouped into the following categories:

- soil chemical properties
- soil physical properties
- waste properties.

2.1.1 Soil Chemical Properties

Soil chemical properties influence the nature of the contamination in the soil by a number of mechanisms. Some of the more important chemical characteristics include:

- the presence of carbonate, sulfide, and phosphate ions
- the presence and/or gradual formation of hydrous metal oxides containing iron, manganese, or aluminum
- the presence of silicate clays

- the presence of humus
- soil pH
- soil reduction/oxidation potential.

The presence of carbonate, sulfide, or phosphate anions in the soil can significantly affect the ability of the soil to chemically fix heavy metal contaminants. These ions are usually present in equilibrium with salts in the soil. In addition, carbonate ions can be formed in alkaline soils through adsorption of carbon dioxide by water in the soil. The salts of the heavy metal carbonates sulfides and phosphates are often less soluble in water than the salts of other elements already in the soil, such as calcium. Therefore, the heavy metals will preferentially precipitate if they are present in sufficient quantity. In addition, other heavy metals, which may not be sufficiently concentrated to precipitate by themselves, may coprecipitate with the more prevalent heavy metals and be incorporated into the resulting solid material.

Hydrous iron, manganese, and aluminum metal oxides in the soil can coat mineral surfaces in the soil, causing adjacent particles to cement together and form agglomerations. In addition, these oxides can remove both cations and anions from solution by ion exchange, specific adsorption, and possibly precipitation (Ellis and Fogg 1985).

Silicate clays are high surface minerals composed primarily of aluminum, silica, and water. Clays are well established as an adsorbent of many hydrocarbons as evidenced by their use in kitty litter and as a general purpose adsorbent for spilled oil. Clays carry an electronegative charge that is balanced by loosely held cations such as sodium, potassium, and calcium. Consequently, clays are good ion exchange materials for dissolved heavy metal cations.

All soils contain organic matter, known as humus, which is made up of decomposed vegetable, microbial, and animal materials. Humus has a very high surface area and contains a number of different functional groups including carboxyl(-COOH), phenolic, alcoholic and enolic hydroxy (-OH) and carbonyl (-C=O) groups (Fairbridge and Finkl 1977; Tan 1982). These groups serve

as adsorption sites for both ions and dissolved hydrocarbons through ion exchange, chelation, and other complexation reactions.

All of the chemical processes above take place between the soil solids and material dissolved in water, and depend to some degree on the pH of the water in the soil. For example, most heavy metal precipitates and adsorbed cations are more tightly bound under conditions of high pH. Soil pH can vary when waste or pure water is added to the soil. Also, certain chemical and biological processes produce acids in the soil. In contrast, clays, organic matter, and metal oxides have a buffering capacity, and soils rich in these materials tend to have a more stable pH (Ellis and Fogg 1988).

The reduction-oxidation (redox) potential of a soil is also an important factor in fixing contaminants in the soil. Most heavy metals can exist in more than one oxidation state depending on the redox potential and the pH of the water. Most of these metals are more soluble in a lower oxidation state, and conditions that promote reduction of these metals may cause them to resolubilize. In addition, heavy metals that are bound to manganese (IV) and iron(III) through adsorption and/or ion exchange may solubilize if reducing conditions cause the manganese and iron to form more soluble manganese(III) and iron(II). The redox potential of a soil depends on many factors, including water content, oxygen activity, and pH. Interestingly, oxidation of organic material by bacteria under anaerobic conditions can both reduce soil pH through the formation of organic acids and carbon dioxide and create redox conditions that lead to the reduction of heavy metals (Ellis and Fogg 1985).

2.1.2 Soil Physical Properties

The soil physical properties that have a significant influence on the nature of contamination in the soil are soil texture, structure, and moisture content. Soil texture refers to the relative proportion of soil particles of various sizes. This property affects contamination in two ways. The soil unit surface area available for chemically fixing or adsorbing contaminants is inversely related to the particle size distribution with finer particles having a larger unit surface area than larger particles. For example, fine silt with a uniform particle diameter of 50 μm would have nearly 20 times the surface area of an equal weight of sand with a uniform particle diameter of

1.0 mm, assuming all other properties are the same. The coarseness of the soil also affects the deposition mechanism and soil chemistry by determining soil water holding capacity and permeability, as well as aeration properties.

Soil structure generally describes the character of the soil in terms of size, shape, arrangement, and degree of development of primary soil particles and voids into naturally or artificially formed structural units (Fairbridge and Finkl 1979). These characteristics determine the rate that water passes through various portions of the soil. However, this property does not directly influence soil washing because excavation disturbs the original soil structure by mixing.

Soil moisture is a measure of the fraction of the interstitial spaces of the soil occupied by water. Soil moisture primarily influences the manner and rate in which water passes through the soil and can vary over time. It also influences soil chemistry by controlling the inventory of dissolved material, as well as influencing variations in pH and redox potential. Soil moisture does not directly affect soil washing other than contributing to the total inventory of water used in the washing process.

2.1.3 Waste Properties

The properties of the waste added to the soil can influence soil contamination in several ways. The initial composition of the waste establishes the physical and chemical properties of the contaminants entering the soil. For example, insoluble salts will be deposited as precipitates and form a layer of sediment and/or a coating of fine particulate on soil particles close to the soil surface. The specific mixture of organics in the waste will determine their initial solubility in the waste solution and thus their ability to penetrate the soil surface as well as determine the tendency of individual components in the mixture to adsorb onto the soil. The composition of the waste also alters the inventory of various chemical species in the soil which will change with time as water percolates through the soil and leaches out the more soluble species. Eventually a condition of equilibrium in the soil will then be reestablished.

2.2 SOIL WASHING TECHNIQUES

The overall goal of soil washing is to separate contaminants from the bulk of the soil and to concentrate them in a small fraction of the soil or in the wash water. By separating and concentrating the contaminants, the volume of soil that requires further soil treatment or disposal is reduced.

2.2.1 Physical Separation

The feasibility of concentrating contaminants into a small fraction of the soil is based on three main factors. First, most of the contamination will be found on the outside surfaces of soil particles, because of adsorption and/or ion exchange, or in a coating of metal hydroxides attached to the mineral surfaces. In addition, very fine colloidal material may attach to the surfaces of larger particles through electrostatic forces. Fortunately, very fine soil particles have a much larger surface area per unit weight than coarse particles. Therefore, the majority of the contamination may be associated with the small fraction of the fine material. Second, precipitates present in waste added to the soil will generally be in the form of very fine material. Also, many of the precipitates are softer than the principal soil materials and can be attritted through abrasive actions applied to the soil. As before, these materials would be associated with the fine material in the soil. Third, some of the contaminants have significantly different specific gravity densities than the majority of the soil. When this is the case, it may confine the contamination to that fraction of the soil with a similar density.

The principal physical treatment techniques that capitalize on these properties are physical agitation and hydraulic classification according to particle size and density. Agitation is usually accomplished using either a tumbling motion as would be achieved in a rotating vessel, or by directing a high velocity water stream onto the soil. In some instances, surfactants are added to prevent redeposition of colloidal material onto the larger particles. Hydraulic classification is usually accomplished using screens and hydraulic cyclone separators, which primarily separate particles according to size, and hydraulic concentrators such as hydraulic jigs, which separate particles based on both size and specific gravity. Hydraulic classifiers are generally

limited to the recovery of particles larger than about 50 μm . Smaller particles, which usually make up only a very small fraction of the soil, are carried with the wash water and would require additional separation techniques such as filtration or flotation to achieve separation from the water.

2.2.2 Chemical Separation

Chemical separation leaches the contaminants from the soil and into the wash water. The wash water is further treated to remove the dissolved contaminants for subsequent treatment and disposal. Certain techniques are used during chemical separation to ensure that the major components of the soil are not dissolved with the contaminants: 1) the pH of the water is varied; 2) chelating and complexing agents are added to selectively solubilize the inorganic contaminants; 3) and surfactants are added to solubilize hydrocarbons.

The principle behind varying the pH is the same in soil washing as it is in the deposition of contaminants. For example, decreasing the pH with an acid will increase the solubility of many heavy metal salts, as well as many adsorbed cations and organic hydrocarbons. An important consideration in adjusting pH to facilitate removal of contaminants is that the wash water must eventually be neutralized.

The addition of chelating and complexing agents selectively causes certain metals to solubilize as chelated metal ions. Consequently, the metals will partition to the wash water. An important consideration in using these additives is that many water treatment processes to recover the metals do not work as well in their presence.

Other chemicals may be added to facilitate the destruction of insoluble organic constituents. Oxidizing agents such as hydrogen peroxide can be added to the water to oxidize many hydrocarbons. Usually this results in incomplete destruction and smaller hydrocarbons. This technique would be practical only where the residual hydrocarbons are more soluble or nontoxic. One disadvantage of this technique is that the oxidizing agents may react with the mineral components in the soil, which would consume excess oxidant or adversely affect the solubility of any heavy metal contaminants.

Enzymes could also be added to facilitate solubilization of hydrocarbons in the soil. Like oxidants they partially decompose the hydrocarbons but to a lesser degree since enzymes are very specific to the types of chemical bonds they will break. As with chemical oxidation, their use would depend on the solubility and toxicity of the resulting organic residues. However, enzymes would not directly affect the redox potential of the soil water or cause the heavy metals to undergo reduction or oxidation.

Changes in the redox potential of the soil can also be used to change the oxidation state of heavy metals to more soluble forms. This change is accomplished by adding an oxidizing agent such hydrogen peroxide or a reducing agent such as sodium borohydride.

3.0 STATE OF THE ART FOR SOIL WASHING

Soil washing, a relatively new technology, has undergone development and commercialization since the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) was passed in 1980. Consequently there is only a limited amount of published information that provides insight into the prospect of the technology in terms of performance and cost for treating mixed waste soils at Hanford. A review of the literature identified a variety of soil washing processes that have been developed and used commercially in Europe. In the U.S., the EPA and a number of private companies have conducted extensive research and development on soil washing, and several companies are in the process of developing systems for commercial application. A summary of the results of both laboratory research and commercial operations is provided in the following sections.

3.1 LABORATORY AND BENCH-SCALE RESEARCH

A number of laboratory studies have been conducted by various organizations to evaluate the potential of different treatment techniques for removing either hazardous wastes or radionuclides from contaminated soil. In general, each study involved mixing contaminated soil and water for a certain length of time, draining the wash water, rinsing the soil and separating it into two or more fractions, and then measuring the residual levels of contaminants in the fractions. The purpose of these studies was to assess the influence of various key parameters on removing a number of organic and inorganic contaminants simultaneously rather than to optimize operating conditions for any one contaminant or group of contaminants. Only one study investigated a single contaminant.

3.1.1 Hazardous Wastes

Table 3.1 summarizes six studies that involved laboratory and bench-scale soil washing research for hazardous wastes. These studies cannot be directly compared because each investigated different soils with significantly different physical properties and presumably chemical properties. Also, contamination ranged from spiked samples of synthetic soils mixed in the

TABLE 3.1. Summary of Hazardous Waste Soil Washing Laboratory and Bench-Scale Studies

<u>Study (Reference)</u>	<u>Soil Source</u>	<u>Contaminants Studied</u>	<u>Parameters Studied</u>
U.S. EPA (Esposito et al. 1988)	Synthetic soil - 3% gravel, 56% sand, 28% silt, 12% clay	Volatiles, Semivolatiles, As, Cd, Cr, Cu, Pb, Ni, Zn	Water only, EDTA, anionic phosphate based surfactant, particle size
U.S. EPA (Tabak and Traver 1990)	Synthetic soil - 60% sand, 19% silt, 21% clay; selected soils from underground storage tank sites in New Jersey and Ohio	Gasoline, diesel fuel, waste crankcase oil	water only, organic surfactant, citrate solvent (Citrikleen), contact time, water volume and temperature, particle size
Biotrol, Inc., Chaska, Minnesota (Valine 1990)	Various sites	Pentachloro- phenol, PAHs, PCBs, semivola- tiles, pesti- cides, Ag, As, Cr, Cu, Ni, Zn	Not specified
EEC, Inc., Philadelphia, Pennsylvania (Kunze and Gee 1989)	New Jersey - selected locations of one site	PCBs, volatile organics, base semivolatile organics, As, Be, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se, Zn	Surfactant (Triton-X-100), citrate solvent (Citrikleen), HCl, contact time, soil
U.S. EPA (Evangelista and Zownir 1988)	Woodenville, Wisconsin	Pb	Particle size, water, EDTA, rinse water (water only, EDTA), water volume, contact time, wash water recycle
MTA Remedial Resources, Inc. (MTARRI), Golden, Colorado (Trost and Rickard 1987)	Colorado; California	Volatile organics, PAH, Cd, Zn, Cu, Cr	Not specified

laboratory to aged samples from specific sites. In addition, the contamination levels and mix of contaminants varied considerably for the various soils tested. However, several trends can be seen from these experiments.

Physical separation of the soil by particle size was the predominant means of achieving decontamination, with both organic and inorganic contamination partitioning preferentially to the smaller particles. However, the degree of partitioning varied considerably for different soils and types of contaminant.

The contaminant level in the larger particle fractions of the soil ($>250\ \mu\text{g}$) was consistently low for volatile organics (typically 1% to 20% of the contaminant level in the bulk soil), but significantly higher for the semivolatiles. In both cases there appears to be less variation (typically less than 10%) in the amount of contamination remaining in the coarse soil fraction because of variations in soil composition and contaminant levels. The use of additives consistently improved the removal of all organics with the semivolatile residual contamination levels approaching those of the volatiles. Volatile organics showed evidence of significant solubility in wash water not containing additives. Surfactants improved the dissolution of semivolatile organics and appeared to encourage partitioning of the contamination to the smaller particle fractions.

Metal contaminants showed considerable variation in the amount of contamination remaining, with values ranging from 25% to >95%. In addition, these values showed much greater variation as a result of differences in soil contaminant levels and the use of additives.

All of these studies lack a material balance to fully explain the results obtained. As a consequence some speculation has been required in the interpretation of the results. For example, Tabak and Traver (1990) attributed the variation in results to the amount of particulate that remained in solution. Thus, it is not possible to determine how much of the contamination in the water was due to dissolved compounds and how much was due to suspended solids. Similarly, the poor results achieved using Citrikleen to remove

organics from the soil in the same study was attributed to adsorption of Citrikleen by the soil, even though no data were presented to support that hypothesis.

3.1.2 Radionuclides

Four studies involving radionuclides are summarized in Table 3.2. These studies are also discussed in more detail in Appendix A.

Like heavy metals the amount of decontamination achieved in the bulk soil for the radionuclides studied varied considerably. Also, contamination of soil by the radionuclides generally partitioned to the smaller size fractions of the soil. It appeared, however, that some portion of the fine particles adhered to larger particles. Attrition of the particle surfaces using agitation or grinding methods improved the partitioning by removing surface contamination from the larger particles. The addition of certain chemical additives to the wash water, such as oxalic acid, Calgon, and HCL, also improved decontamination of the larger particles. However, the choice of additive appears to be site specific.

3.2 COMMERCIAL AND DEMONSTRATION SCALE PROCESS EXPERIENCE

Information was obtained on 10 different large-scale soil washing systems, including two systems that were used to treat radioactive contaminated soil. Table 3.3 summarizes the information available from 9 of these commercial operations and large-scale demonstrations using these systems. Additional information on these systems is presented in Appendix B.

The values given in Table 3.3 are for that fraction of the soil that is clean enough to be returned to the site. Contaminant levels in the cleaned soil, expressed as a percent of the bulk soil levels, are given for five categories of chemicals described below:

Category 1	Insoluble organics and nonvolatile organics (e.g., polyaromatic hydrocarbons, PCBs, and pesticides)
Category 2	Inorganics soluble at low pH (e.g., heavy metals such as Cd, Cr, and Ni)
Category 3	Radionuclides

TABLE 3.2. Summary of Radionuclide Soil Washing Laboratory and Bench-Scale Studies

<u>Study (Reference)</u>	<u>Soil Source</u>	<u>Contaminants Studied</u>	<u>Parameters Studied</u>
U.S. EPA (Richardson et al. 1989)	Montclair and Glen Ridge, New Jersey	Ra-226, Th-230	Water only, EDTA, NaCl, KCl, CaCl ₂ /HCl, particle size, multiple wash, agitation
Savanna River Laboratory, North Carolina (Horten and Albenesius 1976)	Savannah River Laboratory, Georgia	Pu-238	Water only, agitation, particle size
Rocky Flats Plant, Colorado (Navratil and Kochen 1982)	Rocky Flats Plant, Colorado	Pu-238, Am-241	Water only, detergents, surfactants, oxidizing agents, organic acids, sodium salts
Rocky Flats Plant, Colorado (Stevens, Kochen and Rutherford 1982)	Selected DOE sites (Rocky Flats, Hanford, Mound, Idaho, Los Alamos)	Pu-238, Pu-239, Am-241	pH (12.5), aqueous solution containing 2% HNO ₃ , 0.2%HF, 2% pine oil, and 5% Calgon; 2N HCl, particle size
Rocky Flats Plant, Colorado (Stevens and Rutherford 1982)	Rocky Flats Plant, Colorado	Pu-238, Am-241	Water only, aqueous solution containing 2% HNO ₃ , 0.2%HF, 2% pine oil, and 5% Calgon; 2N HCl; pH (12.5); attrition grinding

TABLE 3.3. Typical Performance of Large-Scale Soil Washing Systems (Assink 1987; AWC 1988, 1990; Garnet, Mitchell, and Faccini 1980; Heimhard 1988; Nunno, Hyman, and Pheiffer 1988; Valine 1990)

Technology	Residual Contamination (Concentration in Coarse Soil Fraction/Concentration in Bulk Soil) x 100								
	Heijmans ^(a) extraction flotation	HMZ ^(a) extraction hydrocyclone	Heidemij ^(a) flotation	BSN ^(a) water-jet scrubber hydrocyclone	Harbauer ^(b) blade washer low-freq. vibration	Klockner ^(b) water-jet scrubber	Biotrol ^(c) attrition scrubber	AWC ^(d) gravity separator	Rocky Flats ^(e) drum washer screener
Category 1 Insoluble and nonvolatile organics including PCBs, oils, PAH	--	13 - 15	2 - 7	3 - 5	13 - 16	1 - 4	4 - 9	--	--
Category 2 Inorganics soluble at low pH including Cd, Cr, and Ni	76 - 95	35 - 40	1 - 14	--	--	1 - 24	13 - 41	--	--
Category 3 Radionuclides	--	--	--	--	--	--	--	1 - 40	1 - 26
Category 4 Soluble and volatile organics such as TCE and chloroform	--	<3	1	19	<1	1	--	--	--
Category 5 Soluble inorganics including sulfates, nitrates, cyanides	99	5 - 6	<1 - 3	--	--	6	--	--	--

(a) Netherlands.

(b) Germany.

(c) Valine 1990.

(d) Las Vegas, Nevada.

(e) Pilot Plant Scale.

Category 4 Soluble organics and volatile organics (e.g., TCE, carbon tetrachloride)

Category 5 Soluble inorganics (e.g., nitrates, sulfates, cyanides).

Direct comparison of the different processes cannot be made because of differences in acceptable contamination levels and differences in the soil particle sizes in the clean soil. For example, the first five processes returned soil with a particle size greater than about 63 μm . The Rocky Flats process returned soil with a particle size greater than 500 μm . Cleaned soil in the AWC process contained substantial quantities of soil from all size fractions.

Approximately 90% reduction of Category 1 chemicals in the coarse soil fraction can be achieved with all of the soil washing processes listed in Table 3.3. These types of contaminants remain primarily with the fine soil fraction. Heavy metal reduction (Category 2) varies widely, from 59% to 99%, depending primarily on the metal and whether additives (chelants, acids) are used.

Only two full-scale processes demonstrating soil washing for radionuclides (Category 3) were identified. Residual levels of plutonium in the cleaned soil for these processes ranged from 1% to 40% of the bulk soil contamination levels.

Soil washing is quite effective for removing volatile organics (Category 4). The residual contamination levels are typically <5%. In processes that are open to the atmosphere such as froth flotation and water-jet scrubbing, volatile organics end up in the off-gas from the facility. The off-gas would have to be collected and treated with activated carbon to eliminate air emissions. Category 4 chemicals will also end up in the fines and in the wash water. Wash water treatment will be required when these chemicals are present.

The only Category 5 material listed in any of the soil washing results is cyanide. Residual levels ranged from <1% to 6%. Category 5 chemicals will be present both in the fines sludge and in the wash water. Wash water treatment will be required.

As indicated previously, the majority of the contaminants remain in the fine fraction of the soil; some are removed in the water, and, depending on the process and the chemicals in the soil, some may be stripped into the off-gas. All of these streams will require some form of treatment for the ultimate disposal of the chemicals.

3.3 COST OF SOIL WASHING

Capital and operating costs for various soil washing systems are shown in Table 3.4. The costs for the first five systems are based on actual operations (Nunno, Hyman, and Pheiffer 1988). The information for AWC was reported by the company for treating radioactive contaminated soil (AWC 1990). The cost for the Biotrol System is an estimate provided by the company (Valine 1990). The costs shown in Table 3.4 do not have the same basis; i.e., different chemicals and different soils are involved in each case. The purpose of Table 3.4 is to provide a general indication of the cost of soil washing and not to compare the various processes.

Operating costs include labor, power to run the equipment, chemicals, etc. It is not clear whether the operating cost includes amortization of the capital cost. Not included in these costs are the cost of excavation; treatment or disposal of the sludge; wash water treatment; treatment that may be required to reduce air emissions; and site restoration using clean soil.

The fines content of the soil has the most significant effect on the cost of soil washing. Increasing the amount of fines in the soil decreases the rate at which the soil can be processed, which increases the cost of processing on a per ton basis. The operating costs shown in Table 3.4 for the first five systems are for treating soils with fines content ranging from 5% to 25%.

TABLE 3.4. Capital and Operating Cost Estimates for Soil Washing^(a)

Soil Washing System	Capacity, tons/h	Capital Cost, \$ million, U.S.	Operating Cost, U.S. \$/ton
Heijmans	33	4.5	73-91
HMZ	22	2.2-3.4	55-82
Heidemij	30	2.8-3.4	90-155
Harbauer	22-44	4.3-6.1	136
Klockner	15-40	(b)	65-99
AWC	20	(b)	400-600
Biotrol	20	(b)	65-100

-
- (a) Where a range of costs is given (except for AWC) the lower number is for sandy soils. The higher number is for soils containing about 25% fines. The higher capacity number is for sandy soils; the lower for soils with 25% fines.
- (b) Information not provided.

4.0 ASSESSMENT OF SOIL WASHING TECHNOLOGY AT HANFORD SITE

This section provides a preliminary assessment to evaluate the potential feasibility and the range of applicability of soil washing technology at Hanford. This assessment is divided into two parts. The first part evaluates the potential applicability of the technology to the site in the context of the environment in which the technology would be used. The second part is an evaluation of a limited number of experiments using a bench-scale soil washing system to treat selected soil samples from the North Pond in the 300-FF-1 Operable Unit at Hanford and from a crib located elsewhere on the site.

4.1 APPLICABILITY TO THE HANFORD SITE CONDITIONS

The majority of the soils contaminated with mixed wastes is generally associated with the major government operations located in the 100, 200 and 300 Areas at the site. Figure 4.1 gives an overview of the site showing these locations. Operations in the 100 Areas (B, C, DR, F, H, KE, KW, and N) include nine production reactors. Eight of these reactors have been shut down and are slated for decommissioning. Only the N Reactor (located at 100-N) is operational, and it has been placed on cold stand-by status. Operations in the 200 Area (200 East and 200 West) are dedicated to chemical separations and waste management including storage of irradiated fuel, waste processing, and waste storage operations. The 300 Area includes fuel fabrication and research and development activities.

Both the local geology at the Hanford Site and the types of soil contamination resulting from operations performed there contribute to contaminated soil conditions that are unique. These conditions are discussed below.

4.1.1 Soil Characteristics

The soil surface at the Hanford Site is characterized by a layer of light brown, fine, slightly silty, wind-deposited sand typically varying from less than 1 ft to over 15 ft in depth. Surface soil samples from two separate locations near the 300 Area contained 69% to 97% sand, 1% to 26% silt, and

FIGURE 4.1. Map of Hanford Site

1% to 5% clay. One site located east of the 200 Area near the Yakima barricade contained 7% to 53% sand, 32% to 75% silt, and 5% to 19% clay (Rockhold, Fayer, and Gee 1988).

Underlying the surface soil are poorly sorted, unconsolidated glaciofluvial sediments informally referred to as the Pasco gravels of the Hanford formation. These sediments were deposited during catastrophic flooding episodes associated with failures of the Lake Missoula ice dam during the late Pleistocene epoch (Baker 1981). The last major flood occurred approximately 13 thousand years ago (Mullineaux et al. 1977). The Pasco gravels of the Hanford formation consist of a variable mixture of boulders, cobbles, gravel, sand, and silt; however, most of the sediments can be classified as a silty sandy gravel consisting of 50% gravel, 40% sand, and 10% silt. (DOE-RL 1988). The thickness of the Hanford formation varies from about 20 ft to several hundred feet.

Beneath the Hanford formation is the Ringold formation, which consists of horizontally stratified deposits of sand silt, clay, and gravel. This formation overlies the Saddle Mountains basalt formation and varies in thickness up to several hundred feet. The uppermost aquifer at Hanford is an unconfined system within the Hanford and Ringold formations. This aquifer ranges from less than 1 ft to over 300 ft in depth. In most places at Hanford where the aquifer is in the Ringold formation the formation is too deep to reach by soil excavation. Therefore, it is generally expected that only the surface deposits and Hanford formation soils are of interest for soil washing.

4.1.2 Soil Contamination

A 1988 study (Stenner et al. 1988) identified and classified 646 individual inactive hazardous wastes sites consisting of 355 engineered-facility sites, and 291 unplanned-release sites. Engineered-facility sites used for liquid waste disposal consist of retention basins and ponds, trenches, ditches, cribs, French drains, and reverse wells. These are briefly described in Appendix C. Unplanned-release sites encompass a broad range of unplanned-release conditions ranging from spills of small amounts of material from a container to large volumes in excess of 1 million gallons caused by a process

pipe or tank rupture. In addition to inactive sites, soils have been contaminated during leaks at a number of active sites, including the single-shell tank farms in the 200 Area.

Estimates of the extent of soil contamination range as high as 1 billion cubic yards (Day and Pimental 1989). Table 4.1 lists the characteristics for 125 of the more important inactive contaminant release sites compiled from Stenner et al. (1988). Collectively the surface extent of these sites alone totals up to more than 50 acres and would account for over 100,000 tons of contaminated soil for every foot of depth.

Table 4.1 also shows that the types of contamination from inactive contaminant release sites at Hanford are primarily radionuclides (U, Sr, Cs, Pu, H, Co, Pr, Ce, C and Eu), heavy metals, and nitrate and sulfate salts. Contamination by organic wastes is generally limited to a few sites. Also, with the exception of an unplanned release of diesel oil, the organic contaminants are in combination with the heavy metal contaminants. Therefore, the applicability of soil washing to Hanford soils will almost exclusively be in treating soils contaminated with inorganic materials.

4.2 RESULTS OF BENCH-SCALE SOIL WASHING TESTS AT HANFORD

The bench-scale treatability tests were conducted using soil samples from the north process pond in the 300 Area (EPA Site No. 316-2). The north pond is part of a waste disposal complex that includes another pond (the south pond), an inactive disposal trench, and an active disposal trench. The one operating trench will be closed in the near future, and the 316 site has been designated as a CERCLA site.

The north pond area consists of seven separate sections as shown in Figure 4.2 separated by 12-ft-wide dikes, with the entire 10-acre area surrounded by a dike 15 ft wide and approximately 10 ft high. The pond has been dredged periodically to increase infiltration rate. Some subdividing dikes have been bulldozed to cover the pond bottom. From 1949 to 1974 the site received low-level radionuclide liquid wastes and cooling water from the 3706 and 321 Buildings, aqueous wastes containing unirradiated uranium from the Works Laboratory, and water from the floor drains in the 303 Area. The waste

TABLE 4.1. Summary of Selected Contaminated Sites at Hanford

Area	Site ID No.	Description (No.)	Nominal Site Size, acres	Depth of Water Table, ft	Inorganics	Organics	Radio-nuclides
300	316-1,2,3	N., S. pond (2), trench (1)	0.1-9	34-43	Cr,Cd,Pb,Ni, Zn,Ag,U,Cu, Hg,Be,Na,Al, NO ₃	TCE	
	UPR-300	Unplanned Rel. (2)	<0.1	34-44	U,NO ₃ ,SO ₄		U,Pr,others
	UPR-300	Unplanned Rel. (2)	Unknown	34-44	Cu,NO ₃ ,SO ₄ , U		U
	UPR-300	Unplanned Rel. (1)	Unknown	34	Na		
200	216	Crib (11)	<0.1-0.6	191-338	K,Na,FeCN, SO ₄ ,NO ₃		H,Sr,Cs,Pu, U,beta
	216	Crib (2), reverse well (2)	<0.1-0.1	222-313	K,Na,FeCN, NO ₃ ,SO ₄		H,Sr,Cs,Pu, Co,beta
	216	Crib (11)	<0.1-0.8	197-310	Cr,Na,FeCN, NO ₃ ,SO ₄	Paraffin HC, butyl phos- phate, tributyl phosphate	H,Sr,Cs,U, Pu,beta
	216	Crib (1)	<0.1	19	Na,NO ₃		Pu,beta
	216	Crib (8), reverse wells (2)	<0.1-0.2	187-282	Cr,NO ₃ ,SO ₄ , Na		H,Co,Sr,Cs, Pu,beta
	216	Crib (10), reverse well (2), drain (5)	<0.1-21	180-305	Al,Na,Cr SO ₄ ,NO ₃		H,Sr,Cs,Pu, Co,U,beta
	216	Pond (2), trench (6), drain (2)	<0.1-2	152-255	NO ₃		Sr,Cs,Pu, beta
	216-U	Ditch (1)	0.40	185			Unknown
	216	Trench (1), well (1)	<0.1-0.2	227-284	NO ₃		Unknown
	216	Pond (1)	28.00	180	NO ₃		Co,Sr,Cs,Pu, U,beta
	107	Retention Basin (8)	1-4	10-70			Present
100	UPR-100	Unplanned Rel. (3)	Unknown	60			H,Co,Sr,Cs, Ce,Pr,Pu,H, others
	UPR-100	Unplanned Rel. (1)	Unknown	70			Pu
	116	Trench (1)	4.60	34	Cr,Cu,Na, SO ₄		H,C,Co,Ni, Sr,Cs,Eu,Pu, U

TABLE 4.1. (contd)

Area	Site ID No.	Description (No.)	Nominal Site Size, acres	Depth of Water Table, ft	Inorganics	Organics	Radio-nuclides
	UPR-100	Unplanned Rel. (2)	Unknown	60		diesel oil	
	116	Crib (1)	<0.1	68	Na		H, Co, Sr, Cs
	UPR-100	Unplanned Rel. (1)	Unknown	60			Present
	116	Trench (1), drain (1)	<0.1-3	13-71	Na, Cr, SO ₄		Co, Cs, Eu
	UPR-100	Unplanned Rel. (2)	<0.1-0.5	60			Present
	100 KE	Dry well (1), drain (1)	<0.1	68	Hg		
	116	Trench (12), drain (3), crib (2)	<0.1-0.7	27-94	Cr, Na		H, Co, Sr, Cs, Eu
	100 KW	Dry well (1), drain (1)	<0.1	72	Hg		
	116	Crib (3), trench (2)	<0.1	61-75			H, C
	116-DR	Crib (1)	<0.1	73	K		
600	White Bluff Crib	Pickling acid crib (1)	<0.1	Unknown	NO ₃ , F		
1100	Acid Pit	Battery acid pit (1)	Unknown	45	SO ₄		
	UPR-1100	Unplanned Rel. (1)	Unknown	45	Anti-freeze		

flowed through the 307 Retention Basin en route to the pond. The site was retired in 1974, and the pond has since dried out.

The estimated inventory of nonradiological chemicals known to be disposed at the site is listed in Table 4.2. The primary chemicals of concern include Hg, Cr, Cd, Pb, U, Ni, Ag, Cu, TCE, and HNO₃. Analyses of soil samples taken from the site are shown in Table 4.3. The sample numbers correspond to the locations indicated on Figure 4.2. Also shown in Table 4.3 for comparison are the average concentrations of these elements for soil samples obtained at depths ranging from 0 ft to 10.7 ft from a location in the 300 Area believed to be representative of uncontaminated soil (Dennison,

R9105120.1

FIGURE 4.2. Diagram of 300 Area North Pond

TABLE 4.2. Estimated Nonradiological Chemical Waste Inventory for the North Process Pond

<u>Chemical</u>	<u>Quantity, kg</u>
Beryllium	30
Cadmium	60
Chromium	3,000
Copper	50,000
Fluoride	5,000
Lead	2,000
Mercury	40
Nickel	8,000
Nitrate	800,000
Nitrite	700,000
Nitric acid	900,000
Silver	900
Sodium	1,000,000
Sodium aluminate	2,000,000
Sodium hydroxide	800,000
Sodium silicate	90,000
Trichloroethylene	100,000
Uranium	30,000
Zinc	3,000

Total Volume of Liquids Disposed:
10,000,000,000 L

Source: Stenner et al. (1988).

Sherwood, and Young 1989). Comparing the ratios of the chemicals disposed with the same ratios in the soil samples indicates that some chemicals were more mobile than others.

4.2.1 Samples Tested

The sample numbers shown in Figure 4.2 correspond to the samples used in the soil washing tests. All samples except N 6-2 were collected in 1987 for a study by Stenner et al. (1989). Sample N 6-2 was obtained during this study. Soil samples taken from the ponds show that the soil is quite sandy with a large amount of gravel and boulders. The particle size distribution for some of the samples is given in Figure 4.3. Rocks and gravel that could not pass a 0.5-in. screen were not included in the samples.

TABLE 4.3. North Pond Soil Sample Composition^(a) (values in $\mu\text{g/g}$ except where noted)

Species	Sample Number											Background Soil ^(b)
	A03	A04	A05	B01	B02	C01	D01	E01	F01	F02	F03	
Beta (pCi/g)	338	201	58	295	72.7	88.2	96.4	68	1440	392	210	21.44
Alpha (pCi/g)	410	231	40	374	42.1	89.6	99.6	81.9	1430	380	235	6.35
Beryllium	1	0.6	0.6	1	1	1	0.6	1		7	1	0.65
Strontium	35			57		30	32	33	93	40	57	31.0
Zinc	68	65	55	132	80	126	92	94	122	62	65	50.2
Calcium	12,000	5,690	4,920	16,500	4,760	5,060	5,090	7,520	25,100	9,550	16,400	7,782.0
Barium	99	70	68	171	93	168	152	193	164	162	113	96.6
Cadmium	0.2	1	1	1	1	2	1	1			1	0.5
Chromium	211	74	7	205	34	75	67	104	546	138	61	9.7
Silver	8	7		45	1	8	8	12	123	22	3	<1.0
Sodium	536	442	361	322	250	255	367	265	270	242	419	315.6
Nickel	142	68	35	216	132	52	123	204	260	68	51	7.6
Copper	11,900	10,800	4,350	3,540	1,110	2,450	2,450	2,920	11,600	2,260	394	18.4
Vanadium	62	76	66	84	76	95	76	59	37	57	83	60.0
Aluminum	19,900	13,500	11,600	20,700	8,640	18,000	12,800	18,300	53,800	16,700	18,200	9,910.0
Manganese	317	329	358	341	442	454	394	461	240	289	322	396.2
Potassium	848	555	405	871	517	2320	924	1680	568	1270	647	1,620.0
Iron	26,800	34,300	35,900	29,900	28,500	34,300	32,900	30,000	22,400	24,200	35,800	27,620.0
Arsenic	7.6	2.7	1.5	14	8.6	10.5	2.5	9.2	61	18.6	15.4	3.04
Mercury	0.243			4.71	1.3	0.52	2.16	1.88	8.08	1.56	0.76	<0.1
Selenium									1.8			<0.7
Magnesium	6,040	6,640	6,290	8,830	5,190	9,100	6,730	9,340	12,000	6,670	9,860	6,188.0
Lead	23.6	19.9	2.3	20.4	8.4	20.6	8.6	6.1	79	18.8	18	5.08
Ar1248	0.6	0.4		2.0	0.62	0.4		0.34	3.4	1.6		--
Ar1254											0.4	--
Methychloride	0			0.03		0.01						--
Butenp...	0		1.1									--
Nitrate	140	90.6	152	3.83	3.75	20.5	20.8	4.16	1.84	3.93	14.6	1.06
Sulfate	26.8	38.5	21	10.3	13.4	11.6	17.9	3.71	18.6	23.9	129	9.68
Fluoride	13.1	13.9	10.4	4.32	4.58		1.8	1	6.09	4.02	2.02	2.44
Chloride	3.67	4.7	1.81							1.16	7.75	1.84
Acetone					0.11							--

(a) Analyses conducted in 1987 (Source: Dennison, Sherwood, and Young 1989).

(b) Preliminary background soil quality data from vertical boring sample S-7 near south process pond. Source: Dennison, Sherwood, and Young (1989).

FIGURE 4.3. Particle Size Distribution

Figure 4.4 is a procedure flow diagram for the bench-scale soil washing system. Soil samples ranging in size from about 100 g up to 500 g were used in each experiment, and a portion of each sample was submitted for analysis. The soil samples were dried and weighed, then mixed with water in a 1-gal polystyrene bottle. The water-to-soil weight ratio ranged from 1:1 to 10:1. The bottle was then placed on a reciprocating shaker for a period of time ranging from 30 min to 1 h and shaken at a stroke length and frequency of 1.8 in. and 4 Hz, respectively.

The flowchart illustrates the sample preparation process for soil analysis. It begins with 'Soil' and 'Wash Solution' being weighed on a 'Scale' and then placed in a 'Shaker'. The shaker output goes to a series of four screens: #9, #60, #250, and a Pan. The material retained on the #9 screen is washed with 'Rinse Water' and the residue is weighed on a 'Scale' to produce a 'Sample'. The material passing through the #9 screen goes to the #60 screen. The material retained on the #60 screen is washed with 'Rinse Water' and the residue is weighed on a 'Scale' to produce a 'Sample'. The material passing through the #60 screen goes to the #250 screen. The material retained on the #250 screen is washed with 'Rinse Water' and the residue is weighed on a 'Scale' to produce a 'Sample'. The material passing through the #250 screen goes to the Pan. The material in the Pan is washed with 'Rinse Water' and the residue is weighed on a 'Scale' to produce a 'Sample'. The material passing through the Pan is collected in a 'Bucket'. The material in the Bucket is filtered through a 'Pressure Filter' to produce a 'Sample'. The material passing through the Pressure Filter is collected in a 'Bucket'. The material in the Bucket is filtered through a 'Pressure Filter' to produce a 'Sample'. The material passing through the Pressure Filter is weighed on a 'Scale' to produce a 'Sample'.

FIGURE 4.4. Procedure Flow Diagram of Bench-Scale Soil Washing

water was added to the Wet-Vac and recirculated. The solids retained on each screen were collected, dried, weighed, and submitted for analysis. The wash water and the recycle water were also submitted for analysis. Analysis of the original sample and each washed fraction was performed using U.S. EPA SW846 methods.

4.2.3 Experimental Results

Eight soil washing tests were performed to gain experience with the soil washing apparatus and to explore some of the parameters known to be important to the process. Table 4.4 shows the concentrations of a number of constituents in the whole soil before washing and in the different fractions following washing for a soil sample obtained from location A03 (Figure 4.2). This test used a wash water/soil ratio of 5:1 and a total washing time of 1 h. Also shown for comparison are the concentrations of these same constituents for an uncontaminated soil sample.

Both the elemental and overall material balances between the total soil and the sum of individual fractions and wash water recovered are shown in Table 4.4. These balances are expressed as a percent of the soil sample values before washing. The amount of material accounted for in the balance is not very good for several of the elements. This trend was observed for all of the tests performed. Only a portion of the poor elemental balances can be accounted for by the apparent loss of material indicated in the material balance. The remaining discrepancies are attributed to analytical error including the method of selecting samples for analysis and the variability introduced by analyzing small (1 g) quantities of material for analysis. The small sample size is particularly important where single grains of soil account for a significant portion of the sample analyzed and individual grains of contaminants can account for a significant portion of the concentrations measured.

It can be seen from the data that there is a definite partitioning of the major contaminants to the smaller fractions. In addition, very little of the contamination partitioned to the wash water. Figure 4.5 shows the cumulative distribution of the total inventory of chromium, copper, lead, nickel, and uranium. This distribution is based on both the contaminant concentrations and soil quantity in each progressively smaller fraction. The figure

TABLE 4.4. Soil Washing Results for A03 Soil Sample Obtained from North Pond

Species	Analysis Values, in $\mu\text{g/g}$						Material Balance (%)
	Soil Size Fraction (quantity)						
	Bulk Soil (282 g)	2 mm/12.5 mm (6.92 g)	250 μm /2 mm (236.3 g)	63 μm /250 μm (9.9 g)	Less than 63 μm (9.7 g)	Wash Water (1.56 L)	
<u>Key Constituents</u>							
Chromium	286	23	110	690	2,180	0.23	67
Copper	12,500	1,560	8,000	22,900	69,000	0.34	79
Lead	92	0.0	60	250	425	0.0	80
Nickel	191	40	140	1,430	820	0.0	103
Uranium	65	5	25	117	316	0.0	55
<u>Other Major Contaminants</u>							
Aluminum	31,500	11,110	21,000	47,000	89,000	0.41	72
Barium	140	89	100	220	342	0.02	75
Calcium	12,600	9,040	8,300	13,800	12,600	27.1	64
Iron	41,500	34,000	33,400	33,100	23,600	0.01	74
Lanthanum	23	--	21	32	51	--	89
Magnesium	8,000	3,900	6,650	9,000	9,900	4.35	90
Manganese	550	390	450	550	650	0.014	78
Phosphorus	450	1,100	1,680	305	230	--	323
Silicon	3,600	4,700	2,200	3,060	3,500	2	61
Strontium	65	42	40	120	110	0.11	65
Neodymium	32	24	25	39	64	--	78
Titanium	4,100	4,780	3,900	2,200	970	0.01	85
Vanadium	132	121	112	102	175	--	81
Yttrium	20	16	20	16	16	--	91
Zinc	59	73	55	124	370	--	110
Zirconium	1,150	58	250	4,400	24,000	0.15	104

Constituents measured below detection limits: Arsenic, Beryllium, Boron, Cadmium, Cobalt, Molybdenum, Silver, Thallium.

FIGURE 4.5. Contaminant Partitioning

shows that there is considerable variation in the degree of partitioning for the different constituents. It can also be seen from this figure that while partitioning of each of these constituents is occurring, a significant fraction of the inventory of each is associated with the -2 mm/+250 μ m fraction mainly because it constitutes 90% of the bulk soil weight. Although Figure 4.5 illustrates partitioning, it does not provide a complete measure of soil washing performance. The distribution curves do not consider the magnitude of the contamination or that portion of the inventory that would be present in uncontaminated soil. Also, the figure does not consider maximum concentrations that may be allowed for the contaminants in treated soil since limits have not yet been established.

Table 4.5 compares the level of contaminants in the -2 mm/+250 μ m fraction to the level in the whole soil for four different soil washing tests performed using a water/soil ratio of 5:1 and a washing time of 30 min. These results show that there is considerable variation in the partitioning of contaminants for soil samples obtained from different locations. These results are significant because this fraction alone represents from approximately 50% to as much as 90% of the amount of soil passing a 1/2-in. screen. Technical feasibility of soil washing will depend on adequate cleaning of this fraction.

The results obtained for tests using a sample collected from N6-2 are particularly noteworthy. This sample was collected at a point close to where samples F01, F02, and F03 were collected; however, observations during collection at the site indicated that it included a substantial quantity of a blue-green sediment. Later tests also showed that the sediment did not readily fall apart during washing. Preliminary analysis also indicated gross alpha levels about four times higher in the blue-green sediment than in the whole soil. The poor partitioning results for this sample suggest that contamination is associated with the sediment and that simple washing does not partition the sediments to the smaller size fractions.

Three additional tests were performed with the soil obtained from the N-2 site. Two tests were performed with HCl and H₂SO₄, respectively, added to the wash water to obtain an initial pH of 2. In both cases the acid caused

TABLE 4.5. Comparison of Soil Washing for Soil Samples Obtained from Four Different Locations in the North Pond

Species	Analysis Values, in $\mu\text{g/g}$											
	A03			F01			N6-2-1			D01		
	Bulk Soil (263.00 g)	Soil 2 mm/250 μm (236.28 g)	% Bulk Value	Bulk Soil (128.00 g)	Soil 2 mm/250 μm (59.57 g)	% Bulk Value	Bulk Soil (324.00 g)	Soil 2 mm/250 μm (192.60 g)	% Bulk Value	Bulk Soil (287.59 g)	Soil 2 mm/250 μm (137.56 g)	% Bulk Value
<u>Key Constituents</u>												
Chromium	286	110	38.46	766	296	38.64	645	800	124.03	75	40	53.33
Copper	12,500	8,000	64	12,400	4,830	38.95	9,070	12,000	132.3	2,070	1,260	60.87
Lead	92	60	65.22	50	69	138.00	NA	NA	NA	NA	NA	NA
Nickel	191	140	73.3	369	156	42.28	325	405	124.62	150	150	100.00
Uranium	65	25	38.46	NA	NA	NA	10	20.1	201	220	40	18.18
<u>Other Major Contaminants</u>												
Aluminum	31,500	21,000	66.67	52,000	26,290	50.56	39,000	47,000	120.51	11,000	7,100	64.55
Barium	140	100	71.43	230	129	56.09	190	200	105.26	145	102.00	70.34
Cadmium	NA	NA	NA	2.10	5.20	247.62	NA	NA	NA	NA	NA	NA
Calcium	12,600	8,300	65.87	27,693	13,028	47.04	15,400	15,900	103.25	6,100	5,260	86.09
Iron	41,500	33,400	80.48	19,109	26,300	137.63	25,400	23,900	94.09	30,500	29,800	97.70
Magnesium	8,000	6,650	83.13	11,318	8,310	73.42	9,070	8,800	97.02	6,630	5,190	78.28
Manganese	550	450	81.82	264	320	121.21	400	370	92.50	560	410	73.21
Strontium	65	40	61.54	141	63.1	44.75	75	88	117.33	24	20	83.33
Zirconium	1,150	250	21.74	126	132	104.76	NA	NA	NA	110	176	160.00

Wt% of soil in 250 μm /12.5 mm size fractions: A03, 92; F01, 82; N6-2-1, 59.44; D01, 86.

foaming during washing, and the final pH was about 5.5, which is the same value obtained for all of the tests. This indicates there is apparently a strong buffering action at this pH. In both cases, very little improvement in partitioning was obtained for the -2 mm/+250 μ m fraction. The third test was performed using a ball mill roller instead of the shaker in order to impart a tumbling action to the soil. Even though there was no obvious increase in the amount of fines due to attrition, the results did indicate a moderate increase in the extent of decontamination of the -2 mm/+250 μ m fraction, on the order of about 25% for several of the key contaminants.

4.3 OTHER TESTS WITH HANFORD SOILS

Bench-scale tests were also conducted by Stevens, Kochen and Rutherford (1982) at Rocky Flats Plant as part of a comparative study of soil washing for different DOE sites. These soil washing experiments are briefly described in Appendix A. The soil tested was described in the report as a sandy loam that underlies a crib drain field. The transuranics in the soil were deposited from an acid solution. The average plutonium and americium concentrations in the soil were 11.2 μ Ci/g and 3.25 μ Ci/g, respectively. Table 4.6 shows how the soil partitioned to a >150 μ m fraction, a <150 μ m fraction, and the soil remaining in the wash water as colloidal and dissolved material following each test. These data, while not directly comparable to the data in Figures 4.3 and 4.4, suggest that the soil tested in these experiments contained significantly more silt and clay.

The experimental results demonstrating the partitioning of the actinides for the different tests are shown in Table A.2 of Appendix A. It can be seen from the data that at high pH, the coarse fraction of the soil still contains approximately one-half of the contamination of the bulk soil for both americium and plutonium. However, the americium appears to preferentially partition to the dissolved and colloidal material in the liquid, whereas the plutonium appears to partition to the fine fraction of the soil. The weak acid-surfactant solution only showed slight improvement in removing plutonium from the coarse fraction and no improvement in removing americium from the

same fraction. The strong acid solution, however, reduced the contamination of both species to less than 5% of the bulk soil.

TABLE 4.6. Percent of Total Soil Remaining in Soil Fraction After Tests

<u>Soil Fraction</u>	<u>pH 12.5 Solution</u>	<u>2% HNO₃, 0.2% HF, 2% Pine Oil, 5% Calgon</u>	<u>2N HCl</u>
>105 μ m	65.1	62.4	62.8
<105 μ m	30.2	30.4	29.7
Liquid	4.7	7.2	7.4

5.0 CONCLUSIONS AND RECOMMENDATIONS

Soil washing is a process for removing a wide variety of contaminants from excavated soil. The applicability of the technology to the Hanford Site depends on a number of considerations, including the type of soil and contaminants being treated, applicable experience with soil washing under similar conditions, and evaluation of tests with Hanford soil. Several conclusions can be made regarding each of these considerations.

Hanford soils of interest to soil washing are composed of two distinct layers, the surface soils and the Pasco gravels. The surface soils vary widely in characteristics and can contain up to about 50% silt and clay. However, this layer may be as little as 1-ft thick, and contaminated facilities which are generally excavated below grade will likely have this layer mixed with the Pasco gravels below. The Pasco gravels typically contain about 90% sand, gravel, and cobbles. Previous soil washing experience at other sites strongly suggests that soils containing less than 25% of silt and clay are usually suitable for soil washing in which the main strategy is to separate the silt and clay from the coarser fractions of the soil. In this regard the Hanford soils gravels appear to be candidates for soil washing, offering as much as 90% volume reduction by separating the silt and clay from the soil.

The major contaminants at Hanford are radionuclides, heavy metals, and nitrate and sulfate salts. Most of the sites contain mixed wastes, with only two primarily containing organics. Other sites contain only minor quantities of organics. Based on previous soil washing experience at other sites, soil washing appears to be applicable to removing the organics where they are present in the soil, because they generally partition to the fine fraction of the soil and they can be removed by separating the fines from the bulk soil.

The applicability of soil washing to removing the inorganic hazardous components and the radionuclides is less certain. Past experience has shown that it is possible to achieve a high degree of decontamination of the coarse fractions of soil containing specific heavy metals or radionuclides. However, there are significant variations in the removal efficiency of different heavy

metals in any one site and there are also significant variations in the removal efficiency for the same heavy metals or radionuclides for different soils. It is believed that in some instances, the soil chemistry allows small particles of solid contaminants to adhere to the surfaces of larger particles. Presumably these variations in removal efficiency are influenced by the deposition and aging mechanisms of the contaminants on the soil.

Based on the limited number of experiments conducted to date it is not possible to draw any firm conclusions regarding the feasibility of soil washing to remediate contaminated soils at the Hanford Site. However, the following conclusions can be made about the character of the contaminated soil in the north pond of the 300 Area and its behavior during soil washing:

- The soil in the 300 Area ponds is, as expected, primarily sand or larger material with at least 80% to 90% of the soil having a particle size greater than 250 μm .
- The primary hazardous contaminant present is copper, and the primary radionuclide present is uranium.
- The initial contamination is spread throughout the range of particle sizes, but, after washing, the contamination is partitioned preferentially to the fine fraction (<250 μm) of the soil.
- The coarse fraction after washing still contains significant levels of contamination which is apparently in the form of discrete particles and as a coating on the sand particles. The amount of decontamination achieved for this fraction also varies significantly between soils from different locations in the pond.
- Very little of the contamination is water soluble indicating that high water recycle ratios can be used.
- Additional unit operations such as attrition scrubbing will be necessary to further reduce the contamination on the coarse fraction.

While some test results are encouraging, additional tests will be needed to fully assess the applicability of the technology and to resolve some of the issues identified in these preliminary tests.

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APPENDIX A

SUMMARY OF BENCH-SCALE TESTS ON SOIL WASHING APPLICABILITY TO RADIONUCLIOE REMOVAL

APPENDIX A

SUMMARY OF BENCH-SCALE TESTS ON SOIL WASHING APPLICABILITY TO RADIONUCLIDE REMOVAL

This appendix gives an overview of five bench-scale studies, that have investigated soil washing for removing radionuclide contamination.

A.1 RESEARCH ON CONTAMINATED SOIL AT SAVANNAH RIVER, SOUTH CAROLINA

Horton and Albenesius (1976) conducted a study to test the effects of soil agitation time during soil washing. The soil samples were taken from a trench that had been filled with plutonium waste in 1964. In this study, 15-g samples were agitated in a flask for varying lengths of time. Fresh water was passed through the flask at predetermined flow rates during washing, causing some partitioning of particles according to size. Results showed that increased scrubbing time both increased the amount of material in the silt-clay fraction and decreased the amount of contamination in the sand fraction. Ninety-five percent of the contamination partitioned with the silt-clay fraction, which comprised about one third of the bulk soil. Similarly, increasing the flow rate of the wash water improved decontamination of the coarse sand by eluting particles as large as 110 μm .

A.2 RESEARCH ON CONTAMINATED SOIL AT ROCKY FLATS, COLORADO

Two studies were conducted at Rocky Flats, Colorado. The first study investigated the merits of wet and dry screening and attrition scrubbing as well as the influence of several additives to the wash water on the efficiency of soil washing (Navratil and Kochen 1982). Soil samples were obtained in 1976 from six different locations in the area contaminated with plutonium and americium from lathe coolant oil and carbon tetrachloride. The plutonium was postulated to be present as both particulate plutonium (plutonium dioxide) and soluble species (perhaps chloride and/or 2,6-di-tert-butyl-4-methoxyphenol

soluble complexes). The contamination level in the soil was determined to be from 900 to 140,000 pCi/g. The soil was primarily rock, gravel, and sand with 60% larger than 4 mm particle diameter.

The attrition scrubbing tests used a laboratory Fagergren flotation machine, which reduced the contamination to <20 pCi/g. The attrition scrubbing device consisted of three six-bladed, stainless steel, opposed-pitch turbine-type propellers on a stainless steel drive shaft. The soil samples and wash solution were mixed about 1 to 1 on a weight basis and scrubbed at 900 rpm for about 10 min.

Soil decontamination tests using different additives to the wash solution were conducted using a Norton variable speed ball mill. A special chamber was designed and fabricated to replace the ball mill jars. A 1-kg sample of homogenized soil was placed in the chamber and mixed with 1 kg of scrub solution. The chamber was rotated at 70 rpm for 6 min.

The test results showed that dry-screening was not an effective means for decontaminating Rocky Flats soil. Wet-screening with water decontaminated approximately 65% of the soil (the > 2.4 mm fraction) to <6 pCi/g plutonium and <3 pCi/g americium. The 2.4 mm to 0.42 mm fraction was decontaminated to 300 pCi/g plutonium by wet-screening. Attrition scrubbing tests reduced the contamination in this fraction to <20 pCi/g.

The scrub solutions tested had different degrees of success. The results of these studies are shown in Table A.1, where considerable variation can be seen. The three additives found to produce the best results were Calgon, oxalic acid, and Turco 4342 detergent (not reported in Table A.1).

The second study (Stevens and Rutherford 1982) tested the effectiveness of a vibratory grinder. The vibratory grinder used in the experiments was a Roto-Finish Spiratron ST-1. The machine is produced commercially for metal finishing processes. Four different scrub solutions were tested; water and the three scrub solutions tested in the first study. The soil used was also similar to the soil used earlier, primarily gravel and sand with 70% >2.4 mm.

The experiments showed that vibratory grinding is more effective than a rotating mill for decontamination of Rocky Flats soil. All four scrub

TABLE A.1. Effects of Wash Water Additives on the Decontamination of Rocky Flats Soil^(a)

Actinide content of soil: Pu = 3.7×10^3 dpm/g; Am = 6.3×10^3 dpm/g

Solution	Solution pH		Weight (%)	4.0 to 0.42 mm Fraction	
	Before	After		Pu (dpm/g ^c)	Am (dpm/g ^c)
Distilled Water ^b	6.7	-	97	740 ± 285	120 ± 72
Distilled Water	6.7	-	80	125 ± 89	28 ± 6.2
Hot Distilled Water (-80°C)	6.7	-	80	180 ± 0	35 ± 3.6
Calgon 5 wt%	6.2	6.9	82	140 ± 18	18 ± 15
Calgon 10 wt%	5.9	6.5	80	66 ± 15	15 ± 1.8
Citric Acid 0.1M	2.0	3.2	-	160 ± 36	32 ± 20
Oxalic Acid 0.1M	1.3	1.3	79	68 ± 2.7	21 ± 8.9
Sodium Silicate 0.1 wt%	10.4	10.2	-	150 ± 18	27 ± 3.6
Basic-H Detergent 1 vol%	6.0	-	87	460 ± 142	61 ± 21
OT-B (Anionic Surfactant) 0.1 wt%	5.8	-	85	220 ± 107	47 ± 18
C-61 (Cationic Surfactant) 0.1 wt%	8.4	-	80	170 ± 18	36 ± 18

a) Composite soil of weighted portions of six samples (P-1 thru P-6) from under the asphalt pad (<4.0 mm).

b) No attrition scrub.

c) Mean = standard deviation. Two determinations on each sample.

solutions reduced the >0.42 mm fraction (85% of the soil) from 3200 pCi/g to <14 pCi/g. The weak acid/surfactant and the strong acid solutions improved the decontamination of the 4 mm to 0.42 mm fraction compared to water and the pH 12.5 solution.

A.3 COMPARATIVE BENCH-SCALE RESEARCH ON CONTAMINATED SOIL FROM SELECTED DOE SITES

Another study conducted at Rocky Flats (Stevens, Kochen, and Rutherford 1982) compared soil decontamination using three scrubbing solutions: 1) a pH 12.5 NaOH solution; 2) a 2% HNO₃, 0.2% HF, 2% pine oil, and 5% Calgon

solution; and 3) a 2N HCl solution for transuranic-contaminated soils obtained from five different DOE sites (Rocky Flats, Hanford, Mound, INEL, and LANL). All of the tests used the Norton variable speed ball mill. In each test, 1 kg of soil mixed with 1 kg of scrub solution was sealed in a container and rotated for 6 min at 70 rpm. The solids were then separated by centrifugation and/or filtered through Whatman 42 filter paper. The solids were then mixed with 500 mL of washing solution and returned to the sealed chamber for subsequent washing. This second cycle of washing was repeated three more times, then a wash water cycle was used.

A comparison of the decontamination achieved for each solution is shown in Table A.2. The results showed that the scrub solutions had different degrees of success decontaminating each type of soil. For example, the pH 12.5 NaOH solution was effective only in reducing plutonium contamination levels for the Rocky Flats soil where the activity of the >150 mesh (105 micron) fraction was reduced to 2.5% of the average level of contamination in the total soil. On the other hand, the HNO₃, HF, pine oil, Calgon solution was the most effective solution with the LANL soil. It reduced the plutonium and americium contamination in the >150 mesh fraction to 18.5% and 31.5%, respectively, of the level in the whole soil. As was discussed in Section 4.3 of the report the HCl solution was most effective for the Hanford soils. Residual levels of plutonium and americium contamination in the >150 mesh fraction were 4.4% to and 1.0%, respectively. The HCL solution was also found to be the most effective for the INEL soils and for removing plutonium from the Mound soil. For each of these soils the HCl removed the contamination into the water, so water treatment requirements would be significant. Based on the wide variations in the results, the authors concluded that the selection of additives will have to be tailored to each soil.

A.4 BENCH-SCALE RESEARCH ON CONTAMINATED SOIL FROM MONTCLAIR AND GLEN RIDGE, NEW JERSEY SITES

Richardson et al. (1989) conducted soil washing studies using soil from the Montclair and Glenridge Sites. Soil from the Glen Ridge and Montclair sites are contaminated with radium-226 and thorium-230. Barium-radium

TABLE A.2. Soil Washing Tests for Contaminated Soils at Several DOE Test Sites

Enrichment Factors for ^{239}Pu

Results are the average of two runs.
Numbers in parentheses are standard deviations.

Soil	Fraction	pH 12.5 Solution	2% HNO_3 , 0.2% HF, 2% Pine Oil, 5% Calgon	2N HCl
Rocky Flats	+150	0.025 (0.026)	0.037 (0.014)	0.057 (0.035)
	-150	6.0 (1.98)	2.06 (1.78)	2.25 (0.120)
	Liquid	0.28 (0.339)	9.5 (3.39)	8.70 (2.40)
Hanford	+150	0.58 (0.396)	0.465 (0.106)	0.044 (0.054)
	-150	2.05 (0.834)	1.05 (1.05)	0.055 (0.060)
	Liquid	0.005 (0.007)	5.31 (3.37)	13.1 (2.40)
Mound	+150	0.26 (0.325)	0.535 (0.304)	0.246 (0.288)
	-150	2.02 (0.240)	0.965 (0.742)	2.5 (0.0)
	Liquid	0.022 (0.011)	2.96 (1.65)	0.143 (0.109)
INEL	+150	0.625 (0.148)	0.815 (0.247)	0.062 (0.003)
	-150	1.38 (0.064)	0.905 (0.078)	0.18 (0.014)
	Liquid	0.05 (0.071)	1.69 (0.707)	4.65 (0.071)
LANL	+150	0.745 (2.90)	0.185 (0.105)	0.77 (0.679)
	-150	1.60 (0.417)	1.83 (0.064)	0.76 (0.120)
	Liquid	0.395 (0.064)	1.68 (1.08)	5.92 (0.686)

Enrichment Factors for ^{241}Am

Results are the average of two runs.
Numbers in parentheses are standard deviations.

Soil	Fraction	pH 12.5 Solution	2% HNO_3 , 0.2% HF, 2% Pine Oil, 5% Calgon	2N HCl
Rocky Flats	+150	0.096 (0.119)	0.015 (0.008)	0.021 (0.004)
	-150	4.66 (0.651)	0.44 (0.269)	0.825 (0.191)
	Liquid	2.35 (0.495)	16.9 (4.95)	12.1 (3.32)
Hanford	+150	0.453 (0.505)	0.465 (0.262)	0.035 (0.010)
	-150	0.825 (1.01)	1.06 (1.28)	0.052 (0.026)
	Liquid	9.6 (13.6)	5.57 (7.82)	13.1 (1.98)
Mound	+150	0.825 (0.926)	0.395 (0.318)	1.5 (0.778)
	-150	1.31 (0.905)	1.47 (0.742)	1.18 (0.382)
	Liquid	0.335 (0.021)	1.17 (1.12)	0.257 (0.258)

TABLE A.2. (contd)

Soil	Fraction	pH 12.5 Solution	2% HNO ₃ , 0.2% HF, 2% Pine Oil, 5% Calgon	2N HCl
INEL	+150	0.605 (0.304)	0.725 (0.488)	0.052 (0.061)
	-150	1.4 (0.156)	0.89 (0.156)	0.108 (0.016)
	Liquid	0.091 (0.111)	1.80 (1.46)	4.9 (0.0)
LANL	+150	1.07 (0.509)	0.315 (0.106)	0.51 (0.028)
	-150	0.12 (0.170)	0.54 (0.014)	0.555 (0.346)
	Liquid	3.31 (1.98)	7.03 (2.33)	5.16 (1.79)

sulfate, partially extracted ores and other radiominerals from a radium extraction mill are mixed with native soil and constitute a radiological hazard due to elevated levels of radon and gamma radiation. Soil samples from the site were characterized with respect to radionuclide distribution and particle size by wet-screening and by radiochemical analysis.

The Montclair soil contained about 130 pCi/g of Ra-226 and Th-230 and the Glen Ridge soil contained about 830 pCi/g of Ra-226 and Th-230. By combining vigorous shaking with water followed by vacuum wet sieving, up to 56% of the Montclair soil (fraction >74 μm) was recovered with a specific activity of 16 pCi/g. About 67% of the soil (fraction >37 μm) was recovered with a specific activity of 19 pCi/g. For the Montclair soil, 61% of the soil (>74 μm) was recovered with a specific activity of 161 pCi/g.

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APPENDIX B

DESCRIPTION OF COMMERCIAL AND DEMONSTRATION SCALE SOIL WASHING SYSTEMS

APPENDIX B

DESCRIPTION OF COMMERCIAL AND DEMONSTRATION SCALE SOIL WASHING SYSTEMS

Soil washing is a relatively new technology and there has been only limited experience with commercial-scale systems. This experience is important however, in that it provides information on system performance under full scale conditions where conditions cannot be carefully controlled as they are in bench-scale systems. Information is also provided on process scale, unit operations employed in an integrated system, and some of the operating parameters that are controlled to meet site specific conditions. This appendix summarizes information that was reported in the literature on 10 commercial-scale and pilot-scale units.

Throughout the following descriptions of the various soil washing technologies, soil fractions are often referred to as "clean." In reality, the "clean" soil fractions from all of the processes will have some residual levels of chemicals. For many of the processes, the actual levels of chemicals present in the "clean" soil fractions after washing are not given. The use of the word "clean," when referring to a particular soil fraction, does not necessarily imply that if the process were used at a mixed waste site, the clean fraction could be redeposited at the site. Treatability studies with actual soils from a specific site would be required to determine if the chemical level in the "cleaned" soil would meet the remedial action criteria established EPA, the Washington State Department of Ecology, and DOE.

The soil washing processes described in this appendix and the primary unit operations used in each process are identified in Table B.1. These systems are organized and discussed under separate sections for the European and U.S. systems for convenience.

B.1 SOIL WASHING IN EUROPE

Information was found on four soil washing plants in operation in the Netherlands and three in Germany. They range in capacity from 6 to 40 tonnes

TABLE B.1. List of Soil Washing Technologies

<u>Company</u>	<u>Country</u>	<u>Primary Unit Operations</u>	<u>Reference</u>
Heijmans	Netherlands	Extraction, flotation	Nunno, Hyman, and Pheiffer (1988); Assink (1987)
HMZ	Netherlands	Extraction, hydro-cyclones	Nunno, Hyman, and Pheiffer (1988); Assink (1987)
Heidemij	Netherlands	Flotation	Nunno, Hyman, and Pheiffer (1988)
BSN	Netherlands	Water-jet scrubber, hydrocyclone	Assink (1987)
Harbauer	Germany	Bladescrubber, low frequency vibration	Nunno, Hyman, and Pheiffer (1988); Sonnen and Klingebiel (1988)
Klockner	Germany	Water-jet scrubber	Heimhard (1988)
Oil CREP	Germany	Solvent extraction	Nunno, Hyman, and Pheiffer (1988)
Biotrol	U.S.	Attrition scrubbing, screen, froth flotation, hydrocyclones, spiral classifiers	EPA (1989); Valine (1990)
AWC	U.S.	Trommel washer, jig	AWC (1988) AWC (1990)
Rocky Flats	U.S.	Drum washer	Garnett, Mitchell, and Faccini (1980)

(6.5 to 30 tons) of soil per hour. Three of the washing plants use extraction processes; one uses froth flotation; two use a high-pressure water-jet system; and one uses a bladescrubber combined with low frequency vibration (Verhagen 1988; Assink 1987; Nunno, Hyman, and Pheiffer 1988; Heimhard 1988; Sonnen and Klingebiel 1988).

B.1.1 Heijmans Soil Washer

Heijmans has developed a simple, semi-transportable soil washer capable of handling 10 tonnes (11 tons) per hour of soil. Figure B.1 is a flow

FIGURE B.1. Process Flow Scheme for the Heijmans Soil Washing Plant (adapted from Assink 1987)

diagram for the system. Wet sieves are used to separate out larger than 100-mm coarse material and larger than 5-mm particles prior to scrubbing. The slurry of smaller than 5-mm particles is mixed in an extractor (which is referred to as a scrubber) with "extracting agents and oxidizing chemicals" that are not identified. The solids from the scrubber ($63\ \mu\text{m} < x < 5\ \text{mm}$) are passed through hydroclones and a dewatering sieve. This cleaned sand is often used as an aggregate for asphalt. The scrubbing water and the contaminated fines ($< 63\ \mu\text{m}$) are further treated by coagulation, flocculation, and precipitation followed by froth flotation to remove additional solids.

The Heijmans soil washing plant has been in use since 1985, primarily for removal of the following:

- cyanides
- water-immiscible and low-density hydrocarbons
- heavy metals (such as Cr, Cd, Ni, Pb, and Zn)
- combinations of these contaminants.

Soils containing chlorinated hydrocarbons and aromatics cannot be treated because no form of wash water cleanup is included in the system. Wash water treatment with activated carbon could be added for soils containing these materials. The process has been used on soils with fine fractions ($< 63\ \mu\text{m}$) up to 30%, but it works best on sandy soils with a minimum of humus-like compounds.

B.1.2 HMZ Soil Cleaning Process

This cleaning process combines particle sizing, soil washing, and water treatment. The system was designed to be mobile but has become a fixed treatment facility with a capacity of 20 tonnes (22 tons) per hour. The soil is wet sieved to remove larger than 50-mm coarse material and then larger than 4-mm particles. The rest of the soil is fed to a scrubber with two mixing propellers. Typically, the pH is adjusted to 12-13 by addition of NaOH and detergents. After scrubbing, the fines ($< 63\ \mu\text{m}$) are removed by hydroclones and dewatered. The majority of the contaminants are concentrated in this fraction of the soil, which requires further treatment or disposal. The

cleaned sand ($63 \mu\text{m} < x < 4 \text{ mm}$) may be used as asphalt aggregate or returned to the site as fill. The contaminated scrub water and overflow from the wet sieves, hydroclones, and belt press are cleaned in a water treatment system. The water is treated in a tank by precipitation, neutralization, coagulation, and flocculation to remove the dissolved contaminants. Cyanide can be removed from the wash water as iron cyanide by the addition of ferrous sulfate. Iron hydroxide particles are removed by sand filtration and dissolved organics by activated carbon. The cleaned water is discharged or recycled. Figure B.2 is a flow diagram for the process.

A full-scale HMZ system was built in 1984. HMZ claims it can be used to remove a variety of chemicals including the following:

- complex and free cyanides
- heavy metals (Pb, Zn, Cr, As, Hg)
- aromatics
- chlorinated aliphatic and chlorinated aromatic hydrocarbons.

From an economic standpoint, when the fines fraction is greater than about 20% of the original soil, the volume reduction of contaminated soil is generally not sufficient to warrant treatment.

B.1.3 Heidemij Soil Washing Using Froth Flotation

Froth flotation used in the mining industry has been adapted to soil washing by Heidemij Uitvoering. The process has been tested on laboratory- and pilot-scale systems, and a full-scale mobile system was scheduled to begin operating in 1988. The full-scale system has a throughput of about 27 tonnes (30 tons) per hour.

The first step of the process is removal of coarse particles ($>4 \text{ mm}$) by wet sieving. The resulting slurry (25% soil, 75% water) is conditioned with "cleaning agents" before entering the flotation cell. The residence time in the cell is dependent on the type of contaminants. The system can have multiple cells for flexibility. The contaminated float (including the soil fines) is skimmed off and either incinerated or sent offsite for disposal. The cleaned soil is dewatered and returned to its original site. The water is

FIGURE B.2. Process Flow Scheme for the HWZ Soil Cleaning Plant (adapted from Assink 1987)

completely recycled. No special water treatment has been necessary because the volatile organics were effectively stripped from the water by air in the flotation process.

The process has been used with soils containing a variety of chemicals by slightly adjusting it and using the appropriate proprietary "cleaning agents." Pilot-scale tests have been conducted with soils containing the following chemicals:

- oil products
- heavy metals
- inorganic compounds
- aromatic hydrocarbons
- polycyclic hydrocarbons
- chlorinated hydrocarbons
- pesticides, herbicides, and fungicides.

The Heidemij system has not been used to treat soils with a fines fraction ($<50\text{ }\mu\text{m}$) over 20%; it is not economically practical and the efficiency of the soil washing process is not good enough to reach accepted standards.

B.1.4 Bodemsanering Nederland (BSN) High-Pressure Water-Jet System

This installation has been in operation since 1983 and was originally developed to separate oil from sandy soil. It has a capacity of about 20 tonnes (22 tons) per day and can be transported easily.

Separation of the oil from soils is based on a high-pressure water-jet curtain that physically removes the fine particles and contaminants from the sand particles. Following the water-jet scrubber, the slurry is passed through sieves, hydroclones, and a gravity separator to remove particles larger than $63\text{ }\mu\text{m}$ that are free of contamination. The remaining slurry is passed through an oil/water separator where oil and a sludge are produced. The sludge contains the fine ($<63\text{ }\mu\text{m}$) fraction of the soil and many of the original contaminants and requires further treatment or disposal. The water is recycled to the water-jet scrubber. Any volatile organics are stripped to

the air in the water-jet scrubber. If necessary, the off-gas can be treated by activated carbon. BSN claims that soils containing water-soluble organics can be treated if a microbiological wash water treatment step is added, but these steps have not yet been added to the operating system. Figure B.3 is a flow diagram for the process.

The high-pressure water-jet system has been used primarily to remove crude oil from soil, but BSN claims the water-jet scrubbing system can be used for soils containing the following materials:

- low density aliphatic and aromatic hydrocarbons (e.g., <1 g/mL)
- volatile organics
- contaminants that are largely adsorbed to the soil particles and will end up in the residual sludge
- water-soluble and biodegradable organics, provided a microbiological treatment step is added.

As with other soil washing processes in the Netherlands, the process is used to treat sandy soils with 20% or less fines.

B.1.5 Harbauer Soil Washing Using Low-Frequency Vibration

The Harbauer process is unique because it uses a low-frequency vibration step to improve contaminant removal; it is especially effective in soil with small particles. Harbauer claims the process can effectively clean all particles larger than 15 μm compared with 63 μm , which is typical of conventional soil washing processes. A fixed facility with a capacity of 20 to 40 tonnes (22 to 44 tons) per hour has been operating in Berlin since 1986. Three other units, which can be either mobile or stationary, are being planned.

Contaminated soil is screened and passed through an electromagnet before entering the first blade washer, as shown in Figure B.4. Clean gravel, 10 mm to 60 mm in diameter, is separated in the first blade washer. Depending on the application, HCl, NaOH, or surfactants are added to the slurry which then enters the low-frequency vibration unit. From the vibration unit the slurry enters a second blade washer where a clean sand fraction (0.2 mm to 10 mm) is separated. A "clean" fine sand (20 μm to 0.2 mm) is separated in hydroclones

FIGURE B.3. Process Flow Scheme for the BSN Plan (adapted from Assink 1987)

FIGURE B.4. Process Flow Scheme for Harbauer Soil Washing Installation (adapted from Nunno, Hyman, and Pfeiffer 1988)

and the fines fraction ($<20\ \mu\text{m}$) is separated as a sludge using a belt filter press. The sludge is contaminated and requires further treatment, either incineration or disposal as a hazardous waste. An extensive water treatment facility including flotation, air stripping, sand filtration, and activated carbon adsorption is included in the system. The clean water is recycled back to the process.

Although specific data are not available to determine the exact mechanism by which the low-frequency vibration improves soil washing efficiency, the vibrations apparently dislodge more contaminated fines from the soil matrix and improve desorption of the chemicals from these smaller particles once they have been dislodged.

Harbauer claims the system can be used for a wide variety of contaminants including the following:

- aliphatics, aromatics, and phenolics
- chlorinated aliphatics and chlorinated aromatics including PCBs
- polyaromatic hydrocarbons (PAH)
- cyanides
- heavy metals (Pb, Cd, Cr).

To date, the Harbauer process has cleaned 10,000 tonnes (11,000 tons) of soil contaminated with organics. No data on inorganic removal are available. The grain-size distribution was given for one soil described as extremely fine grained. The soil contained 23% fines smaller than $63\ \mu\text{m}$ (Sonnen and Klingebiel 1988).

B.1.6 Klockner Umwelttechnik High-Pressure Soil Washing Process

The Klockner high-pressure soil washing system being used to clean soil in Berlin was adapted from a high-pressure soil washing process developed in the Netherlands. The plant in Berlin has a maximum capacity of 40 tonnes (44 tons) per day of soil containing approximately 5% clay. The maximum feed rate with soils containing 20% to 25% clay is reduced to about 15 tonnes (16.5 tons) per day.

The Berlin plant is very similar to the BSN facility in the Netherlands and has been used to treat soils with less than 20% fines that contain the following chemicals:

- aliphatic hydrocarbons, aromatics, and phenolics
- chlorinated hydrocarbons, including PCBs and pesticides
- cyanides
- heavy metals, including Hg, As, Cr, Cu, Ni, Pb, Zn, and Cd.

B.1.7 The Oil CREP Soil Washer

The Oil CREP Soil Washer was originally developed to remove oil from contaminated beach sand. Oil CREP I (Cleaning Recycling Environmental Protection) is a proprietary combination of surfactants, solvents, and aromatic hydrocarbons that cleans and extracts oil from various media while preserving the structure of the oil so it can be recycled. It is an improved "biodegradable" version of the original Oil CREP. Two full-scale units, which process 8 to 10 m³ of soil per hour, have been built and a third is in the planning stages.

Sand/gravel contaminated with oil is fed into the system via a hopper. Oil CREP I is injected into the sand as it is mixed in a screw mixer. The sand travels to a rotating separation drum where the oil is floated off the sand with water and spilled over into a collection tank. The clean sand is reused onsite. The contents of the oil collection tank, which includes the Oil CREP I, are removed for refining or disposal. The water normally can be recycled.

The Oil CREP I system is used primarily for oils containing aliphatics; aromatics; chlorinated hydrocarbons, including PCBs; and polyaromatic hydrocarbons. A new washing compound CREP II, for use with soil types other than sand, is being developed.

B.2 SOIL WASHING IN THE UNITED STATES

There has been no commercial use of soil washing in the U.S. However, several companies and the EPA are developing soil washing capabilities.

B.2.1 EPA Mobile Soil Washing System

The EPA has had a continuing program of soil washing technology research. Initially soil washing was evaluated as a method of cleaning extracted contaminated soils. Laboratory tests were conducted with three separate chemicals (phenol, arsenic trioxide, and PCBs) and two soils of significantly different character. Based on the test results, a full-scale, field-use, prototype system was designed, engineered, fabricated, assembled, and used for several field demonstrations (Scholz and Milanowski 1983).

The mobile soil-extraction system includes two major soil scrubbing components: a water-knife scrubber and soaking unit of novel design and a four-stage countercurrent extractor. The complete system is shown in Figure B.5 (Traver 1985). Contaminated soil is first passed over a screen to remove oversized nonsoil materials and debris. The soil then enters the drum-screen, water-knife, scrubbing unit, which breaks up aggregates in the soil and solubilizes or disperses the contaminants from the larger particles (>2 mm). This fraction of the soil can then be returned to the site. The smaller fraction (<2 mm) remains in a slurry that is fed to the countercurrent extractor. Each extractor is equipped with an aerator for froth flotation and a hydroclone for liquid/solid separation between stages. The extraction fluid is water or water with a variety of additives, such as acids, alkalis, detergents, and selected organic solvents, depending on the contaminant to be removed. Treatment residues consist of skimmings from the froth flotation in the extractor, fine particles discharged with the used washing fluids, and spent carbon used to remove contaminants from the washing fluid. The nominal process rate is 3.2 m^3 (4 yd^3) of contaminated soil per hour when the soil particles are primarily less than 2 mm in size and up to 14.4 m^3 (18 yd^3) per hour for soil of larger average particle size. EPA has discontinued development of the process and is transferring the technology to private industry.

B.2.2 Biotrol Soil Washing System

Biotrol Inc., Chaska, Minnesota, is developing a soil washing system that uses intensive scrubbing to break up soil aggregates and scour the surfaces of the coarser particles. A system process flow diagram is shown in Figure B.6. In this process, soil is mixed with water, following debris

FIGURE B.5. Process Flow Scheme for EPA Mobile Soil Washer (adapted from Traver and Freestone 1985)

FIGURE B.6. Biotrol Soil Treatment System Process Diagram

removal, and subjected to various unit operations. A mixing trommel, pug mill, or ball mill is used to treat the gravel fraction, and a multistage attrition/classification circuit is used to treat the remaining soil including a flotation unit, attrition scrubbing units, hydrocyclones, and spiral classifiers. The wash water is treated and recycled, and the contaminated fine soil fraction is dewatered and further treated as necessary. The soil washing system has been demonstrated in a pilot-scale unit with a treatment capacity of 500 to 1000 lb per hour. The pilot-scale unit used in an EPA Superfund Innovative Technology Evaluation (SITE) program demonstration in 1988 at the MacGillis and Gibbs Site in New Brighton, Minnesota, to clean soil contaminated with pentachlorophenol (penta) and polyaromatic hydrocarbons (PAHs). In this test the system removed 91% to 93% of the penta and 92% to 96% PAHs from the soil. Low levels of copper, chromium, and arsenic present in the soil were also reduced in the washed soil by 59% to 87%. Approximately 84% of the original soil was recovered as washed sand.

B.2.3 AWC Inc. TRUclean Process

AWC has developed a process to recover large quantities of soils contaminated with radioactive materials and heavy metals. Figure B.7 is a flow chart for the TRUclean process. The soil is sorted by size and the larger pieces are fed to a crusher. The crusher is optional depending on the soil and the contaminant. The soil is then passed through a monitoring sorter where it is leveled and spread prior to passing beneath an array of radiation monitoring detectors. If the soil is clean, it is diverted to the clean soil stockpile. Contaminated soil is slurried with water and passed to the decontamination section. The slurry flows into a gravimetric separator, which is the heart of the TRUclean process. Here it is subjected to a pulsed pressure wave generated by a diaphragm pulse system. Through continued agitation,

FIGURE B.7. Process Flow Scheme for AWC Soil Washer (adapted from AWC 1988)

the radioactive materials are separated from the soil particles, which have lower specific gravities. After dewatering, the decontaminated soil is passed through radiation detectors to determine if it meets the criteria for clean soil. The company claims that the process has been successfully tested on materials having as little as a 2 unit difference between the contaminant's specific gravity and that of the soil.

The TRUclean system has been tested on a large scale (15 cubic yards per hour) at Johnston Atoll and at the Nevada Test Site. Both of these sites were contaminated from weapons testing. During the Johnston Atoll project, ^{239}Pu was successfully removed from the native coral soils. An overall volume and activity reduction of 98% and 97%, respectively, were achieved at this site and the decontaminated soil contained less than 10 pCi/g. (AWC, 1988, 1990). The TRUclean system was also tested on contaminated soil from Nevada Test Site, Nevada; Rocky Flats Plant, Colorado; FUSRAP Site at Hazelwood, Missouri; Monasanto-Mound site, Ohio; and Fort Dix, New Jersey. Activity reduction in these tests ranged from 90% to 99% with volume reduction ranging from 62% to 99% (AWC 1988).

Tests were also conducted on radium-contaminated soils obtained from Montclair and Glen Ridge, New Jersey, and Denver, Colorado (AWC 1988). Results from tests achieving the highest activity reduction are shown in Table B.2. These results are considerably lower than those achieved at the other sites. AWC attributed this to the adhesion of $< 50\ \mu\text{m}$ particles to the larger particles making separation by gravity less efficient. Their test results showed that most of the activity in the soil was collected as suspended particles in the wash water.

B.2.4 Rocky Flats Demonstration

In the 1970s, Rockwell International conducted laboratory, bench-scale, and pilot-scale soil decontamination tests with plutonium-contaminated soil at Rocky Flats. Results of these tests indicated that the process concept was feasible, but there was no further development or application.

A wide variety of concepts were studied initially but scrubbing and wet screening appeared particularly suitable for large-scale application at Rocky

TABLE B.2. Results of Soil Washing Tests Achieving the Best Activity Reduction for Glen Ridge, Montclair, and Denver Soils

Site	Bulk Soil Sp. Activity pCi/g	Percent of Soil Cleaned	Clean Soil Sp. Activity pCi/g	Percent Activity Reduction
Glen Ridge	732	57	181	75
Montclair	111	45	22	80
Denver	46	48	18	61

Flats. The laboratory studies found that the plutonium is more closely associated with smaller particle size fraction of the soil, and that the coarse materials could be cleaned.

Figure B.8 is a flow diagram of the pilot-scale system that was built. A vibratory feeder with an attached hopper was used to feed soil into the scrubber. The scrubber was a drum roller equipped with a modified 30-gal drum. The drum contained small lifters to agitate the slurry. A trommel

FIGURE B.8. Process Flow Scheme for Rocky Flats Soil Washer (adapted from Garnett, Mitchell, and Faccini 1980)

screen was attached to the discharge end to separate +5 mesh ($>4\text{mm}$) rocks. The -5 mesh slurry was funneled into a vibratory screener with a 35 mesh ($500\ \mu\text{m}$) screen. The screen was continuously washed with a NaOH solution. The -35 mesh slurry was passed through a hydroclone and the underflow solids were clarifuged. The clarifuge solids $-500\mu\text{m} + 10\mu\text{m}$ were intended to be returned to the site as clean but were still quite contaminated. The overflow water from the hydroclone was treated by flocculation, centrifugation, and ultrafiltration to remove the very fine solids and was then recycled to the scrubber.

Table B.3 shows the test results obtained in four pilot-scale experiments. The +35 mesh fraction accounted for 58% to 87% of the soils fed and the radioactivity in this fraction was reduced 74% to 99% compared to the feed soil.

TABLE B.3. Results of Pilot-Scale Testing at Rocky Flats

<u>Run</u>	<u>Feed, dpm/g</u>	<u>Total Product, +35 Mesh</u>		<u>% Reduction</u>
		<u>dpm/g</u>	<u>Weight Fraction</u>	
2	630	26	0.58	96
3	16,700	192	0.78	99
4	2,900	756	0.87	74
5	1,500	198	0.58	87

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APPENDIX C

DESCRIPTION OF ENGINEERED FACILITIES
FOR LIQUID WASTE DISPOSAL

APPENDIX C

DESCRIPTION OF ENGINEERED FACILITIES FOR LIQUID WASTE DISPOSAL

Several types of liquid waste disposal facilities have been used at Hanford. The information used for the following test was taken from Stenner et al. (1988).

C.1 TYPES OF DISPOSAL FACILITIES

Contaminated liquid wastes have been generated at the Hanford Site since 1944 (ERDA 1975). These wastes have been discharged to ponds, French drains, cribs, ditches, trenches, and reverse wells. The different types of facilities and their functions are discussed below.

Cribs are soil-covered, liquid-waste disposal facilities, usually rock-filled and equipped with a liquid-dispersion system Figure C.1. Various designs have been used in the construction of cribs. A number of older timbered cribs were built like boxes, open only at the bottom and buried deep enough to avoid radiation problems at the surface. The liquid waste was discharged into the ground inside the box, which was also equipped with a vent line. Some cribs were dual structures, with a second cavity catching any overflow from the first via an overflow pipe. Tile fields were also used in conjunction with box-like cribs to disperse the liquid wastes over a wider area (Figure C.2).

Several cribs were built by partly filling an excavation with sorted rock or gravel topped by an impermeable membrane or layer of asphalt. A distribution pipe was placed in the rock or gravel to provide uniform flow of the liquid over the crib bottom. The top of the crib was backfilled with soil to provide radiation protection and prevent dispersal of potentially contaminated soil just above the crib.

French drains (Figure C.3) are covered or buried rock-filled encasements with the bottom end open to allow seepage of liquid into a gravel-filled

FIGURE C.1. Typical Crib

FIGURE C.2. Box-Like Cribs with Tile Field (ready for dirt backfill)

FIGURE C.3. Typical French Drain

excavation. French drains are very similar to cribs, but their volume capacity is much smaller; they were used primarily for small-volume waste streams.

Ponds are bodies of water enclosed in a natural or diked surface depression used for the disposal of high-volume, low-level liquid effluents. As the liquid soaked into the ground, many of the radionuclides were absorbed by the soil and were concentrated enough that subsequent drying of the pond muds could have caused dispersal of activity by wind erosion. Consequently, the pond bottoms were covered with clean soil and stabilized after deactivation (Figure C.4).

Ditches are long, narrow, unlined excavations in the ground used for conveying large volumes of liquid to a pond. Ditches have essentially the same levels of contamination as ponds and were also covered up on deactivation.

FIGURE C.4. Typical Pond

Reverse wells are buried or covered, encased, drilled holes with the lower end of the pipe perforated or open to allow liquid to seep to the ground (Figure C.5). Reverse wells were used to a limited extent early in Hanford Site history for some low-level wastes, but proved unsatisfactory because they plugged easily and introduced the waste into the ground close to the water table.

Liquid-waste trenches (Figure C.6) are long, narrow, unlined excavations used for disposal of low-level liquid wastes. The 100-Area trenches were usually used over long periods for disposal of reactor-coolant water containing fuel failure debris. The 200-Area trenches were generally used over short periods for disposal of limited quantities of liquid on a specific-retention basis. Both open and covered trenches were employed for disposal of liquid wastes.

FIGURE C.5. Typical Reverse Well

FIGURE C.6. Typical Liquid-Waste Trench

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