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ENGINEERING ANALYSIS OF REMEDIAL ACTION ALTERNATIVES PHASE I

Weldon Spring Site Remedial Action Project
St. Charles, Missouri

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Weldon Spring Site Remedial Action Project

Engineering Analysis of Remedial Action Alternatives
Phase I

Revision 0

November 1992

Prepared by

MK-FERGUSON COMPANY
and
JACOBS ENGINEERING GROUP
7295 Highway 94 South
St. Charles, Missouri 63304

for the

U.S. DEPARTMENT OF ENERGY
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Under Contract DE-AC05-86OR21548

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1 INTRODUCTION

1.1 Purpose

The applicability of various technologies for remediating the Weldon Spring site has been examined in numerous separate remedial technology evaluation studies. The purpose of this report, the *Engineering Analysis of Remedial Action Alternatives, Phase I*, (Phase I EAA) is to summarize these technology evaluation data to support the evaluation and screening of remedial action technologies in the *Feasibility Study for Remedial Action at the Chemical Plant Area of the Weldon Spring Site* (DOE 1992a). It should be noted that the costs and design concepts presented throughout this Phase I EAA report for the various remedial technologies are preliminary in nature. A companion document, *Engineering Analysis of Remedial Action Alternatives, Phase II* (Phase II EAA) (MKF and JEG 1992a), presents more definitive data to support the feasibility study evaluation of remedial action alternatives.

1.2 Report Organization

Data to support the initial technology screening process is summarized below in Section 1.3. The various types of waste present at the Weldon Spring site are summarized in Section 2. Greater detail on the waste can be found in the *Remedial Investigation for the Chemical Plant Area of the Weldon Spring Site* (RI) (DOE 1992b). In Section 3, individual treatment technologies are identified and information is provided to support the feasibility study evaluation of effectiveness, implementability, and relative cost. Potentially feasible remedial action alternatives are discussed in Section 4. References cited are listed in Section 5, and acronyms and abbreviations are defined in Section 6.

1.3 Summary of Initial Technology Analysis

Based on the preliminary screening process documented in Sections 3 and 4 of the site FS, the technologies considered to be the best or appear to be the most promising for treatment and/or remediation of site wastes are retained for further consideration and analysis. In the FS, these potentially viable technologies are assembled into alternatives representing a range of treatment and containment combinations. The rejected technologies receive no further consideration unless additional information becomes available which warrants further evaluation. The following discussion provides information to support this process.

1.3.1 Removal

As a result of characterization work carried out at the Weldon Spring site, it has been determined that all affected media at the site can be removed using conventional construction equipment. Characteristics of contaminated materials are presented in the site RI and supporting characterization reports.

1.3.1.1 Standard Excavation Practices. The physical nature of the site soils and sediment allows these materials to be removed and transported using conventional construction/earth-moving equipment. The optimal equipment fleet would consist of backhoes and front-end loaders for excavation, coupled with haulage trucks. Selected excavation methods may include:

- Backhoe loaders, operating from the top of the soil to be excavated, will place the soil into over-the-highway trucks for transportation to an appropriate storage, loadout or disposal location.

- Backhoe with shovel front, operating from the bottom of the excavation, will place soil into over-the-highway trucks for transportation to the appropriate storage, loadout, or disposal location.

- A front-end loader, operating from the storage area base or from the bottom of the excavated area, will remove soils and place the material into over-the-highway trucks for delivery to the appropriate location.

- Scrapers will remove soils from large areas of relatively shallow depth and transport the material to the appropriate location.

1.3.1.2 Dredging. Neither conventional earth-moving equipment nor draglines would be effective in removing the raffinate pit sludge because the sludge is a very fine, gelatinous material. Because of these physical characteristics, this material is more amenable to removal using a pumping operation. Two pumping operations were identified, a monitor slurry system and a cutting head dredge system. The monitor slurry system is as effective in removing sludge as the cutting head dredge system. However, the monitor slurry system requires (1) that the sludge be dewatered and recirculated to maintain a specified percent of solids in the slurry, (2) that the system be enclosed or (3) that continuous spraying be applied to control dust generation, thereby significantly increasing costs and the time required to implement.

1.3.2 Land Disposal

1.3.2.1 Off-Site Land Disposal. The Envirocare of Utah complex at Clive, Utah, can presently accept RCRA wastes, and a permit is pending which will allow Envirocare to accept by-product radioactive waste including treated and untreated soils and sludges, contaminated soil, and size reduced rubble and other material. However, all materials must pass the toxicity characteristic leaching procedure (TCLP) criteria. This facility can accept both containerized and bulk waste.

The DOE Hanford facility at Richland, Washington, is considered a representative federal disposal facility. However, the administrative procedures required for this facility to accept Weldon Spring site wastes are not in place.

1.3.2.2 Transport to Off-Site Land Disposal Facility. Transport by truck or barge to an off-site disposal facility would raise the risk of accidents which could potentially result in spills and injuries or fatalities and would be more expensive than rail transport. Transport by barge is more expensive than rail and approximately the same as truck. Therefore, trucking containerized waste designated for off-site disposal to a railroad siding and transporting the material by rail to the disposal facility would appear to be the preferred off-site transport option.

1.3.2.3 On-Site Land Disposal. On-site lagoons and waste piles will not provide a long-term solution for containment. Wastes handled in this manner would continue to pose a threat to human health and the environment. A cap and cover system would be appropriate for areas of contamination which have been treated or contained in situ.

Compared to disposal cells, vaults may provide some incremental additional protection against contaminant migration and intruder exposure, however costs are much higher. It is also much more difficult to incorporate design changes during both vault design and construction, which could significantly impact cost and schedule. In addition, material placement is hampered by equipment maneuverability constraints imposed by the vault structure.

Three types of engineered cells were examined for containment of site wastes. The first configuration is comprised of a double-lined engineered cell which complies with the joint Environmental Protection Agency-Nuclear Regulatory Commission guidance for construction of a combination disposal cell. This cell could effectively contain both untreated and treated chemical and radioactive (by-product) wastes. The second type of facility consists of an unlined, Uranium Mill Tailings Remedial Action (UMTRA)-type cell to contain untreated radioactive

waste or a vitrified product. A third option, a single-lined sanitary landfill, could contain untreated, nonhazardous or nonradioactive wastes. Land disposal of sludge is not a viable option without additional treatment because the untreated sludge could not support a cover. The capacity of a particular on-site disposal facility would depend on the amount and type of waste that is identified for emplacement.

1.3.3 Physical Treatment

1.3.3.1 Size Reduction. Sized reduction equipment examined in Section 3 includes crushers, impactors, shredders, shears, and cutting torches. Application of each of these methods is technically feasible. A rotary shear can cut and shred feed materials consisting of rebar, wood materials, metal siding, office and laboratory equipment, conduit, pipe, tanks, and equipment pieces. An impact crusher can process concrete pieces, cinder block, glass, and ceramics. Drums containing used personal protective equipment (PPE) can be crushed using a compactor. An impactor could also be used to process both concrete and metal-like materials. A cutting torch can be used on all metal plates or materials that can be oxidized rapidly. However, many alloys are resistant to oxidation and high temperatures.

1.3.3.2 Dewatering and Drying. Raffinate sludge dewatering and drying are considered both as a treatment and as a precursor to subsequent treatment. Dewatering of raffinate pit sludge using a system of cyclones, thickeners, and filter plates is considered to be both technically and economically feasible. A direct-fired rotary kiln system could also be used for drying sludge; however, field tests would be required to assess the feasibility of this method on the Weldon Spring waste media.

Because dewatering and drying have a major impact on the implementability and cost of treatment alternatives, additional studies would be necessary to evaluate and determine the best application of these processes for the Weldon Spring sludges.

1.3.3.3 Physical Separation. The physical separation methods described in Section 3 include screening, classification, flotation, gravity separation, evaporation, ultrafiltration, and electrofiltration. All of these technologies are potentially feasible. Although these technologies are effective in isolating radioactively contaminated materials and in separating metals, the effectiveness of these technologies in isolating chemical contaminants is not known. If these technologies are to be considered further, additional bench-scale and pilot-scale tests would be required; a detailed evaluation of the cost to implement each technology would also be required.

1.3.3.4 Hydrolasing and Liquid Abrasive Blasting. Hydrolasing and liquid abrasive blasting are effective means of decontaminating concrete slabs and structural steel, respectively, and thereby reducing the volume of contaminated material requiring disposal. Size reduction and disposal of these materials may be more cost effective than a long, labor-intensive decontamination effort. However, this expense would constitute only a small fraction of the total cost. Other costs such as resulting waste stream disposal would also need to be addressed.

1.3.4 Hydrometallurgical Treatment

1.3.4.1 Solvent Extraction. Neither the nitric acid leach nor the sulfuric acid leach methods are considered to be technically viable alternatives for reprocessing the raffinate pit sludges. In addition, a system involving sulfuric or nitric acid leaching, with sequential solvent extract of uranium and thorium and precipitation of radium, has never been constructed.

1.3.4.2 In Situ Leaching. There are many fatal flaws associated with in situ leaching technology for the Weldon Spring site. Most of the soil and sediment contamination at the site is at or just below the surface. In situ leaching is more effective at depth. Furthermore, lixiviant (leach solution) control would be extremely difficult due to the complex fracture/conduit flow groundwater system present at the site. Finally, environmental acceptability is unlikely because the lixiviant, if not properly controlled, would itself be a contaminating agent.

1.3.5 Chemical Stabilization

1.3.5.1 Cement-based Stabilization. Pug mill-mediated chemical solidification/ stabilization using a cement/fly ash blend is a potentially viable treatment technology for the Weldon Spring site soils, sediments, and sludges. This technology offers a significant advantage over in situ chemical stabilization because the process allows superior mixing control and visual observation of reagent and treatment material mixing. The treated product would require secondary containment to prevent contaminant migration.

1.3.5.2 Thermoplastic Encapsulation. Because xylene and toluene diffuse quite rapidly through asphalt, asphaltic-based thermoencapsulation methods cannot be used to treat nitroaromatic-contaminated soils. In addition, rehydration of dehydrated salts, which may form in a sulfate-rich dewatered raffinate, can cause swelling, cracking, and rupture of the encapsulating surface.

1.3.5.3 In Situ Chemical Stabilization. Several difficulties were identified regarding in situ stabilization of contaminated soils, sediments, and sludges at the Weldon Spring site. Site soils requiring treatment are located in thin, sporadic, discontinuous zones of contamination. Raffinate sludges do not have sufficient compressive strength to support mixing equipment. Consequently, the mixing equipment would be required to work from areas of previously stabilized sludge, or sufficient contaminated soil would have to be added to increase the bearing strength. In addition, maintaining quality control during reagent addition and mixing is difficult, and without complete solidification, the contaminants could become readily mobile.

1.3.6 Thermal Treatment

1.3.6.1 Induction Furnace Melting. This melting decontamination process may be technically feasible for reducing contaminant mobility and waste volume decontamination for scrap metal comprised of steel, aluminum, copper, and nickel. However, aluminum waste may be difficult to decontaminate if it contains a significant amount of magnesium. This process is not an effective means of treating soils, sediments, sludges, concrete debris, or asbestos-containing materials. The effectiveness of this technology varies depending on the type of metal alloy(s) and the specific chemical or radiological contaminants. Tests would be required using samples of Weldon Spring waste media to determine the effectiveness of this technology to decontaminate the various waste materials.

1.3.6.2 Vitrification. Joule-heated ceramic melting, fossil fuel-heated ceramic melting, and plasma arc torch melting technologies are potentially applicable in treating Weldon Spring site soils and a mixture of soils and sludges. The product of each technology is a structurally sound, leach-resistant glass. The higher melt temperatures achieved by the plasma arc torch process, however, cause more corrosion of the melter construction materials, requiring more expensive, complex alloys for the construction of the plasma arc system. High-pressure water is also required for cooling because of the high temperatures at the electrodes. Compared to the joule-heated and fossil fuel-heated ceramic melting systems, the plasma arch torch melting system poses increased difficulties associated with implementing and maintaining this process option, with no increase in effectiveness. Off-gas treatment from all vitrification processes are untested for large scale systems and would add to the cost of the process.

1.3.6.3 In Situ Vitrification. The results of bench-scale testing suggest that the product of in situ vitrification of site soils and sediments will comply with U.S. Environmental Protection Agency (EPA) minimum destruction and removal efficiency (DRE) requirements for hazardous organics, polychlorinated biphenyls (PCBs), and dioxins under appropriate conditions,

and will also meet TCLP leach test criteria. However, the raffinate sludge would not produce a structurally sound, leach-resistant vitrified glass without the addition of contaminated soil.

Several difficulties may arise in attempting to implement in situ vitrification technology at the Weldon Spring site. This technology requires that the medium to be processed be a minimum of 5 to 7 feet thick. Most of the widely distributed zones of surficial contamination at the site are only 1 to 2 feet thick. Another concern regarding this technology is the inability to directly view the process and final product. Monitoring the leachate and verifying the effectiveness of stabilization would be difficult.

1.3.6.4 High-Temperature Slagging Incineration. Slagging incinerators operate at temperatures high enough to melt Weldon Spring soils and a mixture of soils and sludge and produce a leach-resistant product. Refractory failure, caused by acid and metal halide attack and abrasion, is a major problem of direct-fired units. The spent refractory material would be a disposal problem because of radionuclide and toxic metal contamination.

1.3.6.5 Rotary Kiln Incineration. Although rotary kiln incineration is a proven technology for the elimination of hazardous organic wastes, it is not an effective treatment process for radionuclide and most inorganic constituents. In addition, conventional rotary kilns do not operate at temperatures high enough to melt the soil constituents. The results of TCLP leaching tests show that the ash residue from this process is frequently susceptible to leaching and usually requires either secondary containment or further treatment.

1.3.6.6 Liquid Injection Incineration. The Toxic Substance Control Act (TSCA)-approved incinerator at the Oak Ridge Gaseous Diffusion Plant or a similar facility may be able to accept the containerized, radiologically contaminated liquid process chemicals stored in Building 434. Further characterization of these materials is required.

1.3.7 Biological Treatment

Organic debris removed during site preparation and clearing and grubbing activities can be composted on site. Composting of organic debris at the Weldon Spring site could result in an 80% to 90% volume reduction over a period of one to two years.

2 CONTAMINANTS AND SOURCE AREAS

The following discussion describes the quantities and primary contaminants present in the various Weldon Spring source areas. This discussion also addresses temporary site storage facilities that will be used to control contaminated and uncontaminated materials during interim and final remedial action. More detailed discussions of site contaminants can be found in the site RI document (DOE 1992b).

- Raffinate sludges
- Soils and sediments
- Temporary storage area (TSA)
- Materials staging area (MSA)
- Ash Pond spoils pile
- Mulch pile
- Asbestos-containing material (ACM) storage area
- Building 434
- Building foundations and underground piping and sewers

2.1 Raffinate Sludges

During site operations, the Weldon Spring raffinate pits received process wastes from the uranium feed materials plant. Pits 1, 2, and 3 contain raffinate sludges resulting from refining of uranium ore concentrates. In addition to uranium processing sludge, pit 4 contains thorium processing wastes and drums and rubble from partial dismantling of the plant when operations ceased in the mid-1960s. These four pits cover 25.8 acres and contain approximately 220,000 cubic yards of contaminated sludges. Contaminant ranges for radionuclides and inorganic ions present in the sludge are listed in Table 2-1; metals concentrations are listed in Table 2-2.

2.2 Soils and Sediments

An estimated 302,200 cubic yards of contaminated soils and sediments are in place at the various site locations described in the following subsections. Since cleanup levels and action levels for treatment are expected to be based on the radionuclide levels, chemical contaminant concentrations are not discussed in detail in this section. The volumes of soil presented are based on the 15 pCi/g reference level discussed in the site RI report and do not necessarily represent volumes based on anticipated cleanup criteria. Concentrations of specific chemical

TABLE 2-1 Raffinate Sludge Contaminant Ranges

Contaminant	Minimum	Maximum
Radionuclides		
Total Uranium*	10 pCi/g	3,400 pCi/g
Thorium-230	8 pCi/g	34,000 pCi/g
Thorium-232	3 pCi/g	1,400 pCi/g
Radium-226	1 pCi/g	1,700 pCi/g
Radium-228	4 pCi/g	1,400 pCi/g
Inorganic Ions		
Nitrite	ND	1,640 µg/g
Nitrate	ND	161,000 µg/g
Sulfate	ND	7,683 µg/g
Chloride	2 µg\g	296 µg/g
Fluoride	ND	165 µg/g

ND = Not Detected
Source: Modified from DOE 1992b.
*Values are based on net weight.

TABLE 2-2 Raffinate Sludge Metals Summary

Contaminant	Minimum	Maximum
Aluminum	ND	28,700 µg/g
Antimony	ND	87 µg/g
Arsenic	3 µg/g	1,060 µg/g
Barium	ND	7,740 µg/g
Beryllium	ND	25 µg/g
Cadmium	ND	321 µg/g
Calcium	ND	86,100 µg/g
Chromium	ND	169 µg/g
Cobalt	ND	441 µg/g
Copper	4 µg/g	611 µg/g
Iron	30 µg/g	22,800 µg/g
Lead	ND	644 µg/g
Lithium	ND	122 µg/g
Magnesium	ND	17,110 µg/g
Manganese	ND	3,010 µg/g
Mercury	ND	15 µg/g
Molybdenum	ND	1,600 µg/g
Nickel	11 µg/g	8,790 µg/g
Potassium	ND	1,470 µg/g
Selenium	ND	81 µg/g
Silver	ND	5 µg/g
Sodium	ND	23,800 µg/g
Thallium	ND	58 µg/g
Vanadium	ND	26 µg/g
Zinc	8 µg/g	1,580 µg/g
Zirconium	ND	2,120 µg/g

ND = Not Detected
Source: Modified from DOE 1992b.

contaminants in soils and sediments are thoroughly addressed in Section 5 of the site RI report (DOE 1992b).

2.2.1 Ash Pond

During site operations, Ash Pond received fly ash slurry from the power plant. Ash Pond, which covers a 376,345-square-foot area, contains approximately 8,200 cubic yards of contaminated sediment and soil. The sediment is contaminated with uranium and nitrate, and the underlying soil may also be contaminated with uranium as a result of contact with the contaminated surface water and sediment. The primary contaminant of concern is uranium-238, with concentrations ranging from 0.3 pCi/g to 14 pCi/g (DOE 1992b). Above background concentrations of radium-226 are present and range from 3.8 to 6.5 pCi/g. The combination of uranium and radium contamination in parts of the Ash Pond area result in above-mixture rule concentrations as discussed in Section 5.2.2 of the site RI report (DOE 1992b).

2.2.2 Frog Pond

Frog Pond previously received flow from storm and sanitary sewers at the pilot plant. This 81,338-square-foot area contains an estimated 7,000 cubic yards of contaminated soil and sediment. Uranium-238 concentrations in the sediment range from 0.3 pCi/g to 280 pCi/g (DOE 1992b). Soil in the berm and beneath the pond is expected to contain elevated concentrations of uranium resulting from contact with and leaching from the sediment and surface water. Chloride is also expected due to the close proximity of the State Highway Department salt storage pile.

2.2.3 Busch Lakes 34, 35, and 36

Lakes 34, 35, and 36, located in the Busch Wildlife Area, receive runoff and groundwater recharge from the site. These three lakes contain an estimated 20,000 cubic yards of uranium-contaminated sediment: 8,000 cubic yards in Lake 34, 5,000 cubic yards in Lake 35, and 7,000 cubic yards in Lake 36. Sample results from Lake 34 showed average uranium-238 concentrations in the sediment ranging from 3.0 Pci/g to 46.8 pCi/g. Average values in Lakes 35 and 36 ranged from 1.0 pCi/g to 23.6 pCi/g and 11.4 pCi/g to 30.3 pCi/g, respectively (DOE 1992b).

2.2.4 North Dump

Radioactive scrap material and ore drums were previously stored at the North Dump. The 82,506-square-foot North Dump area now contains approximately 7,600 cubic yards of contaminated sediment and soil. Uranium-238 concentrations at the North Dump range from 0.3 pCi/g to 1,380 pCi/g (DOE 1992b).

2.2.5 South Dump

The South Dump covers 182,290 square feet and contains approximately 16,900 cubic yards of radiologically contaminated soils resulting from prior disposal of contaminated equipment, used ore containers, personnel protective equipment, and other refuse. Uranium-238 concentrations in the South Dump soils range from 0.3 pCi/G to 2,105 pCi/g; thorium-230 concentrations range from 0.8 pCi/g to 123 pCi/g (DOE 1992b).

2.2.6 Raffinate Pits

The estimated 153,500 cubic yards of soil beneath the pits and in the berms is expected to contain elevated concentrations of the contaminants listed in Tables 2-1 and 2-2. This volume estimate includes approximately 50,000 cubic yards of pit clay bottom material that will require treatment. Contamination in this 1,123,848-square-foot area is the result of contact with and leaching from the pit sludges and surface water. To more accurately identify the contaminant types and concentrations in the raffinate pit clay bottom and underlying soils, additional characterization will be performed after the surface water and sludge are removed.

2.2.7 Other On-Site Surfaces

In addition to the specific source areas identified above, an additional 85,400 cubic yards of contaminated soil are present around and beneath the chemical plant buildings and in open areas, including the coal storage area. The area around the chemical plant buildings encompasses 1,530,985 square feet. The areas adjacent to the chemical plant were previously used to unload and store process materials and house electrical equipment, and contain soil contaminated with uranium, thorium, radium, sulfate, nitrate, pesticides, polynuclear aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). Past spills and overland flow have contaminated the soils in the areas adjacent to the raffinate pits with uranium, thorium, fluoride, sulfate, and nitrate. An estimated 20,000 cubic yards of the above total is comprised of contaminated soil surrounding underground piping.

2.2.8 Vicinity Properties

Approximately 3,600 cubic yards of uranium-contaminated soil are present on vicinity properties associated with the Weldon Spring site. Vicinity properties include certain areas which are near the chemical plant and quarry sites but are outside current fenced boundaries, and contaminated properties located along ditches, drainage ways, roads, and railroads. These vicinity properties include Army properties 1,2, 3, 5, and 6 (3,100 yd^3) and Busch properties 3, 4, and 5 (500 yd^3). Uranium-238 concentrations in these soils range from less than 0.5 pCi/g to 29,530 pCi/g (DOE 1992b).

2.3 Raffinate Pit Rubble

An estimated 500 cubic yards of concrete, tanks, barrels, pipe, wood, and structural debris are present on the east bank of raffinate pit 4.

2.4 Temporary Storage Area

An estimated 100,400 cubic yards of contaminated material will be stored at the temporary storage area (TSA). Approximately 96,800 cubic yards of bulk waste excavated from the Weldon Spring quarry will be stored at the 544,500-square-foot TSA. The various materials include:

- Metal building and equipment debris (10,500 yd^3).
- Concrete building debris (30,200 yd^3).
- Contaminated quarry soil and sediment (52,000 yd^3).
- Contaminated quarry sediments (4,100 yd^3).

Chemical and radiological contamination at the Weldon Spring quarry is the result of past disposal practices during site operations. Uranium, thorium, radium, and radon are the radioactive constituents of concern. Average radionuclide concentrations in the quarry soils are 108 pCi/g for radium-226, 380 pCi/g for thorium-230, 198 pCi/g for uranium-238, 96 pCi/g for radium-228, and 26 pCi/g for thorium-232 (DOE 1989). Average radionuclide concentrations in the quarry pond sediments are 905 pCi/g for uranium-234, 107 pCi/g for uranium-235, 889

pCi/g for uranium-238, and 316 pCi/g for thorium-230 (DOE 1989). Known chemical contaminants include nitroaromatic compounds, PAHs, PCBs, and heavy metals.

Approximately 3,600 cubic yards of containerized residues from operation of the water treatment plants at the site (3,100 yd^3) and the quarry (500 yd^3) will also be stored at the TSA. These materials are contaminated with radionuclides, arsenic, manganese, fluoride, and 2,4-DNT.

2.5 Material Staging Area

The material storage area (MSA) will be used to store approximately 77,078 cubic yards of chemically and radiologically contaminated materials resulting from building demolition and site debris consolidation. These materials will include:

- Non-friable asbestos-containing material (ACM) removed from buildings prior to dismantlement (5,111 yd^3)

- Debris and rubble from building demolition (71,967 yd^3) consisting of concrete and concrete block (18,223 yd^3), metal (51,385 yd^3), wood (2,078 yd^3), and miscellaneous other debris (281 yd^3).

An alternative storage area for concrete and concrete block would be within an expanded Ash Pond spoils pile area.

2.6 Ash Pond Spoils Pile

The 4.1-acre Ash Pond spoils pile has a capacity of approximately 40,000 cubic yards and will serve as a temporary storage and staging area for contaminated soils removed during site preparation activities which cannot be transported directly to an on-site disposal facility or to a staging area for off-site transport. This area could be expanded to encompass the remaining Ash Pond area if required. The 5,800 cubic yards of material currently in place include:

- Contaminated soil removed during site preparation for the TSA (4,100 yd^3). Uranium-238 contamination in the soil ranges from less than 2.4 pCi/g to 2,259.3 pCi/g (DOE 1992b).

- Contaminated soil removed during site preparation for the water treatment plant (1,700 yd^3). The soil in this 91,321-square-foot area contains above-reference-level concentrations of thorium-230 and uranium-238 to a depth of 6 inches.

2.7 Mulch Pile

The mulch pile is located in the northeast portion of the site and may be used for composting 30,652 cubic yards of cleared and grubbed material and other organic debris from the chemical plant site and the quarry. These materials include:

- Chipped vegetation from the quarry (5,300 yd^3)
- Chipped railroad ties (1,200 yd^3) from initial quarry cleanup activities
- Chipped debris from clearing and grubbing at raffinate pits (5,900 yd^3)
- Chipped debris from clearing and grubbing at the chemical plant area (17,500 yd^3)
- Paper debris removed during building dismantlement activities (2 yd^3)
- Chipped railroad ties from chemical plant area (750 yd^3)

2.8 ACM Storage Area

An estimated 1,483 cubic yards of friable ACM has been double bagged and is stored on site in Building 103. Approximately 20 pieces of equipment containing small quantities of asbestos are also stored in Building 103. Another 3,233 cubic yards of friable ACM throughout the site buildings will also be removed and may be stored in Building 108, along with the ACM relocated from Building 103. Alternatively, all friable asbestos may be containerized and stored within an area prepared to the north of Buildings 403 and 404.

2.9 Building 434

Building 434 is being used to support various interim response actions. The 5,139 cubic yards of waste materials which are or will be stored in this building include:

- Approximately 400 55-gallon drums of waste including paints, solvents, and oils (111 yd^3).

- Approximately 100 55-gallon drums of containerized chemicals including nitric and sulfuric acid, sodium hydroxide, flammable and reactive solids, and oxidizers (28 yd^3) which will be deactivated on site prior to disposal.

- Used personal protective equipment (5,000 yd^3 over a 10-year period).

2.10 Building Foundations and Underground Piping and Sewers

Building foundations and underground piping beneath the chemical plant area are chemically and radiologically contaminated. The quantity of material is estimated to be 40,591 cubic yards of concrete foundation and 1,309 cubic yards (64,240 lineal feet) of 12-inch-diameter (average) concrete and clay piping. This material would be stored at the MSA or, alternatively, the concrete may be stored on an expanded Ash Pond spoils pile.

2.11 Roads and Embankments

If a removal, on-site treatment, and disposal alternative is implemented, as much as 76,930 cubic yards of road materials and aggregates may be used to stabilize working surfaces in pits and to construct retention dikes. These materials could become contaminated during site operations. If contamination occurs, these materials would be reclaimed and placed within an on- or off-site disposal cell. Quantities of required materials include:

- 15,400 yd^3 of aggregate for bottom stabilization in the raffinate pits.
- 10,800 yd^3 of material for raffinate pit roads.
- 1,830 yd^3 of retention pond material.
- 1,800 yd^3 of material for Army 5 and 6 access road.
- 4,000 yd^3 of aggregate for bottom stabilization in Ash Pond.
- 800 yd^3 of aggregate for bottom stabilization in Frog Pond.
- 25,900 yd^3 of material for water control dikes and sediments.
- 16,400 yd^3 of material for chemical plant roads and work areas.

2.12 Facilities Closure

Facilities closure will involve the removal and size reduction of an additional 38,300 cubic yards of building materials if a removal and on-site waste treatment remedial action alternative is implemented. The volumes involved in facilities closure include:

- 22,000 yd^3 of TSA foundation.
- 400 yd^3 of site water treatment plant.
- 14,500 yd^3 of MSA foundations.
- 900 yd^3 of waste treatment facility.
- 500 yd^3 of volume reduction facility.

2.13 Waste Materials and Quantities Summary

The estimated in-place quantities of the Weldon Spring Chemical Plant area waste materials are summarized in Table 2-3.

TABLE 2-3 Waste Material Quantities

Material/Source	Quantity		Tonnage
Raffinate Sludge	220,000	cubic yards	222,200
Soils and Sediment			
• Ash Pond	8,200	cubic yards	12,460
• Frog Pond	7,000	cubic yards	10,640
• Lakes 34, 35, 36	20,000	cubic yards	30,400
• North Dump	7,600	cubic yards	11,550
• South Dump	16,900	cubic yards	25,690
• Raffinate Pits	153,500	cubic yards	233,320
• Other On-Site Surfaces	85,400	cubic yards	129,810
• Vicinity Properties	3,600	cubic yards	5,470
Raffinate Pit Rubble	500	cubic yards	3,310
TSA	100,400	cubic yards	220,040
MSA	77,078	cubic yards	61,685
Ash Pond Spoils Pile	5,800	cubic yards	8,810
Mulch Pile	30,652	cubic yards	19,151
ACM Storage Area	4,716	cubic yards	2,929
Building 434	5,139	cubic yards	1,035
Building Foundations and Underground Sewers	41,900	cubic yards	63,931
Subtotal	769,395	cubic yards	1,062,429
Roads and Embankment Removal	76,930	cubic yards	116,930
Facilities Closure	38,300	cubic yards	78,210
Subtotal	115,230	cubic yards	195,140
TOTAL WASTE VOLUME	903,615	cubic yards	1,277,568

Source: MKF and JEG 1991.

3 IDENTIFICATION AND ANALYSIS OF TECHNOLOGIES

The data presented in Section 2 illustrate the diversity of the various contaminants and waste media present at the Weldon Spring site. This section discusses technology types and process options which are evaluated in the FS and may be appropriate for remediation of site wastes. This *Engineering Analysis of Remedial Action Alternatives, Phase I* provides data to support the FS screening and evaluation of these technologies for effectiveness, implementability, and relative cost. It should be noted that the costs presented throughout this report are preliminary in nature and are based on the basic technology concepts described. If any assumptions regarding the technology concepts are changed, the costs will also change.

Effectiveness focuses on the degree to which a particular treatment reduces the toxicity, mobility, or volume of contaminated media. Implementability focuses on the technical and administrative feasibility of implementing the technology. Alternatives that are considered technically infeasible or that would require equipment, specialists, or facilities that are not available within a reasonable period of time may be eliminated from further consideration. The relative costs to construct, operate, and maintain the treatment facility or supporting infrastructure are also considered for each technology.

The equipment and operational concepts described in this section represent a reasonable basis for conducting remedial actions. They are not intended to represent the selected equipment or operating methodologies. That selection process would be based on optimization considerations and additional information developed prior to final design.

3.1 Removal

For this discussion, removal of contaminated material is interpreted to mean physical displacement. Removal measures can be applied to all affected media at the site. The appropriate technology for implementing removal of contaminated material is a function of the physical and chemical properties of the media.

Recognizing the regulatory preference for remedial actions which emphasize treatment as a method to permanently or significantly reduce contaminant mobility, toxicity, or volume, removal of waste material by itself is not considered to be a remedial solution. Rather, removal of specified waste media is viewed as one step in the remedial action process at the Weldon Spring site.

3.1.1 Conventional Excavation

Because of the physical nature of site soils, sediments, and rubble, these materials may be removed and transported using one or several combinations of conventional construction/earth moving equipment. However, this equipment is not effective in removing high-water-content sludge, such as that present in the four raffinate pits. Specific quantities of material requiring removal may vary depending upon the specific treatment method selected (i.e., in situ stabilization versus removal prior to treatment).

Potential excavation equipment for soils, sediments, and rubble may include backhoes, front shovels, wheel front-end loaders, and other types of conventional equipment. Front-end loaders can excavate shallow, more areally extensive zones of contamination, while backhoes can more efficiently remove localized, deeper contamination, such as contamination that may be related to leaking buried pipes or sewer lines. Front-end loaders operate from the bottom of an ordinary excavation face, while backhoes operate from the top of the face. Moderately sized backhoes, such as the Cat 225, can excavate to depths in excess of 20 feet below the unit (Caterpillar 1984). Large front shovels, such as the Cat 245, can excavate bench heights of 30 feet. Excavation of an out ramp allows virtually any depth to be reached by either type of equipment. However, a backhoe requires somewhat less excavation to reach an equivalent depth since less ramping is required. Excavating small, deep holes is not practical with a front-end loader. However, for removal of areally extensive horizons, front-end loaders and front shovels are excellent choices. The rapid mobility of the front-end loader also enhances the ease of movement between widely spaced work areas.

Backhoes in the Cat 245 class with 3-cubic-yard buckets can only efficiently excavate a minimum 2-foot-thick lift on a continual basis. Front-end loaders in the Cat 988 class can excavate approximately a minimum 1-foot-thick lift but require a sufficient lateral extent of material to be excavated to fill the bucket. Both methods demand careful monitoring to limit the amount of excess material removed. With careful supervision, 6-inch lifts may be removed with some over-excavation. It may be practical to use an elevating scraper, such as a Cat 613C (Caterpillar 1990) to selectively remove thin lifts of contaminated waste or a motor grader to windrow the waste material for subsequent removal by front-end loader or backhoe. The unit cost for excavation using selective equipment is high. Using less selective and more versatile equipment with some over-excavating may be more cost effective than using smaller, more specialized excavation equipment.

Contaminated soil areas at the site are numerous but isolated (DOE 1992b). Contamination in some areas can extend to depths of up to 10 feet. Small, isolated deep pockets of contaminated material are not amenable to removal by either dozer-assisted scrapers or self-propelled scrapers, both of which function best in removal of shallow soils of uniform depths over large, geometrically simple areas.

Draglines, stripping shovels, clamshells, or bucket wheel excavators are not recommended because they typically are too large and costly and lack the selectivity necessary for excavation of contaminated soil and sediment at the Weldon Spring site.

During excavation of contaminated soils and sediment, some volume increase is likely. Swell, or bulking, factors can range from near zero to 45% (Caterpillar 1984). However, virtually all of the volume increase would be reversed if the material were placed in an engineered cell and compacted.

Potential transport equipment includes dozers, wheel front-end loaders, scrapers, and trucks. Different types of equipment have tight limits on optimum transport distances (Pfleider 1968).

Equipment	Optimum Transport Distance
Dozer	<300 feet
Wheel front-end loader	300 feet to 600 feet
Scraper	600 feet to 1 mile
Truck	600 feet to 2.5 miles

Due to the size of the site and the assumption that haulage would likely be to a central treatment, disposal, or load out point, much of the contaminated media at the Weldon Spring site would probably be transported distances of over 600 feet. Therefore, a scraper or truck fleet would be the most appropriate choice for haulage.

The optimal equipment fleet would be backhoes and front-end loaders for excavation coupled with haul trucks. The equipment required for excavation and movement of waste material is readily available.

Removal activities can be impacted by adverse weather conditions. For example, heavy rainfall can cause muddy conditions that can significantly decrease the productivity of mobile excavation equipment due to the rolling resistance factor and reduced trafficability (Caterpillar

1990). Heavy snow or icy conditions can hamper productivity, and temperature extremes typically decrease worker performance and productivity.

Radiological and chemical analyses of soil, groundwater, and air samples are the primary methods of monitoring the effectiveness of excavation activities. The WSSRAP Health and Safety Manual, Environmental Protection Implementation Plan, and Waste Management Plan provide for monitoring which will require specialized equipment and personnel qualifications to allow effective, safe handling of wastes. All on-site personnel involved in field and remediation work require hazardous waste safety training. Equipment operators also need the specialized skills normally required for construction operations. Environmental engineers, geologists, geochemists, industrial hygienists and other professional staff will assist the equipment operators in waste removal and correct application of appropriate technology to ensure worker safety.

The unit costs for waste removal, reclamation, and related operations listed in Table 3-1 were developed from cost estimates for the excavation, removal, and transport of various waste media (engineering calculations developed by the project), except where otherwise indicated. It should be noted that these costs are preliminary in nature.

TABLE 3-1 Unit Cost Summary for Removal and On-Site Transport Activities

Activity/Media	$ Cost/yd³
Remove surface soils in the chemical plant area	8.51
Remove raffinate pit soils and clay bottom	12.58
Remove contaminated soil surrounding underground piping and sewers	12.85
Remove soils and sediment from Frog Pond	13.62
Remove soils and sediment and organic debris from Ash Pond, the North South Dumps, and the mulch pile	13.83
Place pond aggregate base	23.57
Remove soil and sediment from Busch Lakes 34, 35, and 36	20.00[a]
Remove soils from Army Properties 1,2, and 3 and Busch Properties 3, 4, and 5	207.77[b]
Remove soils from Army Properties 5 and 6	207.83[b]
Remove roads and embankments	10.44
Remove raffinate pit rubble	234.08
Remove concrete foundations and haul to MSA	18.42
Underground piping and sewers (remove and backfill)	45.30/linear foot

TABLE 3-1 Unit Cost Summary for Removal and On-Site Transport Activities (Continued)

Activity/Media	$ Cost/yd³
Haul material from the TSA or MSA to the VRF or on-site cell	23.46
Haul material from the VRF to on-site cell	23.46
Haul stabilized sludge to on-site cell	7.47
Facilities removal	
• TSA	11.93
• MSA	21.02
• VRF	254.87
• Site WTP	254.87
Raffinate pit reclamation	
• Borrow	13.80
• Berms	2.55
• Topsoil	17.52
• Seed and mulch	0.046/ft²
Chemical plant reclamation	
• Fill	8.50
• Topsoil	17.52
• Seed and mulch	3,700.00/acre
Operations	
• MSA	5,163,948. Lump Sum
• Site Water Treatment Plant (7.5 years)	3,456,940. Lump Sum
• Construct Decontamination Pad	43,016./ea
• Decontamination Pad (8 years)	1,186,407. Lump Sum
• Dewater Raffinate Pits (53 months)	1,393,365. Lump Sum

(a) *Cost Estimate for Excavation and Transportation of Vicinity Property Soils*, MKES Report No. 5121-V:EN-R-05-0071-00. November 1992.

(b) Includes excavation, transport, decontamination, and reclamation.

3.1.2 Dredging

The raffinate sludge is a very fine-grained, gelatinous material averaging 27% solids and 73% water. These physical characteristics lend themselves to a pumping operation as opposed to other, more conventional removal, loading, and hauling methods.

The *Raffinate Sludge Dredging and Dewatering Study* (MKES 1992b) examined four methods of removing sludge from the raffinate pits: cutting head dredge, monitor slurry system, scraper, and dragline. The efficiency of each method necessary to provide the required results is largely dependent upon the nature of the sludge material and the working characteristics of the specific equipment.

An initial evaluation of each sludge removal method resulted in the elimination of scrapers and draglines as alternatives. Scrapers are rubber-tired vehicles which load and carry the material to a designated lay-down location and consequently require the removal of surface water prior to operation. Due to the liquid state of the sludges, scrapers could not operate efficiently if at all. Additionally, the sludge material would be difficult to handle since it would not stack upon discharge, but would spread over a wide area. While a dragline operation effectively removes liquid materials from a pit area, it requires that the material be dumped directly into transportation vehicles in a semi-liquid condition or into a pile for subsequent loading and transporting. As in the case of the scraper, the raffinate sludge material with its high moisture content would not stack but would spread over a wide area.

The two sludge removal systems retained as viable alternatives are the cutting head dredge method and the monitor slurry system. The cutting head dredge method involves the use of a dredge, suspended on the ponded water of the raffinate pit, to cut and direct the sludge material to a slurry pump. The sludge is then pumped through a pipeline to a sludge holding bin prior to treatment and/or disposal. A monitor slurry system consists of a submersible slurry pump, which can handle up to 40% solids, equipped with an in-line solids monitor to ensure the appropriate solids concentration (25% to 30%) is maintained within the sludge slurry. As with the cutting head dredge method, the sludge is pumped through a pipeline to a holding bin. Another alternative investigated is to remove surface water and to excavate on an advancing face with a shovel-front and truck spread.

Because water is retained over the sludge, the dredging process will not generate contaminated airborne particulates. The ponded water in the raffinate pits will also minimize radon emissions during the dredging of the underlying sludge. However, enclosure of the pit or continuous dust suppression by fogging and applying dust inhibitors, as well as remote, peripheral operation, may be required to contain any airborne contaminants generated during the monitor slurry system process. The monitor slurry system also requires that the sludge be dewatered and recirculated to maintain the proper percent of solids in the slurry, significantly increasing costs and the time required to implement.

Program requirements for hazardous waste safety training, equipment operating skills, and worker safety will be similar to requirements described in Section 3.1.1.

Both sludge removal methods (dredge or slurry) can be combined with a dewatering technique, either a cyclone or belt press system. Preliminary cost estimates for 220,000 cubic yards of sludge were developed (MKES 1992b) for viable combinations of the dredging and

dewatering methods. These estimates include capital and operating costs as well as bond, insurance, and profit.

Dredge with cyclone	$11,747,000
Slurry with cyclone	13,393,000
Slurry with belt press	16,235,000

Based on the costs developed by MKES (1992b), dredging would cost an estimated $49.20 per cubic yard without a dewatering component and $53.40 per cubic yard with dewatering. Therefore, dredging the 220,000 cubic yards of raffinate sludge and pumping the material directly to a holding tank would cost an estimated $10,824,000. Dredging and monitor slurry system equipment is available from industrial suppliers.

3.2 Land Disposal

Land disposal involves the controlled placement of the waste media into or onto the ground surface to isolate the hazardous constituents in the waste. Off- and on-site land disposal options were evaluated for disposition of various Weldon Spring site waste materials. Land disposal facilities can be constructed of naturally occurring materials, such as clay, soil, and gravel, or of manufactured materials such as concrete. Disposal facility configurations for contaminated solid waste materials typically include engineered disposal cells or concrete vaults. Siting, design, and construction of either an on-site or off-site disposal facility would be subject to numerous regulations.

The Weldon Spring waste is considered a by-product material resulting from the extraction or concentration of uranium or thorium from ore (11e[2], Atomic Energy Act). The EPA regulates by-product material under the authority of Section 275 of the Atomic Energy Act of 1954 and the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). The regulations provide standards for management of uranium and thorium by-product materials (40 CFR 192.30 *et seq.*). In general, these standards require that, at the end of closure, disposal areas must comply with the closure performance standard in 40 CFR 264.111 with regard to nonradiological hazards. Disposal areas must be designed to provide reasonable assurance that radiological hazard control will be effective for 1,000 years (or to the extent reasonable achievable) and for at least 200 years. In addition, releases of radon-220 and -222 must be limited to less than 20 pCi per square meter per second above the cell. There is an exemption (40 CFR 192.32(b)(2)) for portions of a site with land concentrations of radium-226 and -228 (averaged over areas of 100 square meters) which do not exceed the background level by more

than 5 pCi/g averaged over the first 15 centimeters below the surface, and by 15 pCi/g averaged over 15-centimeter-thick layers more than 15 centimeters below the surface.

Section 121(d)(3) of CERCLA requires that the transfer of hazardous substances off site be made only to facilities that are operating in compliance with sections 3004 and 3005 of the Solid Waste Disposal Act (or, where applicable, in compliance with the Toxic Substances Control Act or other applicable federal law) and all applicable state requirements. In addition, the disposal cell must not be releasing any hazardous waste, or constituent thereof, into the groundwater, surface water, or soil, and all such releases from other cells at the facility must be controlled by a corrective action program.

3.2.1 Off-Site Land Disposal

Off-site land disposal provides an option for managing contaminated materials at sites where on-site disposal may not be feasible. Although the principal advantage for off-site disposal is the permanent removal of contaminated materials, other advantages include no requirement for long-term maintenance of an on-site facility, and greater site accessibility for additional remedial actions that may be required. Disadvantages include the potential risks of traffic accidents and contaminant spills associated with transport to the off-site facility, continuing responsibility for waste materials placed at an off-site facility with less control over actual disposition, and significantly higher costs for off-site transport and disposal.

The cost of off-site transport of waste material is dependent upon the treatment method selected. For example, vitrification of site soils, sediment, and sludges will require transport of less material, whereas, chemical stabilization would require the transport of an increased volume of material.

3.2.1.1 Off-Site Land Disposal Facilities. During a previous study (MFK and JEG 1992b), eleven off-site land disposal facilities were evaluated as potential disposal sites for Weldon Spring wastes. The results of this evaluation are summarized below.

- **Amereco, Kingsville, Missouri.** This facility is closed.

- **Environmental Services, Inc.** Located in Kansas City, Missouri. This facility cannot accept or dispose of radioactive waste or mixed waste.

- **Resources Recovery, Inc.** Located in Hannibal, Missouri. This facility cannot accept or dispose of radioactive waste or mixed waste.

- **Waste-Tech Services, Kimball, Nebraska.** The Waste-Tech facility cannot accept or dispose of radioactive waste, by-product material, or mixed waste.

- **Barnwell, South Carolina.** Managed by Chem Nuclear for the DOE, this facility may be able to accept by-product waste but cannot accept mixed waste. This facility is scheduled to close at the end of 1992.

- **Hanford Reservation, Richland, Washington.** This facility is operated by Westinghouse for the DOE and may be able to accept by-product waste and store mixed waste until an on-site mixed-waste disposal facility is constructed. Administrative procedures necessary for the disposal of Weldon Spring waste are not presently in place at Hanford.

- **Beatty, Nevada.** Operated by U.S. Ecology for the DOE, this facility can accept by-product waste but cannot accept mixed waste. This site is also scheduled for closure at the end of 1992.

- **Envirocare, Clive, Utah.** This facility can accept bulk waste and does not require that the incoming waste be containerized. The Clive facility can land dispose of mixed waste and has submitted an application for a license to accept by-product waste. An environmental impact statement (EIS) is being prepared to assess impacts associated with the facility accepting 11(e)2 by-product waste. The EIS is scheduled to be finalized in mid-1993. The Clive facility has sufficient capacity to accept all of the Weldon Spring site wastes. However, Condition 10 of the facility's Radioactive Material License states that not more than 300,000 cubic yards of radioactive material can be in storage or processing. As stated in Condition 22, the facility must also receive prior approval from the Utah Bureau of Radiation Control, on a case-by-case basis, prior to receiving by-product waste. The moisture content of the incoming waste must be limited to 5% of optimum as determined by the standard Proctor test. Condition 21 of the Radioactive Material License states that waste can contain no more than 0.5% by volume of free standing liquid per container.

- **Midwest Compact.** This facility will be constructed for disposal of low-level radioactive waste generated within the compact member states. This facility is not designed or intended for disposal of large quantities of by-product material.

- **Existing Missouri Sites.** No existing Missouri disposal facilities are licensed to receive mixed or by-product waste.

- **Hypothetical Missouri Site.** The hypothetical disposal facility would be located within 100 miles of the Weldon Spring site and would be accessible by rail or road. This hypothetical site would have to comply with all federal and state regulatory requirements for the siting of a waste disposal facility. A difficult, costly, and lengthy screening process would likely be required for site identification. A suitable site, acceptable to the local residents, might not be found.

Facility shutdown is a potential risk if waste is disposed of off site. Shutdown may be caused by revocation of a facility's operating license due to regulatory violations. Generator liability for wastes disposed off site presents additional risks. The generator (DOE) remains liable for the safety and security of the waste even though the waste is in the physical control of the facility owner/operator. Additionally, the Weldon Spring waste may be placed with wastes received from other generators. If disposal cell failure is caused by another generator's waste, distinguishing liability and blame among the different waste generators may be difficult. In addition, the application of joint and several liability may impose a much greater liability on the DOE.

Disposal fees at the Envirocare disposal facility range from $104.50 per ton for disposal of 1 million cubic yards of non-RCRA soil to $156.50 per ton for 500,000 cubic yards for non-RCRA stabilized or vitrified waste (Winner 1991). A preliminary disposal fee quoted for the Hanford facility is $1,944 per cubic yard or $1,296 per ton (MKF and JEG 1992b). Disposal costs for Envirocare and Hanford are discussed in more detail in the Phase II EAA (MKF and JEG 1992a).

3.2.2 Off-Site Transport Requirements

The Weldon Spring site waste media include two types of radioactive materials (natural uranium and thorium and their respective daughter products) that are regulated by the U.S.

Department of Transportation (DOT) if off-site transportation is involved. The requirements for the safe transportation of radioactive materials are cited in Title 49 Code of Federal Regulations.

Specific requirements for the off-site transport of wastes are identified in:

- DOE Order 5480.3, Safety Requirements for the Packaging and Transportation of Hazardous Materials, Substances, and Wastes
- DOE Order 5820.2, Radioactive Waste Management
- Title 10 CFR Part 962, Byproduct Material Interpretation
- Title 40 CFR 262, Manifest for Hazardous Waste
- Title 49 CFR 173, Container Requirements
- Title 49 CFR 174, Rail Transportation

Materials contaminated with natural uranium and thorium can be packaged and shipped as radioactive material, limited quantity, in accordance with 49 CFR 173.421. The material must be shipped in a strong, tight container, marked "radioactive," and must include the shipping notice described in 49 CFR 173.421-1a. Limited quantity shipments are excepted from specification packaging, marking, labeling, shipping papers, and vehicle placarding. Package limits for radioactive materials are specifically listed by isotope in 49 CFR 173.435.

The raffinate sludge contains high concentrations of thorium-230 and must be classified as Radioactive Material, Low Specific Activity, and transported as exclusive use material (49 CFR 173.425). By transporting as exclusive use material, a strong, tight container can be used instead of a DOT type A certified container. Exclusive use shipments of radioactive materials are excepted from the DOT package labeling requirements. However, the following DOT requirements will still be imposed: shipping papers, package marks, vehicle placards, and exclusive use instructions.

Any RCRA hazardous waste, as well as any non-RCRA DOT-listed hazardous material, will also be regulated by the DOT. In addition to the federal DOT requirements, some states have their own special requirements. Many states require advance notification and permitting for shipments of radioactive material entering their domain.

The *Off-Site Transport and Disposal Options Study* (MKF and JEG 1992b) identified Envirocare's Clive facility as the only potentially feasible commercial disposal facility for off-site disposal of Weldon Spring waste. If the Weldon Spring waste is transported by truck or rail to the Envirocare site in Utah, the following agency coordination will be required.

- **Department of Transportation.** Coordination is recommended, but not required, with the DOT. However, compliance with DOT hazard classification, manifesting, and shipping requirements for the waste is mandatory.

- **State of Missouri.** Haulers must be registered through the Waste Management Program of the Department of Natural Resources to haul hazardous (but not radioactive) waste. Special notification is not required. Manifesting of all shipments of hazardous wastes must be coordinated through the Missouri Department of Natural Resources.

- **Kansas.** Haulers must obtain a Hazardous Waste Transporter Permit from the Division of the Environment, Department of Health and Environment, to haul hazardous waste. Kansas does not regulate low-level radioactive waste.

- **Colorado.** Haulers must obtain a Hazardous Material Transportation Permit from the Colorado Public Utilities Commission to haul hazardous waste. Radioactive waste shipments require a permit only for highway-route-controlled quantities (which does not apply to Weldon Spring site waste).

- **Utah.** No permits or special fees are required for shipment of hazardous or low-level radioactive wastes in Utah.

The Hanford facility near Richland, Washington, is considered a representative federal disposal facility, although the administrative procedures required to dispose of Weldon Spring waste are not in place. If the Weldon Spring waste is to be transported by truck or rail to the Hanford reservation, in addition to the states of Missouri and Kansas, the shipments will also pass through the states of Nebraska, Wyoming, Montana, Idaho, and Washington. Each of these states requires that shipments of radioactive and hazardous wastes comply with all applicable federal regulations; there are no state-specific permitting or agency coordination requirements.

3.2.3 Transport to Off-Site Disposal Facility

Three transport options were investigated in the *Off-Site Transport and Disposal Options Study* (MKF and JEG 1992b); truck, rail, and barge. Transport options to off-site disposal facilities were developed considering the following criteria:

- Unpackaged (bulk) waste transport
- Containerized transport
- Methods of loading waste
- Regulatory compliance
- Accident potential

3.2.3.1 Truck Transport. Two trucking options were evaluated: bulk and containerized. Bulk transportation would consist of transporting the waste in lined and covered trucks. The waste would be loaded directly into lined trucks, covered, transported to the disposal facility, and placed directly into the disposal cell. Containerized truck transport would consist of loading the soil into enclosed containers for subsequent truck transport to the disposal facility. All trucks would be covered to prevent the loss of contaminants. Empty containers would be returned to the Weldon Spring site for reuse. The following preliminary cost estimates were developed for various off-site trucking and disposal options (MKF and JEG 1992b):

Clive, Utah[1] (includes $96/ton disposal fee)	
Bulk transport	$448/ton
Containerized transport	$560/ton
Richland, Washington[2] (includes $1296/ton disposal fee)	
Bulk transport	$1601/ton
Containerized transport	$1847/ton
Hypothetical Missouri Site (within 100 miles—no disposal fee)	
Bulk transport	$114/ton
Containerized transport	$152/ton

(1) 1,600 miles one way

(2) 2,200 miles one way

Truck transportation services would be provided by trucking companies licensed to transport hazardous waste; however, the probability of accidents occurring while en route is directly proportional to the hauling distance and the number of trips required for off-site disposal. Truck transportation of contaminated media to an off-site disposal facility could be hampered by inclement weather.

3.2.3.2 Rail Transport. Bulk and containerized rail transportation options were also developed. The bulk rail transportation option would consist of loading the waste material directly into trucks. The trucks would transport the material to a rail siding where the material would be dumped into hopper railcars. The railcars would be emptied at the disposal site and the waste material hauled to and placed in the disposal cell. Containerized rail transportation would consist of loading the waste into containers that could then be completely closed. The containers would be transported by truck to a rail siding and placed on flatbed rail cars. The containers would be hauled to the disposal facility and the contents placed in the disposal cell. Empty containers would be returned to the site for reuse.

The Union Pacific and Burlington Northern Railroads serve the St. Louis area. The Clive, Utah disposal facility can be accessed by Union Pacific. The Burlington Northern Railroad serves Richland, Washington, where a DOE-owned rail spur extends to the Hanford reservation. The Burlington Northern Railroad does not allow bulk transfer of hazardous or radioactive material on railroad property.

Preliminary unit costs were developed for the following off-site rail transport and disposal options (MKF and JEG 1992b):

Clive, Utah[1] (includes $96/ton disposal fee)	
Bulk transport	$264/ton
Containerized transport	
(disposal—rail haul—other cost)	$312/ton - (96 + 57 + 159)

[1] 1,600 miles one way

Richland, Washington[1] (includes $1296/ton disposal fee)	
Bulk transport	$1437/ton
Containerized transport (disposal—rail haul—other cost)	$1503/ton - (1296 + 80 + 127)
Hypothetical Missouri Site (no disposal fee)	
Bulk transport	$133/ton
Containerized transport	$160/ton

All rail transport options would also require the construction of a local railroad siding at an estimated cost of $4.3 million (MKF and JEG 1992b). The rail transport costs to the Envirocare facility and to the Hanford facility were estimated at $57/ton and $80/ton, respectively.

3.2.3.3 Barge Transport. The Hanford, Washington site is the only available non-landlocked disposal facility. The nearest existing barge terminal to the Weldon Spring site is located at Sauget, Illinois. The waste would need to be trucked through or around St. Louis, Missouri, to the terminal for transloading to barges. Barging the material would involve transporting material down the Mississippi River, through the Gulf of Mexico and the Panama Canal, up the Pacific coast to Portland, or up the Columbia River to Richland, Washington, a distance of approximately 7,000 miles. The waste would be transferred to trucks in Richland for transport to the Hanford disposal facility.

A preliminary unit cost of $1,483/ton was developed for bulk barge transport to the DOE's Hanford facility near Richland, Washington (MKF and JEG 1992b). This unit cost includes the $1,296/ton disposal fee.

3.2.4 On-Site Land Disposal

The volume of treated waste disposed of on site would vary depending on the treatment method selected. On-site land disposal of the various waste media would not specifically reduce contaminant toxicity, mobility, or volume. However, disposal in an engineered cell or vault would help meet these criteria by isolating contaminants from the environment. Placement of contaminated material into a land disposal facility does not emphasize treatment as a principal element and is highly reversible.

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[1] 2,200 miles one way

Groundwater monitoring would be required to verify the effectiveness and integrity of an on-site land disposal facility. However, because the groundwater at the Weldon Spring site is already contaminated, determining the source(s) of contamination could be difficult. Geochemical characterization, contaminant transport and tracer studies, and effluent quantity from the leachate detection, collection, and removal systems built into an engineered cell would assist in determining whether groundwater contamination was caused by failure of the bottom liner.

Disposal facility construction can be affected by weather extremes. Rain, high winds, and cold temperatures can cause a variety of problems. Muddy conditions slow the mobility of equipment, while wind disrupts liner installation or can tear loose an installed liner. Liners become brittle and difficult to place under extremely cold temperatures.

After May 1992, the RCRA hazardous portion of mixed waste must be treated prior to landfilling, as mandated by the RCRA land disposal restrictions (54 FR 48511, 40 CFR 268.35[g]). These restrictions require that all hazardous wastes meet set treatment standards by established deadlines. By-product material must be disposed of in compliance with regulations promulgated under the Uranium Mill Tailings Radiation Control Act (UMTRCA) (40 CFR 192.30).

A situation requiring additional remedial action beneath a completed on-site cell could present difficult problems and could require the waste cell be relocated. However, the other areas of the site would be accessible to additional remedial actions. The waste would be accessible, and other technologies could be used to treat it after excavation from the cell.

The *On-Site Disposal Options* (MKF and JEG 1992c) examined on-site disposal options for Weldon Spring site wastes. The six options identified included lagoons, waste piles, vaults, landfills, cap/cover systems, and engineered cells.

3.2.4.1 Lagoons. Disposal lagoons are earthen structures equipped with a bottom liner of clay and a leachate collection and removal system. The liner system is designed to prevent migration of constituents into the groundwater or soil. A disposal lagoon would retain material transported by a slurry pipeline. Lagoons are simple in design and easy to construct. However, disposal lagoons are not amenable to long-term disposal requirements.

3.2.4.2 Waste Piles. Waste piles are a noncontainerized accumulation of material, usually mounded together, at ground level, by mechanical means. The waste pile is placed on

a composite double liner to prevent migration of constituents into the soil or groundwater. Waste piles are simple in design and easy to construct. However, waste piles are not amenable to long-term disposal requirements.

3.2.4.3 Vaults. Vaults are similar to engineered cells. The major difference is that the waste is contained within a reinforced concrete structure which, in turn, can be enclosed by earth-based bottom liner and cover systems. Vaults are amenable to long-term disposal requirements but must meet stringent federal, state, and local design and location criteria. Design criteria include provisions for liners and leachate collection systems to prevent migration to the soils, strict siting limitations which will prevent contamination of ground or surface waters, and cover requirements which will limit radon emissions and infiltration. Vaults can be designed and constructed to meet both RCRA and UMTRCA requirements. Concrete vaults are typically used for the disposal of containerized waste.

Although concrete vaults are structurally stable, these structures can be more permeable than structures constructed using clay. As a result, disposal of leachable material within a vault would require an additional low permeability lining of clay or other material. Compared to an engineered cell, the capability to incorporate design changes to a vault (e.g., increase or decrease vault size) during both the engineering and construction phases is more difficult and could prolong the schedule. In addition, material placement is hampered by equipment maneuverability constraints imposed by the vault structure and construction costs are greater than those for an engineered cell.

3.2.4.4 Landfills. Two types of landfills were considered in the *On-Site Disposal Options* (MKF and JEG 1992c): sanitary landfills constructed with bottom liner and cap/cover systems and direct-burial landfills with only minimal cover.

A sanitary landfill has all of the basic components of an engineered cell. However, only a vegetative and compacted soil cap is required. The soil cap is constructed of materials with sufficient thickness to prevent radiation emissions. The bottom liner contains a soil filter barrier, a leachate collection and recovery system, and a bottom soil liner. Only one leachate collection system is included. Sanitary landfill costs as presented in the *On-Site Disposal Options* (MKF and JEG 1992c) ranged from \$14.00 per cubic yard (590,000-yd^3-capacity) to \$22.76 per cubic yard (114,000-yd^3-capacity). However, sanitary landfill design and construction standards permit only disposal of nonhazardous or non-radioactive waste. This disposal option does not appear to be viable for the Weldon Spring site since most of the Weldon

A direct burial landfill has a similar cover system to that of the sanitary landfill; however, the bottom liner system is eliminated. As direct burial landfills have no bottom liner system, they cannot provide groundwater or soil protection. Unit costs for unlined (compacted clay bottom), direct-burial landfills ranged from $6.64 per cubic yard (476,000-yd^3-capacity) to $6.86 per cubic yard (276,000-yd^3-capacity) (MKF and JEG 1992c).

3.2.4.5 Cap/Cover Systems. Capping or covering is an alternative for areas or pockets of waste either contained or treated in situ. The cover for in situ treated material would be similar to the cap/cover design for an engineered cell. It also contains an erosion protection and drainage layer. Radioactive waste that has been chemically solidified and stabilized requires an additional radon barrier cap.

Cap/cover systems are simple in design and easy to construct. Installation costs for cap and cover systems developed by MKF and JEG (1992c) for 26- and 30.7-acre areas averaged $164,500 per acre.

3.2.4.6 Engineered Cells. Engineered cells consist of an earth-based bottom liner (possibly equipped with geosynthetic membranes and leachate collection and recovery systems) and an earth-based cover system. These structures contain the waste and prevent precipitation infiltration, wind erosion, intruder exposure, and contaminant migration into the environment. The cell may be built at or below grade. The *On-Site Disposal Options Study* (MKF and JEG 1992c) determined that varying the shape of the footprint shape configuration of an engineered cell has no significant effect on the volume of waste that could be stored in the disposal cell. However, a square cell footprint has advantages in ease of construction, expansion, and equipment maneuverability.

Engineered cells are amenable to long-term disposal requirements but must meet stringent federal, state, and local design and location criteria. Design criteria include provisions for liners and leachate collection systems to prevent migration to the soils, strict siting limitations imposed to prevent contamination of ground or surface waters, and cover requirements which will limit radon emissions.

An engineered cell can be designed and constructed to contain all solid waste media present at the Weldon Spring site. The type of cell construction could be directly related to the treatment method selected for remediation of the waste. A disposal facility could be designed as a combination cell (double lined) for containment of both untreated and chemically stabilized wastes. The combination cell would incorporate a double leachate collection and recovery

system. Alternatively, the facility could be constructed to incorporate a double-cell design, with an unlined (compacted clay bottom) cell for vitrified wastes and a double lined cell for untreated wastes. The double lined cell would incorporate a double leachate collection and recovery system.

A combination disposal cell could isolate chemically contaminated demolition rubble, wood, debris, soils, and chemically stabilized and solidified waste. The cell would be comprised of three elements: a bottom liner system, a top cover and side slopes, and the compacted wastes. The bottom layer would consist of four sublayers. From the top down, these sublayers would be a filter layer; a leachate collection and removal system; a second leachate collection and removal system; and a clay liner. The waste would be placed directly on the filter layer. The top cover, from the top down, would consist of a vegetative chock rock layer or riprap at least 1 foot thick, a frost cover at least 2 feet thick, a filter layer at least 6 inches thick, a drain layer at least 1 foot thick, a second filter layer at least 6 inches thick, and a radon barrier layer at least 4 feet thick. The layered side slopes, from the top down, consist of a vegetative chock rock layer at least 6 inches thick and/or a riprap layer 1 foot thick, a filter layer, a frost protection layer, and the continuation of the top cover radon barrier.

Vitrified waste material could be placed in an unlined cell that retained low-level radiation control characteristics. An unlined cell is similar to a low-level radioactive waste disposal cell, such as those being designed and constructed for the DOE's UMTRA Project. A lining system is not required in this type of cell, but a cover that prevents infiltration and provides radon attenuation is required.

An unlined cell may involve both below-grade and above-grade construction. An earthen embankment would be constructed using the excavated material to attain the cell's design height of approximately 35 feet. This cell would feature a cover consisting of a filter layer to maintain waste separation from the infiltration/radon barrier, an infiltration/radon attenuation barrier, a frost protection layer, and an erosion protection layer (riprap or topsoil with grass). Costs for an unlined cell with a radon attenuation barrier cover would be a combination of unlined direct-burial landfill and double lined disposal cell costs.

Preliminary unit costs for a combination (double-lined) cell ranged from \$20.07 per cubic yard (660,000-yd^3 capacity) to \$36.48 per cubic yard (70,000-yd^3 capacity). Unit costs for single-lined engineered cells ranged from \$13.98 per cubic yard (660,000-yd^3 capacity) to \$22.75 (184,000-yd^3 capacity) (MKF and JEG 1992c).

3.3 Physical Treatment

Physical treatment technologies examined included size reduction, raffinate sludge drying/dewatering, hydrolasing, liquid abrasive blasting, and physical separation of contaminated soils prior to disposal.

3.3.1 Size Reduction

Building material size reduction can be implemented as a preliminary component of remedial action. The types of debris, equipment, fixtures, buildings, structures and materials may vary widely at a site and the variety of materials to be processed will guide the selection of equipment to separate, remove, dismantle, or demolish each type. The *Size Reduction, Development and Evaluation of Process Options, Phase I Report* (JEG 1992a) and the *Sizing of Building Materials and Structures Study* (MKES 1992c) identified equipment and procedures for the dismantlement/demolition and sizing of building materials and debris at the Weldon Spring site. These studies emphasized that initial separation and processing is optimally accomplished during dismantlement as the debris, equipment, fixtures, buildings, and structures are being removed. Backhoes, front-end loaders, and cranes outfitted with shears, grapples, wrecking balls, and hoe rams have been recommended to accomplish this work.

Sizing of the Weldon Spring site waste material would result in an overall decrease in the processed debris volume. This predicted decrease, however, would likely be rather small, perhaps less than 10%. If land disposal was a selected method of containment, sizing of these materials, although not required for placement within the disposal facility, would facilitate handling and subsequent placement in the disposal facility. Contaminant mobility and toxicity would not be significantly reduced. Volume reduction of metal building debris can also be accomplished by induction furnace metal melting, which is discussed under thermal treatment processes.

A number of regulations would affect material sizing work performed at the site. The regulatory framework primarily includes air emissions limitations and worker protection standards. The sizing process would generate dust. To control dispersion of fugitive dust, the process equipment would be housed in an enclosed, baghouse-equipped structure. Emissions from the baghouse must meet the EPA regulations for ambient air quality standards; the 24-hour average particulate level limit is 150 $\mu g/m^3$. Fugitive dust from stockpiles would be controlled using water sprays and wind fences where appropriate. The primary control method would be

spraying water amended with surfactant during work activities. Water would be reapplied frequently to maintain effectiveness.

3.3.1.1 Jaw Crusher. Jaw crushers consist of vertical stationary jaws and inclined swing jaws to provide a variable opening from the top feed point to the bottom discharge point. The top opening is fixed; the bottom opening is adjustable and determines the size of the product discharged. The swing jaw action is produced either by an overhead eccentric shaft with a toggle arrangement to maintain the position of the bottom of the swing jaw or by an eccentric shaft operating a single or double toggle attached to the bottom of the swing jaw with the top of the swing jaw positioned by a pivot shaft. Jaw crushers are generally used for primary size reduction limited to a 3:1 to 4:1 size reduction. Jaw crushers can generally accept particle sizes from 12 inches to 48 inches. To prevent choking the crushing chamber, jaw crushers are generally uniformly fed with a feeder. Jaw crushers can process:

- Rock, non-ferrous and ferrous ores
- Concrete
- Asphalt surfacing
- Brick
- Metal melting slag

3.3.1.2 Impactor. An impactor consists of a rotor with swing hammer and breaker blocks mounted on a stationary housing. The material enters through an opening in the top of the housing and drops vertically. The rotating swing hammers strike the material driving it against the stationary breaker blocks. The material rebounds and is again struck by the rotating swing hammers. The cycle is repeated until the reduced size material is discharged through the bottom opening. There are no cage bars, so no crushing by attrition or compression occurs. Crushing or size reduction occurs by impact on the rotating swing hammers and stationary breaker blocks. Due to the repeated crushing, cycle size reduction up to 35:1 is feasible. Impactors are usually uniformly fed by a feeder or scalping screen. Impactors can process:

- Friable rock and ore
- Concrete
- Brick
- Floor and wall tile
- Asphalt surfacing
- Metal melting slag

3.3.1.3 Rotary Shear Shredder. A rotary shear shredder consists of electrical or hydraulicly driven, disk-type knives configured either as a single rotor with breaker bars or a counter-rotating type. The rotating knives operate at a low speed to produce a high torque for the shearing action. The shredder can be continuously fed from a hopper with or without a hydraulic ram assist. The material discharged would depend on knife or knife and breaker bar spacing to establish the maximum dimension in one direction. Rotary shear shredders can handle:

- Structural shapes in lengths, depending on machine width, knife circle diameter, and metal thickness
- Steel- and alloy-fabricated plate shapes
- Siding
- Rebar
- Electrical switchgear
- Transformers
- Conduit
- Pipe
- Vehicles and parts
- Railroad ties, power poles, and miscellaneous timber
- Process equipment
- Concrete

Shredders have been used effectively to process material in a variety of industry applications. Weldon Spring materials which could be processed using shredders include reinforced concrete and pavement and a large percentage of the metals. Rotary shears can easily process rebar, wooden materials, metal siding, office and laboratory equipment, conduit, pipe, and tanks.

3.3.1.4 Hammer Mill Shredder. The hammer mill shredder consists of a rotor with swing hammers and a stationary housing. The top portion of the stationary housing is equipped with breaker blocks, and the bottom portion is equipped with cage bars. The crushing or size reduction occurs due to impact in the upper portion as described for impactors and from attrition and compression of the material on the cage bars by the rotating swing hammers. The material enters the machine at the top through an opening on one side of the rotor tangential to the swing hammer circle. The material discharges through an opening in the bottom. Hammer mill type shredders are generally uniformly fed and can process:

- Siding
- Brick
- Floor and wall tile
- Concrete
- Vehicles
- Metal turnings

3.3.1.5 Shear. A shear consists of a horizontal table or platform and a vertical guillotine blade driven by gravity and an energy-storing flywheel driving an eccentric motion device. Shears are generally fed by placing the material on the horizontal platform with the portion to be sheared off extending beyond the vertical guillotine blade and advancing the material after each stroke of the blade. Materials that can be processed by shears include:

- Railroad rails
- Process equipment
- Vehicles and parts
- Conduit
- Pipe
- Electric motors
- Electrical switchgear and controls
- Transformers
- Siding
- Rebar

3.3.1.6 Cutting Torch. A cutting torch is a hand-held tool comprised of a mixing chamber with an oxygen bypass valve and a nozzle (cutting tip) to burn the gas and oxygen mixture. A gas (such as acetylene, propane, or methane) and oxygen are pressure regulated and supplied to the cutting torch where they are mixed and burned. Molten metal is produced under the torch flame as the metal mass is heated. Once molten metal is formed, a high volume of oxygen is bypassed through the bypass valve and is applied through the tip to the molten metal causing rapid oxidation of the metal. Movement of the torch across the metal plate or material continues the rapid oxidation, causing the separation or cutting of the plate. The cutting torch can be used on all metals that can be oxidized rapidly. However, many alloys are resistant to oxidation and high temperatures.

3.3.1.7 Other Equipment. Concrete saws or pavement breakers can effectively cut or fracture concrete. This material can also be rubblized using wrecking balls or hoe rams.

Pulverizers can crush unreinforced concrete and pavement, and can crush reinforced concrete to separate reinforcing bar and steel beams. Tractor-crawlers may be used to flatten pipe, tanks, and miscellaneous equipment, fixtures, and debris.

Standard, commercially available compacting machines can be used to condense and bale garbage, refuse, trash, and other similar waste. In-drum compactors, which condense material at an 8-to-1 ratio, can process small quantities of miscellaneous waste. The final product of compaction, however, is not as amenable to further treatment or disposal as the product of a shredder.

Preliminary relative cost comparisons for the various size reduction equipment and the various waste media to be processed were developed in a previous study (JEG 1992a). These cost rankings are presented below in Table 3-2.

TABLE 3-2 Size Reduction Equipment Cost Comparison

Waste Media	Crusher Type		Shredder Type		Shear	Cutting Torch
	Jaw Crusher	Impactor	Rotary	Hammer Mill		
Structural Steel			1		2	3
Fabricated Steel Plate			1		2	3
Fabricated Alloy Steel Plate			1		3	
Siding			1	2	3	
Re-Bar			1	3	3	3
Concrete/Rock	1	1				
Brick	1	1		2		
Floor and Wall Tile	1	1		2		
Glass		1		2		
Asphalt Surfacing		1		2		
Tar and Gravel Roofing		1		2		
Railroad Ties and Timber			1	2		
Railroad Rail					1	2
Vehicles			2	1	1	3
Metal Melting Slag	1	1		3		
Pipe			1		2	3
Conduit			1		2	3
Electric Motors					1	2
Electric Switchgear			1		2	3
Transformers			1		2	3
Process Equipment			1		2	3

1 = Least Costly
2 = Average
3 = Most Costly

3.3.2 Dewatering and Drying

Dewatering and/or drying may be performed to facilitate material handling or as a precursor to several treatment technologies and therefore could have a major impact on the implementability and cost of these remedial technologies.

3.3.2.1 Dewatering. Dewatering is a broad term referring to any process that reduces the water content by mechanical removal of free water. This action reduces the volume of waste which subsequently increases the solids content of the remaining waste. Three studies examined the possibility of dewatering the raffinate pit sludge: *Weldon Spring Special Studies Phase II Report on Dewatering/Drying* (JEG 1992b), *Raffinate Sludge Dredging and Dewatering Study* (MKES 1992b), and *Drying (Mechanical and Thermal), Development and Evaluation of Process Options* (JEG 1992c).

The JEG study (1992b) focused solely on a rotary vacuum filter system to dewater the raffinate. In this system, the drum rotates in a vat containing the suspension to be dewatered. Liquids/solids separation is accomplished by vacuuming the liquid from the interior and drawing it through a filter medium, leaving solids on the medium for separate collection. As the drum rotates, this medium provides a continuous filter layer which undergoes the following sequence: 1) cake formation, 2) liquid extraction or drying with applied vacuum, and 3) filter cake removal with belt-type discharge. High-pressure water sprays dislodge particles that could build up and clog the medium.

The MKES (1992b) study examined three dewatering methods: a cyclone system, a belt filter press system, and pressurized electro-osmotic dewatering. Cyclone system dewatering is accomplished using centrifugal force, plate thickeners, and filtering methods. Belt press dewatering is typically accomplished using a belt press, screen, and flocculation. Although bench-scale testing of the pressurized electro-osmotic dewatering process has been promising, this method is still in the laboratory stage and was not considered further.

Three categories of dewatering methods were evaluated in the earlier JEG study (1992c): clarifiers and thickeners, mechanical filters, and expression presses.

Clarifiers are employed with dilute suspensions to produce a relatively clear overflow. Continuous thickeners are used in applications where large quantities of solids must be concentrated or removed from large volumes of solid-liquid slurries. Suspended solids are separated by gravity settling and continuously withdrawn in the underflow. Although clarifiers

and thickeners have different sizing criteria, these devices are very similar. Clarifiers usually employ a mechanism of lighter construction with a lower torque drive head.

Mechanical filtration involves the separation of fluid-solids mixtures by pumping the mixture through a porous barrier which retains most of the solid particulates. Expression pressing is a form of solid-liquid separation. This method is different from filtration in that pressure is applied by moving the retaining walls instead of by pumping the material into a fixed space. Expression presses can dewater materials that may appear entirely solid and not pumpable. Continuous expression equipment include screw presses, rotary mills, and belt presses.

The *Raffinate Sludge Dredging and Dewatering Study* (MKES 1992b) predicts achieving a product having a 75% to 85% by weight solids content using a belt press system and 85% solids content using a cyclone system. In contrast, the *Weldon Spring Special Studies Phase II Report on Dewatering/Drying* (JEG 1992b) suggests a product containing only 24% to 32% solids (68% to 76% moisture) by weight is possible using a rotary drum vacuum filtration system.

The physical dewatering of raffinate sludge could lead to significant reductions in volume and tonnage. MKF and JEG (1992c) estimated that dewatering 220,000 cubic yards of sludge to 20% moisture would result in a volume reduction of 175,000 cubic yards (80%), and a weight reduction of 147,300 tons (66%). The remaining 45,000 cubic yards of dewatered sludge would have an estimated density of 1.67 tons per cubic yard.

Nitrates and other soluble compounds would be contained in the wastewater stream pumped from the dewatering circuit to the wastewater treatment plant. Assuming that all of the nitrates in the raffinate sludge are soluble and that the dewatering process achieves raffinate sludge dewatering to 80% solids, approximately 90% of the nitrates would be removed from the sludge.

Cyclone-based dewatering of the Weldon Spring raffinate has not been demonstrated. Dewatering by cyclones is optimal for a suspended particle slurry, not for a gelatinous chemical precipitate such as the Weldon Spring raffinate. Most of the raffinate pit sludge (89-99.9%) has a particle size of less than 0.003 inch (i.e. particles that pass the 200 mesh sieve) (MKF and JEG 1989). Once the raffinate is dewatered, it could be difficult to handle and particulate emissions could be difficult to control. Consequently, due to the poor weight bearing capacity of the unstable dewatered sludge, subsidence of a disposal cell cover could occur. For

a case study investigated for the belt press system, a polymer was added to aid flocculation (MKES 1992b). Other potential additives could include fly ash, lab pac, desiccant, flocculent, and proprietary chemicals.

Filtration systems require that the original mixture is sufficiently fluid to be pumpable. Filters cannot be optimally sized based on theory; small-scale tests must be performed to select the appropriate filter. Many types of filters are available for heavy duty, continuous service. Expression presses can dewater material that may appear entirely solid and not pumpable. In some applications, this technology is competitive with thermal drying.

Most dewatering equipment is available from industrial equipment suppliers; this process requires only standard machinery. Dewatering cost estimates for the cyclone and belt filter press systems are presented in Section 3.1.2 in conjunction with the dredging and slurry sludge removal options. Preliminary costs developed for sludge dewatering using a rotary drum vacuum filtration system are presented below (JEG 1992b). These capital and operating costs are based on a 3-year operation at 260 days per year, 24 hours per day. The estimated cost of dewatering 226,993 tons of raffinate pit and quarry sludges is summarized below. Additional testing will be required to determine the effectiveness of various dewatering processes.

Feed Rate (lb/day)	Media	Costs
582,000	Raffinate and quarry sludges	$1,700,000 ($7.49/ton)

3.3.2.2 Drying. Drying involves the physical removal of free water from solid materials by evaporation. Mechanical dewatering often precedes drying because it is less expensive and is frequently easier.

Several alternative technologies for thermally drying the raffinate sludge have been studied (JEG 1992c). Thermal dryers can be classified as direct or indirect, based upon the method of transferring heat to the wet solids. Direct dryer heat transfer is accomplished by direct contact between the combustion gas and the wet solids. The vaporized liquid is carried away by the hot gas. Indirect dryer heat transfer is accomplished by conduction through a hot surface. The vaporized liquid is removed independently of the heating medium. The thermal drying technologies include continuous tunnel, circulation, rotary, agitated, pneumatic conveyor, fluidized bed, solar beds, and rotary kiln.

In the continuous tunnel system, feed material is placed in trays, trucks, or on conveyor belts which move progressively through the tunnel chamber in contact with hot gas. Air flow is horizontal or across the material being dried. The tunnel drying system is workable for large quantity production situations involving most forms of particulate solids and large solid objects.

Continuous feed circulation dryers are similar to tunnel dryers except that the hot gas is circulated vertically through a permeable bed of wet material. Success of these dryers depends upon properties of the granular or pelleted feed material. Characteristics of the feed material must be such that hot air can be readily blown through the bed and the dry solids can be removed.

In a rotary dryer, feed material moves through a slightly inclined, horizontal, rotating cylinder which can employ either direct or indirect drying. Direct-heat dryers are usually equipped with interior flights for lifting and showering the solids through the gas stream. Rotating dryer equipment is applicable for processing materials which are relatively free flowing. These systems generally discharge a granular product.

Agitated dryers are similar to rotary dryers, except that the housing enclosing the process is stationary while solids movement is accomplished by an internal mechanical agitator. Like rotary dryers, these systems are applicable to processing materials which are relatively free flowing. These systems generally discharge a granular product.

Pneumatic conveyor dryers consist of a long tube carrying gas at high velocity, a fan to propel the gas, a suitable feeder for addition and dispersion of particulate solids in the gas stream, and a cyclone collector to recover the dried solids. Pneumatic conveyor dryers are basically utilized for the removal of surface moisture.

Fluidizing converts a bed of solid particles into an expanded, suspended mass that has many of the properties of a liquid. Fluidized beds are successful in the roasting of sulfide ores; coking of petroleum residues; calcination of limestone, aluminum hydroxide, and phosphate ores; drying; and waste combustion.

Solar drying beds usually involve spreading waste sludges on the ground for draining and for exposure to solar radiation. After sufficient drying, the material can be collected by common earth moving equipment. This practice is particularly effective in arid climates but can also be utilized with some success in other climates.

Another study (JEG 1992b) addressed drying as a single treatment component that can be incorporated into other waste treatment/handling systems. Direct-fired rotary kilns were evaluated for drying both raw, untreated sludges and dewatered sludges. The rotary kiln dryer consists of a revolving, elongated cylinder which is horizontally inclined and supported by riding rings. The cylinder is arranged so that the hot gases and materials pass continuously in opposite directions (countercurrent flow). The interior of the dryer is fitted with spiral flights at the feed end to quickly move the solids into the active section where longitudinal parallel lifting flights pick up the material and cascade it in thin, even sheets so that drying is more efficient. The cylinder is rotated by a chain and sprocket arrangement in conjunction with a drive unit, which features a reducer and electric motor.

Drying the raffinate sludge could achieve compliance with federal restrictions on the placement of free liquid-bearing materials into a land disposal cell. The JEG report (1992b) suggests a product containing 1% moisture by weight is possible using a direct-fired rotary dryer.

Drying of Weldon Spring waste media, however, could release radioactive particulates. The potential for acidic organic vapor emissions also exists, primarily for the quarry materials. Dust generation from the dried product could pose significant problems if adequate controls were not implemented. Drying of the sludges is not required nor operationally advantageous for chemical stabilization. A dried feedstock could potentially cause bridging during the feeding of vitrification units if this remediation technology was used.

Direct-fired rotary kiln designs can be adapted relatively easily to accommodate widely varying quantities and characteristics of waste media. However, this system requires high gas throughput and has high dusting or solids entrainment characteristics. Field tests would be required to evaluate the technical feasibility of this technology for drying Weldon Spring sludges. The applicable standards for radioactive particulate emissions must also be determined to optimize the thermal drying system.

Another drying study (JEG 1992c) examined thermal drying processes for soil, sediments, and sludges and developed the relative cost comparison presented below for those processes considered technically feasible.

Thermal Dryer Type	Relative Cost
Continuous Tunnel	High
Continuous through Circulation	High
Rotary Dryer	High
Agitated Dryer	High
Pneumatic Conveyor	High
Solar Drying Bed	Low

The JEG (1992b) report on drying/dewatering presents preliminary capital and operating cost estimates for drying both untreated and dewatered media using a direct-fired rotary dryer.

Media	Tons	Cost
Raffinate and quarry sludges (untreated)	226,992	$8,300,000
Raffinate and quarry sludges (dewatered)	175,037	7,100,000
Soil and clay (untreated)	768,894	12,300,000

These cost estimates are based on a 3-year operation, 260 days per year, 24 hours per day.

3.3.3 Physical Separation

Physical separation techniques involve mechanical methods of separating mixtures of solids to obtain a concentrated form of the solids. Physical separation of contaminants confined or adhering to a volumetrically minor specific size fraction of soil or sediment can, in theory, significantly reduce contaminant volume. A combination of processes may be needed to achieve the specified cleanup criteria for a given contaminant. A combination of processes may be needed to achieve the specified cleanup criteria for a given contaminant in the soil. Potential methods of physically separating soils into contaminated and uncontaminated fractions evaluated in the *Evaluation of Physical Separation Techniques for the Treatment of Contaminated Soils* (MKF and JEG 1992d) include screening, classification, flotation, gravity, evaporation, and ultrafiltration separation technologies.

A primary constituent of Weldon Spring site soils is clay. The site soils generally consist of clay-sized (30 to 48% of soil) or silt-sized (39 to 68% of soil) particles. Because of the chemical activity of clays and the amount of clay- and silt-sized particles present, the majority of contamination is absorbed onto the finer grained fraction of the soils. All of the separation

techniques evaluated are effective in isolating radioactively contaminated materials and separating metal contaminants from the soils. The effectiveness of treating the chemical contaminants needs to be verified.

Most physical separation processes require substantial amounts of water. The contaminated fraction of soil must then be separated from the water prior to disposal. The separated water is usually purified and recycled to reduce the volume of water necessary for the process. Mechanical separators would require dust control measures and process water treatment. No additional environmental controls or permitting would be necessary.

The MKF and JEG report (1992d) developed relative cost data for the physical separation processes evaluated.

Technology	Relative Cost
Screening	Low
Classification	Low
Flotation	High
Gravity	Med.
Evaporation	Med.
Ultrafiltration	High

3.3.3.1 Screening. Screening is the mechanical separation of particles based on size, which is usually achieved using uniformly perforated openings (such as sieves). Particles larger than the screen are retained while the smaller particles pass through. Screens are generally used to separate material that would not require subsequent treatment, such as contaminated soil mixed with rubble. Screening is normally limited to particles larger than 250 microns. The efficiency of screening is also affected by the amount of moisture in the soil and the amount of clays. Screening must be performed using either a wet or dry process. Damp materials are poor candidates for screening because they tend to agglomerate and clog the screen openings. Wet screening requires large amounts of water; however, wet screening performs better because the finer particles that adhere to the coarser particles can be washed off, achieving greater separation and allowing the screen to be cleaned during the process.

Although remote, it is possible that implementing screening to remove clay-sized grains from the soil matrix could result in some uranium mobilization due to separation of the clay fraction. In general, contaminants are more commonly absorbed onto finer grain particles.

Imperfect separation of the fractions could result in some finer particles (and contaminants) remaining in or on the coarser particles. Slowing the feed process could likely remedy this situation if it was found to be a problem.

3.3.3.2 Classification. Classification is the separation of particles according to their settling rate in a fluid (usually water). Various categories of classifiers are available: (1) nonmechanical which relies on gravity or centrifugal force, (2) hydraulic nonmechanical which relies on gravitational or centrifugal force to separate particles, and (3) mechanical. Three types of nonmechanical classifiers commonly used are the hydrocyclone, settling cone, and elutriator (sized according to upward current of air or water). Hydraulic classifiers use a fluidized bed to separate particles. Mechanical classifiers are usually used with slow settling particles which are carried along by the fluid, while the coarser, faster settling particles are dragged upwards against the flow by mechanical methods. Commonly used types of mechanical classifiers include rake, spiral, sedimenting, drag, counter current, and air.

The size and quality of separation using classification depends on the feed rate, speed of removal, degree of agitation, and height of overflow. Soils containing a great deal of clay would be difficult to process using a classification system. This problem may be remedied by modifying the unit design, by mixing the clayey soils with more silt, or by combining different types of classifiers (mechanical, non-mechanical, etc.)

3.3.3.3 Flotation. Flotation is usually applied to materials contaminated by sulfide or metals. In flotation systems, particles are suspended in water by means of mechanical or air agitation at a pulp (froth) density of 15% to 35% solids. Through the use of modifying agents (promoters or collectors), metals are first depressed and then, by vigorous agitation and aeration along with chemical additives to promote frothing, become attached to "bubbles" and rise to the surface where they are skimmed. The effectiveness and implementability of the flotation process is dependent upon particle size, feed rate, and control of chemical additives.

Flotation is economical when separating particles ranging from 0.01 to 0.001 mm. Coarse materials cannot be properly or sufficiently mixed to be suspended by flotation. The flotation process requires using suitable modifying chemicals that are compatible with the subject metallic or nonmetallic materials. However, the addition of these chemical agents increases the volume of waste.

3.3.3.4 Gravity Separation. Gravity separation methods are widely used because of their simplicity and because they do not require chemical additives. Three types of gravity

separators are commonly used: (1) jigs — oscillating motion, (2) shaking — horizontal motion, and (3) sluices and troughs — slurry flows down an inclined surface (limited primarily to coarser-grained particles).

Modern gravity separation techniques have proved to be effective for particle sizes ranging from 50 to 100 microns. The efficiency of the gravity separation method is dependent upon depth and surface area of the container, settling time/holding time, the difference in density and settling velocities between contaminated and uncontaminated media, particle size, and flow rate of fluid. This process is most effective in isolating materials with extremely different settling velocities, such as gold nuggets from quartz sand or chromite grains from serpentine. Gravity separation is a slow process with a low processing capacity. This method also requires large amounts of clean water. Gravity separation probably could not generate a releasable solid.

3.3.3.5 Evaporation. Evaporation is the physical separation of a fluid from a dissolved or suspended solid by applying energy to volatilize the liquid. Evaporation is effective in separating liquids from solids but not for separating specific solid size fractions from one another. Application of this technology to Weldon Spring site raffinate sludges would be dependent upon the need to keep the sludges wet to prevent radon emissions.

3.3.3.6 Ultrafiltration and Electrofiltration. Ultrafiltration consists of forcing an aqueous solution through a semi-permeable membrane. This technology is dependent upon a pressure driving force and a membrane that is permeable to some components in a solution and impermeable to others. Ultrafiltration can separate particles with diameters as small as 10 to 50 atomic mass units (amu) and as large as 500,000 amu and is a proven technology in the treatment of radioactive wastewater.

Electrofiltration can also achieve separation of fine-grained particles. The aqueous solution is placed in a direct current electric field which causes the positively charged particles to migrate toward the anode, and the negatively charged particles to migrate toward the cathode. In the cathode, the slurry/solution is filtered by vacuum filtration.

Ultrafiltration and electrofiltration are designed to separate liquids from solids, not to separate specific solid size fractions from one another. The filtration media is subject to clogging; ultrafiltration membranes are subject to fouling by inorganic materials, ferric materials, other particulates, and organic materials.

3.3.4 Hydrolasing

A previous decontamination study (JEG 1992d) examined the use of hydrolasing for decontamination of concrete slabs at the Weldon Spring Chemical Plant. Hydrolasing, or hydroblasting, achieves decontamination by bombarding contaminated surfaces with water particles at pressures up to 35,000 psi. Surface coatings and contamination are generally removed.

The hydrolasing system consists of a hand-held, hydraulic-motor-driven, high-speed water jet, water collection sumps, water storage tanks, and conventional water pumps. The application wand shoots a rotating pattern of water jets which must be maintained at a distance of 1 inch or less to effectively clean or remove the surface of the material being decontaminated. The removed surface debris and spent water are collected in a sump system. Solids are separated by settling, and the water is recycled to the process.

Remotely operated hydroblasting can be used to decontaminate floors. These units consist of a high-pressure water jet and vacuum collection system mounted on a cart. The cart moves in a pre-set pattern at a predetermined rate, blasting a clean path in the concrete floor. The water and removed debris are vacuumed up and routed through hoses to a holding tank where the debris settles and is removed for disposal.

The *Weldon Spring Site Remedial Action Project Decontamination Study* (JEG 1992d) indicates that hydrolasing can decontaminate smooth, noncomplex, metal and concrete surfaces such as concrete slabs. Decontamination is estimated to be 95% effective after one application. Approximately 446 cubic yards of contaminated concrete waste would be created by hydrolasing 603,000 square feet of concrete slab (0.02 ft^3/ft^2 surface area).

Hydrolasing of structural steel is a viable option to liquid abrasive blasting. Hydrolasing has been used extensively to decontaminate nuclear facilities and has been employed commercially to clean bridges, piping, highways, and many other structures.

Surface contamination guidelines for release of surficially contaminated material for unrestricted use are provided in DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. The order states that prior to being released, site materials shall be surveyed to determine whether both removable and total surface contamination (including contamination present on and under any coating) is greater than specified maximum level. The order also

states that contaminant removal complies with the requirements of the ALARA process (as low as reasonably achievable).

It may be more cost effective to treat and dispose of certain metal and concrete materials rather than attempt a long, expensive, and labor-intensive decontamination effort. Decontamination of 603,000 square feet of concrete slabs would cost approximately $540,000 ($0.90 ft^2) over a period of 1.5 years (JEG 1992d).

3.3.5 Liquid Abrasive Blasting

The decontamination study (JEG 1992d) also suggested that liquid abrasive blasting can effectively decontaminate radioactively contaminated metal pieces with exposed surfaces, such as structural members or siding. The principle of liquid abrasive blasting is to bombard contaminated surfaces with a high-volume recirculating flow of solid particles in water at a pressure of about 100 psi. The solid particles, made of aluminum oxide or glass beads, abrade the surface and remove corrosion. Surface coatings and a thin layer of the parent material are removed along with the surficial contamination. A water layer between the component surface and the abrasive particles prevents particle impregnation, surface damage, and excessive breakdown of the abrasive particles. A water rinse of the decontaminated surface is used immediately after liquid abrasive blasting to remove the abrasive grit. The surface being decontaminated must be within several inches of the work nozzle for the process to be effective.

The spent grit and surface debris are recirculated with the slurry. The grit must be replaced routinely, due to grit breakdown. The spent abrasive grit and decontamination debris are separated from the process water suing a hydroclone. The grit and debris are placed in temporary storage containers to allow the solid material to settle. The clarified water is recycled to the process, while the dewatered waste is sealed in a drum and transferred for disposal. An estimated 0.06 cubic feet of waste will be generated from each ton of steel treated.

Liquid abrasive decontamination methods are effective for smooth, noncomplex, metal and concrete surfaces. Liquid abrasive blasting will effectively decontaminate structural steel, but is not effective for decontaminating process equipment or piping. The estimated decontamination effectiveness after one application is 95% (JEG 1992d). Several control variables affect the surface removal effectiveness of the material being decontaminated. These variables include water pressure, air pressure, and the abrasive material used.

Approximately 390 cubic feet of sludge consisting of the removed metallic layer and disintegrated grit would be generated by liquid abrasive blasting 6,500 tons of structural steel (0.06 ft^3/ton of steel).

Liquid abrasive cleaning equipment is routinely used in the chemical industry. Water abrasive techniques, both with and without an added abrasive cutting medium, have been used for decontamination for many years.

It may be more cost effective to treat and dispose of certain metal and concrete materials rather than attempt a long, expensive, and labor-intensive decontamination effort. Decontamination of 6,500 tons of structural steel over a 2.75-year period would cost approximately $1,190,000 or $182 per ton (JEG 1992d). The value of the scrap steel is approximately $80 per ton.

3.4 Hydrometallurgical Treatment

Hydrometallurgical treatments involve reacting a leach solution, or lixiviant, with contaminated material resulting in the dissolution of the contaminants. Separation of the contaminant-bearing liquor from the insoluble residual can potentially result in an uncontaminated residual. The uncontaminated residual may be releasable or require less stringent containment than untreated material. The processes described in this section are considered off-site treatments. Remediation of contaminated material would occur at some existing off-site uranium mill.

3.4.1 Solvent Extraction

Reprocessing the Raffinate Pit Sludges at the Weldon Spring Site (JEG 1992e) evaluated two solvent extraction processes which may potentially be employed to reprocess the raffinate pit sludges: (1) nitric acid leach solvent extraction process and (2) sulfuric acid leach solvent extraction process. Reprocessing would be applicable only to the raffinate pit sludges. No other Weldon Spring site media would be amenable to reprocessing because of the low contaminant concentration levels present.

According to the reprocessing study (JEG 1992e), it may be technically feasible that the 220,000 cubic yards of raffinate pit sludges could be reprocessed using the nitric acid solvent extraction process in a new on-site plant or a modified existing building. Reprocessing could potentially also be carried out by drying the sludge and shipping it off site for processing using

the sulfuric acid solvent extraction process at an existing uranium mill to recover the uranium, or at a modified uranium mill to recovery both uranium and thorium. However, it should be noted that the reprocessing study suggests that leach and solvent extraction recoveries of 99.5% are obtainable. These values are significantly higher than recoveries obtained in uranium mills which are specifically designed to maximize uranium recovery. Acid-leach uranium mills typically extract 85% to 95% of the uranium in the leach cycle. Solvent extraction systems usually can reach an extraction efficiency of 97% to 98%. Overall recoveries typically range from 90% to 95%. Variations in recoveries occur periodically due to changes in ore types or mill plant operation. Residual materials, with levels of unleached contaminants exceeding the regulatory limits for simple landfilling, would be produced. The reprocessing study did not identify an existing plant that was able to generate a releasable waste using either leaching technique.

Either a hydrochloric acid leach system or a sodium carbonate-ammonium hydroxide leach system would be appropriate for the high-calcium-carbonate-bearing raffinate. A hydrochloric acid leach system is employed to process Blind River uranium ores in Ontario, Canada. A sodium carbonate-ammonium hydroxide lixiviant was used to treat high-calcium-content uranium ores in Grants, New Mexico; Riverton, Wyoming; and Three Rivers, Texas. Alkaline leach systems usually show relatively low leach efficiencies of 75% to 85%.

The reprocessing study (JEG 1992e) suggests that the hydrometallurgical processing of the raffinate to remove uranium thorium, and radium may yield a residual which requires only landfilling. However, there are no published guidelines defining the limits for radionuclides in nonhazardous waste. Specific regulatory requirements would depend on the specific process alternative and site selected. The reprocessing study concludes that on-site nitric acid leach processing in a new or modified facility or off-site processing in an existing or modified uranium mill may be technically feasible.

3.4.1.1 Nitric Acid Leach. The objective of reprocessing the Weldon Spring raffinate sludges using a nitric acid leach process would be to produce a radiologically safe residue. This process, which is capable of separating the uranium, thorium, and radium from the remainder of the sludge, consists of a nitric acid leach, followed by solvent extraction and precipitation of uranium, then thorium, and finally precipitation of radium.

Since radium must be dissolved to separate it from the remainder of the sludge components, the initial extraction process requires the use of nitric acid. Nitric acid was employed as a leaching agent at the Weldon Spring uranium feed material plant to dissolve both

uranium and thorium. After filtration to remove insoluble materials, the uranium was extracted by tributyl phosphate (TBP) dissolved in kerosene. However, instead of producing uranium metal as was previously done, the sludge reprocessing plant would produce yellow cake. The uranium would be stripped from the TBP and precipitated with ammonium hydroxide. The precipitate (yellow cake) would be filtered and calcined. If the precipitate met commercial specifications, it could possibly be sold rather than processed for disposal.

The second step in the extraction process involves the leaching of thorium in TBP-kerosene, after the uranium has been removed from solution. The thorium is stripped from the TBP by sulfuric acid. Oxalic acid is added to precipitate thorium oxalate, which is filtered and calcined to the oxide, thoria.

Radium is the third radionuclide extracted. The commercial procedure involves adding barium chloride to the solution, followed by the addition of sulfuric acid. As the barium sulfate precipitates, it occludes radium sulfate in its crystal structure. The precipitate is allowed to settle and is filtered or trapped within a porous sand bed. The precipitate is then disposed. An alternate method of radium removal is to adsorb it onto a proprietary ion exchange resin. Since a small quantity of resin is required to adsorb the radium, the resin could be physically removed and disposed.

After extraction of uranium, thorium, and radium, the remaining solution is treated with calcined lime to precipitate any remaining metals and to neutralize any remaining acid. The precipitate is thickened and filtered. The insoluble materials obtained by leaching and the lime precipitate may then be considered for removal and disposal into a sanitary landfill if the leached materials pass a TCLP test.

Nitric acid leach/tributyl phosphate solvent extraction was used at the Weldon Spring site to process uranium yellow cake concentrate. Neutralization of the waste stream by calcium oxide produced the raffinate sludges. Attempting to re-leach the calcium-rich raffinate sludge with sulfuric acid would generate massive quantities of radioactive gypsum. Gypsum formation would cause plugging of screens, filters, and pipes.

A relatively suspension-free aqueous liquor is required to react with the extracting organic reagent in solvent extraction systems. Aqueous liquor, with a high suspended particle component, tends to develop an aqueous/organic emulsion at the aqueous/organic interface. The emulsion reduces the effectiveness of the solvent extraction process. Raffinate sludge, which is very fine grained, would be difficult to remove from suspension, even with the use of high-

efficiency thickeners and flocculating agents. Consequently, effective solvent extraction of uranium and associated contaminants may prove to be difficult or impossible.

All of the soluble waste products from the nitric acid leach process would ultimately be processed through the site water treatment plant. Since most metal nitrates are soluble, the metal nitrates from the nitric acid leach would be added to the nitrate already present in the contaminated water. The nitrate removal step would therefore be required to have a significantly greater capacity.

The JEG (1992e) report estimated that on-site nitric acid leach processing of the raffinate pit sludge would cost approximately $55 million. However, as noted previously, the effectiveness of this process would be very questionable.

3.4.1.2 Sulfuric Acid Leach. Sulfuric acid is used as a leaching agent to effectively remove uranium from most of the ores in the western United States. Since thorium and radium are essentially absent from these ores, these facilities do not employ processes to recover any elements that do not dissolve in the sulfuric acid. As a result, the existing uranium mills are configured to recover uranium only, using equipment designed to resist the effects of sulfuric acid but not necessarily equipped to handle nitric acid. A possible exception would be a mill with an unused circuit originally intended for vanadium or molybdenum recovery. In this case, the unused circuit may possibly be modified to recover and precipitate thorium. The following steps describe this process if it were applied to the Weldon Spring site.

The first step of a typical sulfuric acid leach process would be the removal of the soluble components from the sludge using sulfuric acid. The insoluble components would be allowed to settle and would be filtered from the solution. The uranium would selectively removed from solution by an organic secondary or tertiary amine dissolved in kerosene. The uranium would then be stripped from the organic phase and calcined. The resultant product could potentially be sold as uranium concentrate or yellow cake.

The second step in the process would be the extraction of thorium into a solution of a primary organic amine dissolved in kerosene. The thorium would be removed from the amine by an acid strip and precipitated as thorium oxalate. The oxalate would then be filtered and calcined to thoria, or thorium oxide.

The minute quantities of radium that do dissolve would finally be extracted from solution by precipitation as radium sulfate, an accepted practice at existing uranium mills. Barium

chloride would be added to the solution causing barium sulfate to precipitate. The radium sulfate would be co-precipitated with the barium sulfate. The precipitate would be allowed to settle and would be retained within the confines of a lined evaporation pond.

The remaining soluble components in the leach solution would probably not be precipitated by lime in this process. Instead, these components would mix with the other solutions already in the evaporation pond.

Drying the raffinate sludges and shipping it off-site for processing in an existing sulfuric acid leach facility would cost approximately $50 million (JEG 1992e). The sulfuric acid leach process would be employed in an existing mill to recover the approximate 246 tons of uranium contained in the sludges. If this uranium were recovered in the form of yellow cake concentrate that assayed 65% uranium, at a price of $8.75 per pound (November 1991 price), sludge reprocessing could generate $4.3 million in revenue. However, a system involving sulfuric or nitric acid leaching with sequential solvent extraction of uranium and thorium and subsequent radium precipitation, has never been constructed. Extensive bench-scale testing would be required to demonstrate the potential for generating a releasable residual.

3.4.2 In Situ Leaching

The application of in situ leaching for remediating contaminated soil, sediment, and raffinate sludge at the Weldon Spring site was evaluated in a previous study (*In Situ Leaching, Development and Evaluation of Process Options*, JEG 1992f). In order to extract toxic or radioactive components, the in situ process involves adding chemical agents to waste media in place, collecting the resultant leach solution, and recovering the components from the leach solution (lixiviant).

In situ leaching is also known as solution mining, soil flushing, solvent flushing, or ground leaching. In solution mining, a uranium-leaching solution is continuously circulated through the underground ore body. The pregnant leach solution is pumped from wells to the surface, where it is processed to recover uranium. This processed (or regenerated) leach solution is re-introduced to the ore body along with fresh solution to offset solution losses. Commonly used leaching solutions are sulfuric acid, ammonium carbonate, and sodium carbonate. In each case, an oxidant (such as air or oxygen), hydrogen peroxide, or sodium chlorate is added to help solubilize uranium. Two leaching methods, carbonate leaching and acid leaching, and two recovery methods, ion exchange and solvent extraction, were evaluated. Although carbonate leaching with ion exchange and acid leaching combined with either ion

exchange or solvent extraction are technically implementable processes, their use may pose a high risk of groundwater contamination.

Attempted in situ leaching could result in uncontrolled excursions of lixiviant, potentially causing groundwater contamination. In situ leaching of sediment at the Weldon Spring site also appears impractical because much of the contamination is at and just below the surface. Control of lixiviant at the surface would be impossible. For sludges, permeability is a primary concern, because solution must be circulated through the media for the process to be effective in removing contamination. Because the raffinate sludges are very fine grained, it would be difficult for the lixiviant to uniformly penetrate and circulate. Channeling of lixiviant could occur, and solution contact and contaminant removal within the raffinate sludges would be minimized.

The JEG report (1992f) indicated that there was minimal variation in cost among the solvent extraction and recovery options evaluated. The effectiveness of in situ leaching for treatment of hazardous wastes has not been demonstrated at the project scale, and the environmental acceptability of this process is questionable.

3.4.2.1 Carbonate Leaching. A leach solution which contains an oxidant and either ammonium carbonate or sodium carbonate is circulated through the medium continuously. Uranium and other heavy metals in the medium are dissolved by and then recovered from the leach solution. After the metals are recovered from the leach solution, the solution is recirculated through the medium, and make-up solution is added as necessary.

3.4.2.2 Acid Leaching. The acid leaching process is essentially the same as the carbonate process, except the leach solution contains an oxidant such as air, hydrogen peroxide, or sodium chlorate with the sulfuric acid. Because sulfuric acid lixiviant generates massive amounts of gypsum, ammonium carbonate lixiviant should be used for any attempt to leach the raffinate sludge in situ. Unfortunately, the contaminant-bearing ammonia lixiviant itself would be very difficult to remediate during restoration of the subject media.

3.4.2.3 Ion Exchange. The leach solution is pumped through an ion exchange column to remove uranium. Uranium is then eluted from the ion exchange resin by contact with a chloride solution, or other eluant, and precipitated with hydrochloric acid followed by ammonium hydroxide. The resulting slurry is dried to produce uranium oxide (yellow cake). Many variations of this basic process can be used, depending on the composition of the medium, components to be removed, and other factors.

Many variations on the basic ion exchange process are available, depending on the composition of the medium, components to be removed, and other factors. Fixed-bed and moving-bed ion exchange systems are common, and ion exchange recovery can be used with both the acid and carbonate leaching processes.

3.4.2.4 Solvent Extraction. This process is sometimes used to recover uranium and other components from acid-leach liquors which have uranium concentrations greater than 1 gram per liter. Organic amines or organic phosphates are diluted with kerosene and used as a solvent. Due to excessive solvent losses, this process is not normally used with carbonate leaching or with less rich, acid leach liquors. Spent solvent of the type used in the solvent extraction process is one of the components to be removed from the Weldon Spring site, so the feasibility of this technology is questionable.

3.5 Chemical Stabilization

Chemical stabilization of removed material involves mixing reagents with contaminated material to solidify the media and immobilize the contaminants.

3.5.1 Cement-Based Stabilization

Cement-based solidification, the mixing of wastes directly with Portland cement, has been implemented as a remedial technology at other sites (Rich and Cherry 1987). Most solidification is accomplished using Portland cement and additives. Siliceous compounds, including fly ash, blast furnace slag, soluble sodium or potassium silicates, and proprietary agents, are commonly used in conjunction with the Portland cement. Portland cement absorbs significant quantities of water during hydration reactions, minimizing the quantity of drainable water in a solidified mass. With the silicate-only based processes, however, a large amount of non-chemically bound water remains in the solid after solidification. To prevent the escape of this water, a silica-only solidified product is likely to require some form of secondary containment (Rich and Cherry 1987) such as within a disposal cell. However, the chemically stabilized media is less likely to settle within a cell than unsolidified material. Settling within a disposal cell could ultimately cause cell cover failure.

Chemical stabilization produces significant increases in tonnage (64%) and volume (32%) of materials. According to JEG (1992b), 32% less treated product would require disposal if the raffinate sludge were dewatered prior to stabilization. Chemical stabilization, using cement and

fly ash, would immobilize, not destroy, hazardous compounds. A mixture of silicates and cement can stabilize a wide range of materials including metals, waste oil, and solvents.

Gilliam and Francis (1989) observed a wide range of setting rates, duration of drainable water, and unconfined compressive strengths with variations in reagent blend additions and raffinate water content. These variations suggest that strict quality control procedures be implemented to ensure a stable, high-quality product. Their study demonstrated that the addition of a cement/fly ash mixture to untreated raffinate sludge results in a solidified mass with properties similar to concrete. The study found that a blend of 40% (by weight) Type II Portland cement and 60% ASTM Class F fly ash mixed at a ratio of 0.6:1 (by weight) cement/ fly ash to raffinate sludge was required to stabilize the sludge. This blend achieved initial set within 1 day and final set within 7 days. The solidified mass met the performance criteria of (1) no drainable water within 28 days, (2) unconfined compressive strength of at least 410 kPa (60 psi), and (3) resistance to thermal cycling.

The cementitious reactions which occur during cement-mediated stabilization result in a significant loss of permeability and an increase in the amount of free water. The quantity of drainable free water from raffinate quickly decreases with time. Gilliam and Francis (1989) observed that the drainage of free liquid ceased 21 days after treatment of raffinate samples containing approximately 80 weight percent and 65 weight percent moisture using a cement/fly ash stabilizing agent. Dewatering to decrease the initial amount of free water in the raffinate or mixing drier soils and sediments with the raffinate may decrease the quantity and duration of drainable free water after treatment. Upon cessation of free water drainage, soluble contaminants can be mobilized only through leaching.

The RCRA metals of concern generally show increased mobility in acidic solutions. Mobilization of selenium and arsenic is also strongly influenced by the redox potential (Eh) of the solution. Cement-stabilized products typically show a high capacity to buffer acidic solutions because of the alkaline constituents, CaOH and silica. Therefore, rapid dissolution of the stabilized mass by acidic solutions is unlikely. A buffering capacity of 4×10^{-3} meq/g of pH greater than or equal to 7 would neutralize infiltrating solutions and maintain an alkaline and therefore less corrosive leachate for over a 100 year exposure period to acid rain.

Contaminant mobility is attenuated as a result of adsorption onto ferric hydroxide precipitates, precipitation as relatively insoluble hydroxide compounds, and/or encapsulation into the cementitious mineral structure. The leachability of contaminants from chemically stabilized sludge is currently being investigated. Preliminary results show that all treated media will pass

TCLP. Researchers have demonstrated that cement, fly ash, pozzolonic materials, and proprietary additives can effectively immobilize RCRA metals, PCBs, and volatile organics (Gilliam and Loflen 1985; Gilliam et al. 1986; Stinson and Sawyer 1989; and Grube 1989). The rate of soluble toxic component leaching will be diffusion controlled (Bishop 1989). Bishop (1989) suggests that the rate of contaminant leaching should be very slow, and the contaminants would disperse harmlessly into the environment. These authors indicate a level of uncertainty regarding the long-term stability of the solidified concrete mass.

Gilliam and Francis (1989) noted that, although the consolidated waste demonstrates a penetration resistance of 4,000 psi and a compressive strength exceeding 200 psi, it is still possible to excavate the solidified mass. This material could be broken into excavatable blocks by ripping with a dozer.

Mixing can be accomplished using commercial cement mixing equipment, ribbon blenders, and single- or double-shaft mixers. Equipment requirements include chemical storage hoppers, weight- or volume-based chemical feed equipment, mixing equipment, and waste handling equipment.

Pug mill-mediated chemical stabilization is a widely used and established remedial technology. A pug mill blender can be constructed by a number of companies. This technology does not require further development prior to implementation and should be readily available for full-scale use. An abundance of vendors are available to give competitive bids. An adequate supply of the necessary reagents, cement and fly ash, is also available. Operation of a pug mill blender requires minimal skill, and specialists are not required.

As stated previously, chemically stabilized waste would require secondary containment (Rich and Cherry 1987). For Weldon Spring wastes, burial of the chemically stabilized media would be required to attenuate radiation. However, the chemically stabilized material must pass the TCLP test before land disposal of restricted compounds would be permitted. Breaching of a disposal cell containing chemically stabilized material would result in a reduced and slow release of contaminants; whereas, breaching of a disposal cell containing untreated waste could result in a more immediate release of contaminants.

The EPA has accepted the use of solidification/stabilization as an implementable remedial action at several Superfund sites. The Records of Decision for 62 NPL sites recommend chemical stabilization as the remedial technique (Chemical Engineering Progress 1991). On-line

sampling controls and the ability to make immediate modifications to the cement mixture would ensure that this technology would meet process efficiency and performance specifications.

Preliminary estimates indicate that the chemical stabilization plant would require approximately 413 horsepower of electricity-driven motors, averaging 250 kilowatts. Adequate electrical power is available at the site. Preliminary construction and operating costs for a pug mill-mediated, cement-based chemical solidification/stabilization process facility are estimated to be approximately $19.8 million ($41.71/yd^3) (MKES 1992d). This estimate is based on a 4.5-year operating period and processing 474,700 cubic yards of sludge and soil. As stated, these costs are preliminary in nature. Other estimates have ranged to $6.3 million ($28.63/yd^3) for treating 220,000 cubic yards of sludge (JEG 1992g). More definitive costs are being prepared in the Phase II EAA to support the site FS.

3.5.2 Thermoencapsulation

Chemical stabilization may also involve a thermoplastic encapsulation process that can be applied to a dewatered waste. This process involves sealing wastes in a matrix such as asphalt bitumen, paraffin, or polyethylene. The waste is dried, heated, and dispensed through a heated plastic matrix. The mixture is then cooled to form a rigid but deformable solid. Relative to cement-based solidification, the increase in volume is significantly less and the rate of leaching significantly lower. Thermoplastics are little affected by either water or microbial attack. Bitumen solidification is the most widely used thermoencapsulation technique.

Thermoplastic solidification using an asphaltic binder is most suitable for heavy metal or electroplating wastes. Toluene, which is a by-product of nitroaromatic degradation, is known to diffuse quite rapidly through asphalt. Consequently, this encapsulating media would not be effective for treating the nitroaromatic-contaminated soils at the Weldon Spring site.

The plasticity of the thermoplastic mixture generally requires containers for transportation and disposal. Moreover, swelling and cracking of the encapsulating surface can be caused by rehydration of dehydrated salts, such as anhydrite ($CaSO_4$) which could form in the dewatered raffinate sludge. High equipment and energy costs are other disadvantages of the thermoplastic solidification process. Specialty equipment and trained operators are also required.

The EPA (1986) reports that asphaltic-based thermoencapsulation methods are typically more expensive than conventional chemical solidification/stabilization treatment systems. Therefore, the cost of this technology would likely exceed the cost of cement-based stabilization.

3.5.3 In Situ Chemical Stabilization

In situ chemical stabilization is used to solidify material and reduce the mobility of waste constituents by the addition of chemical reagents in place. In situ chemical solidification/stabilization requires mixing an additive directly into the material using conventional draglines or backhoes. Mixing can also be accomplished by using equipment specifically designed for this process and which allow injection of solidification/stabilization material concurrent with mixing.

An alternative method for in situ stabilization is the shallow soil mixing (SSM) process by which contaminated waste is treated in place by concurrently mixing soil and adding fly ash/cement to solidify the mixture. The technology was developed and is being implemented by Geo-Con, Inc. Geo-Con's shallow soil mixer is a crane-mounted mixing system used in soft soil and sludges which are up to 30 feet deep. Soils or sludges being mixed can vary in moisture content from dry soil to fluid sludge, without adversely affecting the process. Dry treatment chemicals are transferred pneumatically, and fluid chemicals are pumped. Geo-Con representatives have indicated that using fluid chemicals is easier and reduces dust emissions. Fly ash and cement can still be used, but water must be added to the mixture. A bottom-opened cylinder, which contains the mixing blades, is lowered into the wastes, and the blades rotate while chemicals are introduced. The blades mix through the total depth of waste in an up-and-down motion. Negative pressure is maintained on the head space of the cylinder to pull any vapors or dust into a vapor treatment system. After the mixing of the waste is complete, the blades are retracted inside the bottom-opened cylinder, and the cylinder is removed. The cylinder is then placed adjacent to and overlapping the previously-mixed waste, and the process is repeated until all of the waste has been treated. The vapor treatment system is comprised of a dust collection system followed by an in-line activated carbon treatment system to capture any organic vapors. An induced draft fan is located at the carbon treatment system, and filtered air is exhausted to the atmosphere after being monitored by an in-line organic vapor detector. By working along the perimeter of the raffinate pits, the cement/fly ash reagent could possibly be mixed directly into the raffinate sludge using backhoes and draglines. Once the raffinate sludge-cement-fly ash mixture sets, the backhoe or dragline could advance onto the stabilized zone and reach more untreated raffinate. Water would be removed from the ponds prior to stabilization treatment.

The in situ chemical stabilization process cannot assure uniform solidification and does not result in the destruction of the contaminants. Without complete solidification, the contaminants may become readily mobile. Moreover, a stabilized mass will deteriorate, both

physically and chemically, over time. In situ chemically stabilized material is not protected by secondary containment, and release of contaminants from a stabilized mass cannot be controlled. In addition, contaminants would be susceptible to leaching from the chemically stabilized mass over time. Monitoring the leach rates and effectiveness of stabilization requires drilling through the hard, chemically stabilized material. Existing groundwater contamination would make groundwater monitoring and testing results difficult to interpret.

In situ chemical stabilization of raffinate sludge using Geo-Con equipment may be difficult. Studies have shown that the raffinate sludge has a limited compressive strength which is too low to support the Geo-Con track-mounted auger equipment. Therefore, the auger would have to remain on previously stabilized areas, always advancing into the untreated sludge. Contaminated sediment and soil could be excavated and mixed with the raffinate sludge in an attempt to create a media which would require less cementitious material and possess increased bearing strength.

The raffinate sludge could be slurry dredged, dewatered, and delivered to a process area. Once there, it could be mixed with excavated soil and sediment and in situ chemical stabilization could be initiated. The dewatered sludge may require the readdition of water to allow complete hydration of cementitious products during chemical solidification/stabilization. Without dewatering, the raffinate sludge will be more difficult to mix with other soils and sediments.

The level of quality control that can be maintained during backhoe mixing is questionable. Significantly different settling rates, duration of drainable water, and unconfined compressive strengths have been shown with each different additive ratio and raffinate sludge water content examined by Gilliam and Francis (1989). Although methods of blending reagent and raffinate sludge could probably be developed using backhoes or draglines, it is possible that a wide range of reagent-to-raffinate sludge blends would result.

The relatively thin, widespread contaminated soils at the Weldon Spring site are not amenable to in situ chemical stabilization. This method is designed to stabilize material up to 30 feet deep and is inefficient at 1-foot to 2-foot depths. However, it may be that the shallow soil mixing process described earlier would allow in situ stabilization to be used. As with the raffinate sludge, it may be possible to use backhoes or draglines for mixing the soil and sediment, but maintaining quality control on reagent and water addition would be difficult. In addition, multiple equipment mobilization and demobilization set-ups would likely be required.

Shallow soil mixing is a technology presently in use, and further development of this technology would not be necessary for use at the Weldon Spring site. Geo-Con is the only vendor providing the shallow soil mixing service at the commercial level.

The in situ chemical stabilization technique is the fastest and most economical of the bulk stabilization methods to implement because wastes typically are handled only once or not at all if left in place. A preliminary cost estimate of $40,493,600 ($98 yd^3) was developed for implementing the in situ chemical stabilization process for the 413,200 cubic yards of material at the raffinate pits, Ash Pond, Frog Pond, South Dump, and the North Dump. This cost estimate is based upon a reagent adjustment, escalation to 1990 dollars, and modification of the unit cost presented in the *Handbook of Remedial Action at Waste Disposal Sites (Revised)* (EPA 1985). Material from the North Dump would be excavated and transported to the South Dump where it would be mixed and treated in situ with the South Dump soils.

3.6 Thermal Treatment

Thermal treatment processes involve the application of heat to induce sintering and/or melting to reduce the volume, toxicity, or mobility of contaminants within the treated media. Viable thermal treatment processes identified include metal melting, joule-heated ceramic melting, fossil fuel-heated ceramic melting, plasma arc torch, in situ vitrification, slagging incineration, and rotary kiln and fluidized bed incineration. These treatment processes were evaluated for effectiveness in decontaminating metals, vitrifying soils and sludges, and incineration of other waste media.

Additional thermal treatment technologies are either available or in development. However, review of the capabilities of these processes, as described below, indicated that the those technologies are primarily designed to remediate organically contaminated wastes.

The **high-temperature fluid wall** process quickly reduces organic wastes to their elemental state in a very high temperature process (about 4,000°F). The process is carried out in a patented reactor which consists of a tubular core of refractory material capable of emitting radiant energy supplied by large electrodes in the jacket of the vessel. However, this system is no longer commercially available. J.M. Huber Corporation stopped manufacturing this unit several years ago.

The **molten salt incinerator** is used for the destruction of organic hazardous wastes, particularly chlorinated hydrocarbons (including PCBs) and chlorinated solvents. Organic wastes

undergo catalytic destruction upon contacting molten salt maintained at a temperature between 760°C and 1,040°C. The Weldon Spring site soils, sediment, and raffinate sludges would not be melted at this temperature, and consequently, contaminant leaching would not be decreased. In addition, the molten salt incinerator cannot process high-ash-content materials such as the Weldon Spring site soils, sediments, and raffinate sludge.

Flaring is a special category of combustion where wastes are exposed to an open flame, and no special features are employed to control temperatures or time of combustion. Flaring is only appropriate for gaseous waste streams consisting of relatively simple hydrocarbons, such as fuel tank emissions and landfill methane gas.

Wet air oxidation involves aqueous-phase oxidation of dissolved or suspended organic substances at relatively low temperatures (350°F to 600°F). This technology is not appropriate for treating the inorganic and radiologic contaminants present at the Weldon Spring site, because only a small fraction of the waste materials meet the chemical characteristics required to make this process feasible.

Super critical water oxidation relies on the unique physical/chemical properties of water when it is heated to its critical temperature (Rich and Cherry 1987). When maintained above 705°F and at 3,200 psi, water is an excellent solvent for organics. This technology is inappropriate, however, for the largely inorganic and radiologic contaminants present at the Weldon Spring site.

Infrared, fluid bed, and circulating fluid bed incinerators are designed for the destruction of organic contaminants. Operating temperatures are insufficient to cause melting of soil, sediment, or raffinate sludge and, consequently, will not cause a decrease in leaching of non-pyrolyzed inorganic and radiologic contaminants.

3.6.1 Induction Furnace Melting

Two studies examined induction furnace melting of metal debris and decontamination of the metal through concentration of radionuclides into an immiscible slag fraction: *Special Study Phase II Report—Metal Melting Technology, Including Size Reduction Before Melting, for Radioactively Contaminated Metal at the Weldon Spring Site* (JEG 1992h) and *Metal Melting, Development and Evaluation of Process Options, Phase I Report* (JEG 1988). The *Weldon Spring Site Remedial Action Project Decontamination Study Report* (JEG 1992d) also examined various metals melting technologies as an alternative for the treatment of all categories of steel.

The melting process purifies contaminated metal by induction melt refining and casting. Melting of metal debris in induction furnaces is derived from a commercial pyrometallurgical process for removing internal and external radioactive contaminants from steel scrap and recovering the refined metal in an ingot form for potential unrestricted release.

The decontamination melting process involves heating the scrap metal inductively and subjecting the resulting melt to thermochemical treatments designed to alter chemical equilibrium, thereby promoting partitioning and migration of the radioactive contaminants to the slag phase for removal. The slag chemistry selected for preferential removal of radioactive contaminants is achieved by small additions of fluxing agents, whereas the viscosity of the slag at operating temperature is controlled by the use of surfactants and diluents. Approximately 0.5 cubic feet of slag will be generated from each ton of steel that is melted.

A variation of the metal melting process is to melt the metal and mold it into products for limited use in the nuclear industry. The radioactive contaminants are not removed from the metals, but rather, these constituents become incorporated into the metal, thereby reducing environmental hazards. Only one company Scientific Ecology Group, Inc., (SEG) located in Oak Ridge, Tennessee, offers the services required to melt and mold the Weldon Spring scrap metal into products for limited use in the nuclear industry.

All categories of steel and some quantities of copper, lead, aluminum, and other metals could be decontaminated by induction furnace melting. Iron and aluminum are the major components of scrap metal waste at the Weldon Spring site. The *Scrap Metal Program, Phase I Decontamination Demonstration Project* (BNI 1988) showed that decontaminating iron waste is technically feasible. However, aluminum waste was found to be difficult to decontaminate if it contains a significant amount of magnesium.

Based on experiments conducted by Bechtel National, Inc. (BNI 1988) and Scientific Ecology Group, Inc. (SEG 1987), melt refining can reduce alpha and gamma radiation to acceptable levels in copper and steel, result in significant movement of nuclides from molten metal to slag for copper and steel, and reduce uranium concentration and alpha radiation through nickel refining.

Because the flux formulations are specific to waste types, some experimentation with Weldon Spring site wastes is necessary before the effectiveness of metals melting can be established. Effective removal of radionuclides from contaminated metal during melting should be demonstrated prior to application of this technology to Weldon Spring site debris.

Surface contamination guidelines for release of surficially contaminated material for unrestricted use are provided in DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. The order states that prior to being released, site materials shall be surveyed to determine whether both removable and total surface contamination (including contamination present on and under any coating) is greater than specified maximum levels. The order also states that contaminant removal complies with the requirements of the ALARA process (as low as reasonably achievable). The federal government has no regulations regarding the release of internally radioactively contaminated metal.

The use of induction melting as a refining technique for purifying radioactively contaminated steel scrap has been successfully tested at the DOE Oak Ridge Operations facility. Success of metal melting and refining for Weldon Spring debris can be established only after testing representative samples of scrap metal. Melting scrap metal and molding it into products for limited use in the nuclear industry would cost approximately $750 to $1,000 per ton of metal, including transportation. Decontamination of structural steel would cost approximately $1,438 per ton. Decontamination of all categories of steel would cost approximately $307 per ton (JEG 1992d). The wide cost range reflects the efficiencies of scale.

3.6.2 Vitrification

Vitrification is the process of melting the contaminated waste media which, upon cooling, solidifies into a glass-like product. Vitrification processes were evaluated as a treatment method for the Weldon Spring site sludge, soils, and sediment. Metallic building debris is not amenable to vitrification. Vitrification methods are being used for the treatment of high-level radioactive waste at quantities up to several hundred tons at a few select locations.

3.6.2.1 Joule-Heated Ceramic Melting. The joule-heated ceramic melting (JHCM) process involves feeding contaminated soil, sludge, or liquid with glass-forming additives into an enclosed tank and passing an alternating electric current through the contaminated materials. Heat is generated by the resistance of the material in the melt to the potential applied to it; this is known as the joule principle.

Both horizontal and vertical melter configurations exist. Horizontal melters consist of a relatively long, shallow chamber of refractory linings which can be half filled with molten glass. Electrodes are situated in arrays along the length of the melter. Horizontal melters are similar to the standard fuel-fired melters traditionally used in the glass-making industry. These melters allow a longer residence time for off-gases produced in the vitrification process than do

vertical melters, which may ensure more complete combustion of any organic compounds present.

Vertical melters are a newer design; they have a smaller volume capacity but require a shorter melt residence time. In the vertical configuration, feed is generally added on top of the molten material and is withdrawn from the bottom of the melter. The feed material can be placed uniformly on the surface of the entire melt at a rate equal to withdrawal or production (pull) rate, which helps to incorporate volatile materials into the melt. This is referred to as the cold-cap or batch blanket method. Variations in the cold-cap method include the cold top (complete cover) and semi-cold top (partial cover) and involve the type of feed charging system used for the melter. A true cold top is achieved only when the feed material is evenly fed to the entire surface of the melt. A semi-cold top occurs when a fixed position batch charger is used to feed the melter. The cold top method is preferable for the vitrification of waste materials containing volatile compounds and for overall melter process control (Steitz and Hibscher 1980).

Koegler et al. (1988, 1989) examined the use of JHCM technology to vitrify Weldon Spring raffinate sludge, soil, and sediment. The studies determined that JHCM is capable of producing a leach-resistant product with desirable structural properties (such as an unconfined compressive strength >50 psi). Glass-forming additives are required to adjust the electrical conductivity and to lower melting temperatures. Quantities of required additives might be significantly reduced if higher processing temperatures are used. In general, higher melting temperatures produce a glass, which is more resistant to leaching. The lowest leaching rates attained for glasses are associated with a narrow range of compositions (Marples 1988).

Koegler et al. (1988, 1989) also determined that to optimize melting behavior a 25% by weight addition of 90% by weight Na_2O and 10% by weight B_2O_3 to the contaminated media was required. These studies demonstrated that raffinate sludge only generated an excessively devitrified inferior glass product. The addition of an equal dry weight portion of soil to raffinate sludge was suggested by Koegler et al. (1988, 1989) to generate a leach-resistant glass product. Modification of the additive mixture may be required due to different raffinate sludge chemical compositions. Variation in sludge chemistry is somewhat minimized by the addition of relatively uniform soil and melt modifiers.

Soil is generally not a very conductive material, but its conductivity increases with temperature allowing conductance through the molten soil instead of through the refractory lining of the melter. For this reason, a molten glass starter must exist in the melter prior to the

addition of waste materials. Temperatures of up to 1,200°C can be obtained in the melt (Buelt 1989). Higher temperatures may be obtained through the use of specially designed melters. Optimum process conditions occur when the melting temperature is between 1,070°C and 1,250°C, the mixture has a viscosity of 100 poise (Marples 1988), and the electrical conductivity is between 0.18 and 0.5 ohm-cm^{-1} (Koegler et al. 1989).

A melt composed of only miscible phases is desirable. Elevated sulfur content in the feed may cause an immiscible sulfur phase to develop and separate from the silicate melt, particularly upon addition of sodium as a melt-modifying additive. Tobie and Weisenburger (1990) demonstrated that the formation of even a thin immiscible metallic layer causes severe electrode corrosion and failure. The severe electrode corrosion is induced by overheating due to excess local current density. Excluding all metal debris from the JHCM is critical to efficient operation. Data developed by Tobie and Weisenburger (1990) and Buelt and Farnsworth (1990) also suggest that the development of an immiscible molten metal phase can readily occur, and the immiscible phase poses a serious problem to conventional electrical melting technologies. Development of an immiscible metal melt fatally flaws the implementation of conventional electrically heated melters.

Feed materials for the JHCM require sizing. Moisture content of the feed can range from dry to a wet slurry. Because the cost of removing water from the melter feed material is usually high, a low moisture content feed is preferred. However, a feed which is too dry can create dust emissions and possibly cause bridging problems in the melter feed system. The final product of the process is discharged from the melter while still in the molten state; this product can be poured into storage containers, shaped, quenched in water to produce a frit, or poured as a slag. Joule-heated ceramic melting allows direct visual observation of the process and real-time modifications to melt chemistry and process temperatures. Therefore, a structurally sound glass product is possible. The JHCM process typically achieves a 50% volume reduction.

Some volatilization of mercury, arsenic, and cadmium is expected. Vapor phases of these elements are captured by the off-gas treatment system. Radon emissions from the joule-heated ceramic melter (JHCM) product does not represent an air emission hazard. Inorganic and radionuclide contaminants, derived from melted metal or concrete, are partitioned into the silica melt and encapsulated upon cooling. Material may be charged to the melter, with off-gas products captured by the off-gas treatment system and ash incorporated into the melt.

If the vitrified waste material is to be disposed on-site, only a relatively cool glass product can be placed in the cell; molten or near-molten glass is more difficult to transport and

place within the disposal cell. Consequently, the vitrified product will need to be containerized, cooled, or fritted in water prior to disposal. Fritted glass is expected to have a particle size of ⅛ to ¼ inch.

JHCM technology has had limited application for large-scale waste remediation. However, bench-scale testing is being conducted at the Vitreous State Laboratory, located at Catholic University in Washington, D.C. These bench-scale tests will be used to develop a process parameter database and a basis for design of a pilot-scale facility.

Joule-heated ceramic melting is currently applied as a vitrification method for liquid high-level nuclear wastes worldwide (Buelt 1989). In the United States, this process is being used for the DOE's Hanford Reservation near Richland, Washington, and at the West Valley Site in New York. Both of these JHCM melters are slurry-fed systems.

Approximately 0.5 to 2 acres are required for the process facility. Joule-heated ceramic melters and ancillary upstream processing/feeding and downstream handling/molding equipment are available from a number of vendors. JHCM units are available which process 100 tons per day. Larger units have not yet been developed. Penberthy Electromelt representatives indicated they could mobilize needed specialists to operate the system from among their ceramic- and glass-making industry contacts.

Based on data provided by Koegler et al. (1989), the capital and operating costs for a JHCM to process 334,100 cubic yards (386,000 tons) of sludge, soil, and sediment would be approximately $59,006,000 ($152.86/ton).

3.6.2.2 Fossil Fuel-Heated Ceramic Melting. The fossil fuel-heated ceramic melting (FFHCM) process is an adaptation of commercial glass-making technology. Contaminated soil, sludge, or liquid is fed into an enclosed melter and melted by heating with a fossil fuel-generated flame. The addition of an oxidant gas to the fossil fuel is required to generate a flame. Usually the oxidant gas is air, but the air may be supplemented with oxygen to increase the temperature of the flame. Temperatures of up to 1,900°C can be obtained in the melt; organic and nitroaromatic compounds are readily destroyed at these temperatures.

Vortec Corporation has a 20-ton-per-day fossil fuel-fired plant in operation. This plant can be used as a small-scale production facility or as a pilot plant. The construction of larger-capacity plants is possible. Vortec employs patented and patent-pending processes which are refinements of the fuel-fired glass-making processes.

One of the Vortec refinements to the fuel-fired melters is a more efficient heat exchanger for the recovery of heat energy from the off-gas stream. This development significantly reduces the fuel consumption per ton of glass produced. The melter is completely enclosed, unlike conventional glass-making furnaces. Another refinement of the Vortec melter is the use of a proprietary cyclone melting system. Waste material is injected into a counter-rotating vortex combuster where incineration and melting occur. This allows for a higher retention of volatile inorganics and lower particulate emissions.

The FFHCM process yields a glass product similar to that produced by JHCM. A significant reduction in volume is achieved (68%) with respect to the JHCM treatment volume reduction (50%), because the JHCM process required additives to reduce melting temperatures. Melt-modifying reagents are not required because of the high operating temperatures (>1,600°C) that can be achieved with the FFHCM process. However, melt modifiers can be added to decrease the melting temperature and save on fuel costs.

Feed requirements for the FFHCM vary. Typically, FFHCM systems are not very sensitive to variations in feed. However, depending on the feedstock, additives may enhance the vitrification processes. Waste glass, as an additive, may be used instead of the more expensive, high-purity additives typically used for glass making. The addition of glass may be necessary to vitrify the raffinate sludge. Feed material is fed to the melter by a screw conveyor, pneumatic transport (dry), or by slurry. Fossil fuel-heated ceramic melting allows direct visual observation of the process and real-time modifications to melt chemistry and process temperatures, ensuring a structurally sound glass product that will not devitrify.

Air emissions could result from the volatilization of waste constituents and the combustion of the fossil fuels, and an off-gas collection and treatment system will be required. Combustion of the fossil fuels may cause a higher level of NOx and SOx in the flue gas than could be normally attributed to the waste. Emissions from the melter could be reduced through the use of plasma arc torch boosting or joule heating electrode boosting. The latter is the most common method of emissions reduction for fossil fuel-heated melters in the glass industry.

If the vitrified waste material is to be disposed of on-site, only a relatively cool glass product can be placed in the cell; molten or near-molten glass will be more difficult to transport and place within the cell. Consequently, the vitrified product will need to be containerized, cooled, or fritted in water prior to disposal.

A fossil fuel-heated ceramic melter requires approximately 0.5 acre for facility construction. Vendors can construct turnkey units and provide trained operators and treatment process management. However, the advanced fossil fuel-heated ceramic melting process with counter-rotating vortex has limited availability, and only one vendor, Vortec Corporation, was identified. Other direct-fired systems are more widely available. In addition, the Vortec system is developed only to the pilot scale at 20 tons per day. It has not seen widespread usage and operators may require specialized training. Based on data provided by Vortec Corporation (1990), the capital and operating cost of processing 334,100 cubic yards (386,000 tons) of soils, sediment, and sludges using the FFHCM process would be approximately $30,362,000 ($90.88/yd^3) (including labor costs).

3.6.2.3 Plasma Arc Torch Melting. The plasma arc torch process is a stabilization/destruction process which vitrifies waste materials using electrical energy. As with other vitrification technologies, the final product is a leach-resistant material with a significantly reduced volume. The process is similar to other electrically powered vitrification methods. However, the energy source used to vitrify the materials is an electrically generated plasma which can create extremely high temperatures, significantly reducing the requirement for additives.

A plasma is created when gases are ionized by passing through an electric field which strips electrons from the gas molecules. The aggregate gas remains electrically neutral because it is made up of equal numbers of positively and negatively charged particles. The charged particles contain a high energy level. When the ionized species in the plasma recombine with the stripped electrons, significant amounts of energy are released (Staley 1990). Temperatures ranging from 12,000°C to 20,000°C can be created in the arc path (Lee 1989). Air is generally the gas used to generate the plasma, but a variety of other gases can also be used. Air, argon, oxygen, carbon monoxide, hydrogen, methane, nitrogen, helium, and various mixtures of these gases have been used to fuel plasma arc torches.

Many configurations of plasma arc torches are available for use in industrial applications. The commercially available torches are one of two configuration types: the transferred type or the non-transferred type. Heat energy is delivered to the work piece from the transferred torch by plasma-heated gas and is generated in the work piece itself by the resistance of the arc attachment point (joule-heating). The heat energy from the non-transferred arc torch is delivered to the work piece by the plasma-heated gas alone.

Two process technologies for plasma arc torches also exist: direct injection and indirect heating. Liquid and gaseous wastes can be directly injected into the plasma plume where the plasma energy breaks apart molecules of the compounds in the feed into their constituent atoms. Indirect heating uses the plasma to create a bath of molten material into which solid or liquid waste is fed. The waste is then heated by radiative heat transfer or conductive heating and melted. Non-volatile components are incorporated into the melt. Organic components are destroyed and the breakdown products of the volatile organic components remain in the hot fluid along with the destruction products from the organics.

Melt temperatures can reach 3,000°C. The higher melt temperatures achieved by the plasma arc torch could cause more loss of volatile metals and metalloids. High temperatures also cause more corrosion of the melter construction materials and require more expensive complex alloys for the construction of the plasma arc system. The high temperatures at the electrodes require high-pressure water for cooling.

Plasma arc technology advantages over more conventional vitrification technologies include faster heat transfer, a high operational temperature, and relatively easy incorporation of metallic debris into the melt. Metal in the melt can actually improve the effectiveness of the process by providing higher heat retention. Operation at higher temperatures generally negates the need for feed additives to process the material, with the exception of the raffinate sludge. Because the raffinate sludge lacks sufficient glass-forming elements, addition of soil or sediment will be required.

The electrodes are the only directly consumable part of the torch and can be made from a variety of materials. Copper alloys, steel, tungsten, and graphite are typical materials used. Torches with an electrode life in excess of 1,000 hours in oxidizing environments are available. The Weldon Spring materials would probably also be vitrified in an oxidizing environment; however, the various process parameters have not yet been determined.

A significant reduction in volume is achieved compared to that achieved using JHCM technology. Melt modifiers can be added to decrease the melting temperature and save on electricity costs. Plasma arc torch melting allows direct visual observation of the process and real-time modifications to melt chemistry and process temperatures. Therefore, a strong, leach-resistant glass product is possible.

As with the JHCM process, the plasma arc torch process is an adaptation from the commercial metal melting industry, but is only in the developmental phase for hazardous waste

application. Based on vendor discussions and pilot-scale testing, it appears this method can be applied to large-scale waste disposal systems and could be used to treat Weldon Spring wastes.

Plasma arc technology is currently used commercially in steel works for ladle heating, production of ferro-alloys, reclamation of platinum from catalytic converters, melting of scrap iron in foundries, and in the treatment of hazardous wastes at Love Canal. Other applications are in varying stages in the steel, ceramics, cement, and chemical industries.

Plasma arc equipment is widely available from numerous vendors. Vendors can construct turnkey units and can also provide trained operators and treatment process management. Complete systems for handling large volumes of mixed and radioactive wastes are in the development stages. Experienced operators are few, but may be available.

Based on data provided by Plasma Energy Corporation (1990), a preliminary capital and operating cost for processing 334,100 cubic yards (386,000 tons) of soil, sediment, and sludge using the plasma arc torch melting process would be approximately $57,994,000.

3.6.2.4 In Situ Vitrification. In situ vitrification (ISV) is the process of electrically melting inorganic materials to thermochemically treat free or contained contaminants present within the treatment volume. Most ISV applications involve melting of natural soils; however, other naturally occurring materials or process residuals, such as sludge, tailings, and sediments, may also be treated. Using soil, the process simultaneously destroys and removes organic contaminants while chemically incorporating inorganic contaminants into a chemically inert, stable glass product.

Four electrodes are placed in the material to be treated to the desired treatment depth. Because soil typically is not sufficiently electrically conductive to allow initiation of the ISV process, a conductive mixture of graphite and glass frit is placed on the surface of the material between the electrodes to serve as a starter path. As electric potential is applied between the electrodes, current flows through the starter path, heating it and the adjacent soil to temperatures above 1,600°C. Upon melting, the electrical conductivity of the soil increases, and the molten mass becomes the primary conductor and heat transfer medium, allowing the process to continue.

Continued application of electric energy causes the molten volume to grow downward and outward, eventually encompassing the desired treatment volume. Individual settings (i.e., the melt involved with a single placement of electrodes) may grow to encompass a total melt

mass of up to 1,000 tons and a maximum width of about 28 feet. Single setting depths as great as 30 feet are considered possible with the existing large-scale ISV equipment. Several methods, based on geophysical, optical, and thermal principles, may be used to determine the physical extent of melting for control purposes.

The molten soil mass is usually in the 1,600°C to 2,000°C temperature range; specific temperatures are dependent on the overall chemistry of the melt. A vigorous, chemically reducing environment is present within the melt. Because the soil has low thermal conductivity, a very steep thermal gradient (i.e., 150°C to 250°C per inch) precedes the advancing melt surfaces. In most cases, the 100°C isotherm is less than 1 foot away from the molten mass; however, the isotherm moves an additional 5 to 7 feet away before the molten mass cools.

The large-scale ISV systems melt soil at a rate of 4 to 6 tons per hour. Accordingly, the rate of melt advance is in the range of 1 to 2 inches per hour. As the thermal gradient advances on solid or liquid organic materials, these materials first vaporize and then pyrolyze into elemental components. Pyrolysis is decomposition in the absence of oxygen. Organic pyrolysis products are typically gaseous; these gases move slowly (because of the high viscosity of the molten material) through the melt toward the upper melt surface. Some of these gases may dissolve into the molten mass; remaining gases move to the surface where volatiles combust in the presence of air. Pyrolysis and combustion products are collected in an off-gas collection hood and are subsequently treated to ensure process air emissions meet regulatory requirements. Because of the high temperature of the melt, virtually none of the original organic contaminants remain in the vitrified product.

As the melt grows in size, its electrical resistance decreases, making it necessary to periodically adjust the ratio between the voltage and the current to maintain operation at the desired power level. When the power is shut off, the extent of melting is limited to the point achieved at that moment, and the melt begins to cool. Gaseous emissions from the melt cease within a few hours, and the off-gas hood may be removed. The subsidence volume may then be filled to the desired depth with clean backfill. The melt should not be force-cooled. Slow cooling produces a vitreous (amorphous) and micro-crystalline structure which provides excellent structural properties. The vitrified product is monolithic in nature. Assuming contiguous settings at a site, a single large monolith could be produced.

Power is provided by a utility distribution system or by on-site generators and transformed to the voltages required for processing. The voltage-adjusted power is supplied to the array of electrodes placed in the soil. The maximum spacing between electrodes is about

18 feet, which allows formation of a maximum melt width of about 28 feet. The processing area is covered by an octagonal-shaped collection hood through which off-gases, combustion products, and air are drawn into the treatment system. The off-gas treatment system includes the following unit processes: quenching, pH controlled scrubbing, mist elimination, temperature and dew point control, particulate filtration, and activated carbon adsorption. Off-gas treatment wastes are continually recycled to subsequent vitrification processes, necessitating disposal of only the waste generated during the last ISV setting. A self-contained glycol cooling system is used to cool the quenching/scrubbing solution, reducing the need for water. A backup off-gas treatment system and generator are included in the event of a power failure.

The ISV process incorporates contaminants into the melt, thermally decomposes organic materials, and vaporizes some elements. Total destruction/removal efficiencies (DRE) for typical organic contaminants exceed 99.99%. Conversely, the percent retention of mercury, arsenic, and cadmium is 97%, 99.98%, and 99.96%, respectively (Hansen and FitzPatrick 1989). During ISV, the precursor to radon-222, radium-226, is immobilized by chemical incorporation into the ISV residual product. When the radium-226 decays to radon-222 within the monolith (less than four days), the radon gas is contained within the vitrified product until it decays back to a solid form, polonium-218. This capability is a significant advantage of the ISV process for remediating radon-producing wastes.

The behavior of certain inorganic materials, upon exposure to the advancing thermal gradient, is similar to that of the organics. Inorganic compounds may thermally decompose or otherwise enter into reactions with the melt. Nitrates and sulfates, for example, yield gaseous decomposition products, such as N_2, SO_2, and O_2, which may dissolve into the melt, or may evolve through it and be collected in the off-gas collection hood. The elements of the inorganic compounds originally present are incorporated into the vitrified residual. As with organics, it is possible for some inorganics to evolve from the melt in the vapor state; the percentage evolved is usually quite small, often less than 0.1%. The degree of retention of inorganic vapors within the melt is a function of elemental vapor pressure, solubility in the glass, and depth of melt. For hazardous inorganics, the ISV residual product will meet EP TOX and TCLP leach testing criteria.

The void space present in particulate materials (e.g., 20% to 40% for typical soils) is eliminated during ISV processing, thereby reducing the volume. Also since some of the materials (humus, organic contaminants, and limestone, for example) present in the soil are removed as gases and vapors during processing, further volume reduction occurs. Calculations

demonstrate a 68% decrease in volume of contaminated material. The volume reduction creates a subsidence volume above the melt and an angle of repose in the soil adjacent to the melt.

A *Vitrification Technologies for Weldon Spring Raffinate Sludges and Contaminated Soils Phase II Report: Screening of Alternatives* (Koegler et al., 1989), determined that the vitrified Weldon Spring product had a significantly lower normalized elemental release than high-level nuclear waste borosilicate glass through 7-day and 28-day MCC-1 and MCC-3 leach test procedures. Radon emanation was 0.1% of the maximum theoretical radon emission level from the glass. Air emissions from the vitrified product can be considered safe (Koegler et al., 1989).

The ISV process can accommodate significant quantities of inclusions in the treatment volume. Inclusions are defined as highly concentrated contaminant layers, void volumes, containers, metal scrap, general refuse, demolition debris, rock, or other non-homogeneous materials or conditions within the waste volume. Most inclusions, with the exception of very high melting point ceramics, are treated in the same manner as the hazardous organic and inorganic contaminants during ISV.

Buelt and Farnsworth (1990) determined that the ISV processing of metal-bearing soils, such as those present at the Weldon Spring site, requires a self-feeding electrode technique. Molten metal pooling on the bottom of the melt chamber was found to cause shorting between electrodes as well as severe electrode corrosion. The new electrode feeding system has only been successful in bench-scale tests.

Monovalent alkali cations, such as sodium and potassium, are necessary to provide the degree of electrical conductivity needed for the process to operate efficiently. This requirement can be satisfied by adding fluxing materials to the base inorganic material. Most naturally occurring soils, sediments, tailings, and process sludges, such as those present at the Weldon Spring site, meet these conditions.

Differences in soil types (e.g., clay versus sand) relate primarily to particle size and shape differences and mineral types resulting from weathering of rocks. These differences affect important soils properties such as permeability and density, but do not generally affect overall chemical composition and ability to be processed by ISV. These differences can, however, affect melt temperature and electrical conductivity.

The ISV processing rate is dependent upon the water content of the processed material. A high water content slows ISV processing. Therefore, a higher than expected water content of the mixed sludge/soil could drastically slow the ISV processing rate.

Several difficulties may arise in attempting to apply ISV technology to the Weldon Spring site. The economic limit on minimum thickness to vitrify is 5 to 7 feet. The areas to be remediated at the Weldon Spring site include relatively thin, widely distributed 1-foot- to 2-foot-thick zones of surface soil contamination. Moreover, the raffinate sludge will not produce a high-quality glass product (Koegler et al., 1989). Inadequate silica content causes the melted raffinate sludge to excessively devitrify upon cooling, yielding an inferior product. Mixing of soil with the sludge would solve the above concerns, but not dewatering the sludge prior to ISV processing may overtax the off-gas treatment system, may slow melting rates, and may cause excessive consumption of electricity.

The process and final product of ISV treatment cannot be directly viewed. During processing, thermocouples can measure the temperature regime. However, even during bench-scale testing of the ISV technology, the thermocouples continually failed. After processing, subsurface sonic measurements could be performed to identify non-vitrified zones. However, as described for in situ chemical stabilization, site monitoring after in situ vitrification would be difficult. Monitoring the leach rates and effectiveness of vitrification would require drilling through the hard, vitrified waste and would be especially difficult to verify at the deepest extent of the melt. Remediation of deficient zones would also be very difficult. The absence of secondary containment protection for the ISV-treated media could potentially allow contaminants escaping from poorly vitrified material to be released into the environment.

The ISV process has been tested over 70 times on 18 different soil types (Geosafe 1990) collected from government and private sites throughout the United States and Canada. In addition, ISV has been selected for cleanups at 7 Superfund sites and 2 military bases. However, Geosafe, Inc., is the only firm presently providing this technology. Geosafe holds worldwide exclusive rights to the use of ISV technology in the field of hazardous waste remediation. Geosafe can supply their technology as a contractor or as a subcontractor. No competitive bids are possible, except for related site preparation and contractor support work. The commercial experience base is not sufficiently developed to warrant implementation without a thorough evaluation of all aspects of ISV applicability. Importantly, the DOE recently suspended the use of the ISV process indefinitely after a fire started during large-scale testing of the process at the Hanford Reservation near Richland, Washington.

The cost of implementing ISV is impacted significantly by the numerous applications that would be required at the Weldon Spring site. For example, based on a maximum electrode spacing of 18 feet, allowing formation of a 28-foot-maximum melt width, 1,400 applications would be required for treatment of the raffinate pit area alone.

The *Vitrification Cost Study* (MKES 1992e) reported two independently derived preliminary cost estimates for implementing the in situ vitrification process to treat 569,000 cubic yards (752,680 tons) of sludge, soil, and sediments. The capital and operating costs derived by Pacific Northwest Laboratory (PNL) were \$128,946,381 (\$266.62/yd^3), compared to an MKES estimate of \$112,421,506 (\$197.58/yd^3). These estimates are very similar for this level of study (within +50/-30%).

3.6.3 High-Temperature Slagging Incineration

Slagging incinerators, unlike conventional rotary kiln or fluidized bed incinerators, operate at temperatures sufficient to induce melting of the soil constituents. Upon cooling, the melt forms a glass. Organic contaminants are pyrolyzed, and residual inorganics are contained within the leach-resistant glass. Volatilized inorganic compounds are captured in the off-gas treatment system.

Weldon Spring Special Studies Phase II Report on Slagging Incineration (JEG 1992i) examined the applicability of slagging incinerators to remediate contaminated materials at the Weldon Spring site. Direct-fired units are simply rotary kiln incinerators that operate at temperatures ranging from 1,200°C to 1,400°C. These temperatures are sufficient to cause melting of soil and sediment. Raffinate sludge alone can be melted only when the appropriate melt-modifying reagents are added.

Refractory failure is a major problem for slagging incinerators due to acid and metal halide attack and abrasion (JEG 1992i). The spent refractory may be a disposal problem at the Weldon Spring site because of radionuclide and toxic metal contamination.

Melting studies indicate that a temperature of 1,400°C is required to melt soil from the Weldon Spring site (JEG 1992b). Raffinate sludge melts at 1,200°C and generates a fluid (1 poise), highly corrosive melt. Upon cooling, the melt undergoes complete devitrification, yielding a soft, granular product. The excessive devitrification is due to the low silica and high-alkaline earth content of the sludge.

Previous tests have shown that a mixture of 50% soil and 50% raffinate sludge begin to melt at 1,150°C but are not completely molten until the temperature reached 1,250°C. Consequently, a 50:50 soil/raffinate mixture probably could be melted in a slagging incinerator without the addition of melt-modifying reagents. Soil and sediment alone, however, probably would not melt without the use of melt-modifying additives. In this case, the required use of reagents significantly lowers the volume and tonnage reduction that can be achieved using other vitrification technologies which do not require additives.

Slagging incineration could achieve approximately a 50% reduction in tonnage, primarily as a result of the volatilization of water. Density is increased due to sintering. The temperature reached during slagging incineration causes decomposition of nitroaromatics. However, the temperature is not sufficient to induce melting without the use of additives. Consequently, the toxicity and mobility of inorganic and radioactive components is unchanged. Radon emanation flux rate is also unchanged. Unlike the products generated by vitrification, the incinerated product would probably require physical isolation for final disposal.

Information was obtained from two vendors: Von Roll and WTE Umwelttechnik. Their experience has involved units with throughput capacities ranging from 1 ton per day (FLK-60) to 600 tons per day (Von Roll). The FLK-60 slagging incinerator operating at the Belgian Nuclear Research Center in Mol, Belgium is not commercially available. Approximately 1 acre would be required for a slagging incinerator process facility.

Preliminary costs developed in the *Weldon Spring Special Studies Phase II Report on Slagging Incineration* (JEG 1992i) estimate a cost of approximately $105 per ton ($87.2 million) for implementing a direct-fired slagging incinerator to treat 573,360 cubic yards (832,120 tons) of soils, sludges, and debris over a 4.8-year period.

	Total Cost	Duration	Cost/Ton
Direct-fired	$87.2 million	4.8 yrs	$105
Electrically heated	$170 million	23.1 yrs	$210

3.6.4 Rotary Kiln Incineration

Two studies examined the application of rotary kiln incineration for remediating Weldon Spring site materials: *Evaluation of Rotary Kiln and Fluidized Bed Incineration Technologies for the Treatment of Contaminated Soils and Sludges* (JEG 1992j) and *Special Study Phase II*

Report—Thermal Treatment of Soils/Sediments, Sludges, and Combustible Debris at the Weldon Spring Site (JEG 1992k).

A rotary kiln incinerator is a slightly inclined, refractory-lined rotating cylinder. Solid waste and auxiliary fuels are introduced into the high end of the kiln. The rotation of the kiln agitates the solid materials and improves the burnout of and heat transfer to the solids. Combustible wastes are oxidized to gases and inert ash in the kiln where temperatures exceeding 1,000°C are achieved. Solids are removed at the lower end of the kiln; flue gases are passed through a secondary combustion chamber, or after burner, for further oxidation. Gas temperatures in the secondary combustion chamber exceed 1,200°C. The gases are finally passed through air pollution control units for particulate and acid gas removal.

Rotary kiln incineration is a proven technology for the elimination of hazardous organic waste (McCormick and Duke 1989). Radionuclide and most inorganic constituents are not destroyed by incineration. The *Special Study Phase II Report—Thermal Treatment of Soils/Sediments, Sludges, and Combustible Debris at the Weldon Spring Site* (JEG 1992k) examined the ENSCO Environmental Services rotary kiln incineration system. This system is permitted by the EPA and has successfully demonstrated the destruction and detoxification of hazardous organic wastes.

The solid product of incineration is an ash residue. The results of EP TOX and TCLP leaching tests show that ash is frequently susceptible to leaching of contaminants and usually requires further treatment or containment. Unlike slagging incinerators, conventional rotary kiln incinerators do not operate at temperatures high enough to melt the soil constituents.

Rotary kiln incineration technology has been demonstrated at full scale and is available from a number of vendors. However, the applicability of on-site incineration is affected by a number of factors such as heating value and the contents of the feedstock including moisture, halogen, sulfur, phosphorus, alkali metal, and toxic metals.

Rotary kiln incineration technology has high capital and operating costs. Preliminary capital and operating costs were estimated in the JEG report (1992k) for thermal treatment of 507,000 cubic yards (769,000 tons) of soil/sediment, 62,000 cubic yards (61,300 tons) of dried sludges, and 6,000 cubic yards (1,800 tons) of combustible debris over a 3-year period. These costs were:

Soils/sediment	$70,000,000
Dried sludges	$ 8,000,000
Combustible debris	$ 2,700,000

3.6.5 Liquid Injection Incineration

A liquid injection system consists of a single or double refractory-lined combustion chamber and a series of atomizing nozzles. Two-chamber systems are more common. The primary chamber is usually a burner where combustible liquid and gaseous wastes are introduced downstream of the burner in the secondary chamber. Single-chamber incinerators are used for systems handling only combustible wastes.

The most commonly used liquid injection incinerators are horizontally and vertically fired units. A liquid waste has to be converted into a gas before combustion. The liquid is atomized during passage through the burner nozzle while entering the combustor. This is necessary to ensure complete evaporation and oxidation. If viscosity precludes atomization, mixing and heating or other means should be applied prior to atomization to reduce waste viscosity.

The operating temperatures vary from 1,300°F to 3,000°F, with the most common temperatures being about 1,600°F. Residence times vary from less than 0.5 seconds to 2 seconds. The process usually requires 20% to 60% excess air to ensure complete combustion.

Liquid injection can be used to destroy virtually any pumpable waste or gas and the process can effectively destroy organic contaminants. These units have been used for the destruction of PCBs, solvents, still and reactor bottoms, polymer wastes, and pesticides (EPA 1985). Unlikely candidates for destruction include heavy metal wastes and other wastes high in inorganics. It does not have a need for a continuous ash removal system other than for pollution control. However, when combustible wastes are oxidized to gases, an ash residue is generated. The ash is susceptible to leaching and typically requires restrictive disposal or treatment.

Liquid injection incineration is applicable to wastes having sufficiently low viscosity values (less than 750 Saybolt Seconds Universal [164.63 centipoise]) such that the waste can be atomized in the combustion chamber (EPA 1985). However, viscosity is temperature dependent so that while liquid injection may not be applicable to a waste at ambient conditions, it may become applicable when the waste is heated. In addition, the waste particles and the concentration of suspended solids need to be sufficiently low to avoid clogging of the burner nozzle (or atomizer openings).

Liquid injection incinerators have no moving parts and require the least maintenance of all types of incinerators. The major limitations of liquid injection are its ability to incinerate only wastes which can be atomized in the burner nozzle and the burner's susceptibility to clogging. It also needs a supplemental fuel. These incinerators are also highly sensitive to waste composition and flow changes. Therefore, storage and mixing tanks are necessary to ensure a reasonable steady and homogeneous waste flow.

Because of the radioactive constituents in drummed process chemicals being held in controlled storage at the Weldon Spring site, no TSCA-permitted commercial facility will accept this material for incineration. However, the DOE recently developed a Toxic Substances Control Act (TSCA) incinerator designed to destroy uranium-contaminated PCB waste and hazardous organic materials. The TSCA incinerators will provide disposal capabilities for seven DOE facilities: Oak Ridge Gaseous Diffusion Plant, Paducah Gaseous Diffusion Plant, Y-12 Plant, Portsmouth Gaseous Diffusion Plant, Feed Materials Production Center, Oak Ridge National Laboratory, and RMI Extrusion Plant. The K-1435 incinerator, located at Oak Ridge, is designed to destroy liquid, sludge, and solid PCB contaminated materials and hazardous waste. Depending upon the results of more detailed waste characterization, the DOE's K-1435 incinerator may be able to accept and incinerate the drummed process chemical wastes.

Preliminary data indicates that incineration costs at the Oak Ridge facility could be approximately $2 to $4 per gallon, with an additional $1 per square foot for storage (R.E. Hlavacek 1990). It is anticipated that transport of 400 drums (111 yd^3) of containerized liquid chemicals to Oak Ridge and incineration in the K-1435 incinerator would cost about $995 per cubic yard.

3.7 Biological Treatment

Bioremediation is the process of reducing the concentration or volume of a contaminant using biological organisms. Bioremediation may be conducted in situ or ex situ and generally involves the use of bacteria or fungi to break down organic compounds in their metabolic processes.

3.7.1 Bioremediation of Soils

Bioremediation processes, such as surface impoundments, contact digestion, attached growth, and land application, are effective in treating organic contaminants. These processes, however, are not effective in treating inorganic contaminants such as the metals and

radionuclides, and inorganic contaminants which predominate in the site soils. Bioremediation would be applicable only to a limited volume of organically contaminated soils as a pre-treatment to chemical stabilization.

3.7.2 Composting

Composting involves the aerobic degradation of a waste material placed in small piles or windrows so that the heat produced by microbial action is contained. Vegetation, wood, and other organic debris are chipped and placed in a compost pile to facilitate biodegradation. Maintenance of an abundant supply of oxygen in the compost pile, coupled with elevated temperatures and sufficient moisture, results in a much more rapid degradation process than would otherwise occur.

Chipped vegetation and organic debris could be composted prior to disposal. This material may consist of clear and grub materials, railroad ties, wooden building materials, and other wood products. Composting can result in an 80% to 90% volume reduction over a period of one to two years, depending on the compost component. Maximum volume reduction can be achieved by adding bacteria and nutrients and by maintaining optimal temperatures within the pile. Runoff or leachate from the compost pile may contain contaminants and therefore must be contained, monitored, and treated. No permits or agency coordination is required.

The EPA (1985) states that bioremediation costs are a function of site geology and geohydrology, the extent of contamination, type and concentration of contaminants, and soil requiring treatment. Costs provided by actual site cleanups indicate that biological treatment can be far more economical as an alternative to or in conjunction with excavation and removal. Costs to compost clear and grub materials and other organic debris are expected to be minimal.

4 PRELIMINARY ASSEMBLY OF ALTERNATIVES

The assembly and evaluation of remedial action alternatives is a primary purpose of the *Feasibility Study for Remedial Action at the Chemical Plant Area of the Weldon Spring Site* (DOE 1992a). The information presented in this section supports the FS assembly and evaluation process and includes a brief description of the basic concepts of each alternative.

4.1 Description of Alternatives

A number of potentially feasible remedial action alternatives have been identified by combining the various treatment and containment options described in Section 3. A no action alternative has been included as a baseline option in accordance with CERCLA guidance.

- No Further Action
- Minimal Treatment and On-Site Disposal
- Minimal Treatment and Off-Site Disposal
- In Situ Chemical Stabilization and On-Site Disposal
- In Situ Chemical Stabilization and Off-Site Disposal
- In Situ Vitrification and On-Site Disposal
- In Situ Vitrification and Off-Site Disposal
- Chemical Stabilization and On-Site Disposal
- Chemical Stabilization and Off-Site Disposal
- Thermal Treatment and On-Site Disposal
- Thermal Treatment and Off-Site Disposal

4.1.1 No Further Action

The no further action alternative is based on the assumption that no additional intrusive actions would be undertaken at the site other than the interim response actions (IRA) identified for implementation by the U.S. Department of Energy (DOE) with the concurrence of the U.S. Environmental Protection Agency (EPA).

Under this alternative, contaminated soil, raffinate sludges, and sediment would remain in place, and surface water, groundwater, and air monitoring would be continued. Implementation of this alternative would involve operation and maintenance of the material staging area (MSA), the temporary storage area (TSA), and the site and quarry water treatment plants. The raffinate pit dikes, pond dikes, roads, the remaining buildings, as well as the fences

and other institutional controls, would also require ongoing maintenance. Long-term site security would also be required. Annual inspections would be required to ensure the facility's integrity.

Implementing the no further action alternative would cost an estimated $1,181,320 per year.

4.1.2 Minimal Treatment and On-Site or Off-Site Disposal

This alternative provides for minimal treatment of contaminated material followed by on-site or off-site disposal in an engineered cell. Minimal treatment of the soil and sediment would consist of excavating and hauling contaminated media using conventional construction equipment. The raffinate sludge would be dredged and dewatered using a cyclone system. Contaminated building materials would be size reduced to facilitate handling, compaction, and disposal.

Under the on-site disposal option, the engineered cell would be an earthen structure designed to contain the dewatered raffinate sludge, contaminated demolition rubble, debris, and soils. However, since the dewatered raffinate sludge would be difficult to place within the disposal facility, this material would require blending with soils prior to placement. A double-lined (combination) cell would be used to accommodate the radioactive and chemically hazardous waste. Under the off-site disposal option, the contaminated material would be containerized and hauled off-site by rail to Envirocare's Clive, Utah, facility or the DOE's Hanford facility in Richland, Washington, for disposal.

Minimal treatment and on-site disposal would cost an estimated $75,729,849. Off-site disposal at Clive, Utah, and Richland, Washington, would cost $404,362,626 and $1,745,769,252, respectively.

4.1.3 In Situ Chemical Stabilization and On-Site or Off-Site Disposal

This alternative involves the in situ solidification/stabilization of the raffinate pits, Frog Pond, North Dump, South Dump, and Ash Pond. Material from the North Dump would be relocated to the Ash Pond for treatment to minimize the surface area requiring capping and to provide more area for construction materials staging. The 3,600 cubic yards of water treatment plant residues would be mixed with the raffinate sludge prior to in situ stabilization. A cap and cover system would be installed at each of the in situ treated areas (48.7 acres) after the

stabilization process has been implemented. Contaminated building debris would be size reduced to facilitate handling, compaction, and disposal.

Under the on-site disposal option, the soils and sediments from the remaining source areas which cannot be effectively stabilized in place would be removed and disposed of in an on-site engineered disposal cell. Because the materials requiring on-site disposal would consist of both untreated radioactively and chemically contaminated media, the disposal cell would include a double liner system, double leachate collection and removal system; a leachate detection, collection, and removal system; and a cover system that includes a radon attenuation barrier. Building dismantlement/demolition debris would be size reduced to facilitate handling, compaction, and disposal.

Under the off-site disposal option, the remaining radioactively and chemically contaminated materials would be containerized and hauled off site by rail to either Clive, Utah, or Richland, Washington, for disposal. In situ stabilization and on-site disposal would cost an estimated $85,867,716 if the raffinate pit soil is not treated in situ and $100,910,712 if the raffinate soil is treated. In situ treatment and off-site disposal at Clive, Utah, would cost $293,557,476 if the raffinate pit soil is not treated in situ and $308,600,476 if the raffinate pit soil is treated in place. Disposal at Hanford would cost $1,155,363,885 if the raffinate soil is not treated in situ and $1,170,406,885 if the soil from the pits is treated in situ.

4.1.4 In Situ Vitrification and On-Site or Off-Site Disposal

This remedial action alternative involves the in situ vitrification (ISV) of the raffinate pits, Frog Pond, North Dump, South Dump, and Ash Pond. As with the in situ chemical stabilization alternative, material from the North Dump would be relocated to Ash Pond for treatment, and the 3,600 cubic yards of water treatment plant residues would be treated with the raffinate pit sludges. A cap and cover system would be installed over the treated areas (48.7 acres). Effective in situ treatment of the raffinate pit sludge would require mixing the sludge with 60,000 tons of excavated soil, which further reduces the amount of material requiring disposal. Contaminated rubble and debris would be size reduced to facilitate handling, compaction, and disposal.

Under the on-site disposal option, the untreated materials would be removed and disposed of in an engineered cell and would cost an estimated $132,348,374 if the raffinate pit soil is not treated in situ and $167,792,634 if the raffinate pit soil is treated in situ.

Under the off-site disposal option, these materials would be containerized and hauled off-site by rail to either Clive, Utah, or Richland, Washington, for disposal. Treatment and disposal at Clive would cost $318,758,086 if the raffinate pit soil is not vitrified in place and $354,202,346 if these soils are treated in place. Treatment and disposal at the DOE's Hanford facility would cost $1,091,239,495 if the raffinate pit soils is not treated in place and $1,126,683,755 if these soils are treated in situ.

4.1.5 Removal, Chemical Stabilization and On-Site or Off-Site Disposal

Under this alternative, the raffinate pit sludge and clay bottom, the water treatment plant residues, and contaminated quarry soils would be chemically solidified/stabilized in a pug mill-mediated process facility. Contaminated debris would be size reduced to facilitate handling, compaction, and disposal.

The on-site disposal option involves the disposal of the stabilized product and the remaining untreated materials in an on-site disposal facility. This facility would be a double-lined disposal cell equipped with a leachate detection, collection and removal system which incorporates features of both low-level radioactive waste cells and chemical waste cells. Chemical solidification/stabilization and on-site disposal would cost an estimated $98,358,417.

An off-site disposal option would require that the chemically-stabilized product be a soil-like material to facilitate removal from the containers and handling and placement at the off-site disposal facility. The stabilized product and remaining untreated materials would be placed in containers and hauled off-site by rail to either Clive, Utah, or Richland, Washington, for disposal. Treatment combined with disposal at Clive would cost an estimated $540,703,866. Disposal at the DOE's Hanford facility near Richland would cost approximately $2,350,162,773.

4.1.6 Removal, Thermal Treatment and On-Site or Off-Site Disposal

This alternative involves the on-site thermal treatment of soils, sediment, dewatered raffinate pit sludge, and water treatment plant residues. The fossil fuel-heated ceramic melting process was selected for this alternative. Contaminated building debris would be size reduced to facilitate handling, compaction, and disposal.

The thermally-treated waste and the remaining untreated materials would be disposed into two on-site engineered cells under the on-site disposal option. The vitrified waste cell would be an unlined facility while the untreated material would be placed in a single lined facility.

Alternatively both treated and untreated waste could be placed in the same single lined disposal facility. For the off-site disposal option, material would be containerized and hauled by rail to either Clive, Utah, or Richland, Washington.

Thermal treatment, using a fossil fuel-heated ceramic melter, and on-site disposal of the treated product and remaining materials would cost an estimated $100,560,063. Treatment and off-site disposal at Clive, Utah, or Richland, Washington, would cost approximately $421,225,983 or $1,710,329,844, respectively.

4.2 Cost Analysis

Preliminary cost estimates were developed for each of the alternatives described above and are summarized below in Table 4-1. These cost estimates are considered study estimates with an expected accuracy of +50% to -30%. The estimates, summarized in Table 4-1, are for comparison purposes only and should not be considered to be final engineering or construction estimates. The basis for the cost estimates developed for each alternative are presented in Tables 4-2 through 4-12.

TABLE 4-1 Alternative Cost Estimate Summary

Alternative	Waste Quantity (yd^3)	Disposal Volume (yd^3)	Total Project Cost ($)	Cost Per yd^3 of Waste ($)
No Further Action				
Table 4-2	NA	NA	1,181,320 /yr	NA
Removal, Minimal Treatment and Disposal	902,715	727,804		
Table 4-3				
On-site disposal			75,729,849	84
Table 4-4				
Off-site disposal–Envirocare			404,362,676	448
Off-site disposal–Hanford			1,746,769,252	1,934
In Situ CSS & Disposal	882,515	465,576		
Table 4-5				
On-site disposal			85,867,712 [a]	95
			100,910,712 [b]	114
Table 4-6				
Off-site disposal–Envirocare			293,567,476 [a]	333
			308,600,476 [b]	350
Off-site disposal–Hanford			1,155,363,885 [a]	1,309
			1,170,406,885 [b]	1,326

TABLE 4-1 Alternative Cost Estimate Summary (Continued)

Alternative	Waste Quantity	Disposal Volume (yd³)	Total Project Cost ($)	Cost Waste (yd³) ($)
In Situ Vitrification & Disposal	882,515	416,234		
Table 4-7				
On-site disposal			132,348,374 [a]	150
			167,792,634 [b]	190
Table 4-8				
Off-site disposal–Envirocare			318,758,086 [a]	361
			354,202,346 [b]	401
Off-site disposal–Hanford			1,091,239,495 [a]	1,237
			1,126,683,765 [b]	1,277
Removal, CSS, and Disposal	903,615	1,007,065		
Table 4-9				
On-site disposal			98,358,417	109
Table 4-10				
Off-site disposal–Envirocare			540,703,866	598
Off-site disposal–Hanford			2,350,162,773	2,601
Removal, Vitrification, and Disposal	903,615	682,414		
Table 4-11				
On-site disposal			100,560,063	111
Table 4-12				
Off-site disposal–Envirocare			421,225,983	466
Off-site disposal–Hanford			1,710,329,844	1,893

[a] Raffinate pit soil (153,500 yd³) not treated in situ

[b] Raffinate pit soil (153,500 yd³) treated in situ

TABLE 4-2 No Further Action

Activity	Quantity	Unit Cost ($)	Total ($)
Environmental Monitoring			
Monitoring Wells - 49 x 4 times/year	196 EA	604.00	118,384
Surface Water - 15 x 4 times/year	60 EA	604.00	36,240
Surface Water - 5 x 12 times/year	60 EA	604.00	36,240
Radon - 19 x 12 times/year	228 EA	102.00	23,256
Air Monitoring - 40 x 4 times/year	160 EA	1,080.00	172,800
Air Monitoring - 8 x 104 times/year	832 EA	36.00	29,952
Equipment	12 MO	1,500.00	18,000
Labor – Weekly – 52 x 1.25 days x 8 x 2	1,040 MHRS	60.00	62,400
Quarterly – 4 x 5 days x 8 x 2	320 MHRS	60.00	19,200
Report – 40 days x 8 x 2	640 MHRS	60.00	38,400
Inspections			
Annual Site Walk Through			
3 days x 8 x 2	48 MHRS	60.00	2,880
Report – 2 days x 8 x 2	32 MHRS	60.00	1,920
Annual Berm Inspection			
2 days x 8 x 2	32 MHRS	60.00	1,920
Report – 1 day x 8 x 2	16 MHRS	60.00	960
Annual Detailed Inspection			
20 days x 8 x 3	480 MHRS	60.00	28,800
Report – 10 days x 8 x 3	240 MHRS	60.00	14,400
Equipment	25 DAYS	125.00	3,125
Security			
24 hrs 7 days/week			
365 x 24 x 1.33	11,650 HRS	8.25	96,113
Equipment	12 MO	1,500.00	18,000
Maintenance			
Grade Roads – 20,000 x 20/9	44,400 YD^2	0.15	6,660
Seal Coat Roads – 10,000 x 26/9 x 3 years	9,600 YD^2	0.65	6,240
Mowing and Maintenance – 50 acres	50 AC	200.00	10,000
Berm Repair Allowance – 15 YD^3	15 YD^3	30.00	450
General Building Repair/Demolition	1 LOT	5,000.00	5,000
Fence – replace 3 times/100 years			
3 x 10,000 x 0.10 PW	3,000 LF	15.00	45,000

TABLE 4-2 No Further Action (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Gravel Roads – replace 8 times/100 years			
8 x 20,000 x 20/9 x 0.10 PW	27,000 YD^2	2.50	67,500
Asphalt Roads - replace 4 times/100 years			
4 x 10,000 x 26/9 x 10 PW = 11,500 YD^2			
Binder Coat - 1½"	11,500 YD^2	3.50	40,250
Wearing Coat - 1½"	11,500 YD^2	3.80	43,700
Monitoring Wells - replace 60 wells every two years	30 LF	30.00	900
Monitoring Equipment	1 LOT	1,500.00	1,500
Operate Water Treatment Plant			
Single Train = ½ (462,259)	1 YR	LUMP SUM	231,130
ANNUAL COST			1,181,320

Note: PW = Present Worth

TABLE 4-3 Minimal Treatment and On-Site Disposal

Activity		Quantity	Unit Cost ($)	Total ($)
<u>Removal and Transport</u>				
Ash Pond		8,200 YD^3	13.83	113,406
Frog Pond		7,000 YD^3	13.62	95,340
Lakes 34, 35, 36		20,000 YD^3	20.00	400,000
North Dump (Relocate to Ash Pond)		7,600 YD^3	13.83	105,108
South Dump		16,900 YD^3	13.83	233,727
Raffinate Pit Soils		153,500 YD^3	12.58	1,931,030
Other Site Surface Soils		65,400 YD^3	8.51	556,554
Underground Soils		20,000 YD^3	12.85	257,000
Vicinity Property		3,600 YD^3	207.80	748,080
Raffinate Pit Rubble		500 YD^3	234.08	117,040
TSA		100,400 YD^3	23.46	2,355,384
MSA		77,078 YD^3	23.46	1,808,250
Ash Pond Spoils Pile		35,400 YD^3[a]	13.83	489,582
Mulch Pile		30,652 YD^3	13.83	423,917
ACM Storage		4,716 YD^3	23.46	110,637
Building 434 –	Drummed process chemicals	111 YD^3	994.60[b]	110,401
	PPE and drummed waste	5,028 YD^3[c]	23.46	117,957
Building Foundations		40,591 YD^3	47.41	1,924,419
Underground Piping		64,240 LF[d]	45.30	2,910,072
Haul Foundations & Pipe to Volume Reduction Facility		41,900 YD^3	23.46	982,974
Haul from Volume Reduction Facility		122,000 YD^3	23.46	2,862,120
Roads and Embankments		76,930 YD^3	10.44	803,149
Facilities Removal –	TSA	22,000 YD^3	11.93	262,460
	MSA	14,500 YD^3	21.02	304,790
	Volume Reduction Facility	500 YD^3	254.87	127,435
	Site Water Treatment Plant	400 YD^3	254.87	101,948

(a) 5,800 + 22,000 + 7,600

(b) 92 tons @ $0.60/lb to Oak Ridge

(c) 5,000 yd^3 + 28 yd^3, respectively

(d) 1,309 yd^3

TABLE 4-3 Minimal Treatment and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Tributyl Phosphate	30.3 TON	1,200.00[e]	36,360
Place Pond Aggregate Base	20,200 YD³	23.57	476,114
<u>Operations</u>			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,466,940
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407
Volume Reduction			
Concrete/Rock	90,800 YD³	22.70[f]	2,061,160
Metals/Debris	33,000 TON	90.00[g]	2,970,000
Raffinate Pit Sludge - Dredge and Dewater	220,000 YD³	53.40	11,748,000
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
<u>Cell Construction</u>			
Engineering Design	1 LOT	LUMP SUM	1,550,250
Haul Treated Waste to Cell	45,000 YD³	7.47	336,150
Place Waste – Total Cell Waste	727,604 YD³[h]		
Raffinate Sludge	45,000 YD³	10.04[i]	451,800
Remaining Waste	682,604 YD³	5.02	3,426,672
Dewater Cell	727,604 YD³	0.74	538,427
Cover and Foundation	727,604 YD³	20.07	14,603,012

[e] @ $0.60/lb

[f] $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

[g] $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

[h]

Original waste quantity	903,615 (yd³)
Less to Oak Ridge	-111
Less treatment plant	-900
Less dewatering raffinate sludge	-175,000
Total cell waste	727,604 (yd³)

[i] @ 5.02 x 2 = 10.04/yd³

TABLE 4-3 Minimal Treatment and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Reclamation			
Raffinate Pits			
Borrow	111,400 YD^3	13.80	1,537,320
Berms	180,000 YD^3	2.55	459,000
Topsoil	50,000 YD^3	17.52	876,000
Seed and mulch	2,178,000 FT^2	0.046	100,188
Chemical Plant			
Fill	263,000 YD^3	8.50	2,236,500
Topsoil	37,000 YD^3	17.52	648,240
Seed and mulch	46 AC	3,700.00	170,200
TOTAL COST			75,729,848

TABLE 4-4 Minimal Treatment and Off-Site Disposal

Activity		Quantity	Unit Cost ($)	Total ($)
Removal and Transport				
Ash Pond		8,200 YD³	13.83	113,406
Frog Pond		7,000 YD³	13.62	95,340
Lakes 34, 35, 38		20,000 YD³	20.00	400,000
North Dump		7,600 YD³	13.83	105,108
South Dump		16,900 YD³	13.83	233,727
Raffinate Pit Soils		153,500 YD³	12.58	1,931,030
Other Site Surface Soils		65,400 YD³	8.51	556,554
Underground Soils		20,000 YD³	12.85	257,000
Vicinity Property		3,600 YD³	207.80	748,080
Raffinate Pit Rubble		500 YD³	234.08	117,040
Building 434–	Drummed process chemicals	111 YD³	994.60[a]	110,401
	PPE and drummed waste	5,028 YD³[b]	23.46	117,957
Building Foundations		40,591 YD³	47.41	1,924,419
Underground Piping		64,240 LF[c]	45.30	2,910,072
Haul to Volume Reduction Facility		117,000 YD³[d]	23.46	2,744,820
Roads and Embankments		76,930 YD³	10.44	803,149
Facilities Removal –	TSA	22,000 YD³	11.93	262,460
	MSA	14,500 YD³	21.02	304,790
	Volume Reduction Facility	500 YD³	254.87	127,435
	Site Water Treatment Plant	400 YD³	254.87	101,948
Drummed Tributyl Phosphate		30.3 TON	1,200.00[e]	36,360
Place Pond Aggregate Base		20,200 YD³	23.57	476,114
Operations				
MSA		5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant		7.5 YRS	LUMP SUM	3,466,940
Construct Decontamination Pad		1 EA	LUMP SUM	43,016

[a] 92 tons @ $0.60/lb to Oak Ridge

[b] 5,000 yd³ + 28 yd³, respectively

[c] 1,309 yd³

[d] 122,000 - 5,000 = 117,000 yd³

[e] @ $0.60/lb

TABLE 4-4 Minimal Treatment and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407
Volume Reduction			
Concrete/Rock	90,800 YD³	22.70[f]	2,061,160
Metals/Debris	33,000 TON	90.00[g]	2,970,000
Raffinate Pit Sludge - Dredge and dewater	220,000 YD³	53.40	11,748,000
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
<u>Reclamation</u>			
Raffinate Pits			
Borrow	111,400 YD³	13.80	1,537,320
Berms	180,000 YD³	2.55	459,000
Topsoil	50,000 YD³	17.52	876,000
Seed and mulch	2,178,000 FT²	0.046	100,188
Chemical Plant			
Fill	263,000 YD³	8.50	2,235,500
Topsoil	37,000 YD³	17.52	648,240
Seed and mulch	46 AC	3,700.00	170,200
SUBTOTAL			<u>48,535,494</u>

[f] $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

[g] $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 ≈ $90.00/ton

TABLE 4-4 Minimal Treatment and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Load and Transport Off-Site			
To Envirocare by Rail/Container to Clive, Utah[h]	1,126,286 TON	312.00	351,401,232
Added Cost Sludge Placement	45,000 YD³	5.02	225,900
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT ENVIROCARE FACILITY			404,462,626
To Hanford by Rail/Container to Richland, Washington[h]	1,126,286 TON	1,503.00	1,692,807,858
Added Cost Sludge Placement	45,000 YD³	5.02	225,900
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT DOE'S HANFORD FACILITY			1,745,869,252

[h] Total Tons Waste 1,277,568
Less to Oak Ridge -92
Less treatment facility -3,890
Less dewatering -147,300
1,126,286 tons

TABLE 4-5 In Situ Chemical Stabilization and On-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Lakes 34, 35, 36	20,000 YD^3	20.00	400,000
North Dump (Relocate to Ash Pond)	7,600 YD^3	13.83	105,108
Other Site Surface Soils	65,400 YD^3	8.51	556,554
Underground Soils	20,000 YD^3	12.85	257,000
Vicinity Property	3,600 YD^3	207.80	748,080
Raffinate Pit Rubble	500 YD^3	234.08	117,040
TSA	100,400 YD^3	23.46	2,355,384
MSA	77,078 YD^3	23.46	1,808,250
Ash Pond Spoils Pile	27,800 YD^3[a]	13.83	384,474
Mulch Pile	30,652 YD^3	13.83	423,817
ACM Storage	4,716 YD^3	23.46	110,637
Building 434 – Drummed process chemicals	111 YD^3	994.60[b]	110,401
PPE and drummed waste	5,028 YD^3[c]	23.46	117,957
Building Foundation	40,591 YD^3	47.41	1,924,419
Underground Piping	64,240 LF[d]	45.30	2,910,072
Haul Foundations & Pipe to Volume Reduction Facility	41,900 YD^3	23.46	982,974
Haul from Volume Reduction Facility	122,000 YD^3	23.46	2,862,120
Roads and Embankments	56,730 YD^3[e]	10.44	592,261
Facilities Removal – TSA	22,000 YD^3	11.93	262,460
MSA	14,500 YD^3	21.02	304,790
Volume Reduction Facility	500 YD^3	254.87	127,435
Site Water Treatment Plant	400 YD^3	254.87	101,948
Tributyl Phosphate	30.3 TON	1,200.00[f]	36,360
Operations			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,466,940

(a) 5,800 + 22,000

(b) 92 tons @ $10.60/lb to Oak Ridge

(c) 5,000 yd^3 + 28 yd^3, respectively

(d) 1,309 yd^3

(e) 76,930 - 20,200 pit aggregate

(f) @ $0.60/lb

TABLE 4-5 In Situ Chemical Stabilization and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407
Volume Reduction			
Concrete/Rock	90,800 YD³	22.70[g]	2,061,160
Metals/Debris	33,000 TON	90.00[h]	2,970,000
In Situ Stabilization Total Sludges	263,328 YD³[i]	98.00	25,806,144
With Raffinate Soils	416,828 YD³[j]	98.00	40,849,144
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
<u>Cell Construction</u>			
Engineering Design	1 LOT	LUMP SUM	1,550,250
Place Waste	465,576 YD³[k]	5.02	2,337,192
Dewater Cell	465,576 YD³	0.74	344,526
Cover and Foundation	465,576 YD³	25.47[l]	11,858,220
Cap In Situ	48.7 AC	164,500.00	8,011,150

(g) $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

(h) $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

(i)

Raffinate sludge	220,000	yd³
Ash Pond	8,200	yd³
Frog Pond	7,000	yd³
South Dump	16,900	yd³
North Dump (relocated to Ash Pond)	7,600	yd³
Water treatment plant and drums	3,628	yd³
	263,328	yd³

(j)

In situ stabilized sludge	263,328	yd³
Raffinate soils	153,500	yd³
	416,828	yd³

(k)

Original waste quantity	903,615	yd³
Less to Oak Ridge	-111	
Less treatment plant	-900	
Less in situ treatment	-416,828	
Less pond aggregate	-20,200	
	465,576	yd³

(l) [(36.48 - 20.07) ÷ (660,000 - 70,000) x (466,000 - 70,000)]
16.41 ÷ 590,000 x 396,000 = 11.01
36.48 - 11.01 = 25.47

TABLE 4-5 In Situ Chemical Stabilization and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
<u>Reclamation</u>			
Raffinate Pits	[m]		
Chemical Plant			
Fill	178,840 YD^3 [n]	8.50	1,520,140
Topsoil	25,160 YD^3 [o]	17.52	440,803
Seed and mulch	31.3 AC	3,700.00	115,810
TOTAL COST FOR ON-SITE DISPOSAL			
1) Raffinate pit soil (153,500 yd^3) not treated in situ			<u>85,867,712</u>
2) Raffinate pit soil (153,500 yd^3) treated in situ			<u>100,910,712</u>

[m] Sludge volume increase 220,000 x 1.32 = 290,400 yd^3
Soil volume increase 153,500 x 1.32 = 202,620 yd^3
Cap = 48.7 x 43,560 x 3 ÷ 27 = 236,000 yd^3
Required 111,400 + 180,000 + 50,000 = 341,400 yd^3
No added backfill required

[n] 31.3 Acres ÷ 46 = 0.68
0.68 x 263,000 yd^3 = 178,840 yd^3

[o] 0.68 x 37,000 yd^3 = 25,160 yd^3

TABLE 4-6 In Situ Chemical Stabilization and Off-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Lakes 34, 35, 36	20,000 YD^3	20.00	400,000
North Dump (Relocate to Ash Pond)	7,800 YD^3	13.83	105,108
Other Site Surface Soils	65,400 YD^3	8.51	556,554
Underground Soils	20,000 YD^3	12.85	257,000
Vicinity Property	3,600 YD^3	207.80	748,080
Raffinate Pit Rubble	500 YD^3	234.08	117,040
Building 434 – Drummed process chemicals	111 YD^3	994.60[a]	110,401
PPE and drummed waste	5,028 YD^3[b]	23.46	117,957
Building Foundations	40,591 YD^3	47.41	1,924,419
Underground Piping	64,240 LF[c]	45.30	2,910,072
Haul to Volume Reduction Facility	117,000 YD^3[d]	23.46	2,744,820
Roads and Embankments	56,730 YD^3[e]	10.44	592,261
Facilities Removal – TSA	22,000 YD^3	11.93	262,460
MSA	14,500 YD^3	21.02	304,790
Volume Reduction Facility	500 YD^3	254.87	127,435
Site Water Treatment Plant	400 YD^3	254.87	101,948
Tributyl Phosphate	30.3 TON	1,200.00[f]	36,360
Operations			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,466,940
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407

[a] 92 tons @ $0.60/lb to Oak Ridge

[b] 5,000 yd^3 + 28 yd^3, respectively

[c] 1,309 yd^3

[d] 122,000 - 5,000 = 117,000 yd^3

[e] 76,930 - 20,200 pit aggregate

[f] @ $0.60/lb

TABLE 4-6 In Situ Chemical Stabilization and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Volume Reduction			
Concrete/Rock	90,800 YD³	22.70[g]	2,061,160
Metals/Debris	33,000 TON	90.00[h]	2,970,000
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
In Situ Treatment	263,328 YD³[i]	98.00	25,806,144
	416,828 YD³[j]	98.00	40,849,144
<u>Cell Construction</u>			
Cap In Situ	48.7 AC	164,500.00	8,011,150
<u>Reclamation</u>			
Chemical Plant			
Fill	178,840 YD³	8.50	1,520,140
Topsoil	25,160 YD³	17.52	440,803
Seed and mulch	31.3 AC	3,700.00	115,810
SUBTOTAL 1) Raffinate pit soil (153,500 yd³) not treated in situ			<u>63,594,588</u>
2) Raffinate pit soil (153,500 yd³) treated in situ			<u>78,637,588</u>

(g) $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

(h) $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

(i) Raffinate pit soil (153,500 yd³) not treated in situ.

(j) Raffinate pit soil (153,500 yd³) treated in situ.

TABLE 4-6 In Situ Chemical Stabilization and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Load and Transport Off-Site			
To Envirocare by Rail/Container to Clive, Utah	723,599 TONS[k]	312.00	225,762,888
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT ENVIROCARE FACILITY			
1) Raffinate pit soil not treated in situ			293,857,476
2) Raffinate pit soil treated in situ			308,700,476
To Hanford by Rail/Container to Richland, Washington	723,599 TONS[k]	1,503.00	1,087,569,297
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT DOE'S HANFORD FACILITY			
1) Raffinate pit soils not treated in situ			1,155,463,885
2) Raffinate pit soils treated in situ			1,170,506,885

[k] Total tons waste 1,277,568
Less to Oak Ridge -92
Less treatment facility -3,890
Less in situ treatment -519,283
Less pond aggregate -30,704
723,599 tons

TABLE 4-7 In Situ Vitrification and On-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Lakes 34, 35, 36	20,000 YD^3	20.00	400,000
North Dump (Relocate to Ash Pond)	7,600 YD^3	13.83	105,108
Other Site Surface Soils	65,400 YD^3	8.51	556,554
Underground Soils	20,000 YD^3	12.85	257,000
Vicinity Property	3,600 YD^3	207.80	748,080
Raffinate Pit Rubble	500 YD^3	234.08	117,040
TSA	100,400 YD^3	23.46	2,355,384
MSA	77,078 YD^3	23.46	1,808,250
Ash Pond Spoils Pile	27,800 YD^3[a]	13.83	384,474
Mulch Pile	30,652 YD^3	13.83	423,917
ACM Storage	4,716 YD^3	23.46	110,637
Building 434 – Drummed process chemicals	111 YD^3	994.60[b]	110,401
PPE and drummed waste	5,028 YD^3[c]	23.46	117,957
Building Foundations	40,591 YD^3	47.41	1,924,419
Underground Piping	64,240 LF[d]	45.30	2,910,072
Haul Foundations & Pipe to Volume Reduction Facility	41,900 YD^3	23.46	982,974
Haul from Volume Reduction Facility	122,000 YD^3	23.46	2,862,120
Roads and Embankments	56,730 YD^3[e]	10.44	592,251
Facilities Removal – TSA	22,000 YD^3	11.93	262,460
MSA	14,600 YD^3	21.02	304,790
Volume Reduction Facility	500 YD^3	254.87	127,435
Site Water Treatment Plant	400 YD^3	254.87	101,948
Tributyl Phosphate	30.3 TON	1,200.00[f]	36,360
Operations			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,465,940

(a) 5,800 + 22,000

(b) 92 tons @ $0.60/lb to Oak Ridge

(c) 5,000 yd^3 + 28 yd^3, respectively

(d) 1,309 yd^3

(e) 76,930 - 20,200 pit aggregate

(f) @ $0.60/lb

TABLE 4-7 In Situ Vitrification and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407
Volume Reduction			
Concrete/Rock	90,800 YD³	22.70[g]	2,061,160
Metals/Debris	33,000 TON	90.00[h]	2,970,000
In Situ Stabilization Mix with Sludge	49,342 YD³[i]	10.04	495,394
Without Raffinate Pit Soil	312,670 YD³[j]	232.10	72,570,707
With Raffinate Pit Soil	466,170 YD³[k]	232.10	108,198,057
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
<u>Cell Construction</u>			
Engineering Design	1 LOT	LUMP SUM	1,550,250
Place Waste	416,234 YD³[l]	5.02	2,089,495
Dewater Cell	416,234 YD³	0.74	308,013
Cover and Foundation	416,234 YD³	26.86[m]	11,180,045
Cap In Situ	48.7 AC	164,500	8,011,150

(g) $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

(h) $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

(i) Soil mix for raffinate pit sludge
60,000 ton + 80 = 75,000 ton wet
75,000 ÷ 1.52 = 49,342 yd³
Mix with sludge 5.02 x 2 = 10.04

(j) Without 153,500 yd³ raffinate pit soil
263,328 (Table 4-5) + 49,342

(k) With 153,500 yd³ raffinate soils treated in situ
416,828 (Table 4-5) + 49,342

(l) Table 4-5 465,576 yd³
Less Mix Soil -49,342
416,234 yd³

(m) ([36.48 - 20.07] ÷ [680,000 - 70,000]) x (416,000 - 70,000)
(16.41 ÷ 590,000) x 346,000 = 9.62
36.48 - 9.62 = 26.86

TABLE 4-7 In Situ Vitrification and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Reclamation			
Raffinate Pits			
1) Without soil – Berms	71,800 YD^3 [n]	2.55	183,090
2) With soil – No backfill required			
Chemical Plant			
Fill	178,840 YD^3 [o]	8.50	1,520,140
Topsoil	25,160 YD^3 [p]	17.52	440,803
Seed and mulch	31.3 AC	3,700.00	115,810
TOTAL COST FOR ON-SITE DISPOSAL			
1) If raffinate pit soil (153,500 yd^3) not treated in situ			132,348,374
2) If raffinate pit soil (153,500 yd^3) treated in situ			167,792,834

[n] Sludge Volume Increase 220,000 x 0.153 = 33,600 yd^3
Soil Volume Increase 153,500 x 0.68 = 104,380 yd^3
Cap = 48.7 x 43,560 x 3 ÷ 27 = 236,000 yd^3
Required 111,400 + 180,000 + 50,000 = 341,400 yd^3
Berm 341,400 - 269,600 = 71,800 yd^3

[o] 31.3 Acres ÷ 46 = 0.68
0.68 x 263,000 yd^3 = 178,840

[p] 0.68 x 37,000 yd^3 = 25,160

TABLE 4-8 In Situ Vitrification and Off-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Lakes 34, 35, 36	20,000 YD³	20.00	400,000
North Dump (Relocate to Ash Pond)	7,600 YD³	13.83	105,108
Other Site Surface Soils	65,400 YD³	8.51	556,554
Underground Soils	20,000 YD³	12.85	257,000
Vicinity Property	3,600 YD³	207.80	748,080
Raffinate Pit Rubble	500 YD³	234.08	117,040
Building 434 – Drummed process chemicals	111 YD³	994.60[a]	110,401
PPE and drummed waste	5,028 YD³[b]	23.46	117,957
Building Foundations	40,591 YD³	47.41	1,924,419
Underground Piping	64,240 LF[c]	45.30	2,910,072
Haul to Volume Reduction Facility	117,000 YD³[d]	23.46	2,744,820
Roads and Embankments	56,730 YD³[e]	10.44	592,261
Facilities Removal – TSA	22,000 YD³	11.93	262,460
MSA	14,500 YD³	21.02	304,790
Volume Reduction Facility	500 YD³	254.87	127,435
Site Water Treatment Plant	400 YD³	254.87	101,948
Tributyl Phosphate	30.3 TON	1,200.00[f]	36,360
Operations			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,466,940
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407

(a) 92 tons @ $0.60/lb to Oak Ridge

(b) 5,000 yd³ + 28 yd³, respectively

(c) 1,309 yd³

(d) 122,000 - 5,000 = 117,000 yd³

(e) 76,930 - 20,200 pit aggregate

(f) @ $0.60/lb

TABLE 4-8 In Situ Vitrification and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Volume Reduction			
Concrete/Rock	90,800 YD³	22.70[g]	2,061,160
Metals/Debris	33,000 TON	90.00[h]	2,970,000
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
In Situ Treatment[i]	49,342 YD³	10.04	495,394
Without raffinate pit soil treated in situ	312,670 YD³[j]	232.10	72,570,707
With raffinate pit soil treated in situ	466,170 YD³[j]	232.10	108,198,057
Haul Stabilization Soil	49,342 YD³	23.46	1,157,563
<u>Cell Construction</u>			
Cap In Situ	48.7 AC	164,500.00	8,011,150
<u>Reclamation</u>			
Raffinate Pits			
1) Without soil[j] — Berm	71,800 YD³	2.55	183,090
2) With soil — Not required			
Chemical Plant – Fill	178,840 YD³	8.50	1,520,140
Top Soil	25,160 YD³	17.52	440,803
Seed and Mulch	31.3 AC	3,700.00	115,810
SUBTOTAL			112,195,198
1) Raffinate pit soil not treated in situ			
2) Raffinate pit soil treated in situ			147,639,458

(g) $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

(h) $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

(i) Stabilization mix for raffinate pit sludge:
60,000 tons ÷ 0.80 = 75,000 ton wet ÷ 1.52 = 49,342 yd³
Mix with sludge 5.02 x 2 = 10.04

(j) See Table 4-7.

TABLE 4-8 In Situ Vitrification and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Load and Transport Off-Site			
To Envirocare by Rail/Container to Clive, Utah	648,599 TONS[k]	312.00	202,362,888
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT ENVIROCARE FACILITY			
1) Raffinate pit soil not treated in situ			318,858,086
2) Raffinate pit soil treated in situ			354,302,346
To Hanford by Rail/Container to Richland, Washington	648,599 TONS[k]	1,503.00	974,844,297
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT DOE'S HANFORD FACILITY			
1) Raffinate pit soils not treated in situ			1,091,339,495
2) Raffinate pit soils treated in situ			1,126,783,755

[k] Total tons waste	1,277,568	
Less to Oak Ridge	-92	
Less treatment facility	-3,890	
Less in situ treatment	-519,283	
Less pond aggregate	-30,704	
Less mix soil	-75,000	
	648,599	tons

TABLE 4-9 Chemical Stabilization and On-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Ash Pond	8,200 YD³	13.83	113,406
Frog Pond (Relocate to Ash Pond)	7,000 YD³	13.62	95,340
Lakes 34, 35, 36	20,000 YD³	20.00	400,000
North Dump (Relocate to Ash Pond)	7,600 YD³	13.83	105,108
South Dump	16,900 YD³	13.83	233,727
Raffinate Pit Soils	153,500 YD³	12.58	1,931,030
Other Site Surface Soils	65,400 YD³	8.51	556,554
Underground Soils	20,000 YD³	12.85	257,000
Vicinity Property	3,600 YD³	207.80	748,080
Raffinate Pit Rubble	500 YD³	234.08	117,040
TSA	100,400 YD³	23.46	2,355,384
MSA	77,078 YD³	23.46	1,808,250
Ash Pond Spoils Pile	35,400 YD³[a]	13.83	489,582
Mulch Pile	30,652 YD³	13.83	423,917
ACM Storage	4,716 YD³	23.46	110,637
Building 434 – Drummed process chemicals	111 YD³	994.80[b]	110,401
PPE and drummed waste	5,028 YD³[c]	23.46	117,957
Building Foundations	40,591 YD³	47.41	1,924,419
Underground Piping	64,240 LF[d]	45.30	2,910,072
Haul Foundations & Pipe to Volume Reduction Facility	41,900 YD³	23.46	982,974
Haul from Volume Reduction Facility	122,900 YD³	23.46	2,883,234
Roads and Embankments	76,930 YD³	10.44	803,149
Facilities Removal – TSA	22,000 YD³	11.93	262,460
MSA	14,500 YD³	21.02	304,790
Treatment Facility	900 YD³	183.30	164,970
Volume Reduction Facility	500 YD³	254.87	127,435
Site Water Treatment Plant	400 YD³	254.87	101,948
Tributyl Phosphate	30.3 TON	1,200.00[e]	36,360

(a) 6,800 + 22,000 + 7,600

(b) 92 tons @ $0.60/lb to Oak Ridge

(c) 5,000 yd³ + 28 yd³, respectively

(d) 1,309 yd³

(e) @ $0.60/lb

TABLE 4-9 Chemical Stabilization and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Place Pond Aggregate Base	20,200 YD³	23.57	476,114
Operations			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,485,940
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407
Volume Reduction			
Concrete/Rock	91,700 YD³	22.70[f]	2,081,590
Metals/Debris	33,000 TON	90.00[g]	2,970,000
Raffinate Pit Sludge - Dredge	220,000 YD³	49.20	10,824,000
Treat Waste - CSS	323,628 YD³[h]	41.71	13,498,524
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
Cell Construction			
Engineering Design	1 LOT	LUMP SUM	1,550,250
Haul Treated Waste to Cell	427,189 YD³[i]	7.47	3,191,102
Place Waste	1,007,065 YD³[j]	5.02	5,055,466
Dewater Cell	1,007,065 YD³	0.74	745,228
Cover and Foundation	1,007,065 YD³	20.07	20,211,796
Reclamation			
Raffinate Pits			
Borrow	111,400 YD³	13.80	1,537,320
Berms	180,000 YD³	2.55	459,000

(f) $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

(g) $22.70/2.026 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

(h)

Raffinate pit sludge	220,000	
Quarry and raffinate soil	100,000	
Water treatment plant sludge	3,600	
Drummed waste	28	
	323,628	yd³

(i) 323,628 x 1.32 (CSS swell) = 427,189

(j)

Original waste	903,615	yd³
Less To Oak Ridge	-111	
CSS swell (323,628 x 0.32)	103,561	
	1,007,065	yd³

TABLE 4-9 Chemical Stabilization and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Topsoil	50,000 YD^3	17.52	876,000
Seed and mulch	2,178,000 FT^2	0.046	100,188
Chemical Plant			
Fill	263,000 YD^3	8.50	2,235,500
Topsoil	37,000 YD^3	17.52	648,240
Seed and mulch	46 AC	3,700.00	170,200
TOTAL FOR ON-SITE DISPOSAL			98,368,417

TABLE 4-10 Chemical Stabilization and Off-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Ash Pond	8,200 YD³	13.83	113,406
Frog Pond	7,000 YD³	13.62	95,340
Lakes 34, 35, 36	20,000 YD³	20.00	400,000
North Dump	7,600 YD³	13.83	105,108
South Dump	16,900 YD³	13.83	233,727
Raffinate Pit Soils	153,500 YD³	12.58	1,931,030
Other Site Surface Soils	65,400 YD³	8.51	556,554
Underground Soils	20,000 YD³	12.85	257,000
Vicinity Property	3,600 YD³	207.80	748,080
Raffinate Pit Rubble	500 YD³	234.08	117,040
Building 434 – Drummed process chemicals	111 YD³	994.60[a]	110,401
PPE and drummed waste	5,028 YD³[b]	23.46	117,957
Building Foundations	40,591 YD³	47.41	1,924,419
Underground Piping	64,240 LF[c]	45.30	2,910,072
Haul to Volume Reduction Facility	117,900 YD³[d]	23.46	2,765,934
Roads and Embankments	76,930 YD³	10.44	803,149
Facilities Removal – TSA	22,000 YD³	11.93	262,460
MSA	14,500 YD³	21.02	304,790
Treatment Facility	900 YD³	183.20	164,880
Volume Reduction Facility	500 YD³	254.87	127,435
Site Water Treatment Plant	400 YD³	254.87	101,948
Tributyl Phosphate	30.3 TON	1,200.00[e]	36,360
Place Pond Aggregate Base	20,200 YD³	23.57	476,114
Operations			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,466,940
Construct Decontamination Pad	1 EA	LUMP SUM	43,016

(a) 92 tons @ $0.60/lb to Oak Ridge

(b) 5,000 yd³ + 28 yd³, respectively

(c) 1,309 yd³

(d) 122,900 - 5,000 = 117,900 yd³

(e) @ $0.60/lb

TABLE 4-10 Chemical Stabilization and Off-Site Disposal (Continued)

Activity		Quantity	Unit Cost ($)	Total ($)
Operate Decontamination Pad		9 YRS	LUMP SUM	1,185,407
Volume Reduction				
Concrete/Rock		91,700 YD³	22.70[f]	2,081,590
Metals/Debris		33,000 TON	90.00[g]	2,970,000
Raffinate Pit – Dredge		220,000 YD³	49.20	10,824,000
Treat Waste – CSS		323,628 YD³	41.71	13,498,524
Dewater Raffinate Pits		53 MO	LUMP SUM	1,393,365
Haul Quarry Soil		50,000 YD³	23.46	1,173,000
Reclamation				
Raffinate Pits	Borrow	111,400 YD³	13.80	1,537,320
	Berm	180,000 YD³	2.55	459,000
	Top Soil	50,000 YD³	17.52	876,000
	Seed and Mulch	2,178,000 SF	0.046	100,188
Chemical Plant	Fill	263,800 YD³	8.50	2,235,500
	Top Soil	37,000 YD³	17.52	648,240
	Seed and Mulch	46 AC	3,700.00	170,200
SUBTOTAL				52,489,442

(f) $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

(g) $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

TABLE 4-10 Chemical Stabilization and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Load and Transport Off-Site			
To Envirocare by Rail/Container to Clive, Utah	1,519,277 TONS[h]	312.00	474,014,424
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT ENVIROCARE FACILITY			540,803,866
To Hanford by Rail/Container to Richland, Washington	1,519,277 TONS[h]	1,503.00	2,283,473,331
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT DOE'S HANFORD FACILITY			2,350,262,773

[h] Total tons waste 1,277,568
Less to Oak Ridge -92
Added cement stabilization 241,801
1,519,277 tons

323,628 yd³ treated x 1.32 = 427,189 yd³ @ 1.45 ton/yd³
= 619,424 tons less original tons (377,623)
= 241,801 increased tons

TABLE 4-11 Thermal Treatment and On-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Ash Pond	8,200 YD³	13.83	113,406
Frog Pond	7,000 YD³	13.52	95,340
Lakes 34, 35, 36	20,000 YD³	20.00	400,000
North Dump (Relocate to Ash Pond)	7,600 YD³	13.83	105,108
South Dump	16,900 YD³	13.83	233,727
Raffinate Pit Soils	153,500 YD³	12.58	1,931,030
Other Site Surface Soils	65,400 YD³	8.51	556,554
Underground Soils	20,000 YD³	12.85	257,000
Vicinity Property	3,600 YD³	207.80	748,080
Raffinate Pit Rubble	500 YD³	234.08	117,040
TSA	100,400 YD³	23.46	2,355,384
MSA	77,078 YD³	23.46	1,808,250
Ash Pond Spoils Pile	35,400 YD³[a]	13.83	489,582
Mulch Pile	30,652 YD³	13.83	423,917
ACM Storage	4,716 YD³	23.46	110,637
Building 434 – Drummed process chemicals	111 YD³	994.60[b]	110,401
PPE and drummed waste	5,028 YD³[c]	23.46	117,957
Building Foundations	40,591 YD³	47.41	1,924,419
Underground Piping	64,240 LF[d]	45.30	2,910,072
Haul Foundations & Pipe to Volume Reduction Facility	41,900 YD³	23.46	982,974
Haul from Volume Reduction Facility	122,900 YD³	23.46	2,883,234
Roads and Embankments	76,930 YD³	10.44	803,149
Facilities Removal – TSA	22,000 YD³	11.93	262,460
MSA	14,500 YD³	21.02	304,790
Treatment Facility	900 YD³	183.30	164,970
Volume Reduction Facility	500 YD³	254.87	127,435
Site Water Treatment Plant	400 YD³	254.87	101,948

[a] 5,800 + 22,000 + 7,600

[b] 92 tons @ $0.60/lb to Oak Ridge

[c] 5,000 yd³ + 28 yd³, respectively

[d] 1,309 yd³

TABLE 4-11 Thermal Treatment and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Tributyl Phosphate	30.3 TON	1,200.00[e]	36,360
Place Pond Aggregate Base	20,200 YD³	23.57	476,114
<u>Operations</u>			
MSA	5 YRS	LUMP SUM	5,183,849
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,466,940
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407
Volume Reduction			
Concrete/Rock	91,700 YD³	22.70[f]	2,081,590
Metals/Debris	33,000 TON	90.00[g]	2,970,000
Raffinate Pit Sludge - Dredge and Dewater	220,000 YD³	53.40	11,748,000
Treat Waste – FFHCM	323,628 YD³[h]	90.88	29,411,313
Dewater Raffinate Pits	53 MO	LUMP SUM	1,393,365
<u>Cell Construction</u>			
Engineering Design	1 LOT	LUMP SUM	1,550,250
Vitrified-Waste Cell	102,538 YD³[i]	6.86	703,411
Single-Lined Cell	579,876 YD³[j]	15.46[k]	8,964,883

(e) @ $0.60/lb

(f) $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

(g) $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

(h)

Raffinate pit sludge	220,000	
Quarry and raffinate soil	100,000	
Water treatment plant sludge	3,600	
Drummed waste	28	
	323,628	yd³

(i)

220,000 x 1.01 x 0.27	= 59,994	tons
100,000 x 1.52 x 0.80	= 121,600	
(3,400 + 23) x 0.27	= 924	
	182,518	tons + 1.78 = 102,538 yd³

— Volume Reduction = (323,628 - 102,539)/323,628 = 68%

(j)

Original waste quantity	903,615	yd³
Less vitrified waste cell	-323,628	
Less to Oak Ridge	-111	
	579,876	yd³

TABLE 4-11 Thermal Treatment and On-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Haul Vitrified Waste to Cell	117,919 YD^3[l]	7.47	880,866
Place Waste	697,795 YD^3[m]	5.02	3,502,931
Dewater Cell	697,795 YD^3	0.74	516,369
<u>Reclamation</u>			
Raffinate Pits			
Borrow	111,400 YD^3	13.80	1,537,320
Berms	180,000 YD^3	2.55	459,000
Topsoil	50,000 YD^3	17.52	876,000
Seed and mulch	2,178,000 FT^2	0.046	100,188
Chemical Plant			
Fill	263,000 YD^3	8.50	2,235,500
Topsoil	37,000 YD^3	17.52	648,240
Seed and mulch	46 AC	3,700.00	170,200
TOTAL FOR ON-SITE DISPOSAL			<u>100,580,063</u>

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[k] Single-Lined Cell
([22.75 - 13.98] + [660,000 - 184,000]) x (590,000 - 184,000)
(8.77 + 476,000) x 396,000 = 7.29
22.75 - 7.29 = 15.46

[l] Clay Binder 102,538 yd^3 x 1.15

[m] 117,819 + 579,876

TABLE 4-12 Thermal Treatment and Off-Site Disposal

Activity	Quantity	Unit Cost ($)	Total ($)
Removal and Transport			
Ash Pond	8,200 YD^3	13.83	113,406
Frog Pond	7,000 YD^3	13.62	95,340
Lakes 34, 35, 38	20,000 YD^3	20.00	400,000
North Dump	7,600 YD^3	13.83	105,108
South Dump	16,900 YD^3	13.83	233,727
Raffinate Pit Soils	153,500 YD^3	12.58	1,931,030
Other Site Surface Soils	65,400 YD^3	8.51	556,554
Underground Soils	20,000 YD^3	12.85	257,000
Vicinity Property	3,600 YD^3	207.80	748,080
Raffinate Pit Rubble	500 YD^3	234.08	117,040
Building 434 – Drummed process chemicals	111 YD^3	994.60[a]	110,401
FPE and drummed waste	5,028 YD^3[b]	23.46	117,957
Building Foundations	40,591 YD^3	47.41	1,924,419
Underground Piping	64,240 LF[c]	45.30	2,910,072
Haul to Volume Reduction Facility	117,900 YD^3[d]	23.46	2,765,934
Roads and Embankments	76,930 YD^3	10.44	803,149
Facilities Removal – TSA	22,000 YD^3	11.93	262,460
MSA	14,500 YD^3	21.02	304,790
Treatment Facility	900 YD^3	183.20	164,880
Volume Reduction Facility	500 YD^3	254.87	127,435
Site Water Treatment Plant	400 YD^3	254.87	101,948
Tributyl Phosphate	30.3 TON	1,200.00[e]	36,360
Place Pond Aggregate Base	20,200 YD^3	23.57	476,114
Operations			
MSA	5 YRS	LUMP SUM	5,163,948
Site Water Treatment Plant	7.5 YRS	LUMP SUM	3,466,940
Construct Decontamination Pad	1 EA	LUMP SUM	43,016
Operate Decontamination Pad	8 YRS	LUMP SUM	1,185,407

(a) 92 tons @ $0.50/lb to Oak Ridge

(b) 5,000 yd^3 + 28 yd^3, respectively

(c) 1,309 yd^3

(d) 122,000 - 5,000 = 117,000 yd^3

(e) @ $0.50/lb

TABLE 4-12 Thermal Treatment and Off-Site Disposal (Continued)

Activity		Quantity	Unit Cost ($)	Total ($)
Volume Reduction				
Concrete/Rock		91,700 YD³	22.70[f]	2,081,590
Metals/Debris		33,000 TON	90.00[g]	2,970,000
Raffinate Pit – Dredge and Dewater		220,000 YD³	53.40	11,748,000
Treat Waste – FFHCM		323,628 YD³	90.88	29,411,313
Dewater Raffinate Pits		53 MO	LUMP SUM	1,393,365
Haul Quarry Soil		50,000 YD³	23.46	1,173,000
Reclamation				
Raffinate Pits				
	Borrow	111,400 YD³	13.80	1,537,320
	Barm	180,000 YD³	2.55	459,000
	Top Soil	50,000 YD³	17.52	876,000
	Seed and Mulch	2,178,000 SF	0.046	100,188
Chemical Plant				
	Fill	263,000 YD³	8.50	2,235,500
	Top Soil	37,000 YD³	17.52	648,240
	Seed and Mulch	46 AC	3,700.00	170,200
SUBTOTAL				79,326,231

[f] $18.92/yd³ x 1.2 ancillary facilities = $22.70/yd³

[g] $22.70/2.025 tons per yd³ = $11.21/ton
Production through shear is about 1/8 that through crusher: $11.21/ton x 8 = $90.00/ton

TABLE 4-12 Thermal Treatment and Off-Site Disposal (Continued)

Activity	Quantity	Unit Cost ($)	Total ($)
Load and Transport Off-Site			
To Envirocare by Rail/Container to Clive, Utah	1,082,371 TONS[h]	312.00	337,699,752
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT ENVIROCARE FACILITY			421,325,963
To Hanford by Rail/Container to Richland, Washington	1,082,371 TONS[h]	1,503	1,626,803,613
Railroad Siding	1 EA	LUMP SUM	4,300,000
TOTAL FOR OFF-SITE DISPOSAL AT DOE'S HANFORD FACILITY			1,710,429,844

[h]Total tons waste	1,277,568	
Less to Oak Ridge	-92	
Less sludge	-222,200	
Less raffinate soils	-76,000	
Less quarry soils	-76,000	
Less water treatment plant Sludge	-3,400	
Less drummed waste	-23	
	899,853	tons
Vitrified waste	182,518	tons
	1,082,371	tons

In general, costs contained in the *Off-Site Transport/Disposal Options Study*, the *On-Site Disposal Options*, the *Raffinate Sludge Dredging and Dewatering Study*, and the *Vitrification Cost Study* were based on industry standards, state-of-the-art equipment, and vendor-supplied quotes. Costs have been adjusted to account for reduced working efficiencies resulting from the use of personal protective equipment.

Assumptions and methods used were standardized wherever possible to minimize variability in cost estimate development among the remedial action alternatives and include the following:

1) Vendor cost quotes for specific equipment items or treatment systems were obtained when possible for estimating capital costs. However, some costs were only available on a dollar per unit quantity of material treated basis.

2) Where possible, labor crews were identified regarding size and types required (i.e., laborer, mechanic, equipment operator) for each remedial action work task. Some costs were only available on a dollar per unit quantity of material treated basis.

3) Costs for items such as power, chemicals, fuel, maintenance supplies, and other annual consumable supplies were derived using specific information when available.

4) Efficient qualified labor is available to support construction and scheduling needs.

5) Construction activities are based on 8-hour shifts with 6.5 productive work hours per shift. No allowance has been provided for a winter shutdown.

6) Construction durations will be dependent on size and/or quantity of equipment selected.

7) The following percentages were used to develop the cost estimates for each construction activity required to complete a remedial action alternative. These percentages represent standard estimating multipliers for this type of work.

   a) Site preparation and restoration: capital costs x 10%

b) Labor equipment mobilization and demobilization: capital cost x 5%

c) Direct labor taxes and insurance: direct labor cost x 24.66%

d) Indirect labor: direct labor cost x 25%

E) Indirect labor fringes, taxes and insurance: indirect labor cost x 38.7%

f) Indirect operating expense: direct labor cost x 0.88%

g) Profit margin: total job cost x 10%

h) Bond premiums: total job cost x 2%

i) Package insurance policy: total job cost x 20%

These estimates were developed on the presumption that a prime contractor will be responsible for all work required for the remedial action alternative. As such, the prime contractor will be responsible for overall site preparation and restoration, equipment and labor mobilization and demobilization, construction management, monitoring and support, and development of facilities to support the implemented remedial action alternative.

The pricing structure for determined cost (engineering calculations developed by the project) was developed for a 1990 dollar base using the following criteria:

1) Current labor rates and fringe benefits were computed using as general guidelines the current Davis-Bacon wage determinations. An FICA rate of 7.51% was applied to a $49,500 annual limit and a BIPD rate of 3.35% was included.

2) State unemployment was calculated at 3% with a $9,500 annual limit with federal unemployment based upon 0.8% with a 7,000 annual limit. Workman's compensation was included at an average rate of 10%.

3) Indirect labor was determined using 25% of the direct labor with the addition of 17.60% for fringe benefits. Indirect taxes were calculated at 21.16% of indirect labor and fringes.

4) Plant costs were estimated at 8.8% of the direct labor.

5) Margin was based upon 10% of the total direct cost plus indirects and plant cost.

6) Bond was estimated at 2% of the summation of the total direct cost, indirect cost, plant cost, and margin.

7) Package insurance was calculated at 10% of the total project cost including margin and bond.

8) Other direct costs were determined as follows:

- Equipment rates - 80% of the Rental Rate Blue Book by Dataquest, January 1989 Volume.
- Miscellaneous supplies - 5% for uncontaminated areas and 15% for contaminated areas.
- Materials prices - supplier quotations and means.

9) Productivity rates for handling contaminated materials were adjusted to 6.5 hours of productive time per 8 hour shift. Manual labor productivity associated with wearing protective clothing was addressed by including redundant labor to assure full crew productivity.

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6 LIST OF ACRONYMS AND ABBREVIATIONS

Following is a list of the acronyms, initialisms, and abbreviations used in this document:

-A-

ACM	Asbestos-containing material
AEC	Atomic Energy Commission
ALARA	As low as reasonably achievable
AMU	Atomic mass unit
ANL	Argonne National Laboratory
ARAR	Applicable or Relevant and Appropriate Requirement
ASTM	American Society for Testing and Materials

-B-

BCY	Bank cubic yards
BNI	Bechtel National, Inc.
Btu	British Thermal Unit

-C-

°C	Degrees Celcius
CAA	Clean Air Act
CAT	Caterpillar Tractor Company
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
Ci	Curie(s)
cm	Centimeter
CMS	Combustion/melting system
CRV	Counter-rotating vortex
CSR	(Missouri) Code of State Regulations
CSS	Chemical solidification/stabilization
CWA	Clean Water Act

-D-

DNT	Dinitrotoluene
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DRE	Destruction and removal efficiency
dscf	Dry standard cubic foot

-E-

Eh	Chemical redox potential
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EP-TOX	Extraction Procedure Toxicity Test

-F-

°F	Degrees Farenheit
FCY	Fill cubic yard
FFHCM	Fossil fuel-heated ceramic melter
FHA	Federal Highway Administration
FS	Feasibility study
ft^2	Square foot
ft^3	Cubic foot

-G-

g	Gram(s)
gal	Gallon(s)
gpm	Gallons per minute

-H-

HDPE	High-density polyethylene
HLLW	High-level liquid waste
HMTA	Hazardous Materials Transportation Act
hp	Horsepower
hr	Hour(s)

-I-

in	Inch(es)
IRA	Interim response action
ISV	In situ vitrification

-J-

JEG	Jacobs Engineering Group, Inc.
JHCM	Joule-heated ceramic melter

-K-

kg	Kilogram(s)
kw	Kilowatt(s)
kwh	Kilowatt hour(s)

-L-

l	Liter(s)
lb	Pound(s)
LCRS	Leachate collection and removal system
LDCRS	Leachate detection, collection, and removal system
LLRW	Low-level radioactive waste
LLW	Low-level waste

-M-

m	Meter(s)
m^2	Square meter(s)
m^3	Cubic meter(s)
MDNR	Missouri Department of Natural Resources
MDOC	Missouri Department of Conservation
mg	Milligram(s)
mi	Mile(s)
MKF	MK-Ferguson Company
MKES	MK-Environmental Services Group
ml	Milliliter(s)
mm	Millimeter(s)
mrem	Millirem(s)
MSA	Material staging area
μCi	Microcurie(s)
μg	Microgram(s)
μm	Micrometer(s)

-N-

NCP	National Contingency Plan
NORM	Naturally occurring radioactive material
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	Nuclear Regulatory Commission

-O-

OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response

-P-

PAH	Polyaromatic hydrocarbons
PAT	Plasma arc torch
PCB	Polychlorinated biphenyl
pCi	Picocurie(s)
pH	Negative log of hydrogen ion activity
PIC	Products of incomplete combustion
PNL	Battelle Pacific Northwest Laboratory
PPE	Personal protective equipment
ppm	Parts per million
psi	Pounds per square inch

-R-

RCRA	Resource Conservation and Recovery Act of 1978
RI	Remedial investigation
ROD	Record of decision

-S-

sec	Second(s)
SEG	Science Ecology Group, Inc.
SOU	Separate operable unit
SSM	Shallow soil mixing

-T-

TBP	Tributyl phosphate
TCLP	Toxicity Characteristics Leaching Procedure
TNT	Trinitrotoluene
TSA	Temporary storage area
TSCA	Toxic Substances Control Act

-U-

UCS	Unconfined compressive strength
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978
UMTRA	Uranium Mill Tailings Remedial Action (Project)

-V-

V	Vertical

-W-

WSSRAP	Weldon Spring Site Remedial Action Project
wt.	Weight
wt. %	Weight percent

-Y-

yd	Yard(s)
yd^2	Square yard(s)
yd^3	Cubic yard(s)