PNL-6704
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Vitrification Technologies for Weldon Spring Raffinate Sludges and Contaminated Soils Phase I Report: Development of Alternatives

S. S. Koegler
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December 1988

Prepared for the
Weldon Spring Project Management
Contractor, Weldon Spring, Missouri
under a Related Services Agreement
with the U.S. Department of Energy
Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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PNL-6704

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A10
226-250	A11
251-275	A12
276-300	A13

PNL-6704
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VITRIFICATION TECHNOLOGIES FOR WELDON SPRING RAFFINATE SLUDGES AND CONTAMINATED SOILS
PHASE 1 REPORT: DEVELOPMENT OF ALTERNATIVES

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Richland, Washington 99352

SUMMARY

This engineering evaluation was conducted to evaluate vitrification technologies for remediation of raffinate sludges, quarry refuse, and contaminated soils at the Weldon Spring site in St. Charles County, Missouri. Two technologies were evaluated: in situ vitrification (ISV) and the joule-heated ceramic melter (JHCM). Both technologies would be effective at the Weldon Spring site.

For ISV, there are two processing options for each type of waste: vitrify the waste in place, or move the waste to a staging area and then vitrify. The total time required to vitrify raffinate sludges, quarry refuse, and contaminated soil is estimated at 5 to 6 years, with operating costs of $65.7M for staged operations or $110M for in-place treatment. This estimate does not include costs for excavation and transportation of wastes to the staging location. Additional tests are recommended to provide a more in-depth evaluation of the processing options and costs.

For the JHCM process, about 6.5 years would be required to vitrify the three waste types. Total operating costs are estimated to be $73M if the glass is produced in granular form, and $97M if the glass is cast into canisters. Costs for the excavation and transportation of wastes are beyond the scope of this study and are not included in the estimates. Additional tests are also recommended to better define technical issues and costs.

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INTRODUCTION

This phase I engineering evaluation report was prepared for the Weldon Spring Project Management Contractor (PMC) by Pacific Northwest Laboratory (PNL) to evaluate vitrification technologies for the remediation of raffinate sludges and contaminated soils at the Weldon Spring site in St. Charles County, Missouri. The objective of this project is to perform an engineering evaluation of the in situ vitrification (ISV) and joule-heated ceramic melter (JHCM) processes for remediation of wastes at the Weldon Spring site. A three-phase approach is being used to assist the Weldon Spring PMC in their investigation/feasibility study process: 1) development of alternatives, 2) screening of alternatives, and 3) detailed analyses of alternatives.

This report completes Phase 1 and lists the conclusions and recommendations of the engineering evaluation, followed by a description of the site characteristics. The two vitrification technologies are described and their application at the Weldon Spring site is evaluated. Preliminary cost estimates are also provided.

CONCLUSIONS AND RECOMMENDATIONS

This preliminary investigation shows that both ISV and JHCM technologies would be effective in remediating the raffinate sludges, quarry refuse, and contaminated soils at the Weldon Spring site. Implementation requirements and estimated costs for the two technologies, plus specific processing options, were evaluated and are presented here.

IN SITU VITRIFICATION

In situ vitrification would be effective in fixing or destroying the major chemical and radioactive contaminants in the raffinate sludges, quarry refuse, and contaminated soil. In situ vitrification could be implemented for each of the wastes to process them over a 5- to 6-year period. For ISV, two processing options were considered for each type of waste: vitrify the waste in place, or move the waste to a staging area and then vitrify. The staging option is preferable for the raffinate sludges since dewatering the sludge would be necessary before it could be vitrified in place. However, costs associated with sludge handling and transportation for the staging option were not included in the estimate.

The quarry refuse could be vitrified in place or moved to the main plant site and vitrified. In-place vitrification is the more costly option, although the cost estimate for the staging option does not include excavation and transportation costs. Excavation and transport costs wil be generic to a number of treatment technologies and are therefore not considered in this study. In-place vitrification may be limited by the presence of an unknown quantity of buried metals, the depth of wastes, and the height of the water table. Contaminated soils may be vitrified in place or staged and vitrified. Since soil contamination exists mainly in shallow areas, only the staged operation was considered in this study.

Total estimated equipment costs for six ISV machines with three off-gas systems is $7.3M. The total time required to vitrify raffinate sludges, quarry refuse, and contaminated soil is estimated at 5 to 6 years, with operating costs of $65.7M for staged operation or $110M for in-place treatment.

The costs for excavation and transportation of wastes to the staging location have not been included in the estimates. These costs are not a bid, but represent estimates of anticipated costs on the basis of existing information.

It is recommended that the ISV technology be further evaluated in Phase II of this project, and that two ISV treatability tests be performed to eliminate the major unknowns from the Phase I evaluation. The cost of processing the raffinate sludge using ISV varies significantly, depending on the amount of soil that must be added to the site. A bench-scale ISV experiment with raffinate sludge and clay liner material (similar to material that lines the raffinate pits) and/or soil would demonstrate the processability of the sludge and determine the amount of soil needed to produce a suitable vitrified product. Since silica and alumina are two major constituents of the sludge, it may be possible to vitrify the sludge without adding soil. A second ISV bench-scale experiment is also required to confirm ISV processability of the clay liner alone.

It is impractical to conduct a representative bench-scale ISV test of the quarry waste without additional characterization of the quarry site. However, Phase II should provide a more in-depth evaluation of the ISV processing options and costs. Processability of the contaminated Weldon Spring soil will be determined as part of the raffinate sludge tests; therefore, a separate bench-scale test is not required for the soils.

VITRIFICATION BY A JOULE-HEATED CERAMIC MELTER

A JHCM housed in a treatment and immobilization facility (TIF) should successfully process the raffinate sludges, quarry refuse, and contaminated soil, thus fixing or destroying the major chemical and radioactive contaminants. The TIF would house bulk-handling equipment, a 400 ton/day JHCM, and off-gas treatment equipment. The estimated capital cost of the TIF is $24.1M. A processing period of about 6.5 years will be required to complete vitrification of the 264,000 tons of sludge, soil, and quarry waste. Total operating cost over this period is $73M if the glass is produced in granular form, and $97M if the glass is cast into canisters and placed in a landfill or other storage facility. Secondary wastes generated by the process will be minimal. The costs for excavation and transportation of wastes to the TIF have not been included in the estimates. As with ISV cost estimates, these costs are not a bid, but represent estimates of anticipated costs on the basis of existing information.

It is proposed that the JHCM melter technology be considered for further evaluation in Phase II of this project, and that three laboratory melt tests be performed for the raffinate sludge, a blended raffinate sludge and liner/soil material, and simulated quarry refuse, as proposed in the statement of work. The proposed tests will provide a close approximation of the waste/glass former blend requirements, determine the feasibility of blending the wastes, and determine secondary waste streams. The laboratory results will aid in better defining the energy and raw materials requirements, which are a significant fraction of the operating costs.

BACKGROUND

The Weldon Spring site comprises a 9-acre former limestone quarry, a 52-acre raffinate disposal area, and a 169-acre mothballed uranium feed materials plant. The quarry contains an estimated 95,000 cubic yards of rubble and soils contaminated with trinitrotoluene (TNT), dinitrotoluene (DNT), uranium, thorium, and their decay products (Bechtel 1985). The quarry is located about 4 miles south of the main site. The waste material is piled 40 feet above the floor of the quarry, with most of the waste covered by several feet of soil. Vegetation covers the quarry surface and the lowest area is covered by water. Where a cross section is visible, a large amount of metal (e.g., crushed drums, sheet metal, structural building iron, and process equipment) protrudes from the soil. Large pieces of equipment such as tanks, a fork-lift truck, and up to 3000 drums are also buried, although ground-penetrating radar or similar techniques have not been used to locate these large items. The water table is about 15 feet above the floor of the quarry, and the standing water level is about 6 feet above the water table.

There is much interest in moving the rubble from the quarry to the main site because of its proximity to public areas and water supplies, and to permit geological characterization and estimates of contaminant migration in the underlying fractured limestone. Late in 1986, eighteen boreholes were drilled into the quarry to chemically characterize the quarry for PCBs, TNT, and other hazardous chemicals (Bechtel 1987). The drilling operation was extremely difficult and exposed metal, pieces of concrete, bricks, rebar, and other building materials.

The raffinate disposal area includes four open pits covering a total area of 27 acres and containing about 220,000 cubic yards of sludge (DOE 1987a). Below the sludge is an estimated 130,000 cubic yards of contaminated soil. The sludge is a lime-neutralized material from uranium and thorium processing operations and contains uranium, thorium, radium, and their decay products. The sludge in the pits is about 10 feet deep and is presently covered by 1 to 3 feet of water. The pits are lined with a low permeability clay-soil that has not been sampled for fear of destroying the pit's integrity. Vegetation has been removed from the sides of the pits, leaving only grass. Radiological characterization data exist from previous studies, and additional chemical and physical characterization of the sludges is being performed by the Weldon Spring PMC. The main portion of the site is an inactive uranium feed materials plant consisting of about 50 deteriorating buildings and an estimated 337,000 cubic yards of contaminated soil, equipment, and facilities.

DESCRIPTION OF THE VITRIFICATION TECHNOLOGIES

Pacific Northwest Laboratory has extensive experience in vitrification technologies, beginning with in-can and small-scale joule-heated melter development in the early 1970's. Two vitrification technologies have matured to the point of large-scale deployment: in situ vitrification and the joule-heated ceramic melter (JHCM).

IN SITU VITRIFICATION

In situ vitrification is a patented process originally developed by PNL for providing enhanced environmental stability to contaminated soils without the need for exhumation (Buelt et al. 1987). Figure 1 illustrates the progressive stages of ISV processing. To begin the process, electrodes are inserted in the ground in a desired array (depth and spacing). A graphite-containing starter material is placed on the surface of the soil between the electrodes to form a conductive path. An electric current is passed between the electrodes, creating temperatures high enough to melt the soil (typically about 1700°C). The molten zone grows downward and outward (beyond the electrodes), encompassing the contaminated soil and contained waste materials.

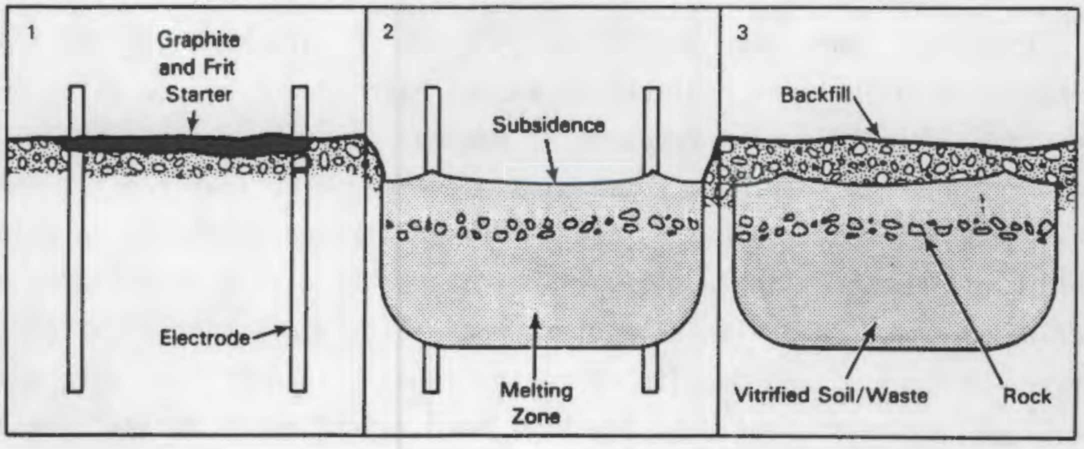

FIGURE 1. ISV Processing Sequence

The resulting ISV product is a glass and crystalline mass resembling natural glass (obsidian). For typical earthen materials within the United States, the final density of the ISV block varies from 2.3 to 2.5 g/cm^3 (144 to 156 lb/ft^3). Although the block is only 3% to 11% heavier than concrete, it possesses about 5 to 10 times the strength of unreinforced concrete in both tension and compression. The ISV block is extremely inert, with a chemical leach resistance approaching that of Pyrex glass. Some crystallization may be present in the block, which results in even greater physical properties.

The ISV process was developed specifically to incorporate long-lived radioactive waste materials into a glass waste form. The U.S. Department of Energy (DOE) has supported the development and performance of field-scale demonstrations of the basic ISV technology. In addition, PNL has performed several bench- and pilot-scale tests on process sludges and other hazardous materials. The tests have shown that the ISV process destroys and/or removes organic and volatile inorganic contaminants from the soil. Any remaining hazardous inorganic materials (e.g., heavy metals or radioactive materials) are incorporated into a final product that prevents releases of contaminants into the environment.

CERAMIC MELTER TECHNOLOGY

Since 1973, more than 200,000 kg (440,000 lb) of waste glasses containing simulated high-level radioactive wastes have been produced using JHCM technology. Vitrification research at PNL has covered a wide range of waste stream compositions for both commercial and defense nuclear reactor operations (Chapman, Pope and Barnes 1986). Waste streams vitrified in existing developmental melters include high fission product nitric acid wastes and alkaline sludges containing refractory materials (e.g., high iron, chromium, alumina, zirconium, and zeolite concentrations). In addition, more than 50 million curies of radioactivity have been vitrified in radioactive process demonstrations.

The JHCM process is an adaptation of commercial glass-making technology. The glass melt is typically operated between 1000°C (1800°F) and 1300°C

(2400°F). The thermal energy required to maintain the temperature of the glass and provide the heat to decompose and melt the soils and sludges is supplied through joule heating of the glass. Joule heating is achieved by passing an alternating electric current between submerged electrodes located in the melt tank. The melt tank is lined with high-temperature refractory materials to resist corrosion and contain the molten glass.

Waste materials are fed into the high-temperature furnace, where they decompose and the residual oxides and any ash material melt to form a glass product. The waste materials are mixed with the appropriate glass-forming chemicals, typically silica, soda ash, and lime. This mixture forms the basic glass structure that allows the inorganic waste materials to be dissolved. The glass formers and waste can be mixed in a batch tank prior to feeding the melter, or in the melt cavity itself.

To process wastes that are liquids or sludges, the mixture of wastes and glass-forming chemicals is deposited directly on the glass surface. The water evaporates and the waste materials decompose to form oxides. Mixtures of solids, such as contaminated soils, incinerator ash, or combustibles, can

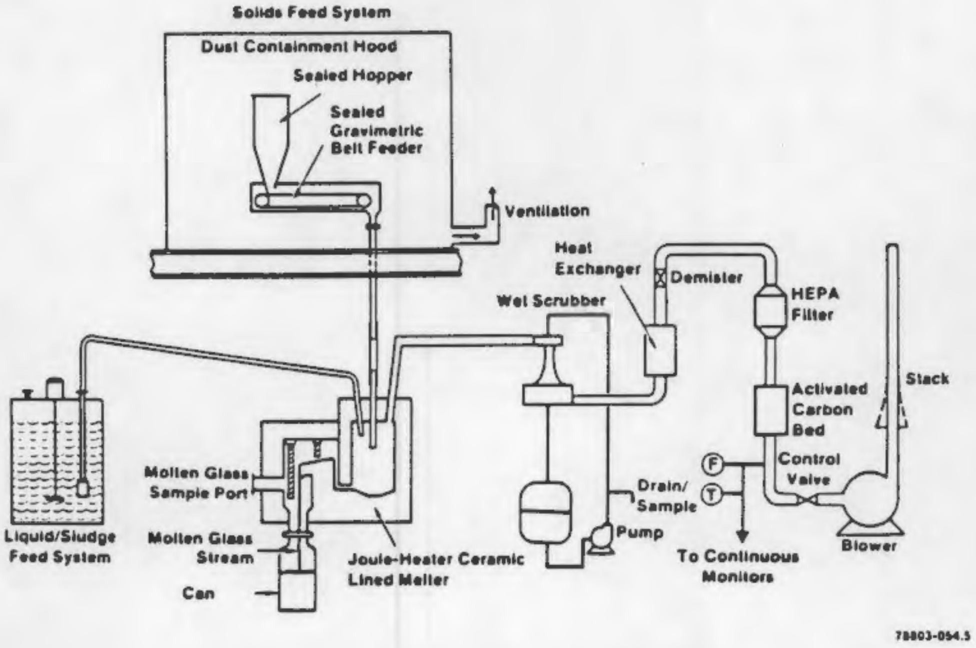

FIGURE 2. Basic JHCM Process for Hazardous Waste Treatment

be deposited on top of, or below, the glass surface. As the waste particles rise to the glass surface, they undergo pyrolysis. Organic compounds are thermally degraded to low carbon chain gases that readily burn in the plenum space or secondary combustion chamber above the melt surface, where additional air is added. Glass is discharged from the melt tank into disposal containers by way of an overflow section, or quenched in water ("fritted") to produce a granular product for bulk disposal.

The necessary components of the off-gas treatment system will depend on the specific waste stream. The components are selected from commercially available equipment. The decomposition of some waste species will result in the generation of hazardous gases such as NO_x or HCl, which escape from the melt and must be treated. The resultant waste streams from off-gas treatment, such as concentrated scrub solutions or filter media, can be recycled to the melter or disposed of directly if they are of low toxicity.

EVALUATION OF THE IN SITU VITRIFICATION OPTION

The application of ISV to raffinate sludges and quarry wastes is evaluated based on projections of process effectiveness using related ISV performance data, an analysis of implementation options, and a preliminary cost estimate of the options.

RAFFINATE PIT SLUDGES

Process Effectiveness

In situ vitrification has been successfully used to solidify 10,000 kg of industrial sludge heavily laden with zirconia and lime (Buelt and Freim 1986). The process was shown to destroy organic constituents, fix heavy metal and radioactive components, and drastically reduce radon emanation from radium sources in the sludge. As a result, the vitrified sludge can be disposed in a smaller area in a form that is unlikely to require further treatment for environmental protection. The sludge was successfully melted to the 3-m depth using the pilot-scale ISV system, reducing its volume by a factor of 6.7 and driving the 55-70 wt% moisture from the sludge.

Previous operating experience indicates that the ISV process would be very effective for treating the Weldon Springs raffinate pit sludges. The sludges contain radionuclides in both the uranium-238 and thorium-232 decay series, with thorium-230 being the principal radionuclide. The sludges have high concentrations of nitrates and fluorides and contain arsenic, chromium, copper, and lead. The processing effectiveness of ISV for these chemical species is listed in Table 1 (FitzPatrick, Timmerman, and Buelt 1987; Buelt, Timmerman and Westsik 1988; Buelt and Carter 1986). Processing effectiveness is measured in terms of the retention factor--the ratio of the material retained by the process to the amount that escapes the system during processing. Vitrified soil retention factors for thorium and uranium are projected to be excellent (i.e., 10^4 to 10^5). Combined retention factors for the soil and off-gas system are projected to range from 10^5 for fluorides, arsenic, and lead, to as high as 10^{10} for thorium and uranium.

TABLE 1. Projected ISV Effectiveness on Raffinate Sludges

	Retention Factors		
Contaminant	Vitrified Soil	Off-Gas System	Combination
Radionuclides:			
Radium[(a)]	10^2	10^4	10^6
Thorium	10^4 to 10^5	10^5	10^9 to 10^{10}
Uranium	10^4 to 10^5	10^5	10^9 to 10^{10}
Heavy metals:			
Arsenic[(b)]	10	10^4	$\sim 10^5$
Chromium	10^3	10^4	10^7
Copper	10^3	10^4	10^7
Lead	3 to 30	10^4	$\sim 10^5$
Anions:			
Nitrate	10^2	3	10^2 to 10^3
Fluoride	10^2	10^3	10^5

(a) Retention factors for radium are estimated based on data for cesium and antimony, which have similar melting and boiling points.
(b) Retention factors for arsenic are estimates for lead.

Implementation

Because of the high moisture content of the raffinate sludges (estimated to be 70-75 wt% water), the alternatives considered for ISV treatment of the sludges include steps to reduce the moisture in the sludge. If not reduced, the high content moisture could prohibit placement of the electrodes and off-gas hood. The high moisture content would also lower the processing efficiency since more energy is required to evaporate the water. Two alternatives for implementing the ISV technology on the raffinate sludges are described below.

Alternative 1: Process the Raffinate Sludges In Place Using ISV

For this alternative, free-standing water in the raffinate pits will be pumped off and treated elsewhere as required. The sludge will then be covered with approximately 1 m of a low permeability clay material and dewatered by one of the technologies suggested in the Hanford Defense Waste Environmental Impact Statement (HDW-EIS) (DOE 1987b) until the moisture content is reduced to a level that will support the weight of the ISV hood and permit effective processing of the sludge. Bench- or engineering-scale ISV testing will be required to determine the sludge moisture content that the process can effectively handle. Besides providing a barrier to moisture, the clay cover also provides an uncontaminated soil base for placing the graphite and frit startup paths. Raffinate pit #4 is only about 12% full and contains some rubble that must be characterized prior to ISV operations. It may be appropriate to remove any large metal objects from pit #4 and consolidate the sludge into one section of the pit.

Alternative 2: Move the Raffinate Sludges to a Staging Area and Apply ISV

A large volume reduction (up to 70%) of the sludge during ISV is anticipated as a result of the moisture that is driven off during processing. Because of the large volume reduction, a substantial quantity of sludge could be processed per ISV setting at staged locations, thereby reducing the number of settings required and thus the electrode costs and equipment setup costs. Prior to sludge removal, free-standing water in the raffinate pits will be pumped off and treated elsewhere as required. The sludges and contaminated soils would then be removed and fed into the ISV system at the staged location. The hood would be designed to permit feeding of the sludge through a port into the melt area. As the sludge is vitrified and consolidated, additional sludge would be added until the melt is at or near grade level. It may be necessary to add soil to the sludge to produce a quality vitrified product. Soil could be added in alternate layers with the sludge or mixed with the sludge. Contaminated soil from other locations on the site would be a logical choice for this application.

QUARRY REFUSE

Process Effectiveness

In situ vitrification has been applied to a variety of soils and other materials (Buelt et al. 1987). Soils normally contain alumina and silica in the 70% to 98% range, which increases the chemical durability of the product. Soils also contain Na_2O and K_2O, which act as the primary charge carriers in the molten soil and thus affect the conductivity and melting temperature. In situ vitrification is also effective in treating soils that contain bricks, chunks of concrete, metals, and organics.

Ceramic materials, especially concrete, are similar to soil in composition and are dissolved by the molten soil during ISV processing. In tests with concrete blocks up to 9% of the soil weight, the thermal expansion of the cement and aggregate with the opposed contraction of the concrete due to water loss tended to fracture the concrete blocks and aid in their dissolution into the glass. A large concrete fraction would not limit ISV performance. The increased electrical resistivity of the molten glass due to concrete inclusions can be accommodated by decreasing the spacing between the electrodes.

Metals up to 5% of the soil weight can be accommodated by ISV, provided the metal occupies less than 90% of the distance between the electrodes. Metals are dissolved in the molten glass as metal oxides and become part of the glass matrix. The unknown metals concentration in the quarry waste poses a potential limitation, as discussed below in the implementation section.

The ISV process can be expected to effectively destroy or immobilize the contaminants in the quarry refuse, including uranium, thorium, PCBs, and nitro-aromatics. Inorganic contaminants are dissolved into the molten glass during processing and are retained by the solidified glass. Organic materials are pyrolyzed as they contact the hot, molten glass and are eventually combusted in the air space above the molten zone, inside the off-gas hood. Expected retention/destruction factors for several organic and inorganic chemicals are shown in Table 2.

Implementation

Two alternatives have been identified for application of the ISV process to the quarry wastes. A portion of the quarry refuse is in an area where the water table is about 15 feet above the quarry floor. Additional electrical power is required to vitrify waste below the water table since water will be recharged into the area that is being vitrified. Because the quarry is a

TABLE 2. Projected ISV Effectiveness on Quarry Refuse

Contaminant	Retention/Destruction Factors		
	Soil	Off-Gas System	Combination
Radionuclides:			
(See Table 1 for uranium, thorium, and radium)			
Heavy metals:			
Zinc	3 to 30	10^4	$\sim 10^5$
(See Table 1 for arsenic, chromium, copper, and lead)			
Anions:			
(See Table 1 for nitrate and fluoride)			
Organics:			
PCBs	10^3	10^3	10^6

fill site, the soil and waste permeability will be high compared to the undisturbed limestone to the side and below the wastes. Therefore, the water recharge will be significant and will likely limit the maximum ISV depth.

Another concern is the metal content and distribution within the quarry site. Metal, which has a much higher electrical conductivity than molten soil, can decrease electrode voltage when present during ISV, and in extreme cases it can result in a short circuit. Engineering-scale ISV tests indicate that metal may occupy up to 90% of the linear separation between electrodes. Despite this high tolerance for metals, a site survey is recommended using ground-penetrating radar or similar technology to identify large metal components that may hinder or prevent ISV operations. Once identified, large pieces of metal could be removed by excavation. Careful placement of the ISV electrodes could eliminate any potential for short circuiting. Two alternatives for implementing ISV at the quarry refuse site are described below.

Alternative 1: Move Wastes from Areas of Water Table Intrusion, Place On Top of Other Waste Areas in Quarry, and Apply ISV In Place

A portion of the quarry waste is buried to 40 ft, which is about 15 ft below the water table in that area. These wastes would be removed and spread over waste areas that are not so deep, to a total waste depth of 20 ft

(6.0 m). Topsoil from portions of the quarry that have very shallow surface contamination would also be moved and consolidated to the 20-ft depth in the vitrification area.

Alternative 2: Move the Quarry Waste to a Staging Area and Apply ISV

This alternative assumes that all of the quarry wastes would be removed and then treated at a staged location. The fenced raffinate pit area would provide a logical staging area. This alternative would provide for the removal of large metal items prior to treatment by ISV, if needed.

CONTAMINATED SOILS

Process Effectiveness

Process effectiveness for the surrounding soils is the same as that for the raffinate pit wastes and quarry wastes (see Tables 1 and 2).

Implementation

This analysis assumes that the vicinity soils will be removed to a staging area and processed by ISV. It is possible that the soils could be treated in place; however, information on the geometry of the vicinity soils is needed before details of in-place implementation can be developed.

PRELIMINARY COST ESTIMATE FOR IN SITU VITRIFICATION

This section presents an economic analysis of ISV based on multiple, large-scale operating systems at the Weldon Springs raffinate pit site. Soil and sludge volumes and process parameters that were used to estimate ISV processing costs for the treatment alternatives are presented in Table 2. A computer model was used to predict run time, mass vitrified, and volume vitrified per ISV operation. The estimated time to vitrify all the wastes ranges from 4.7 years to 5.9 years, depending on the treatment alternative used. These estimates do not include the time for sludge dewatering or waste removal, which depend on the dewatering technology selected.

The equipment accounted for in the ISV cost estimate includes six electrical transformers and six off-gas hoods, with three off-gas treatment systems and three backup blower systems. Each off-gas system and backup blower

TABLE 3. Bases for Cost Estimate for Processing Weldon Springs Wastes Using ISV

Parameter	Raffinate Pits		Quarry Wastes		Stage Vicinity
	In Place	Stage	In Place	Stage	Soils
Waste volume, m^3	170,000	170,000	73,000	73,000	21,000
Contaminated soil, m^3	98,000	98,000	0	0	0
Clay overburden added, m^3	57,000	17,000	0	0	0
Total volume treated, m^3	325,000	285,000	73,000	73,000	73,000
Moisture content, %	70	70	30	30	10
Vitrification depth, m	5.0	6.0	6.0	6.0	6.0
Electrode separation, m	5.5	5.5	5.5	5.5	5.5
Time per ISV setting(a), h	144	528	206	282	182
Volume treated/setting, m^3	268	1,167	395	550	395
Number of ISV settings(b)	1,348	272	206	148	59
Annual processing rate per ISV machine(c), m^3	11,740	13,940	12,090	12,300	13,690
Total time to vitrify(d), yr	4.6	3.4	1.0	1.0	0.3

(a) Time includes 12 h for a low-powered startup and 16 h for moving and setting up hood.
(b) The number of ISV settings accounts for a 10% overlap for each ISV operation.
(c) The annual processing rate assumes operations at 80% capacity.
(d) Vitrification time assumes six ISV hoods and transformers are used at the site.

system would treat off gases from two ISV operations, thus reducing capital costs as well as operational labor costs. Table 4 lists the site equipment costs for both in-place and staged operations. The only difference in capital equipment is that the hood for staged operations includes a conveyor system for feeding the wastes into the ISV zone. Total equipment cost, including design, engineering, and fabrication for in-place operations, is $7.0M. For staged operations, the cost is $7.3M. The cost for waste removal and transport is not included for the staged operations. Site operating costs are listed in Table 5 for each waste type and treatment alternative. These costs are not a bid, but represent estimates of anticipated costs on the basis of existing information.

The greatest operational cost savings would result from staging the raffinate pit sludges ($45.4M) rather than in-place vitrification ($87.8M). The reduced costs are primarily attributed to a reduction in the number of ISV settings, which reduces the costs associated with hood placement labor and

TABLE 4. ISV Site Equipment Costs ($1000)

Equipment Costs	In-place Operations	Staged Operations
Engineering and design	500	500
Transformers (6 required)	1,400	1,400
Off-gas hood and line (6 required)	900	1,200(a)
Off-gas system (3 required)	3,100	3,100
Backup blower system (3 required)	500	500
Power lines	100	100
Electrode power cable	200	200
Electrode placement machinery	100	100
Crane	100	100
Front end loader	100	100
Total equipment costs	7,000	7,300

(a) The hood for staged operations includes a conveyor system for feeding the waste into the ISV zone.

TABLE 5. ISV Site Operating Costs ($1000)

Cost Breakdown	Raffinate Pits In Place	Raffinate Pits Stage	Quarry Wastes In Place	Quarry Wastes Stage	Stage Vicinity Soils
Labor costs					
Vitrification crew	8,400	6,200	1,800	1,800	500
Heavy equipment crew	3,500	700	600	400	100
Total labor	11,900	6,900	2,400	2,200	600
Consumable costs					
Electrodes	44,100	10,600	8,000	5,800	2,300
Energy (6¢/kWh)	31,100	27,800	7,400	7,500	1,800
Secondary waste	700	200	100	100	100
Total consumables	75,900	38,600	15,500	13,400	4,200
Total operating costs	87,900	45,500	17,900	15,600	4,800

the electrodes. Total costs for the in-place ISV of the raffinate and quarry wastes and staging the ISV of vicinity soils is $117.5M (unit volume cost: $280/m^3). The costs for staging the ISV of all the wastes is $73.2M (unit volume cost of $193/m^3).

EVALUATION OF THE JOULE-HEATED CERAMIC MELTER OPTION

The application of the JHCM process to the Weldon Spring wastes is described for each waste type (i.e., the raffinate pit sludges, quarry refuse, and contaminated soils). However, a single vitrification system, established in a TIF, will be required. The following sections describe the use of a TIF for each waste type and possible blending strategies to minimize waste volumes.

RAFFINATE PIT SLUDGES

Process Effectiveness

The radionuclide materials present in the raffinate pits would be effectively immobilized in a glass product. A favorable property of glass is its ability to accommodate a wide variety of compositional variations and still maintain its basic durability. As a result, the possible variability in raffinate sludges between the four pits and within each pit, as portrayed by recent analyses, would not require blending of the sludges within the pits or between the pits. However, to minimize the total volume of glass produced the sludges could be blended amongst themselves or with the other waste candidates, such as the pit liners or quarry refuse. This issue can be resolved following a more rigorous characterization of the raffinate sludges.

Technical issues still to be resolved include the amount of moisture that may be present within the sludge at the time it is to be processed, and the possible requirement for destruction of NO_x in the off-gas treatment system. Because vitrification is an energy-intensive process, it is advantageous to remove as much moisture from the sludge as is practical prior to vitrification. Removing moisture would also affect the design of the off-gas system. If a majority of the water is removed prior to vitrification, no liquid condensate stream is likely to result (however, the vitrification system is fully capable of processing a liquid feed stream). The requirement for equipment capable of destroying NO_x will depend on off-gas emission limits imposed at the site boundary. The nitrate levels listed in the HDW-EIS (DOE 1987b) must be reviewed to determine if NO_x abatement will be required. None will be assumed at this time.

Implementation

Following removal of free-standing water in the pits, the sludge material would be removed and transferred to the TIF. The TIF material-receiving area will consist of crushing and delumping equipment and metal-shearing machinery. An agitated tank may be required in the feed receipt area to handle high-moisture sludge. Each of the solids-handling areas will require enclosures to contain the dust that will be generated. The entire feed preparation system should be tied to a central filter system that would remove any airborne dust and deposit it into the feed storage bin. The filter system would contain a high-efficiency particulate air (HEPA) filter bank for use before venting the air to the environment.

Glass former additives such as soda ash and lime would be transported in bulk by railroad tank car or truck, and transferred to storage silos with a capacity for about a 1-week supply of glass additives. The additives would be blended with the feed stream just before the stream enters the melter, or fed separately to the melter, depending on the water content of the sludge material. For this study, a 400 t/day JHCM system has been assumed in order to complete all vitrification activities at the site in a 6-year period, thereby precluding the need for rebricking the melter.

The feed and glass formers are introduced into one end of the melter and the molten product and off gases are removed from the opposite end. The glass product is continuously discharged into receiving drums or fritted for final disposal. The vapor space serves as a secondary combustion chamber to complete destruction of any organic species present in the off-gas stream. If required, the secondary heating sources used during startup activities also could be designed to function as afterburners.

It is recommended that the raffinate pit clay liner be excavated and vitrified with the sludge material to minimize the amounts of glass additives and vitrified product. The amount of glass to be produced is expected to be determined by the fluoride solubility limit in the glass. Fluoride, a major constituent in the raffinate sludges, has a maximum glass solubility of about 5 wt%. Assuming the 170,000 m^3 of sludge is comprised of 50 wt% solids, of which fluoride comprises 10%, a waste loading in the glass of about 50% would occur. This would result in a total glass production on the order of 300,000 lb-tons. Therefore, a 2.5-yr processing period would be required. The vitrification of the clay liner material (98,000 m^3) from the raffinate pits should be straightforward and require only the addition of glass-forming chemicals. The liner material would result in about 250,000 lb-ton of glass and a production period of 2.1 yr.

The off-gas treatment system described previously should adequately treat the off gases generated during the processing of the raffinate pit sludges and clay liners. However, if the sludges contain a significant amount of water, the off-gas treatment system would require the addition of off-gas line heaters to prevent condensation upstream of the dry filter systems. In addition, a cooler/condenser would be located downstream of the filter systems to remove the water from the off-gas stream prior to off-gas discharge to the stack. This issue will be addressed in a subsequent detailed engineering analysis.

QUARRY REFUSE

Process Effectiveness

The JHCM is capable of vitrifying soils and other materials at temperatures up to 1500°C (2700°F). Because of the high operating temperatures of the system, all classes of organic contaminants present in the feed stream are destroyed via pyrolysis and/or combustion. Final system design can assure effective destruction of all organic priority pollutants. The trace radionuclides in the refuse will be incorporated into the glass matrix of the final product and isolated from the environment upon final disposal.

A relatively small fraction of the material fed to the melter will be transported into the off-gas treatment system. Entrained material and aerosols that have volatilized from the glass surface can be effectively captured using standard dry-filtering techniques. Of the priority pollutant metals, mercury is known to escape from the glass during vitrification due to its high vapor pressure. Based on the data in the Weldon Spring draft EIS (DOE 1987a), complete vitrification of all quarry refuse will result in a maximum of 2,000 lb of mercury. Although wet scrubbing systems will effectively capture the condensed species of mercury, primarily mercury halides, other off-gas contaminants will also be scrubbed. Therefore, a wet scrubber may overly complicate the off-gas treatment design. An alternative approach is proposed in which HEPA filters are used to capture the condensed vapors. Prior to their disposal into the melter's solid feed stream, the HEPA filters would be heated to separate mercury species from the other particulate matter. The mercury species could then be recondensed and packaged for disposal as a minor secondary waste stream. The technical requirements to achieve this approach would be determined during the subsequent phases of this study.

Implementation

The quarry refuse materials would be exhumed using standard equipment. To prevent the dispersion of contamination from the site, either a temporary enclosure or frequent spraying of the quarry materials may be required to minimize dusting. The refuse material would be loaded into enclosed dump trucks or containers for appropriate transportation. Very large structural steel components exhumed from the quarry should be considered for separate methods of decontamination and disposal, rather than inclusion for vitrification treatment. If they are to be vitrified, size reduction will be required.

Upon arrival at the TIF, the refuse materials would be prepared for vitrification. The same TIF described for the treatment of the raffinate pit sludges would be used for the quarry refuse. Because the quarry refuse is comprised primarily of contaminated soils and building rubble, the refuse would be processed through crushing and delumping equipment in the solids receiving area. Shearing equipment would be used to size reduce metal materials, such as iron drums and construction rebar. Once the feed material is properly sized (e.g., less than -10 mesh), it would be stored in a feed storage bin or hopper. The material then would be fed by belt or auger to the JHCM. Glass former additives such as soda ash and lime would be transferred and blended in a feed hopper, then blended with the feed stream just prior to entering the melter.

The roughly 73,000 m^3 of quarry refuse are expected to result in approximately 190,000 lb-tons of final glass product. This estimate is based on the assumptions that the quarry refuse has an average specific gravity of about 1.5 (i.e., ~100 lb/ft^3) and that the final glass product will contain 75% waste and 25% glass former additives, and have a specific gravity of 2.5. Assuming the plant operates 80% of the year, the quarry refuse will be vitrified within 1.5 yr.

The off gases generated during processing will contain volatile species in the form of aerosols, entrained dust material, water vapor, decomposition gases, and air. The previously described off-gas treatment system will be adequate for processing the quarry refuse.

CONTAMINATED SOILS

Process Effectiveness

The TIF already described is fully capable of processing the contaminated soils. The soils would be excavated and transported to the TIF. Upon receipt, the soils would go through the delumper and crusher to reduce the size of any rocks. If wood and other vegetation is also mixed with the soil, a separate shredder may be required. However, the presence of such material in the furnace feed stream would be acceptable. Based on the estimate of 21,000 m^3 of solids requiring solidification, approximately 50,000 lb-ton of glass product would be produced over a 5-period.

PRELIMINARY COST ESTIMATE FOR THE JHCM OPTION

Although a detailed cost estimate has not been performed for the vitrification system to be housed in a TIF, rough capital equipment and operating cost estimates were determined for a system of this scale. Based on this information and standard estimating practices, an order-of-magnitude cost summary for the JHCM was prepared and is given in Table 6. Other costs that have not been included as a part of this evaluation, but that should be

TABLE 6. Cost Summary for the JHCM Option

Capital Equipment Costs	Costs (in $1000)		
Glass-forming chemicals addition system		200	
Feed receipt handling & feeding systems		1,100	
JHCM furnace (400 t/d capacity)		6,500	
Off-gas treatment system		700	
Glass receipt/container system		500	
TOTAL PURCHASED EQUIPMENT COSTS (PE)		$9,000	
Purchased-equipment installation (33% of PE)	2,800		
Instrumentation & control (15% of PE)	1,300		
Process piping (12% of PE)	1,000		
Electrical (20% of PE)	1,700		
Auxiliaries (10% of PE)	800		
Building & facilities (40% of PE)	1,700		
Site preparation (10% of PE)	800		
Contingency (20% of PE)	1,700		
Fees and engineering contingency	3,900		
TOTAL CAPITAL COSTS			$24,700

Projected Operating Costs (6.5-year operation)	Costs (in $1000)	
Direct labor	6,500	
Materials	19,500	
Utilities and services		
Electricity (based on 6¢/kWh)	44,200	
Water	700	
Natural gas (based on 40¢/100 scf)	2,000	
Glass-receiving drums[(a)] (based on 55-gal drums @ $20/drum)	24,000	
TOTAL OPERATING COSTS		$96,900

(a) If the glass product was not collected in a container or drum, drum, this item would be eliminated.

considered, are the additional costs to remove the contaminated materials from their present locations, transport the wastes to the TIF, and transport the resulting glass product to an engineered vault or trench. In addition, costs for final decommissioning and disposal of the TIF components have not been included in the estimates.

Approximately 25% of the capital equipment costs are associated with the JHCM. For this cost estimate, it was assumed that the glass would be collected in some type of container or drum to ease handling and permit convenient retrieval. As a result, additional capital costs (about 5%) and significantly higher annual costs (a maximum of 25%) will be realized. Standard multiplying factors were used to estimate the additional capital costs. Total capital costs of $24.1M were determined. To reduce these capital equipment costs, it is recommended that the glass be fritted in a water bath. The resulting granular glass product could be disposed of in the engineered disposal site. In addition, the smaller-sized glass product should still pass product quality criteria and could be retrieved, if necessary.

The projected annual costs account for labor costs, materials costs, utilities and services charges, and costs for glass-receiving drums (if required). The labor estimate accounts for costs for a supervisor, foremen, operators, support staff, and overheads. Most of the materials costs can be attributed to the purchase of bulk quantities of the glass-forming additives (soda ash and lime). Also considered were the consumption of electrode material and maintenance charges (2% of equipment costs).

The utilities and services charges include costs for energy and water. A local industrial electrical rate of 6¢/kWh was used in this estimate. Vitrification processes are energy intensive and for application of the JHCM process at the Weldon Spring site, about 45% of the annual operating costs will be for electricity. A relatively insignificant amount of natural gas will be used for initial startup of the melter as well as being used as a secondary heat source, if necessary, during the processing of materials that contain high levels of organic contaminants.

The costs to purchase 55-gal glass-receiving drums were conservatively estimated. It is not yet clear if a containerized glass product is required, given the fact the glass will be disposed of on site. As discussed previously, the use of containers will increase annual operating costs by about 25%. Therefore, there is a strong incentive to handle a granulated glass product (i.e., fritted glass) as the final disposal form. Without the canister costs, the annual operating costs for the vitrification system are \$17.9M for each year of operation, or \$73M over the 6.5-year production period. If canisters are used, operating costs over the 6.5-year period will be \$97M. On a cost-per-volume basis, the disposal costs are estimated at $\$256/m^3$ or $\$322/m^3$, depending on whether the glass product is fritted or placed in canisters.

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