COST COMPARISON FOR TREATMENT OF ORNL REMOTE-HANDLED TRANSURANIC SLUDGE BY GROUT AND VITRIFICATION PROCESSES

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EXECUTIVE SUMMARY

The Department of Energy (DOE) is planning the remediation of underground storage tank radioactive waste problems at DOE sites in Hanford, WA, Idaho National Environmental Engineering Laboratory (INEEL), and Oak Ridge National Laboratory (ORNL). Treatment of the tank waste will involve immobilization processes to solidify the waste and stabilize the radioactive and hazardous constituents. The DOE must make informed decisions with regard to the technology used and the potential costs of these processes. To address this need, the DOE Tank Focus Area is evaluating immobilization processes to gain comparative information with regard to effectiveness and cost. ORNL and the Savannah River Technology Center have teamed to evaluate grout and vitrification processes for ORNL tank sludge. This study evaluates the immobilization processes based on actual waste form volume information, actual cost information from waste retrieval and pretreatment projects, and alternative facility options. This information will be valuable to Oak Ridge and to other DOE sites.

This study is the first head-to-head comparison of grout and vitrification processes using actual tank waste samples within the DOE complex. Previous cost comparisons have used estimated final waste form volumes based on literature data. This report updates previous cost analyses using waste form data generated in laboratory studies using actual waste samples. The Savannah River Technology Center and the ORNL Chemical Technology Division developed vitrification and grout formula for the Oak Ridge tank sludges and validated the formula by immobilizing samples of actual tank sludge from several different tank farms. This process was used to obtain chemical costs and final waste form volumes for both technologies. Waste form volume has a significant impact on the cost of waste form management, storage, and disposal. Additional baseline information from past cost estimates, from recent waste treatment technology demonstrations, and from waste disposal sites was used to develop an updated estimate for immobilization of Oak Ridge tank waste. Emphasis was placed on determining the major differences between the cost of grout and vitrification technologies for the MVST application. A more detailed conceptual design study will be necessary to refine the cost estimate. Costs in this report should be used only for comparison purposes and not for budget planning or proposal evaluation. Facility options evaluated include a new “green field” permanent facility, upgrade of an existing facility, or a modular, transportable facility.

The purpose of this report is to evaluate the impacts of waste form volumes on life cycle cost estimates. The estimated volumes of grouted and vitrified waste form produced from treatment of ORNL RH-TRU sludge are 788 m^3 and 179 m^3, respectively. Estimated disposal costs for these waste forms are $26.6 M for grout and $6.9 M for glass. Facility costs ranged from $26 M to $97 M (including contingency) for a temporary facility to a greenfield permanent facility. As facility costs increase along with associated D&D, overhead, and contingency, the cost comparison tends to favor the grout process as the lower cost option. The results of this evaluation indicate that when facility costs are low, the total costs favor the vitrification process. The cost of the vitrifier and associated off-gas system is higher than the cost of the grout equipment, however, this is balanced by the cost of the facility necessary for managing the final

waste forms, which costs more for the grout system due to the greater amount of space required. The cost of processing and decontamination and decommissioning (D&D) costs were higher for vitrification, however, disposal costs overwhelmingly favor the vitrification process.

Most life-cycle cost estimates to date have not included waste transportation and disposal costs or assumed they were similar for the two waste form options. The impact of these incorrect assumptions are significant. Without considering disposal costs, the total cost of vitrification is about 20% higher than grout costs for the temporary facility option. When disposal costs are included, the cost comparison favors vitrification as the less costly option by about 21%.

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1. INTRODUCTION

Producing final waste forms from radioactive sludge is a critical operation in the management of DOE tank waste. The immobilization method must be chosen only after careful evaluation of different technologies, their effectiveness, and impacts on life cycle costs for the project. Grout and vitrification are two common technologies being considered by the DOE for immobilization of radioactive waste. The choice between these technologies must be made based on ability to stabilize the waste sludge, the resultant waste characteristics, the final waste volume, the complexity of the process, and the cost of processing and disposal. This study provides information regarding the comparative costs of grout and vitrification processes for Oak Ridge remote-handled, transuranic (RH-TRU) tank sludge. This information will be useful for Oak Ridge, Hanford, and Idaho tank sludges where these choices have significant economic impact.

Oak Ridge has radioactive waste sludges stored in four separate tank farms with different compositions.[1] These sludges will be consolidated into one tank farm, the Melton Valley Storage Tanks (MVSTs), in FYs 1998 through 2000 and retrieved and immobilized through a private industry contract. The waste forms will be characterized and shipped to the WIPP in Carlsbad, New Mexico and/or the NTS in Nevada.

Cost estimates for treatment of the MVST waste have been performed in the past, but none have used actual waste loading data for comparing grout and vitrification processes for this waste and none have evaluated the service contract concept using vendor-supplied temporary facilities that are provided for a specific task and removed from the site following completion of the project. Recent demonstration projects have been performed in Oak Ridge, which provide valuable cost information for treatment of tank wastes using modular, mobile treatment systems. DOE design criteria does not preclude this type of facility as long as it is designed to minimize risk to the general public and to withstand natural phenomena such as earthquakes and tornadoes. Past economic studies have also provided valuable information with regard to the cost of other facility concepts and for managing the final waste forms. Information from these sources has been used to provide an improved cost estimate and comparison for grout and vitrification processes for the MVST tank waste.

2.0 BACKGROUND

2.1 Past cost estimates for permanent treatment facilities

Several studies have been performed in the past to evaluate the schedule and cost of treatment of the MVST sludges for disposal at the WIPP. These studies have focused on the use of new permanent facilities or modification of existing facilities for the treatment process. Table 1 provides a cost summary for a selection of the various past studies

Table 1. Studies performed to estimate the cost of TRU waste processing at Oak Ridge

Study	Waste Handling and Packaging Plant (WHPP), Sludge and Solids[2]	WHPP Value Engineering Study, 7860 Modification for sludge only[3]	3517 Modification, Sludge only[4]	3517 Modification, Sludge only[4]	7860 Modification, Sludge only[5]	7860 Modification, Sludge only[5]
Date	Dec-90	Apr-95	Sep-95	Sep-95	Sep-95	Sep-95
Organization	MMES Central Eng.	Mason and Hanger Eng., Inc.	Parallax, Inc.	Parallax, Inc.	Parallax, Inc.	Parallax, Inc.
Process	Wiped Film Evaporator	Grout	Grout	Vitrification	Grout	Vitrification
<u>Costs ($ K)</u>						
Program Management	0	0	9,261	9,106	9,261	9,262
Project Management	0	0	45,610	47,361	42,956	47,213
Design	46,478	Included in Construction	17,869	19,123	17,026	18,791
Construction	182,728	68,674	31,621	37,392	28,058	36,126
Operations	Not included	Not included	38,193	47,226	40,772	47,041
Maintenance	Not included	Not included	15,021	14,171	13,747	13,643
On-site Storage	Included in construction	Included in Construction	7,995	5,373	8,426	5,634
D&D	Not included	4,000	16,121	41,471	16,121	41,485
Overhead	48,524	Included in Const. and D&D	52,725	64,209	52,745	64,049
Contingency	63,537	29,069	87,086	106,209	83,350	103,533
Total	341,267	101,743	321,502	391,641	312,462	386,777

Note: None of these studies included cost estimates for transportation and disposal at WIPP or NTS.

The initial conceptual design for the Waste Handling and Packaging Plant[2] (WHPP) included costs for treatment and disposal of TRU tank sludge and TRU solids (contaminated equipment from hot cells, laboratory wastes, drummed waste, etc.) . The study focused on estimating the construction costs only for a new greenfield facility. Costs of equipment for processing solids and sludges at $52 M, was about 29% of the total construction cost of $183 M, not including engineering, overhead, and contingency which made up the balance of the $341 M total. The cost of the sludge treatment system in this case was $13 M, about 4% of the total. Costs were not included for operations, maintenance, transportation and disposal at WIPP, and decontamination and decommissioning (D&D).

The WHPP Value Engineering (VE) Study[3] was performed in April 1995 in an effort to explore new and less expensive capital cost options for treatment of TRU sludge only. Using the existing structure of Building 7860 (the New Hydrofracture Facility, shut down in 1984) was evaluated as a means of reducing overall capital costs for the project. According to the VE study, the construction costs could possibly be reduced by half while reducing total cost to about $102 M for sludge treatment only. Costs were not included for operations, maintenance, and transportation and disposal at WIPP.

Later in 1995, Parallax, Inc performed a more extensive evaluation of the life cycle costs using various facility modification options instead of a greenfield facility for treatment of tank sludge only.[4] Parallax also included major costs for management, operations, and D&D which increased the total life cycle costs to the $312 - $391 M range. Parallax recommended the use of existing Building 7860 as the best option for grouting the sludges.[5] Design and construction costs for the Parallax 7860 option at $53 M were similar to the VE study at $72 M. The Parallax studies did not include transportation and WIPP disposal costs.

2.2 Cost information for temporary treatment facilities

Cost information gained from several Oak Ridge radioactive waste treatment projects was utilized for some of the cost elements of this study. The TVS, recently installed and demonstrated for uranium contaminated sludge,[6] is very similar in concept to what would be expected for the MVST sludge treatment. Cost adders were developed for the TVS to address the higher levels of radioactivity in the MVST liquids and sludges, requiring more shielding and a remote operations and maintenance. Information from the Out-of-Tank Evaporation project[7] and Cesium Removal Demonstration project[8] was useful for estimating the cost of shielded, remotely-operated, modular systems for processing high-activity MVST supernate liquids. The AEA Technology pulse jet mixer was recently demonstrated and operated for mixing and retrieval of sludges from the Bethel Valley Evaporator Service Tanks,[9] which are very similar in design to the MVSTs. At the Old Hydrofracture Facility (OHF) near the MVST area, the use of the Borehole Miner sluicing system has been demonstrated for removing sludge heels from horizontal tanks similar in design to the MVSTs. A pulse jet mixer could possibly be used at the MVSTs for bulk mixing of the settled sludge, followed by the use of the borehole miner for removing the more difficult sludge heels. An additional project currently in the design/fabrication phase will use a modular, remotely operated cross-flow filtration system for separating the sludge and liquid phases of the MVST waste. Preliminary cost information from the cross-flow filtration project was used to estimate the cost of pretreating the MVST sludge prior to immobilization.

2.3 Basis for cost estimate

Information from the technology demonstration projects was used in the present evaluation to estimate the cost for sludge retrieval and pretreatment. The TVS demonstration project information was used to estimate facility capital costs for the grout and vitrification systems. The Parallax and VE studies for the use of Building 7860 were used to estimate costs for grout processing equipment, waste form handling systems, and interim waste storage. Recent cost information from WIPP and NTS was used to estimate the costs of transportation and disposal. The cost comparison addressed in this report includes design, construction, operations, maintenance, waste packaging, transportation, disposal at WIPP, and D&D. Program/project management costs were not included.

3. PROCESS FLOWSHEETS

3.1 General

Figures 1 and 2 show basic process flowsheets for the grout and vitrification processes. Both processes will require a similar sludge retrieval and dewatering system. For the vitrification process, feed preparation will involve addition and mixing of the frit components and other components necessary to obtain proper melt characteristics. An evaporator is provided to further concentrate the slurry. Off-gasses from the melter will be cooled, scrubbed, treated to remove NO_X, and filtered before discharge to the atmosphere. Some of the scrubber blowdown liquids will be recycled to the MVSTs for sluicing additional sludge to the melter feed system. It is assumed that excess scrubber blowdown liquids must be managed by evaporation and solidification in a grout matrix. The melted glass will be poured into canisters designed for shipment and disposal at the WIPP. After cooling in a staging area, the lids for the canisters will be applied using a remotely operated device and the exterior of the canister will be decontaminated prior to moving to the truck bay for loading into interim storage casks. The interim storage facility will be large enough to store all of the waste form canisters generated for the entire sludge volume.

The WHPP VE study describes a reasonable flowsheet for the grout system. Like the vitrification system, an evaporator is provided to further concentrate the slurry. The heart of the system would be a continuous twin screw blender where the grout dry blend and sludge combine. The mixer would discharge to a surge tank which would feed a positive displacement pump designed to meter the grout mixture into canisters designed for shipment and disposal at the WIPP. Local off-gas systems would be necessary to control grout dusts, but an off-gas scrubber would not be required. The loaded canisters would be moved by conveyor to the curing, lidding, and decontamination area prior to loading into a carrier for on-site transport to the interim storage facility.

The basis for the cost estimate is discussed in the following sections. The discussion is broken down by subsystem in the logical order required to complete the entire flowsheet. Following the subsystem discussions, other important cost elements are discussed.

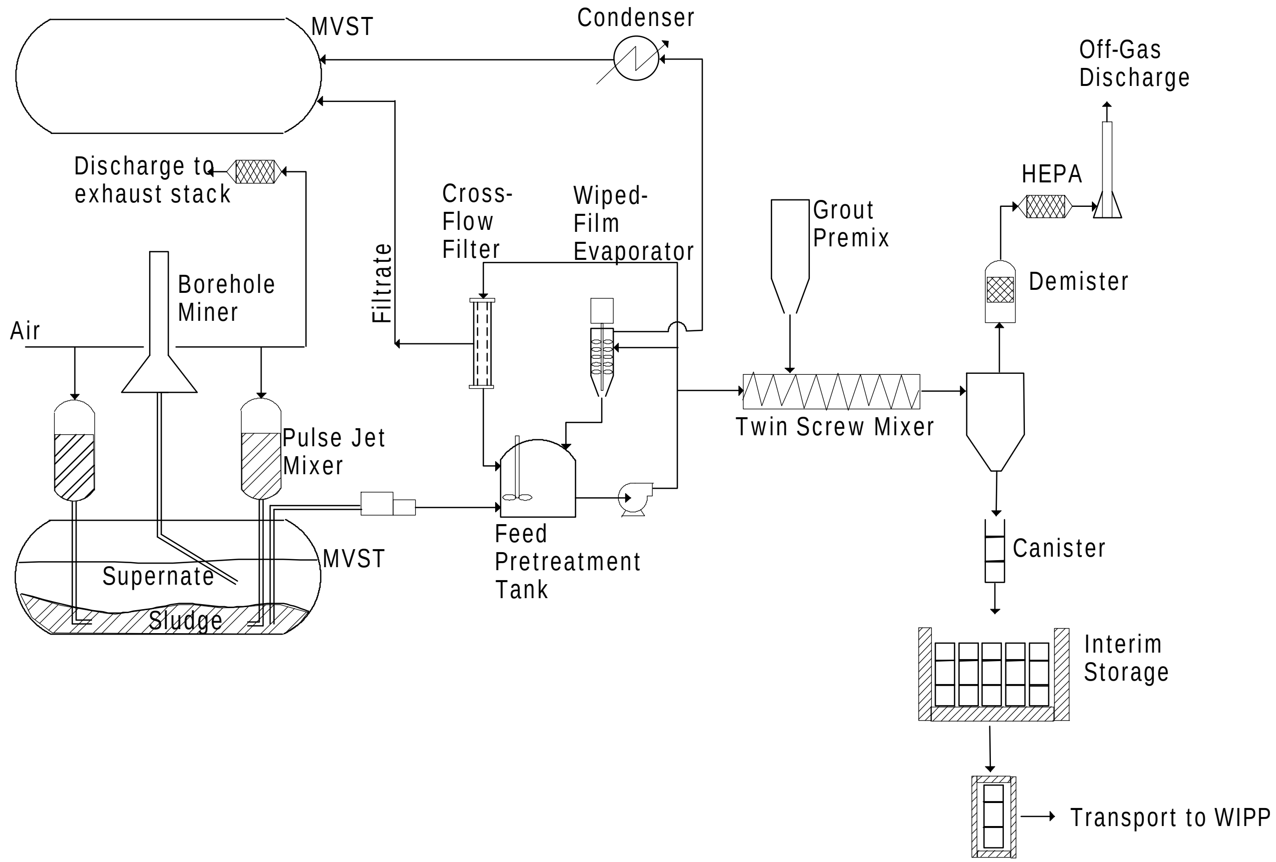


Fig. 1. Flowsheet for grout process.

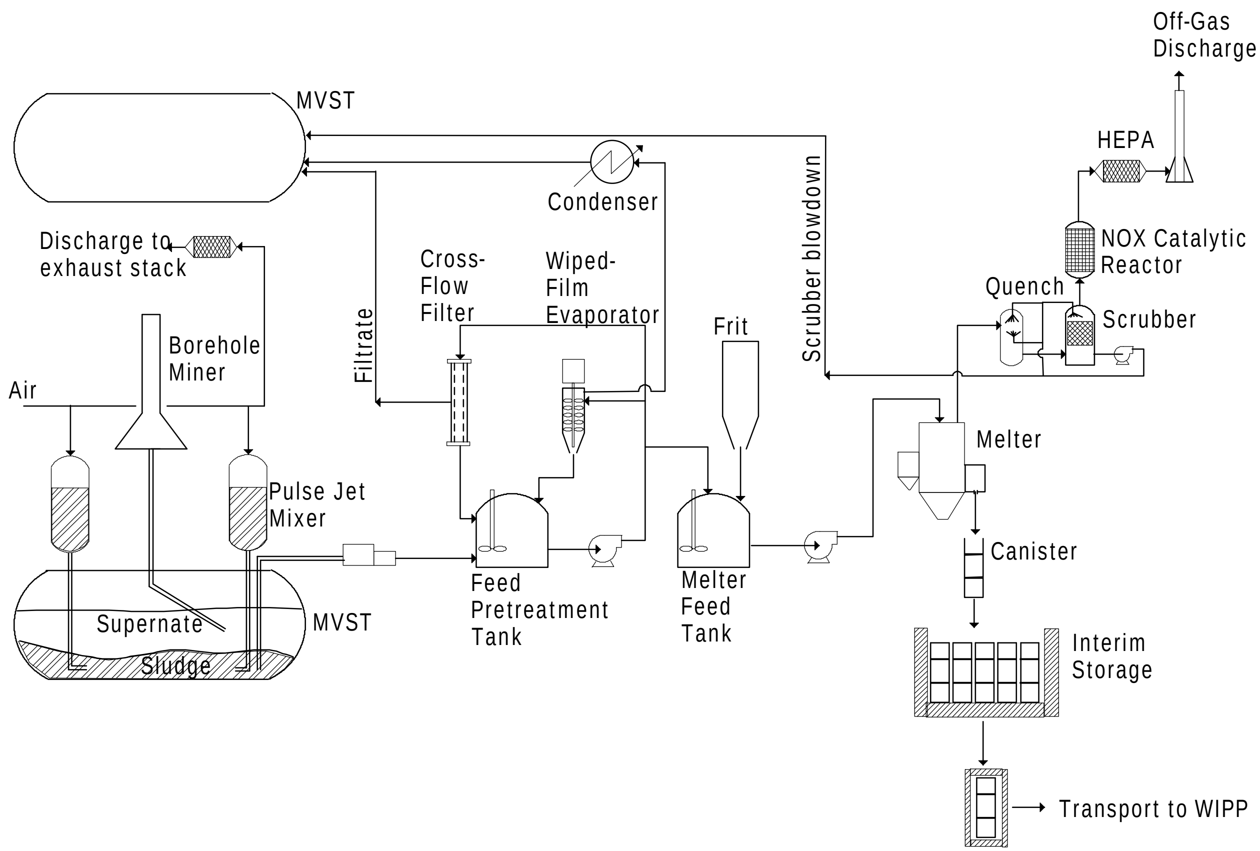


Fig. 2. Flowsheet for vitrification process.

3.2 Sludge mobilization and retrieval

The initial step of the treatment process will involve the mobilization and retrieval of sludges from the MVSTs. All of the Oak Ridge RH-TRU tank sludges will be consolidated in the MVSTs prior to treatment. The sludges will include those from the Bethel Valley Evaporator Service Tanks (BVESTs), Gunite and Associated Tanks (GAAT), the Old Hydrofracture Facility (OHF), and sludges already in storage in the MVSTs. For the sake of simplicity, the final volume of sludge after consolidation is assumed to be 200,000 gal with a total solids content of 50% by weight and a specific gravity of 1.35. The tanks will also contain 160,000 gallons of non-TRU supernate liquid, which is primarily sodium nitrate at a concentration of about 4 M, with a specific gravity of 1.2. It was assumed that the supernate would be used only as necessary to assist in transfer of the sludge to the immobilization feed system. The balance of the supernate would be transferred to other storage tanks for future treatment and disposal.

The initial step in processing the sludge will involve mixing and retrieval of the sludges from the MVSTs. The MVSTs consist of eight horizontal, cylindrical tanks with a volume capacity of 50,000 gal each. It is assumed that the sludge will be evenly distributed between the eight tanks (each tank about half full). Two methods were assumed to be necessary for retrieving the sludges from these tanks. The initial effort may involve mixing of the bulk of the sludge (about 80%) with existing supernate in the tanks and transferring, batchwise, to the feed system for the immobilization process. It is assumed that the AEA Technology pulse jet system will be used for this step. The pulse jet system will use the existing tank sludge jets along with charge vessels and fluidic pumps designed to mix the sludges with existing tank liquids. Once the sludge is adequately mixed with the liquids, the mixture is transferred to the immobilization system feed tank using existing progressive cavity pumps. Cost information from the Bethel Valley Evaporator Service Tanks (BVEST) pulse jet demonstration was used to estimate the cost of bulk sludge retrieval for the MVSTs.

The Pulse Jet system was effective for mixing the bulk of the sludge, but a significant fraction of the sludge (10 to 20%) was left in the tank following the initial transfer effort. Subsequent efforts to remove the remaining tank heel were only moderately successful and about 5% of the sludge was left remaining in W21 after the transfer to the MVSTs. At the OHF, an improved system for sludge heel removal, the borehole miner system, was successfully demonstrated. The system uses an extendable jet nozzle that can be remotely manipulated within the tank to impinge on and move the sludge heel toward pump suction legs installed in the tanks. The heels were transferred to a consolidation tank for mixing and transfer to the MVSTs. It is assumed that this equipment would be effective for mobilizing the sludge heels left in the MVSTs following bulk sludge removal using the pulse jet system. Actual cost information from the OHF sludge retrieval project was used for estimating the cost of a similar system for the MVST sludge retrieval.[10] The borehole miner system will require additional access to the tanks in the form of two additional 24-inch diameter risers for each tank. The cost of installing these risers was obtained from actual costs for riser installation at the BVEST in 1997.[11]

3.3 Feed and pretreatment system

The feed system must be designed to provide a uniformly mixed feed for the immobilization process. The MVSTs are not designed for uniform mixing of liquid and sludge, and the size and design of the MVSTs make them difficult or impossible to retrofit for complete mixing. Therefore, an interim mixed batch tank must be installed for providing a uniform feed. It was assumed that two 5000 gal feed tanks equipped with mixing capability would be provided. The tanks would be installed above ground in a doubly-contained, shielded enclosure. The cost of this system was estimated based on information provided in the WHPP VE study and shielding costs for modular OTE and CsRD demonstration systems. The retrieval processes will use large quantities of supernate liquids to mobilize and transfer the sludge to the feed tanks. This liquid must be removed to concentrate the sludge in feed tank for the immobilization process. It was assumed that cross-flow filtration would be used for dewatering and concentrating the sludge. The system to be deployed in 1998/1999 at the MVST is similar in design and capacity to what might be used for this application. Preliminary cost information from this project was used to estimate the cost of a similar system for the grout or vitrification process. The effectiveness of cross-flow filtration is not sufficient for increasing solids content beyond about 15% by weight suspended solids. To remove enough liquid to reach the settled-sludge solids content of about 25% TSS, additional processing will be necessary. Evaporation is used for concentrating the melter feed at the Savannah River and West Valley Nuclear sites. The feed vessel is fitted with a steam heated jacket and agitator. The glass frit added to the vessel helps control scaling of the vessel heat transfer surface through abrasive action. In the case of the grout system, an alternate method for controlling the extent of heat transfer surface fouling will be necessary. It may be feasible to recirculate the feed slurry through a wiped-film evaporator (WFE) to remove water. The WFE was originally proposed for the WHPP to drive off enough water to supersaturate the sodium nitrate in the feed and produce a solid salt cake. The WFE is designed with agitator blades that continually wipe the heated surface to maintain adequate heat transfer. This same concept can be used to concentrate the slurry feed for the grout process. WFE cost information from a feasibility study by A. L. Lotts[12] was used to estimate evaporator costs for grout feed. It was assumed that costs of evaporation for the vitrifier feed would be similar even though the design would be different.

3.4 Immobilization processes

The two processes evaluated for immobilization of the MVST sludges were vitrification and grouting. The process system would consist of modular units designed for ease of transportation and assembly on site. The TVS, recently assembled and demonstrated at the Oak Ridge K-25 site, is an excellent example of what would be envisioned for the MVST tank sludge treatment. This project used modular, mobile, treatment systems for large-scale vitrification of mixed waste sludge from theY-I 2 West End Treatment Facility and the K-25 Central Neutralization Facility.[13] This system was fabricated off-site and transported to the site by truck for assembly into a complete processing system. The system is self-contained and requires only a concrete foundation and utility hookups for operation. The major radiological components of the Y-12 sludge included uranium, thorium, and protactinium which are alpha emitting materials. Beta emitting radionuclides such as technetium and strontium were also present with minor quantities of gamma emitting radionuclides. Hazardous organics (tetrachloroethane, phenols) and heavy metal contaminants (mercury, chromium, lead) were also present in the sludge. Radioactive and hazardous contaminants must be contained during the process and the TVS was designed for this purpose. Penetrating gamma radiation was minor and alpha and beta radiation does not penetrate normal construction materials, therefore special shielding materials were not required. The TVS off-gas system was designed to contain volatile organics, metals, and radionuclides released from the sludges during vitrification.

Though the TVS was designed for vitrification, most of the general layout and subsystems are consistent with what would be required for a grouting process. The feed system module is similar with respect to the use of batch tanks for mixing the feed sludge with immobilization raw materials. The grout system would likely require larger feed hoppers for grout dry blend components than those provided in the TVS feed system. The processing system would be simpler in that the mixed dry blend and waste requires no further processing and may be delivered directly to the disposal container. The off-gas system would also be simpler due to the lack of volatile components. Control of grout component dusts and potential airborne waste components would be required. The cost of an equivalent grout system was estimated by obtaining cost information for similar scale grout equipment from the Parallax study and other literature.[14] The grout/waste blending system cost was substituted for the estimated cost of the TVS melter module to estimate the total cost of the modular grout system.

3.5 Shielding and containment

The Oak Ridge remote-handled, transuranic waste sludges will require a greater degree of containment and radiation shielding than what is currently provided by the TVS. The principal radionuclides for Oak Ridge RH-TRU sludges include the TRU components (plutonium, curium, americium) and gamma emitting components such as cesium and cobalt at concentrations much higher than wastes treated by the TVS. The ^{137}Cs gamma radiation requires that shielding materials be provided for processing systems to reduce worker exposure to a safe level. The design and fabrication costs for radiation shielding are significant and must be added to the facility costs. The cost of operations is also impacted by the ^{137}Cs due to the special procedures, protective clothing, and the additional time required to perform any activity that involves working in close proximity to waste containing system components.

The transuranium isotopes contained in the tank sludges are highly toxic and must be contained. As such, any component of the system containing these sludges must have secondary liquid containment and airborne particulate containment. The TVS feed and melter modules have ventilation containment, however, the quench, cooler, mist eliminators, and HEPA filters of the ventilation system are not enclosed. Containment of these components is necessary in the event that positive pressure is generated in the system from excessive off-gasses. Since the MVST sludge contains high concentrations of nitrates and radioactive cesium, it was assumed that the melter system would also include additional subsystems for reduction of NO_x and for capturing cesium. The Parallax reference provides cost estimate for an ammonia injection system designed for NO_x reduction and a zeolite filter bed for removal of volatilized cesium.

The main components of the TVS that would require shielding include the feed system, melter, and waste form handling system. The off-gas system must also be designed with gamma radiation shielding due to the volatility of cesium. The cost of shielding the TVS system was estimated based on the shielding costs of OTE and CsRD systems recently designed and demonstrated for treatment of MVST supernate liquids. The cost of the shielding for these systems was determined as a fraction of the total system costs, giving a “shielding factor” value. This value was applied to the total TVS system cost to calculate the TVS shielding costs. Table 2 gives the cost information used to determine the shielding factor.

Table 2. Shielding factor determination

System	A: Shielding Costs ($K)	B: Total System Costs ($K)	A/B: Shielding Factor
Out-of-Tank Evaporator	75	365	0.21
Cesium Removal System	175	645	0.27
Cross-Flow Filter (estimated)	115	830	0.14
Total	365	1,840	0.20 (average)

The estimated cost of replacement for the TVS system is five million dollars.[15] Applying the shielding factor gives a shielding cost of $1,000,000, which agrees with previous Savannah River Technology Center (SRTC) estimates for the shielded TVS.[16]

3.6 Sampling system

A glove box operation will be required for sampling of the feed for both grout and vitrification processes. This was not included in the TVS costs and constitutes an added capital cost for the facility. The unit cost for a glovebox style sampler was obtained from the Parallax report.

3.7 Waste form handling and interim storage

Once poured into the containers the grout or melted glass must be set aside to cure, followed by lidding, decontaminating, packaging, and interim storage while awaiting shipment to WIPP. The TVS systems for waste form handling are not designed for the space, containment, and remote handling necessary for RH-TRU waste forms. The structures, shielding, and equipment needed for staging and storing large amounts of high-activity waste forms cannot be provided using mobile, modular facilities such as the TVS. Consequently, it was assumed that these structures would be similar in design and cost to those developed in the Parallax study using Building 7860 modifications and constructing additional storage bunkers in the Solid Waste Storage Area (SWSA) 5. The storage bunker for the grout was designed to manage up to 9000 drums of waste form. The actual quantity of grout, based on actual waste loading information, is the equivalent of about 4160 drums. The "six-tenths factor"[17] was used to estimate the storage bunker cost for 4160 drums. The storage bunker for the vitrified product was designed to store 3500 drums, so the same rule was applied to estimate the bunker cost for 946 drums, based on actual waste loading information for glass.

4. INSTALLATION COSTS FOR TREATMENT SYSTEMS

Installation costs for retrieval and pretreatment systems was obtained from actual cost data for the field demonstrations. For the immobilization systems, actual cost information for installation is limited to what was needed to install the TVS. The addition of shielding will complicate and increase the cost of installation for these systems. The shielding of the vitrification system will be more extensive due to the required shielding for the off-gas system. Based on engineering judgement, it was assumed that the cost of installing the vitrification system would be twice the cost of installing the TVS as a result of the shielding requirement. Since the shielding for the grout system would be confined to the grout mixing system only, it was assumed that the cost would be 50% higher than the cost of installing the TVS. The cost of the system foundation, equipment module assembly, and utility hookups are included in the TVS installation costs.

5. PERMITTING AND OPERATIONS APPROVAL COSTS

The estimated cost of TVS permits and operational readiness assessments were assumed to be similar to what would be experienced for the RH-TRU sludge treatment system. Since the grout system is less complex and requires a lesser degree of environmental controls than the vitrification system, it was judged that various aspects of permitting and operational readiness assessments would require less effort. A summary of the expected costs are provided in Table 3.

Table 3. Estimated Cost of Permits and Operational Approvals

Element	Vitrification System ($K)	Grout System ($K)
Permit Control	490	330
RCRA Part B Permit	690	290
Air Permit	240	220
Rad/NESHAPS	130	130
Environmental Assesment	290	165
Operational Readiness Assessment	360	225
Total	2,200	1,360

6. OPERATING COSTS

The time and effort necessary to retrieve sludges from the MVSTs was based on Oak Ridge's experience with the AEA pulse jet system in September 1997 through May 1998 at the BVEST and the borehole miner experience at the Old Hydrofracture Facility tanks in June/July 1998. Engineering judgement was used to estimate the labor costs associated with pretreatment of sludge to remove excess liquids. It was assumed that a total of ten months of continuous operation would be required to retrieve the bulk of the sludge from all the MVSTs using the pulse jet and borehole miner systems and to condition the sludge for feed to the immobilization system.

Costs for the grout dry blend ingredients were estimated using the best bulk quantity cost information available from manufacturers. In the absence of bulk cost information for the glass formula ingredients, costs for glass ingredients from the recent TVS demonstration in Oak Ridge were used. Waste loading for the grout waste form was obtained from recent formula development results.[18] A wet sludge loading of 90% by weight results in a volume increase of 4% for the grout waste form. Assuming an initial sludge volume of 200,000 gallons, this gives a final grout volume of 208,000 gallons. Glass formulation studies performed by the SRTC indicate that 45% loading on a dry oxide basis is achievable for the ORNL tank sludge. This results in a final glass volume of about 47,300 gallons, or a volume decrease of 76%.[16]

Costs for utilities and maintenance were obtained from the TVS demonstration experience[19] for vitrification and from literature[13] for the grout system.

Operating costs for the RH-TRU vitrification system were estimated using the operating costs for the TVS and using engineering judgment where appropriate to account for the additional labor cost for handling high-activity waste. Grout system operating costs were assumed to be less than those of the vitrification system due to the higher processing rate and the comparative simplicity of the process. The additional time and effort required to manage the larger volume of final waste form for the grout process increases the waste form management costs.

A summary of the personnel requirements for operating the two processes is given in Table 4. Assuming that WIPP can accept up to eight canisters per week, the minimum processing rate necessary to provide a steady supply of waste forms for shipment is about 117 gal wet sludge (50% total solids) per day. For 200,000 gal of sludge, the time necessary to process and ship would be 4.7 yr. Providing the necessary labor support for processing sludge at this rate is very expensive, therefore, it was assumed that the sludge processing could be completed in two years for either system and the surplus waste forms would be stored in the SWSA 5 bunkers provided for this project for a period of 5 years. Assuming 30% down time for the grout system gives a minimum grout processing rate for a two year operation of about 390 gal/day of wet sludge feed or about 517 gal/d of grout waste form. For the vitrification process, a down time of 50% was assumed, giving a minimum processing rate of about 550 gal/d or 146 gal/d of glass waste form. The treatment systems assumed for this project have capacities that exceed this. The grout system assumed for the Parallax study can produce 10 gal/min of grout or 14,400 gal/d. The TVS vitrifier can produce up to 320 gal/d of glass waste form.

Table 4. Summary of Personnel Requirements for Operation of Grout and Vitrification Systems

Title	Activities	Grout		Vitrification	
		Duration, Years	Number of FTEs	Duration, Years	Number of FTEs
Operations Manager	Overall management, reporting, interfacing with customer	2	3	2	3
Project Engineer	Process optimization, trouble shooting, procedure development	2	3	2	3
Secretary	Communications, time keeping, record keeping	2	3	2	3
Shift Supervisors	Operations management	2	3	2	3
Shift Operators	Process operations	2	12	2	18
Storage Operations	Transport to interim storage, storage surveillance, packaging for shipment to WIPP	5	0.75	5	0.5
Transportation Specialist	Coordinate transportation to WIPP	5	0.5	5	0.3
Maintenance Personnel	Equipment maintenance and repair	2	3	2	3
Radiation Protection	Radiation surveys, maintenance and repair support, waste surveys, sample surveys	2	3	2	3
Quality Assurance	QA of process and documentation	2	1	2	1
Waste Certification	Certify product glass, grout, and secondary wastes, documentation	2	1	2	1
Training	Track and coordinate required training, train operators, update procedures	2	1	2	1
Permit Support	Compliance with permits, environmental sampling, documentation	2	0.5	2	0.5
Total FTEs			73.5		83

The processing time for both of these operations will be limited by the time required for retrieving and pretreating the sludge feed and for packaging and handling of the final waste form. About 1 week at 24 hr/day operation would be required to retrieve, pretreat, and perform sample analysis for a 5000 gal batch of feed for the grout system. This assumes it would take several days to mix and retrieve a 17,000 gal batch of sludge (at 10% suspended solids) in one of the MVSTs. It would also take several days to dewater and concentrate the 10% suspended solids mixture to a 5000 gal, 25% suspended solids mixture (50% total solids). This would leave about a day to sample, characterize, and plan the treatment operation. The grout operation at a 10 gal/min production rate plus time for indexing drums between fills would take three to four 8-hr shifts to complete. Several days would then be necessary for lidding, deconning, smearing, loading drums in canisters, moving to storage bunkers, and packaging for shipment for a total of about 14 days. Many of these operations can be performed in parallel, however, it is reasonable to assume that a 5000 gal batch of sludge would require 2 to 3 weeks to process from start to finish. This is equivalent to 80 to 120 weeks for 200,000 gal of sludge, averaging to about 2 years. The amount of glass waste forms produced for a 5000 gal batch of feed would be a factor of 4 less, but the decreased time for packaging would likely be offset by the greater processing time, additional maintenance requirements, and additional secondary waste processing required for the vitrification system. A breakdown of the estimated labor costs for processing the sludge are provided in Attachment A, Table A-1.

Analytical costs were estimated based on what was judged to be reasonable for control of the immobilization operation and for demonstrating compliance with the WIPP Waste Acceptance Criteria. It was assumed that complete characterization of each 5000 gal batch of feed sludge would be sufficient for WIPP WAC requirements and for confirming the acceptability of the grout and vitrification formula. It was further assumed that sampling the waste form product two times during processing of each 5000 gallon feed batch would be sufficient to confirm adequate performance of the waste form. A significant added cost for the vitrification process is the need to analyze the scrubber solution during the process. This is necessary to determine compliance with the ORNL Waste Management waste acceptance criteria for the liquid low-level waste system.

7. PACKAGING, TRANSPORTATION, AND DISPOSAL COSTS

The most recent cost information was obtained from the WIPP[20] and NTS[21,22] for transportation, and disposal. It was assumed that vitrification secondary wastes from off-gas scrubbing and from flushing the melter with clean glass frit would meet the NTS acceptance criteria. It was assumed that the scrubber liquids would be solidified in grout as routinely performed by ORNL Waste Management at a cost of $50/gal.[23] The quantity of scrubber liquid was estimated by reviewing the composition of the tank sludge and assuming that twice the theoretical amount of sodium hydroxide necessary to react with chloride and sulfate anions in the sludge would be used. This amounted to approximately 15,000 gallons of 4 molar sodium carbonate. This volume of scrubber solution may be conservatively low due to the presence of other anions in the sludge matrix.

The cost for shipment of the RH-TRU canisters is extremely high, mainly because only one canister is shipped per truck. This is due to the size and weight of the standard WIPP shielded overpack. The cost for each shipment is $21,291. Table 5 gives a breakdown of the disposal costs for the grout and vitrification options. Information provided by a past study[23] indicated that the cost of waste form canisters would be $10,000 each. SRTC estimated that the cost of acceptable canisters fabricated using carbon steel instead of stainless steel could be as low as $3000 each.[16] Using $3000 for the canister cost reduces the grout disposal cost by $6.9 M, but transportation costs remain extremely high at $26.6 M.

Table 5. Disposal costs for grout and vitrification processes.

Cost Item	Unit cost, $K	Grout System		Vitrification System	
		Number	Cost, $K	Number	Cost, $K
Canisters	3.0 ea.	911	2,970	225	676
Transportation	21.3 per shipment	911	21,100	225	4,790
Disposal at WIPP	2.5 per shipment	911	2,480	225	563
Treatment and Disposal at NTS	52.2 per 1000 gal	NA	NA	17,000 gal	888
Total Disposal Cost, $K			26,550		6,917

A possible means of reducing transportation costs would involve the selective removal of gamma emitting nuclides such as Cs-137 from the sludge to reduce the radioactive dose rate to the Contact Handled (CH) TRU level. This would allow for shipment of larger volumes of the waste form per shipment, reducing transportation costs to a fraction of those estimated for RH TRU waste.[16] It has been demonstrated that cesium can be removed from the MVST liquids, however, sludge washing tests[24] have indicated that a significant fraction of the cesium is sorbed rather strongly by the sludge solids. In addition, calculations performed by SRTC[25] indicate that cobalt-60 and europium isotopes would contribute enough gamma radiation to exceed the transportation criteria even if cesium were successfully removed.

8. DECONTAMINATION AND DECOMMISSIONING

A significant advantage in using modular, mobile systems for tank sludge treatment is the reduced cost of D&D. Some of the equipment never becomes contaminated and can be reused in other projects. Parts of the equipment that are exposed to radioactive waste can be either decontaminated for reuse or replaced without impacting the future utilization of associated subsystems. In this case, it was assumed that the melter module and off-gas system, and the grout module would undergo complete D&D and be replaced. Likewise the system feed tanks and evaporator would undergo D&D. For the retrieval system, most of the pulse jet system can be reused, except for the charge vessels which can be replaced. Likewise, most of the borehole miner system can be reused, except for the arm/nozzle assembly. It was assumed that the filter module could be decontaminated with the exception of the filter elements, which can be replaced. Estimate D&D costs are summarized in Attachment A, Table A-1.

9. SUMMARY

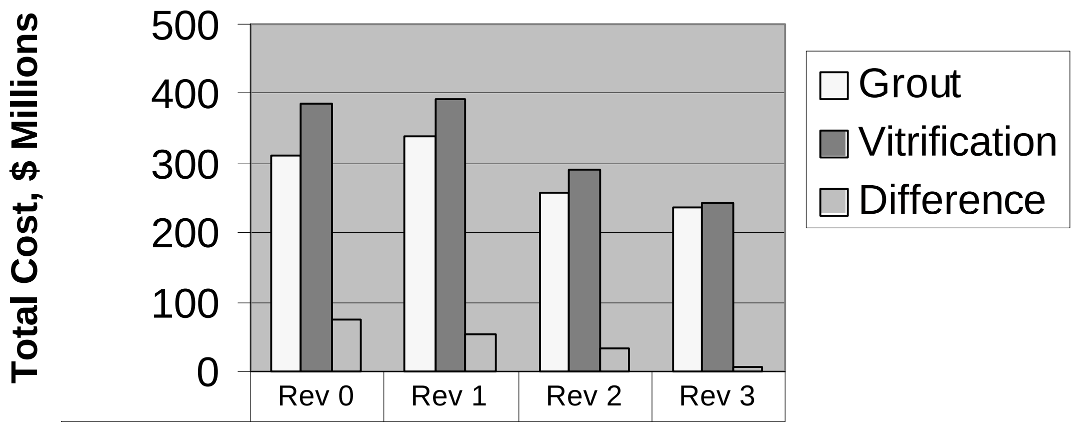
Table 6 shows a summary of the estimated costs for a temporary facility along with the Parallax costs for the Bldg 7860 modification option. The costs of all of the Parallax cost elements are much higher than those estimated for the temporary facility. This is due to the difference in the basis and level of the estimates for these studies and is also due to the facility option chosen for the Parallax study. For a large capital project such as the 7860 modification, disposal costs become a relatively small fraction of the total project costs. Figure 3 illustrates that adding disposal costs and reducing some of the costs associated with this facility option reduces the difference in costs for grout and vitrification. When the estimated disposal costs are added to the Parallax estimates, the cost differential drops to about $54 million with vitrification still the more expensive option. The additional contingency added to the project inflates the cost differential. Removing the contingency dropped the differential to $46 million. The D&D costs estimated by Parallax were extremely high for both processes, but especially high for vitrification where they actually exceeded construction costs. Reducing the D&D costs to the same values as those used for the temporary facility and recalculating overhead rates based on the revised costs reduced the differential for grout and vitrification processes to about $5.7 million in favor of the grout process.

Table 6. Summary of temporary and permanent facility costs for grout and vitrification.

	Temporary Facility ($M)		Permanent Facility, Bldg 7860 Modification ($M)	
Cost Element	Grout	Vitrification	Grout	Vitrification
Program management	0.0	0.0	9.3	9.3
Project management	0.0	0.0	43.0	47.2
Permitting	1.4	2.2	Inc.	Inc.
Design	5.4	5.6	17.0	18.8
Construction	21.7	22.2	28.1	36.1
Operations	8.4	11.3	40.8	47.0
Maintenance	Inc.	Inc.	13.7	13.6
On-site Storage	Inc.	Inc.	8.4	5.6
D&D	3.4	6.9	16.1	41.5
Disposal	26.6	6.9	0.0	0.0
Overhead	Inc.	Inc.	52.7	64.0
Contingency	Inc.	Inc.	83.4	103.5
Total	66.9	55.1	312.5	386.8

Inc.: Cost included in other cost elements

Fig. 3. Cost sensitivity of Parallax estimate.



	Rev 0	Rev 1	Rev 2	Rev 3
Grout	312.4	339	256	237.3
Vitrification	386.8	393	290	243
Difference	74.4	54	34	5.4

Scenario

Rev 0: Bldg 7860 Mod, original estimate
Rev 1: Disposal costs added.
Rev 2: Disposal costs added, contingency subtracted.
Rev 3: Disposal costs added, contingency subtracted, and D&D estimate revised.

The cost summary (with details in Attachment A, Table A-1) indicates that the cost of vitrification for a temporary facility is less than the cost of grouting by 21%. The waste packaging, transportation, and disposal costs account for the difference between the grout and vitrification project costs. If disposal costs are not included, the grout project cost is less than the cost of vitrification by 20%. As long as the waste forms are classified as RH-TRU, however, disposal costs will dominate the comparison and vitrification will be more economical. If it were possible to remove cesium from the sludge and manage the waste forms as contact-handled TRU, disposal costs would decrease drastically and the difference between project costs would be far less significant.[16] Additional development study, however, would be necessary to assess the feasibility of removing cesium from the sludge. As indicated in past economic studies, the type of facility chosen for the project has a large impact on the total cost. For a permanent facility option, the design, construction, and D&D costs are large with respect to the total project costs, and the comparison tends to favor grout as the lower cost option.

10. REFERENCES

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Table A-1. Comparison of grout and vitrification process costs for treatment of Oak Ridge tank sludges.

Cost Element	Grout System ($K)	Vitrification System ($K)	Basis
PERMITS AND DOCUMENTATION	**1,360**	**2,200**	
CAPITAL			
Sludge Mixing and Retrieval			
Installation of Manway Extensions	1,760	1,760	BVEST Manway Extensions @ $220 K ea
Retrieval of Bulk Sludge			
Equipment (design and fab)	2,392	2,392	AEAT Pulse-Jet system
Installation	679	679	AEAT Pulse-Jet system
Retrieval of Sludge Heel			
Equipment	300	300	Borehole miner system
Installation	500	500	Engineering judgement. No vault connections. Move between tanks.
Sludge Treatment			
Feed System			
Two 5,000 gal SS mixed tanks w/ pumps	200	200	WHPP Value Engineering study
Installation, above grade, shielded	750	750	Engineering judgement
Pretreatment system			
Evaporator/Condenser	870	870	Cost of Wiped-Film Evaporator system
Cross-flow filter system	840	840	Cross-flow filter system fabrication contract from NUMET Engineering, LTD
Installation	740	740	April 1998 LMER Engineering cost estimate for installing cross-flow filter in non-radiological area doubled for additional installation of evaporator.
Vitrification System			
Equipment		6,000	Estimate based on TVS designed for RH-TRU sludge treatment (1)
NOX Reduction		256	Parallax study
Site Preparation		700	Based on TVS costs X 2 for shielding allowance
Installation		840	Based on TVS costs X 2 for shielding allowance
Grout System			
Equipment	4,560		Parallax study
Site Preparation	525		Based on TVS costs X 1.5 for shielding (less than vitrification because no off-gas system shielding is required.)
Installation	630		Based on TVS costs X 1.5 for shielding (less than vitrification because no off-gas system shielding is required.)
Glove box sampler	124	124	Parallax study
Emer. Generator	75	75	Parallax study
Material Handling			
Equipment	2,280	2,123	Parallax study
Installation	1,175	653	Parallax study
Loading Area			
Mat'l and labor	1,765	1,765	Parallax study
Storage Bunker			
Mat'l and labor	1,571	695	Parallax study - using 6-tenths rule for cost of smaller capacity bunkers
Subtotal Capital Costs	**21,736**	**22,262**	

Table A-1. Comparison of grout and vitrification process costs for treatment of Oak Ridge tank sludges.

Cost Element		**Grout System ($K)**			**Vitrification System ($K)**		**Basis**
DESIGN		**5434**			**5566**		Assume 25% of capital equipment including installation.
OPERATIONS							
Sludge Mixing, Retrieval, Pretreatment, Immobilization, Storage, and Shipment							
Personnel	Hours		FTEs	Hours		FTEs	
Operations Manager	10560	917	6	10560	917	6	2 Yr Operation
Project Engineer	10560	786	6	10560	786	6	2 Yr Operation
Secretary	10560	563	6	10560	563	6	2 Yr Operation
Shift Supervisors	10560	563	6	10560	563	6	2 Yr Operation
Shift Operators	42240	2,252	24	63360	3,378	36	2 Yr Operation
Storage Operations	7040	375	4	4400	235	2.5	5 Yr Storage Term
Transportation Specialist	4400	235	2.5	2640	141	1.5	5 Yr Storage Term
Maintenance	10560	563	6	10560	563	6	2 Yr Operation
HPs	10560	563	6	10560	563	6	2 Yr Operation
QA	3520	188	2	3520	188	2	2 Yr Operation
Waste Cert.	3520	188	2	3520	188	2	2 Yr Operation
Training	3520	188	2	3520	188	2	2 Yr Operation
Permit support	1760	94	1	1760	94	1	2 Yr Operation
Waste form additives							
Grout dry blend		126					Dry blend formula for Oak Ridge tank sludge (14)
Glass additives					353		Based on TVS demonstration glass formula (15)
Utilities							
Electrical		60			300		Grout (5), Vitrification (6)
Propane					72		TVS (7)
Nitrogen					103		TVS (8)
Air compressor operation		60			60		Using 153 kw air compressor at building 7860 (4)
Maintenance							
Refractory					1,200		TVS (9)
Misc.		100			240		Grout (10), TVS (11)
Analytical							
Feed analysis		342			342		Inorganic, Radiochemical, TOC (12)
Grout analysis		160					(12)
Glass analysis					160		(12)
Off-gas analysis		56			112		Grout (12), Vitrification = Grout costs X 2 due to higher activity
Scrub water analysis		6			42		(12)
Subtotal Operating Costs		**8,384**			**11,349**		
Capital, Operating, Design Total		**35,554**			**39,177**		

Table A-1. Comparison of grout and vitrification process costs for treatment of Oak Ridge tank sludges.

Cost Element	Grout System ($K)		Vitrification System ($K)		Basis
D&D					
D&D and replace melter module			5,000		
D&D and replace grout module	1,500				
D&D and replace pulse jet charge vessels	550		550		
D&D and replace borehole miner arm and nozzle	320		320		
D&D feed tank system	500		500		
Decon filter system and replace filter elements	200		200		
Decon waste form handling system	300		300		
Subtotal D&D	**3,370**		**6,870**		
Total Costs before disposal	**40,284**		**48,247**		
DISPOSAL					
Canisters	2,970	(208,000 gal grout)	676	(47,314 gal glass)	(13)
Transportation	21,100	(991 canisters)	4,790	(225 canisters)	(13)
Waste Form Disposal	2,480		563		(13)
Scrubber solution disposal			860		(16)
Melter glass flushes			28		(17)
Subtotal Disposal Costs	**26,550**		**6,917**		
Grand Total	**66,834**		**55,164**		

Notes:

(1) Vitrification system includes batch tanks, frit storage and feed system, melter, glass pouring system, glass container decon system, melter off-gas system, radiation shielding

(2) Grout system costs determined based on the TVS system costs, subtracting $2 million for the melter system and adding $560 K for grout mixing equipment (Ref 5).

(3) Best engineering judgement used to estimate labor cost.

(4) 153 kw compressor, 1 month per tank, $0.675/kwhr

(5) Electrical costs for grout pilot plant, 3100 gal/day maximum grout production rate (Ref 13)

Notes, Continued

(6) Based on TVS, 6000 kwhr/day for 2 yr @ $0.0675/kwhr

(7) Based on TVS, 109 gal propane/day for 2 yr @ $0.899/gal

(8) Based on TVS, 938 ft3/day for 2 yr @ $0.15/ft3

(9) Based on TVS for complete refractory replacement, once per year @ $600 K

(10) Based on $20 K materials, $40 K labor for 2 yrs, labor cost doubled for high-activity waste (Ref 13)

(11) Based on TVS, $120 K/yr for misc. equipment maint.

(12) Based on ORNL Radiochemical Materials Analysis Lab rates:
- Cations, physical properties, radiochemical, and TOC analyses for each 5000 gal feed batch @ $8500/sample
- Grout and glass waste form TCLP @ $2000/sample, 2 per feed batch
- Off-gas analysis costs same as TVS
- Scrub water analysis for vitrification process including cations, radiochemical, anions @ $4200/sample, 10 samples total
- Scrub water analysis for grout system, pH, cations @ $600/sample, 10 samples total

(13) Based on disposal at WIPP:
- Canisters hold 210 gal of grout or glass and cost $3000 each
- Transportation to WIPP costs $21,291 per canister
- Disposal cost at WIPP is $2500 per canister

(14) Dry blend includes cement, slag, fly ash, perlite, and Indian red pottery clay. Cost estimated at $0.084 per pound of dry blend.

(15) Glass blend based on TVS operation and includes MnO_2, SiO_2, $NaNO_3$, and Na_2CO_3 @$0.65 per kg of glass product.

(16) Estimated cost of vitrification system scrubber solution disposal as a grouted waste form at the Nevada Test Site:
- 15,000 gal of 4 molar sodium carbonate based on quantity of chloride and sulfate compounds in total sludge
- Treatment cost of $50/gal, transportation cost of $93/ft3, and disposal cost of $30/ft3

(17) Based on five melter flushes @ 1500 L glass per flush, transportation cost of $19,950, and disposal cost of $30/ft3

Labor costs per 5000 gal batch sludge

	Duration, d	FTEs/d	Hours	Rate ($/h)	OH ($/h)	Total	
Retrieval and pretreatm	14	6	672	60	8.4	45964.8	
Grout, drum, package	11	6	528	60	8.4	36115.2	About 10 drums per day
Interim storage	40	1	320	60	8.4	21888	33 casks
Load shipping cask	20	0.5	80	60	8.4	5472	
Supervisor	15	3	360	70	9.8	28728	
Radiation Protection	15	1	120	60	8.4	8208	
Analytical	10	2	160	80	11.2	14592	
Waste Certification	15	0.5	60	60	8.4	4104	
Maintenance	15	1	120	60	8.4	8208	
Manager	15	1	120	60	8.4	8208	
		22	2540			181488	