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Integrated Process Analysis of Treatment Systems for Mixed Low level Waste

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ABSTRACT

Selection of technologies to be developed for treatment of DOE's mixed low-level waste (MLLW) requires knowledge and understanding of the expected costs, schedules, risks, performance, and reliability of the total engineered systems that use these technologies. Thus, an integrated process analysis program was undertaken to identify the characteristics and needs of several thermal and nonthermal systems. For purposes of comparison, all systems were conceptually designed for a single facility processing the same amount of waste at the same rate. Thirty treatment systems were evaluated ranging from standard incineration to innovative thermal systems and innovative nonthermal chemical treatment. Treating 236 million pounds of waste in 20 years through a central treatment was found to be the least costly option with total life-cycle cost ranging from \$2.1 billion for a metal melting system to \$3.9 billion for a nonthermal acid digestion system. Little cost difference exists among nonthermal systems or among thermal systems. Significant cost savings could be achieved by working towards maximum on line treatment time per year; vitrifying the final waste residue; decreasing front end characterization, segregation and sizing requirements; using contaminated soil as the vitrifying agent; and delisting the final vitrified waste form from Resource Conservation and Recovery Act (RCRA) Land Disposal Restriction (LDR) requirements.

INTRODUCTION

During 1993 to 1997, the Department of Energy (DOE) Office of Science and Technology (OST) sponsored a series of analyses of different waste treatment systems to guide its future research and development programs on mixed low-level waste (MLLW). MLLW consists of organic and inorganic solids and liquids which contain both radioactive materials and hazardous material regulated under RCRA. Treatment of MLLW is required to destroy organic hazardous materials and to immobilize inorganic hazardous materials. Treatment qualifies the waste for disposal under the Environmental Protection Agency (EPA) promulgated RCRA requirements for land disposal, or disposal as low-level radioactive waste if the waste is delisted or granted other exceptions after treatment. The studies that evaluated thermal systems are termed the Integrated Thermal Treatment Systems (ITTS) studies(1,2). The systems studied are summarized in Table 1.

Based on the recommendations of an Internal Peer Review Panel(3), nonthermal systems (defined as systems of technologies operating below 350°C) were also analyzed and these are termed the Integrated Nonthermal Treatment Systems (INTS) studies(4). On the recommendation of an Independent Peer Review Panel(5) and a Tribal and Stakeholders Working Group, established to review and comment on the INTS studies, enhanced nonthermal systems were also evaluated(6) that included improved nonthermal stabilization technologies, nonthermal organic destruction with vitrification of treated waste, and an increased reaction rate for nonthermal organic destruction. These nonthermal systems are summarized in Table 2.

Following these studies, a detailed comparison of selected thermal and nonthermal systems was performed(7), and a sensitivity analysis(8) of assumptions made in the original studies was performed to determine the effect of these assumptions on cost.

In these systems studies, a determination was made of the effect of various technologies and operating scenarios on system cost and performance in terms of effluent quantity (offgas, wastewater, and solids sent to disposal). By maintaining the same basis in terms of waste input, cost modeling, and mass balance analysis, the systems were compared. Areas where technology development could lead to potential cost savings were identified. Perspectives were provided on which technologies and systems the OST should develop for treatment of MLLW in order to reduce health risks, reduce costs, shorten schedules, and dispose of waste. Of particular interest was a return on investment in development programs that is high enough to justify the investment.

This paper summarizes many DOE documents listed in the references that detail the results of these studies, and in some cases uses the data developed to extend the results to new conclusions.

THE APPROACH

The OST assembled technologies into conceptual systems listed in Tables 1 and 2 to evaluate each system on a comparable basis. Thirty different systems were compared with baseline systems to understand risks, cost, performance, and schedules. Material mass balances were prepared using the Aspen Plus[®] computer code to analyze pre-conceptual system designs. The resulting equipment sizes and the "space footprint" and associated operating and maintenance staff requirements were estimated to develop the total life cycle cost (TLCC) that covered everything from current storage through final disposal and release of effluents in accordance with expected regulations.

Interactive groups and teams of technical, tribal and stakeholder representatives were used during the conduct of the studies as well as an architectural engineering firm to develop pre-conceptual designs and estimate costs. Finally, an independent technical peer review was conducted of the results.

The studies were conducted to compare technologies assembled as a complete systems. A comparable basis among the various systems was made possible by maintaining the following assumptions throughout all of the studies:

- The same waste characteristics and distribution of constituents were used for all analyses.
- All waste coming to the facility was treated by the mainline technology if possible, otherwise auxiliary processes were used to treat portions of the waste to ensure complete treatment and disposition.
- A single, centralized government owned and contractor operated (GOCO) facility capable of treating all DOE MLLW was assumed.
- About 70 percent of the current DOE MLLW inventory or 236 million pounds (107 million kilograms) of waste was treated over the system lifetime of 20 years.
- Waste was treated at a rate of 3,000 pounds per hour (1,361 kg/hr) with 45% percent on-line availability (4032 hours/year of operation out of 8760 hours) due to uncertain equipment life and maintenance requirements with radioactive operations.

Table 1. Thermal Systems Evaluated in the ITTS Studies(1,2)

System	Designation	Treatment		Stabilization	Metals	Mercury ^a
		Inorganics	Organics			
Rotary kiln (RK) with air for combustion and dry/wet APC	A-1	RK	RK	Vit. & Polymer ^b	Decon/Melter ^c	Retort
RK with oxygen for combustion and dry/wet APC	A-2	RK	RK	Vit. & Polymer ^b	Decon/Melter ^c	Retort
RK with air for combustion and wet APC	A-3	RK	RK	Vit. & Polymer ^b	Decon/Melter ^c	Retort
RK with oxygen for combustion and CO ₂ retention	A-4	RK	RK	Vit. & Polymer ^b	Decon/Melter ^c	Retort
RK with air for combustion and polymer stabilization	A-5	RK	RK	Polymer	Decon/Melter ^c	Retort
RK with air for combustion and salt recycle	A-6	RK	RK	Vit. & Polymer ^b	Decon/Melter ^c	Retort
Slagging rotary kiln	A-7	RK	RK	Slag & Polymer ^d	Decon ^e	Retort
RK with air for combustion and grout stabilization	A-8	RK	RK	Grout & Polymer ^d	Decon/Melter ^c	Retort
Indirectly heated pyrolyzer and dry/wet APC	B-1	Pyrolyzer	Pyrolyzer	Slag & Polymer ^d	Decon/Melter ^c	Retort
Plasma furnace with air and dry/wet APC	C-1	Plasma	Plasma	Slag & Polymer ^d	Decon ^e	Retort
Plasma furnace with CO ₂ retention	C-2	Plasma	Plasma	Slag & Polymer ^d	Decon ^e	Retort
Plasma gasification	C-3	Plasma	Plasma	Slag & Polymer ^d	Decon ^e	Retort
Fixed hearth (FH) with oxygen and CO ₂ retention	D-1	Vitrifier	FH	Polymer ^b	Decon/Melter ^c	Retort
Debris desorption with RK for combustibles	E-1	Desorber	RK	Grout/Vit./Poly ^g	Decon/Melter ^c	Retort
Molten salt oxidation (MSO)	F-1	Vitrifier	MSO	Polymer ^b	Decon/Melter ^c	Retort
Molten metal (MM) waste destruction	G-1	MM	MM	Slag & Polymer ^b	Melter	Retort
Steam reforming	H-1	Vitrifier	Gasifier	Polymer ^b	Decon/Melter ^c	Retort
Joule heated vitrification	J-1	Vitrifier	Vitrifier	Polymer ^b	Decon/Melter ^c	Retort
Thermal desorption and mediated electrochemical oxidation (MEO)	K-1	Desorber	MEO ^f	Grout & Polymer ^b	Decon/Melter ^c	Retort
Thermal desorption and supercritical water oxidation (SCWO)	L-1	Desorber	SCWO ^f	Grout & Polymer ^b	Decon/Melter ^c	Retort

- a. In all systems contaminated metallic or elemental mercury is amalgamated for stabilization and disposal. Uncontaminated mercury is recycled.
- b. Stabilization of secondary wastes and salts is in polymer.
- c. Surface contaminated metals are decontaminated and metals with entrained contamination are treated in a metal melter.
- d. Ash is stabilized in the slag from the thermal treatment unit, polymer is used for secondary stabilization of salts.
- e. Metal is treated in the thermal treatment unit and is disposed with the slag (A-7) or separated from the slag and poured into ingots (C-1, C-2 and C-3).
- f. Treats only liquid organic wastes.
- g. Grout for desorbed noncombustibles, vitrification for bottom ash, and polymer for secondary wastes and salts.

Table 2. Nonthermal and Enhanced Nonthermal Systems Evaluated in the INTS(4) and ENTS(6) Studies

System	Designation	Pretreatment		Organic Treatment	Stabilization ^a		Metal	Mercury
		Soil/Debris	Sludge		Soil/Debris	Sludge		
<i>Nonthermal Systems</i>								
Thermal desorption, mediated electrochemical oxidation (MEO) and grout untreated debris	NT-1	Desorber/ None	Desorber	MEO ^b	Grout	Polymer	Decon./Grout ^c	Desorption followed by leaching (D/L)
Thermal desorption with catalyzed wet oxidation (CWO)	NT-2	Desorber	Desorber	CWO ^b	Grout	Polymer	Decon.	D/L
Washing with MEO	NT-3	Wash	Wash	MEO ^b	Grout	Polymer	Decon.	Wash
Thermal desorption, wash and acid digestion	NT-4	Wash	Desorber	Acid Digestion ^d	PBC ^e	PBC ^e	Decon./Grout ^c	D/L & Wash
Thermal desorption, wash, CWO and grout stabilization	NT-5	Wash	Desorber	CWO ^d	Grout	Polymer	Decon./Grout ^c	D/L & Wash
<i>Enhanced Nonthermal Systems</i>								
System NT-5 with grout replaced by vitrification	ENTS-1	Wash	Desorber	CWO ^d	Vitrifier	Polymer	Decon./Melt ^f	D/L & Wash
System ENTS-1 with vitrification of untreated sludge	ENTS-2	Wash	Vitrifier	CWO ^d	Vitrifier	Vitrifier	Decon./Melt ^f	D/L & Wash
System NT-5 with grout replace with polymer	ENTS-3	Wash	Desorber	CWO ^d	Polymer	Polymer	Decon./Polymer ^b	D/L & Wash
System NT-5 with pelletized waste macroencapsulated in polymer	ENTS-4	Wash	Desorber	CWO ^d	Pellets in polymer	Pellets in polymer	Decon./Polymer ^b	D/L & Wash
System NT-5 with 10X the organic destruction rate	ENTS-5	Wash	Desorber	CWO ^d	Grout	Polymer	Decon./Grout ^b	D/L & Wash

- a. All secondary wastes and salts are stabilized in polymer.
- b. Treatment for only organic liquids and sludges.
- c. Surface contaminated metals are decontaminated and metals with entrained contamination are stabilized in grout or polymer.
- d. Treatment for organic liquids, organic sludges, and combustible debris.
- e. PBC = phosphate bonded ceramic
- f. Surface contaminated metals are decontaminated and metals with entrained contamination are treated in a metal melter.

- All waste was assumed to be alpha contaminated and handled in remote sorting cells requiring triple containment.
- A "best" and redundant air pollution control system was used with backup filtration.
- Except where a Joule heated melter is explicitly identified, all vitrification is performed in a high temperature plasma furnace that produces a slag.
- Waste loadings (i.e., mass of waste divided by the mass of the final waste form) of 67 wt% in high temperature slag, 50 wt% in polyethylene, and 33 wt% in grout, were assumed.
- Disposal was in a RCRA engineered on-site disposal facility meeting land disposal restrictions.
- Disposal costs were \$240/ft³ (\$8480/m³).

The actual composition of MLLW stored in drums and boxes is not well known and will not be known until further characterization and operating experience has been acquired. How well the characteristics need to be known in order to treat the waste by various methods is also not known. To establish a consistent and comparable basis, a waste composition was derived based on the best information available at the start of the study(9). The reference composition is shown in Figure 1. The conceptual facility used for each system was required to process all waste coming into the facility. For example, as shown in Figure 2, the mainline thermal process accepted 70% of the waste whereas the mainline nonthermal process was able to treat only 20% of the incoming waste directly with the remainder of the waste treated in auxiliary processes.

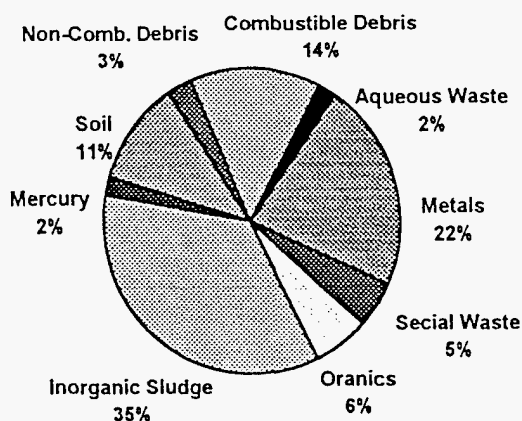


Figure 1. Input Waste Composition

To ensure all incoming waste is processed, all systems required the same set of subsystems. Following is a summary description of these subsystems:

- Receiving and preparation (or front-end handling) in which the waste is received and characterized using real time radiography (RTR), gamma spectroscopy, and passive/active neutron (PAN) assay. The waste is removed from the incoming drums, sorted, separated, size reduced, and transferred to the next process.
- Aqueous waste treatment in which all aqueous waste, including secondary waste generated internally, is treated.

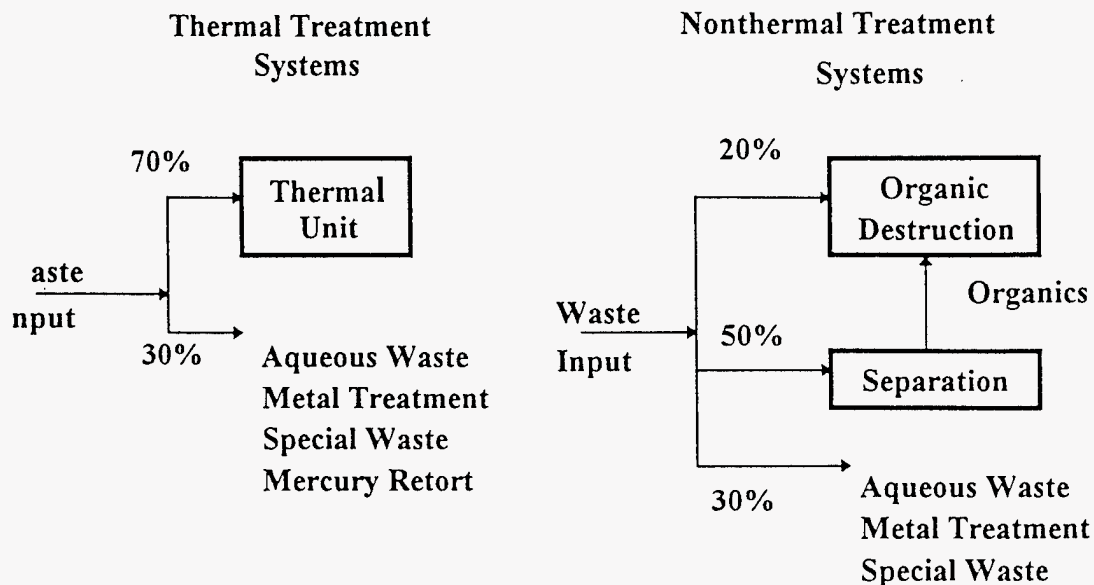


Figure 2. Waste Distribution for Treatment

- Primary treatment which is the main variable in these systems analyses. For thermal systems primary treatment generally consists of a single process (rotary kiln, plasma furnace, metal melter, etc.) although some variations exist with air pollution system designs and combustion gas. For nonthermal systems the primary treatment consists of a chemical oxidation process to destroy organic waste plus a separation process (thermal desorption or washing) to remove organics from inorganic waste matrices.
- Melters are generally used for ferrous metal wastes that cannot be decontaminated to produce ingots for subsequent recycle. However, one system (G-1) also uses a metal melter for primary treatment.
- Metal and lead decontamination uses an abrasive water jet to decontaminate metals for recycle and to decontaminate drums for reuse.
- In thermal systems mercury is removed from inorganic wastes with a retort and in nonthermal systems it is removed by a leaching process. The mercury metal is then amalgamated for disposal.
- Special wastes are highly variable and treatment processes in large part are undefined. Thus, funds were identified for treatment but no treatment process identified.
- Primary stabilization is accomplished by a high temperature vitrifier (or slag former) for most thermal systems. Grout is used for one thermal system and for most nonthermal systems. One nonthermal system uses phosphate bonded ceramic for

primary stabilization. All systems require polyethylene for secondary stabilization of soluble or volatile salts.

SYSTEM TOTAL LIFE CYCLE COSTS

One of the primary products of these studies was the total life cycle cost of these systems of technologies. It should be recognized that actual costs will be dictated by the marketplace, but the cost estimates developed in these studies are appropriate for system comparisons and identification of potential cost savings.

Differences in the TLCC among systems of thermal technologies are minor. Likewise, only small differences were found among systems using nonthermal technologies. However, the cost of nonthermal systems was about 50% more than thermal systems. This difference appears significant since the studies should be within $\pm 30\%$ or even better because of the comparative bases used.

Operating and maintenance (O&M) costs are approximately 50% of the TLCC for both types of systems. TLCCs were estimated to be approximately \$2.1 billion for a thermal metal melting system to \$3.9 billion for a nonthermal acid digestion system. The unit costs for treatment (without disposal) varies between about \$8/lb (\$17.60/kg) to \$13/lb (\$28.70/kg). The total life cycle costs are shown in Figure 3.

The nonthermal system costs are more than thermal systems because the O&M costs are estimated to be 50% higher due to more waste sorting and preparation, and more unit operations requiring more personnel, equipment, and facilities. Also, nonthermal technologies produced more final waste form volume with the associated higher certification, packaging and shipping cost and higher disposal costs. However, there may be niche applications or site specific applications where nonthermal technologies could be used. The typical distribution of subsystem costs for thermal systems are shown in Figure 4, and the distribution of cost elements are shown in Figure 5.

O&M costs are the highest percentage (50 to 60 %) of TLCC, followed by facility (20 % of TLCC) and then by disposal costs for systems that vitrify waste (11% of TLCC). Systems that use a nonthermal waste form (e.g., grout) have a significantly higher disposal cost; about 21% of the TLCC. Because costs are only modestly affected by the choice of treatment technologies or equipment, (i.e., < 5%), *reliability, performance, and safety are the most important considerations in selecting equipment for treatment of MLLW.*

Clearly, the highest cost reduction targets for thermal systems are operating and maintenance followed by facility and disposal (11% to 21% depending on the waste form). Cost saving incentives exist as summarized in Table 3. Because O&M is a major cost contributor to TLCC, and front-end handling is the highest cost subsystem, a 50% decrease in cost in these areas can have a significant impact on total system cost. As will be seen later, equipment reliability and system availability also have a significant impact on TLCC.

Other potential savings were identified by comparing operating strategies for the DOE complex as shown in Table 4. Cost savings were identified by comparing a thermal system using a rotary kiln and stabilizing the ash by high temperature vitrification or grouting. Strategic approaches that favor a single facility over two regional facilities show savings of \$390M may be achievable(8). Further, use of contaminated soil as an additive to achieve vitrification may save up to \$120M by

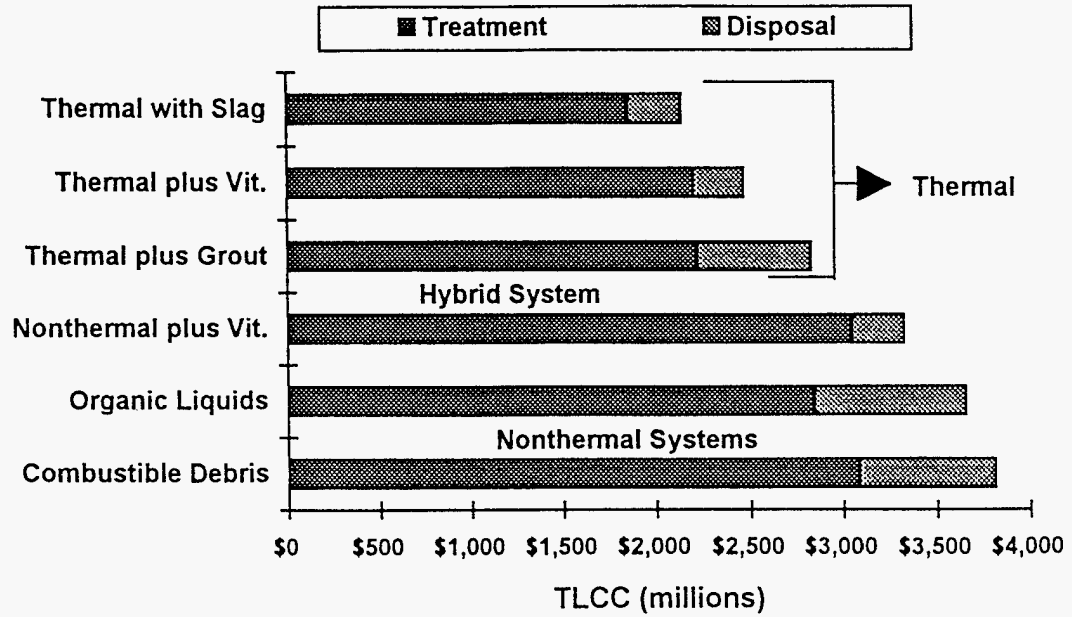


Figure 3. Nonthermal Systems are \$1 to \$1.5 Billion More Costly Than Thermal Systems for a Centralized Treatment Facility. Thermal with slag refers to systems that destroy organics and produce a slag in one operation (e.g., slagging kilns or plasma furnaces). Thermal plus vitrification refers to systems that have separate organic destruction and stabilization units (e.g., rotary kiln plus a vitrifier). Organic liquids refer to nonthermal systems that can destroy only organic liquids, and combustible debris refers to nonthermal systems that can destroy organic liquids as well as organic solids.

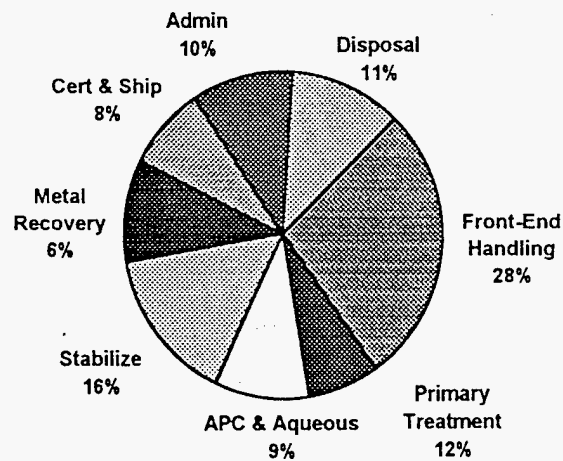


Figure 4. Subsystem Cost Distribution for a Rotary Kiln System with Vitrification

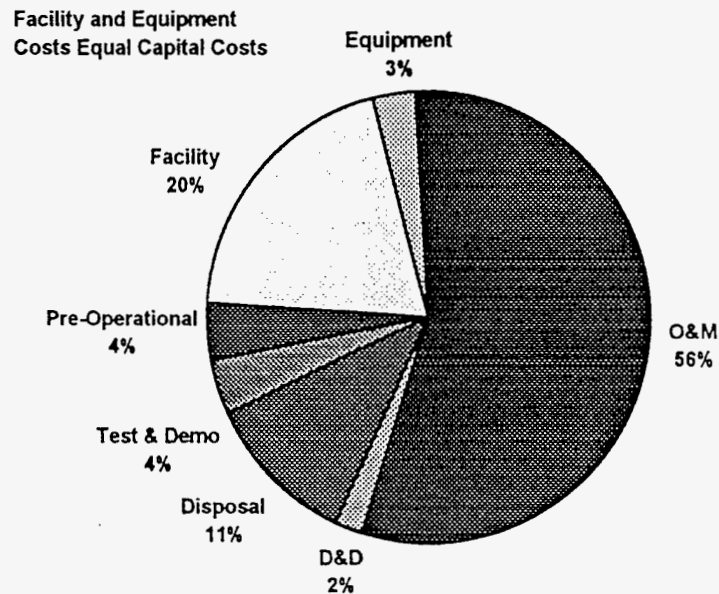


Figure 5. Typical Distribution of Cost Elements for Thermal Systems with Vitrified Waste

Table 3. Cost Saving Incentives for 20 Year Operations

Option	Cost Saving (\$million)
Decrease operating and maintenance costs by 50%	\$680
Decrease front handling (characterization, sorting, shredding etc.) costs by 50%	\$330
Increase online availability from 45% to 70%	\$370

Table 4. Savings from Operating Strategies for 20 Year Operations

Option	Cost Savings (\$million)
High temperature vitrification rather than grout	\$330
Delisting of vitrified waste	\$130
Use of contaminated soil as a glass former & avoiding \$350/ton separate soil treatment	\$120
Privatization of treatment (decrease cost per unit of waste based on quoted costs for the Advanced Mixed Waste Treatment Facility proposed for INEEL - contract DE-AC07-97ID13481)	\$1,500
Using only one central facility with vitrification rather than five regional facilities producing grout	\$2,400

avoiding the cost of separate soil treatment assuming that soil treatment costs \$350/ton (\$386/tonne)(10). The use of contaminated soil as a glass former will likely require high temperature melters (e.g., plasma arc, molten metal, and electric arc furnaces) and would preclude

use of Joule heated melters. However, high temperature melters are expected to have more volatile metals released from the melt, an associated higher volume of secondary waste, and an increased uncertainty in the life of refractory liners.

Energy Use. In all cases, energy costs are less than one percent of the treatment costs, i.e. TLCC without disposal costs. The actual hourly costs ranged from \$80 to \$200/hr with thermal treatment systems using electrical energy (metal melting and plasma systems) having the highest energy costs.

Portable Treatment: In addition to various options for centralized treatment, portable treatment systems may be an option for smaller quantities of waste at specific sites if shipment to a central facility were not possible. However, the unit treatment costs for use of portable systems to treat up to 8.5 million pounds (3.9 million kilograms) of MLLW in 5 years was \$26/lb (\$57.30/kg)(11) compared to the unit cost of about \$7/lb (\$15.40/kg) for a centralized facility using a rotary kiln with grout designed to treat all the DOE MLLW. The unit treatment cost for a new, single central facility that was sized to treat only the 8.5 million pounds in 5 years was \$21/lb (\$46.30/kg). Clearly, all possible waste should be treated through a large central facility if possible. The results are shown in Figure 6.

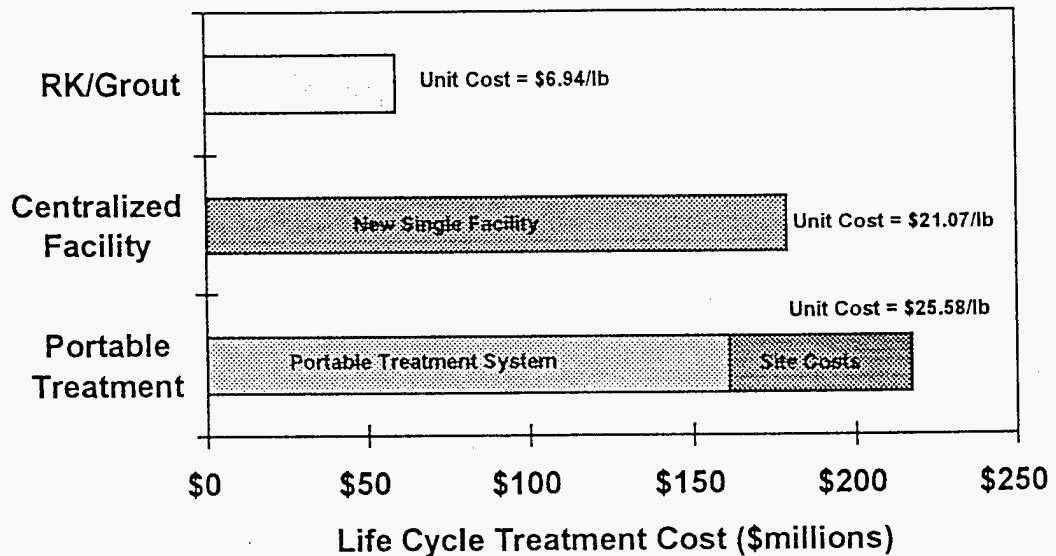


Figure 6. Portable Treatment Costs are 3-4 Times the Treatment Cost for a Centralized Facility Designed for All DOE MLLW.

The waste transportation costs were estimated by assuming a cost-per-loaded-mile of \$4.00/mile (\$2.50/km), an average of 1,000 miles (1600 km) between the central facility and the shipping site, 44,000 lbs (20,000 kg) per shipment, and a fixed cost \$880 per shipment. The cost of shipping 8.5 million pounds of waste to a centralized treatment facility is estimated to be \$943,000; a small fraction of the TLCC. The portable system consists of thirteen trailers and 12 campaigns per year are assumed to treat the waste at various sites. With the same cost assumptions given above, transportation of the portable system is estimated to be \$3.8 million or approximately 2% of the TLCC for the portable treatment system.

Although no economic advantage exists for portable systems, non-economic issues may make portable systems attractive including niche applications for small difficult to treat waste streams or wastes that are difficult to transport (e.g., reactive metals, gas cylinders, liquids, etc.), equity issues, stakeholder opposition to fixed centralized facilities, etc.

Schedule and Storage Effects. The effect on cost of treating the 236 million pounds of MLLW in 10 years rather than 20 years was evaluated by using scaling factors to estimate the costs of a facility with twice the capacity. The affect on cost by increasing capacity depends on the scaling factor used in the exponential scaling relation $C_2=C_1(q_2/q_1)^n$ where C_1 is the cost of a treatment facility of capacity q_1 and the cost of a similar treatment facility of capacity q_2 is given by C_2 where n is the scaling factor. A scaling factor between 0.6 and 0.7 is typically used in industry for a processing plant.

The results of this scaling of capacity is shown in Figure 7 for a rotary kiln system with vitrification and a scaling factor of 0.6. Because equipment costs increase and operating costs decrease, there was little difference in the TLCC for the same operating time per year. Although the shorter processing time does not affect treatment cost significantly, it appears attractive to minimize storage costs, either prior to or during treatment, assuming the logistical and transportation problems are manageable over this shorter operating period.

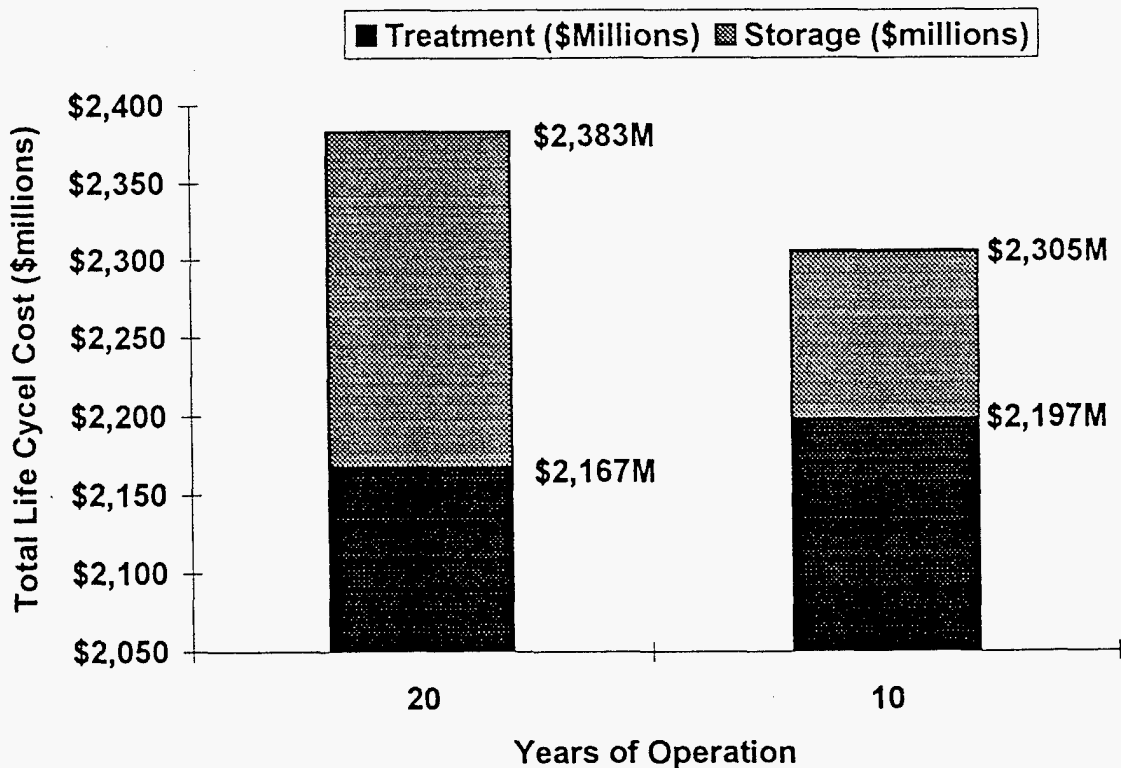


Figure 7. Cost of Waste Treatment and Storage During Treatment

A cost for storage is incurred until the stored waste is completely treated as shown in Figure 7. Treatment of the waste in 20 years incurs a treatment cost of \$2,167 million (unit cost of \$9.18/lb

or \$20.24/kg) and a cost of \$216 million to store the waste as it is being treated assuming a storage cost of \$207/m³/year(12). By decreasing the time required for treatment to 10 years the cost of treatment increases slightly to \$2,197 million with a unit cost of \$9.31/lb (\$20.52/kg), but the storage cost decreases to \$108 million. Thus, treatment of waste in 10 years as opposed to 20 years could save approximately \$78 million.

This shortened operating period required to treat the baseline stored waste allows scheduling of the facility to process additional future waste through the same facility. Additional wastes arise from current and future cleanup operations at each site including site remediation and the decontamination and dismantling of facilities. Doubling the capacity and operating for 20 years to treat twice the total waste (e.g., 472 million pounds or 214 million kilograms) increases the TLCC but decreases the unit cost from the baseline of \$9.18/lb (\$20.24/kg) to \$6.85/lb (\$15.10/kg).

For every year a treatment technology is unavailable, a penalty cost for pre-treatment storage is incurred. If treated waste cannot be disposed for a set time, a penalty cost for post-treatment storage is also incurred.

Post-treatment storage costs can have a significant impact on the TLCC as shown in Table 5. For example, if the treatment process takes 10 years, but a disposal site is not available until 10 years after treatment is completed, then storage for 10 years after treatment is completed accrues an expense of \$120 million for high temperature vitrified waste, or slag, while grout storage would cost \$270 million. *Thus, high temperature vitrification provides a saving of \$150 million in post-treatment storage costs. Placing high temperature vitrified waste into post-treatment storage for 20 years accrues a saving of \$240 million compared to grout.*

Table 5. Post-Treatment Storage Awaiting Disposal is Significant but Small Relative to TLCC

System	20 Year Treatment Cost (\$million)	No Storage	Disposal Cost (\$million)	Total Cost (\$million)
RK with Vit.	\$2,170	0	\$270	\$2,440
RK with Grout	\$2,230	0	\$610	\$2,840
System	10 Year Treatment Cost (\$million)	10 Year Storage Cost (million)	Disposal Cost (\$million)	Total Cost (\$million)
RK with Vit.	\$2,200	\$120	\$270	\$2,590
RK with Grout	\$2,220	\$270	\$610	\$3,100
System	10 Year Treatment Cost (\$million)	20 Year Storage Cost (million)	Disposal Cost (\$million)	Total Cost (\$million)
RK with Vit.	\$2,200	\$180	\$270	\$2,650
RK with Grout	\$2,220	\$420	\$610	\$3,250

Operating Efficiency: Significant cost savings are possible by increasing the operating efficiency from 46% to 67% as shown in Figure 8. Increasing the availability increases the operating hours of the plant from 4032 hours/year to 5850 hours/year with a decrease in total years of operation from 20 to 14. The difference in treatment cost between a rotary kiln system with vitrification and a

rotary kiln with grout drops from \$60 million to \$25 million; and by increasing the availability, a savings of \$370 million is achievable for a rotary kiln with vitrification and \$410 million for a rotary kiln with grout. A greater cost savings is achievable with the grout system because it has a greater initial cost. However, the actual operating efficiency must be established. *Designs should be for maximum efficiency usually achieved by redundancy and readily available spare equipment or improved equipment reliability.* If the operating efficiency of vitrification were less than grout, the cost advantages of vitrification are decreased as will be discussed later.

Waste Volume Reduction & Cost Reduction.

Final Waste Form Volume: Disposal costs constitute about 20% of the TLCC for nonthermal waste forms and about 11% for thermal waste forms. A volume reduction factor (input volume divided by output volume) of 3.4 was generally predicted for all of the waste being treated and stabilized in a high temperature vitrified waste form (slag) with an assumed waste loading of 67 wt%. However, the volume reduction for the rotary kiln with grout was nil to 1.5 assuming a 33 wt% waste loading. The effect of final waste form volume on disposal cost and the cost of handling the final waste form through certification and shipping is shown in Table 6.

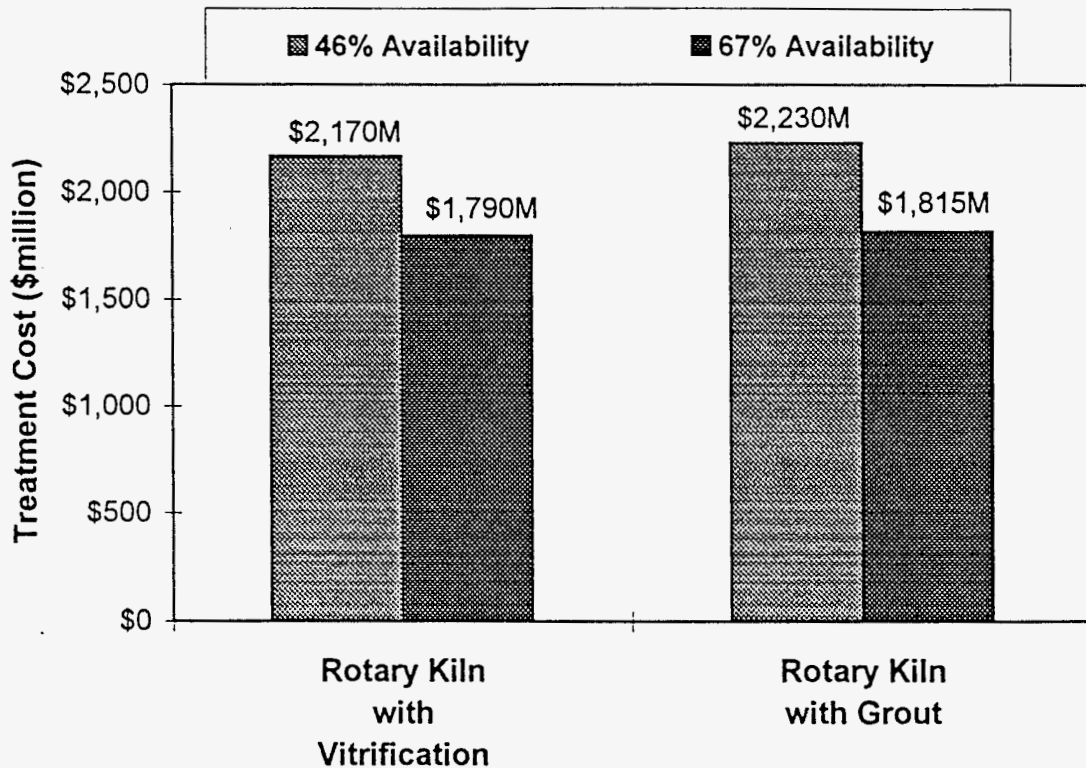


Figure 8. System Availability is an Important Factor in System Cost

In the ITTS and INTS studies, a percentage of the total final waste form volume (10 vol% for grouted waste and 21 vol% for vitrified waste) consisted of polyethylene which was used to immobilize the secondary waste salts. The polyethylene waste loading was assumed to be 50 wt%. Polyethylene was chosen because of its lower leachability characteristics and its capability to provide a more stable waste form incorporating a higher concentration of soluble salts compared to

concrete mixes. Polyethylene was also used to stabilize volatile salts that would go into the offgas of the vitrifier. The disposal volumes in Table 6 and the volumes used to determine disposal costs in Figure 9 reflect the volume of this polymer waste form.

The difference between the total disposal cost of grout and high temperature vitrified waste as a function of the unit disposal cost is shown in Figure 9. A significant cost saving of \$310 million is achieved by using vitrification rather than grout if the disposal cost is \$240/ft³ (\$8480/m³) and all other operating parameters are kept the same. These savings assume a centralized facility treating 236 millions pounds of waste and equal system availability (46%).

Table 6. Waste Form Volume Affects Disposal and Certification & Shipping Costs

System	Total Disposal Volume*	Disposal Cost (\$M) @ \$243/ft ³ (\$8590/m ³)	Certification & Shipping Cost (\$million)	Disposal + Certification & Shipping Cost (\$million)
Rotary Kiln with Vitrification Volume Reduction = 3.4	1,096,700 ft ³ (31,040 m ³)	\$270	\$210	\$480
Rotary Kiln with Grout Volume Reduction = 1.5	2,507,900 ft ³ (70970 m ³)	\$610	\$370	\$980

* Disposal volume of stabilized waste includes the volume of special waste and polymer stabilized waste which are approximately the same for these two systems. Slag waste loading is assumed to be 67 wt% and grout waste loading is assumed to be 33 wt%.

As shown in Figure 10, volume reduction can be achieved through increased waste loading in a final waste form, or by stabilizing waste in a high density waste form. This illustrates a variety of waste forms available for stabilization of treated waste including the following:

- Slag monoliths produced by high temperature vitrification, with a density of about 188 lbs/ft³, and an estimated waste loading between 50 to 70%,
- Glass monoliths produced by low temperature vitrification, with a density of about 188 lbs/ft³, and an estimated waste loading between 30 to 50%,
- Slag or glass marbles with 60% packing fraction and an overall density of about 113 lbs/ft³,
- Phosphate bonded ceramic produced by equipment similar to that used for cement mixing, with a density of about 127 lbs/ft³, and an estimated waste loading of 50 to 70%. Phosphate bonded ceramic is a fast setting ceramic material produced at low temperature from a blend of MgO and phosphoric acid or sodium phosphate and water. These materials are blended with the treated waste and allowed to cure into a high strength, low porosity waste form using equipment similar to that used to produce grout.
- Grout produced by equipment similar to that used for cement mixing, with a density of about 127 lbs/ft³, and an estimated waste loading of 30 to 40%.

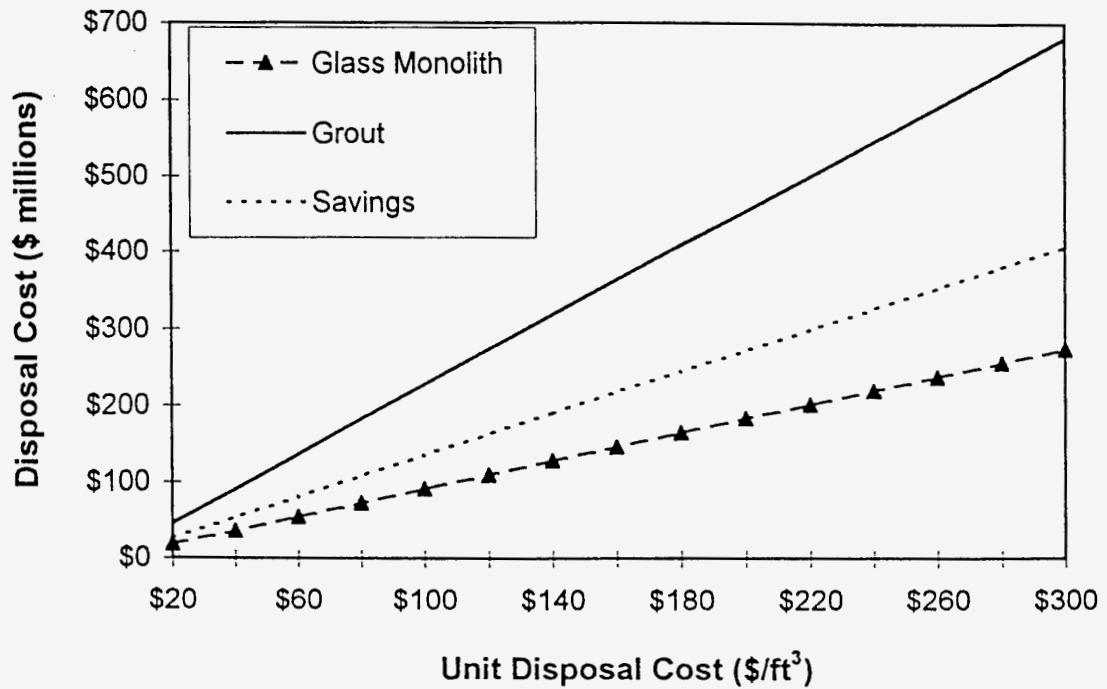


Figure 9. Vitrification Can Save Disposal Costs over Grout Stabilization for the Same System Availability. Assumes a total of 236 million lbs treated with a grout waste loading of 33 wt% and a slag waste loading of 67 wt%.

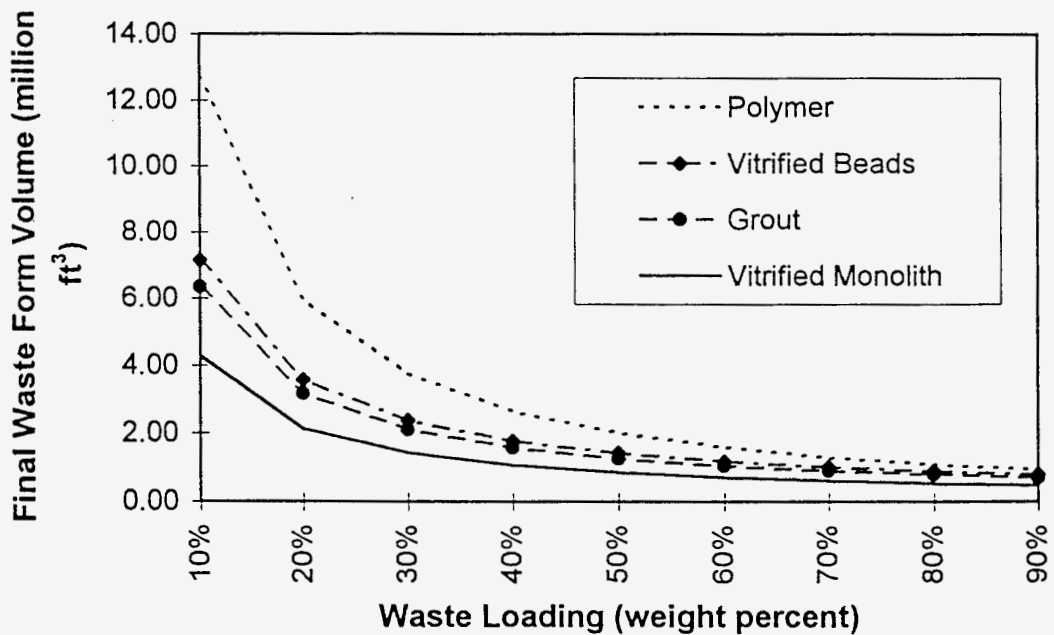


Figure 10. Disposal Volume for Various Waste Forms.

Achievable waste loading depends on the contaminant in the waste and the ability to pass EPA's toxicity characteristic leaching procedure (TLCP) test. Disposal cost is then determined by the

volume of the final waste form and the unit disposal cost (cost per unit volume of waste). Disposal costs for several waste forms, waste loadings and unit disposal costs are shown in Table 7 with the cost associated with waste handling for certification and shipping. As expected, waste form loading and volume reduction also affect costs for certification and shipping of the final waste form. Decreasing the volume of the final waste form will decrease the amount of waste that requires handling, certification and shipping at the end of the treatment process.

This indicates that low temperature vitrification that produces a glass waste form is expected to have a higher disposal volume than high temperature slag, and possibly higher than phosphate bonded ceramic. This would be especially true if the waste form were produced in the form of glass marbles or beads. Thus, for the specified waste loadings in Table 7, the lowest cost waste form is the slag monolith followed by phosphate bonded ceramic, and the highest cost waste form is glass beads.

Table 7. Disposal Cost of Various Waste Forms for 236 Million Pounds of Original Waste

Waste Form	Waste Loading	Waste Form Volume	Certification & Shipping Cost (\$millions)	Unit Disposal Cost		
				\$20/ft ³ (\$707/m ³)	\$100/ft ³ (3534/m ³)	\$240/ft ³ (\$8480/m ³)
				Total Disposal Cost (\$millions)		
High Temperature Slag Monolith	67%	640,000 ft ³ (18,100 m ³)	\$169	\$12.80	\$64.00	\$153.60
Slag Beads	67%	1,067,000 ft ³ (30,200 m ³)	\$202	\$21.30	\$106.70	\$256.00
Phosphate Bonded Ceramic	67%	948,000 ft ³ (26,800 m ³)	\$192	\$19.00	\$94.80	\$227.50
Low Temperature Glass Monolith	33%	1,299,000 ft ³ (36,800 m ³)	\$223	\$26.00	\$130.00	\$311.90
Glass Beads	33%	2,166,000 ft ³ (61,300 m ³)	\$322	\$43.30	\$216.60	\$519.80
Grout	33%	1,924,000 ft ³ (54,400 m ³)	\$290	\$38.50	\$192.40	\$461.90

Thus, if volume reduction is the driving factor, treatment contract terms need to include incentives for volume reduction. Because costs can be avoided by handling and disposing of small volumes of waste, future contracts need to include incentives to produce smaller volumes. For example, payment of a percent of the total cost saved could be appropriate. Otherwise, a treatment contractor can meet a volume reduction requirement but DOE will encounter a higher disposal cost than necessary associated with higher than necessary volumes sent to disposal. Alternatively, contracts could include disposal by the private contractor. However, volume reduction is not the only factor to consider in determining cost effectiveness.

Radionuclide Concentration Effects: Changes in pricing for disposal may be such that the cost of disposal is based not only on volume but also on curie or hazardous material content or concentration because a particular site may be limited in the amount or concentration of radionuclides or hazardous material it can accept. Limitations may be imposed by regulators or

may be recognized through performance assessments that predict the effects of migration from the disposal site. If volume reduction causes the contaminant concentration in the final waste form to increase beyond the waste acceptance criteria for a disposal site, disposal may be more difficult and costly even though the waste volume has been decreased. Thus, the relationship between volume reduction, contaminant concentration and disposal cost needs to be determined on a case-by-case basis.

Using radionuclide concentration as an example, for an initial concentration in ash of 454,000 nCi/ft³ (10 nCi/gram for an ash density of 100 lbs/ft³ or 1600 kg/m³) the concentration in the final waste form increases linearly with waste loading as shown in Figure 11. For vitrified waste, the initial waste concentration occurs at a waste loading of about 50 wt%, whereas for grout or phosphate bonded ceramic the initial concentration is reached at a waste loading of 75 to 80 wt%. Thus, for alpha-emitting transuranic radionuclides with a half-life greater than 5 years, a higher waste loading can be achieved in a grout or phosphate bonded ceramic before the final waste form changes from a Class A low-level waste to a Class C waste with the attendant increase in disposal cost.

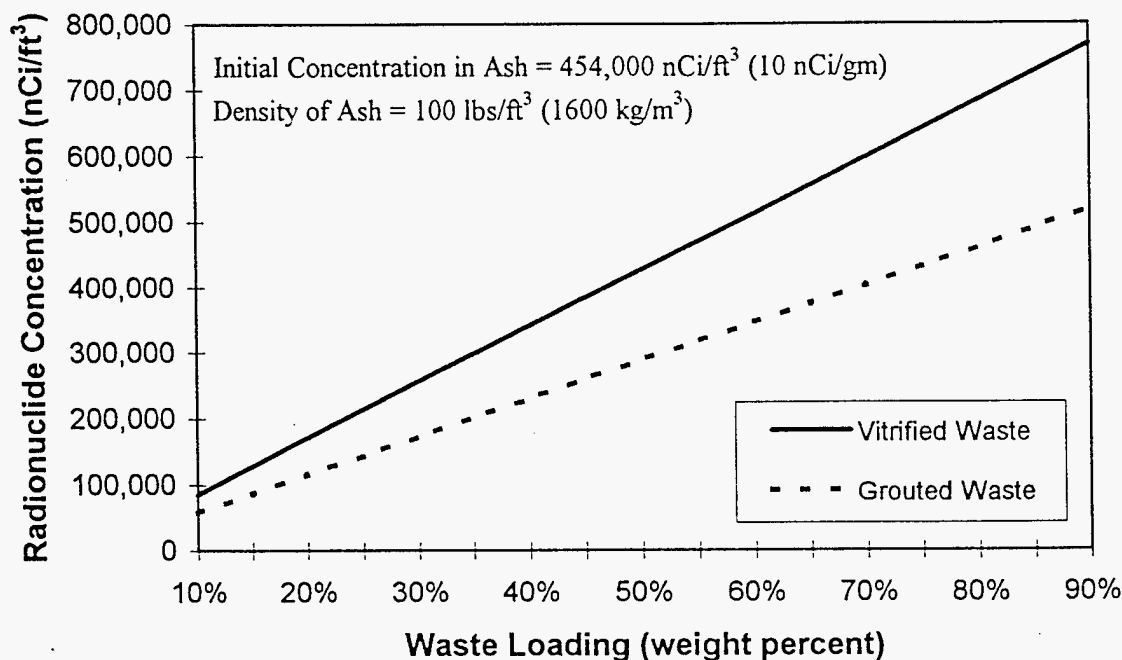


Figure 11. Radionuclide Concentration in the Final Waste Form Increases with Waste Loading and Volume Reduction

The effect on waste disposal cost by consolidating radionuclides can be seen in Figure 12 where the unit disposal cost is assumed to increase by an order-of-magnitude [from \$20/ft³ (\$707/m³) to \$200/ft³ (\$7070/m³)] when the radionuclide concentration increases above 454 μ Ci/ft³ (10 nCi/gm). Even though high waste loadings and high density materials decrease the volume of waste to be disposed (see Figure 10), for this case the disposal cost for high temperature slag (with a waste loading between 50 wt% and 75 wt%) is significantly higher than the disposal cost for grout or a cementitious type waste that can accept a high waste loading (e.g., phosphate bonded ceramic).

Thus, for low temperature glass, in which the waste loading may be similar to that of grout, the disposal cost of grouted waste is higher than that of glass for waste loadings up to 50%. However, if high temperature vitrification (e.g., slag) were used with a high waste loading (e.g., between 50% and 75%), then the disposal cost of grouted waste is less than that of the slag even for low waste loadings in grout. This is because at a waste loading of 50% in slag, the concentration of radionuclides increases beyond 10 nCi/gm. Phosphate bonded ceramics, which can achieve waste loadings of up to 70%, have lower disposal costs than either grout or glass with low waste loadings, or slag with a high waste loading assuming an increase in disposal cost at a radionuclide concentration of 10 nCi/gm.

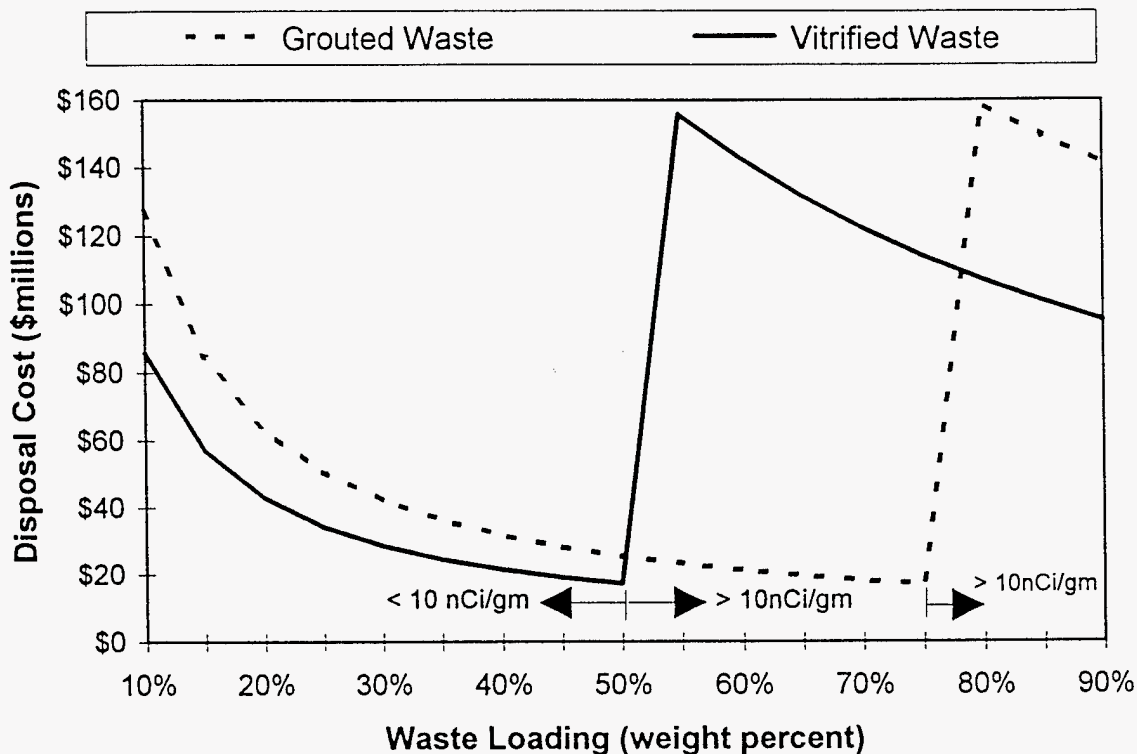


Figure 12. Disposal Cost Varies as a Function of Radionuclide Concentration in the Final Waste Form. Unit disposal costs are assumed to be \$20/ft³ for radionuclide concentrations ≤ 10 nCi/gm, and \$200/ft³ for concentrations greater than 10nCi/gm but less than 100nCi/gm.

Operating Efficiency: On-line operating efficiency or availability is also an important cost factor as indicated in Figure 8, and differences in availability between systems can significantly affect TLCC. As long as the operating efficiency is comparable among technology systems, incentives for high temperature vitrification exist as indicated in Figures 9 and 13. At equal availability of 46%, the treatment cost of a rotary kiln system with grout is about \$60 million greater than the treatment cost of a rotary kiln system with vitrification primarily due to the higher volume of grouted waste and the associated cost of certifying and shipping this waste for disposal. The TLCC of the two systems diverges with increased unit disposal cost. However, if the grout system has a greater availability the relationship between TLCC changes as demonstrated in Figure 13.

With increasing availability the treatment cost for the grout system decreases as shown by the intercept for zero unit disposal cost. For an increase in availability from 46% to 60%, the grout

system has a lower TLCC than a vitrification system with a 46% availability for unit disposal costs less than about \$190/ft³ (\$6714/m³). However, for a unit disposal cost less than \$140/ft³ (\$5,000/m³) a vitrification system with a 70% availability has a lower TLCC than a grout system with an availability of 90%. This illustrates the importance of process reliability and system availability. *Thus, the objective of any technology development effort and any system design should be to achieve the highest operating efficiency achievable.*

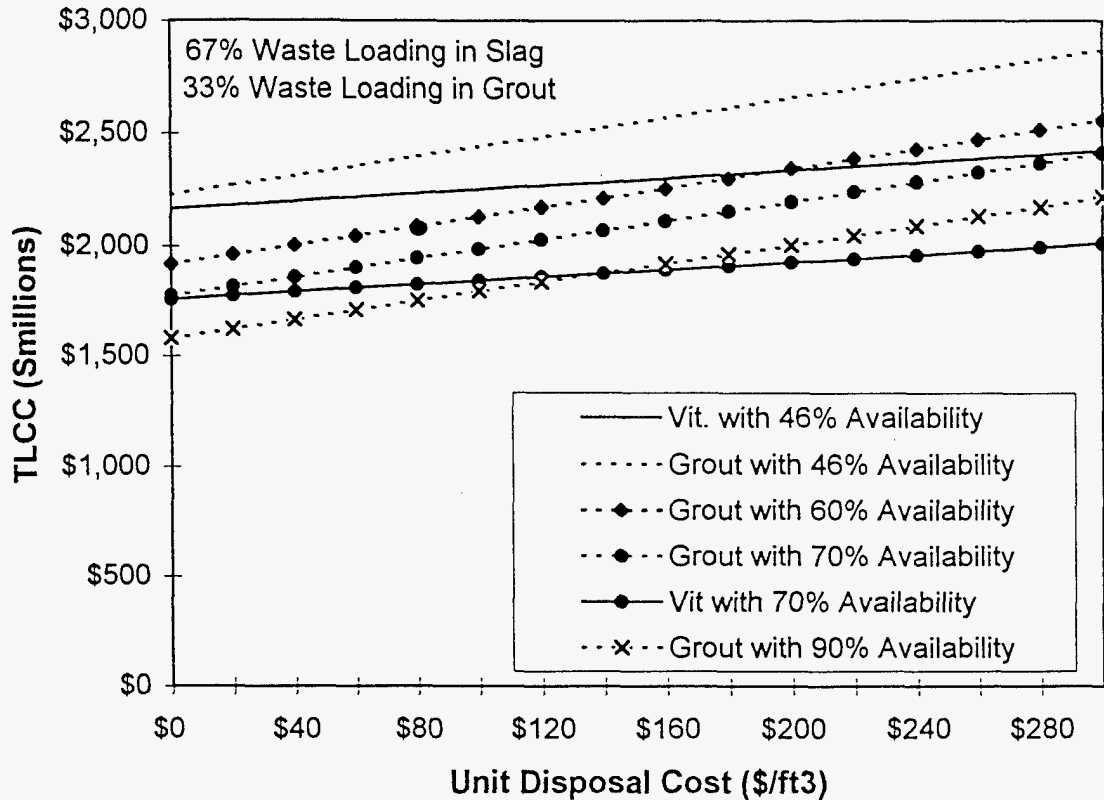


Figure 13. Improved Operating Availability Decreases Treatment Cost and Total Life Cycle Cost

Vitrified Marbles: Vitrified materials can be produced in a monolithic mass or as gem/marble size materials or as cullet. The cost incentives differ. Production of marbles limits the filling of the final volume of a container to about 60% of the total available volume of the container(13) thereby increasing the total disposal volume from that of a vitrified monolith as shown in Figure 10. Since the volume of polyethylene microencapsulated waste was generally about 10 percent of the total volume of stabilized waste in the ITTS studies, this polyethylene waste could be used to fill the void space among the marbles if a physical means of blending the two waste forms were developed in order to fill a single container for the two waste forms. It should be recognized that polyethylene is extremely viscous and will not flow into void spaces. Rather, it must be mixed with particles of another waste form to produce a combined waste matrix.

As seen in Figure 10, the volume of vitrified marbles (assuming a waste loading of 67 wt%) is approximately the same as the volume of grout and therefore the disposal costs are approximately the same regardless of the unit cost. For the waste generated in the ITTS studies (1500 lbs/hr (680 kg/hr) of ash stabilized in grout or by vitrification and 123 lbs/hr (56 kg/hr)

stabilized in polymer) the cost incentive for filling the void space with polymer is a potential saving of \$4 million at a polymer waste loading of 50 wt% and a unit disposal cost of \$20/ft³, and \$50 million for a unit disposal cost of \$240/ft³. Above a certain waste loading in polymer, shown in Figure 14 where the disposal cost of vitrified spheres and polymer in voids becomes constant, the void volume between the marbles is greater than the volume of available polymer stabilized waste. At this waste loading the disposal cost becomes independent of polymer waste loading, and only the cost of polymer disposal is avoided by combining it with the vitrified marbles.

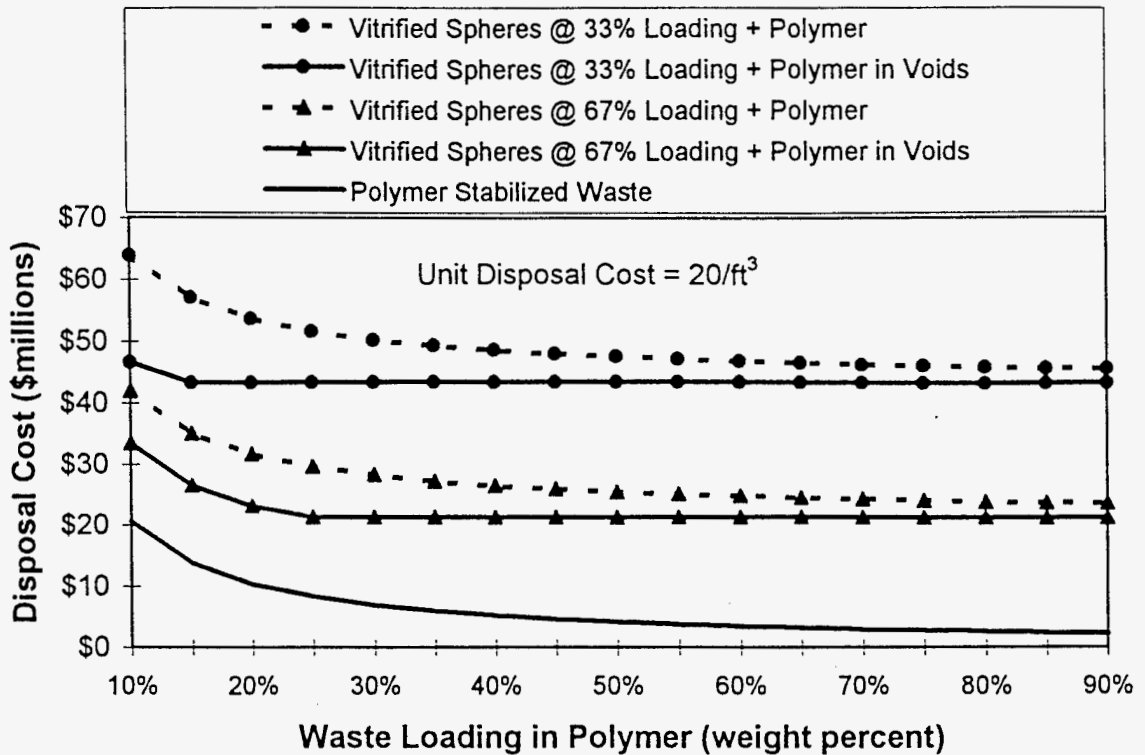


Figure 14. Disposal Cost of Vitrified Spheres with Polymer Disposed Separately or in Voids Between Spheres

Waste Container Size: The size of the container used for collection, transportation and disposal of MLLW can impact the post-treatment cost of certification and shipping for an ITTS type of system. Increasing the size of the container from a 55-gallon drum to a 6'x4'x4' (1.8m x 1.2m x 1.2m) box will decrease the certification and shipping cost by about 90 percent for a cost savings of about \$77 million for vitrified waste and \$175 million for grouted waste over a 20 year period. This assumes that equipment costs for handling the larger boxes are the same as the costs for handling 55-gallon drums throughout the certification and shipping area, and the assay equipment (RTR, gamma and PAN) can be designed to inspect the larger boxes at the same costs per container.

In the ITTS studies, transportation costs alone were generally less than 1 percent of TLCC, or \$24 million, and the cost of transporting 55-gallon drums should be about the same as transporting the larger containers since the total volume and mass will be about the same. In addition to the

potential for decreased certification and shipping labor costs, several other potential advantages of large containers include: capability to dispose large bulky waste in a large container and surround the waste with other stable, solidified waste such as grout; the capability to include compacted empty drums for disposal; economy in the number of post-treatment final characterizations required; and potential economy in shipment and disposal operations due to the smaller number of containers that require handling. Standardization of waste containers for all types of waste could provide a significant cost savings by decreasing the type and quantity of handling equipment and operations required.

The ITTS studies indicate 25,200 55-gallon drums per year containing 11.8 million pounds of waste are delivered to a centralized treatment facility. Of these drums, it was assumed that 50% are undamaged and can be decontaminated for recycle or reuse at a cost of up to \$72/drum or the equivalent of \$1.20/lb (\$2.65/kg) of surface contaminated metal(14). The remainder are assumed degraded to the point that they must be disposed or melted into ingots. Several options may be considered for the 12,600 drums that are reusable. They may be decontaminated for reuse at an annual cost of \$900,000, or compacted and disposed. Assuming a 90% volume reduction of compacted drums, and an 80% fill factor of compacted drums in 6'x4'x4' boxes, then 1,086 large boxes will be required to dispose of 12,600 compacted drums. The final package and disposal costs, including the cost of the large boxes at \$700/box, the cost of certification and shipping, and the cost of compaction, are shown in Figure 15 as a function of unit disposal cost. This indicates that the disposal cost is greater than the decontamination cost and compaction costs have a negligible effect on treating and disposing of drums.

Figure 16 shows the other options for a rotary kiln system with grout where 16,900 drums are required for disposal of grouted waste so that 4,400 additional drums must be purchased (assuming 12,600 of the incoming drums can be recycled) , and a rotary kiln system with vitrification where 7,600 drums are required for disposal of vitrified waste and the remaining 5,000 drums may be compacted and disposed in 6'x4'x4' containers or decontaminated for other uses. In all cases, the disposal cost per compacted drum is greater than the decontamination cost even at low disposal costs of less than \$20/ft³. As the disposal cost increases, the cost difference between disposing of drums versus decontamination increases.

PERFORMANCE ISSUES

Performance of gaseous and liquid effluent treatment systems are important to maintain an efficient on-line processing capability. Air pollution control system costs were less than 5% of the total capital cost even with the assumption of a redundant and "best" APC subsystem. On line continuous monitors for mercury, dioxins and furans, heavy metals, alpha emitting radionuclides, and volatile organic compounds are needed to maintain assurance of adequate performance(15). The total amount of offgases emitted by thermal systems varied between a factor of 4 to a factor of 20 greater than the offgas from nonthermal systems. Internal gas or oil fired rotary kilns using air for combustion produce the largest gas volumes while nonthermal systems produced the lowest gas volumes as shown in Figure 17. Of the thermal systems, rotary kilns using oxygen for combustion and the plasma furnace produced the least offgas.

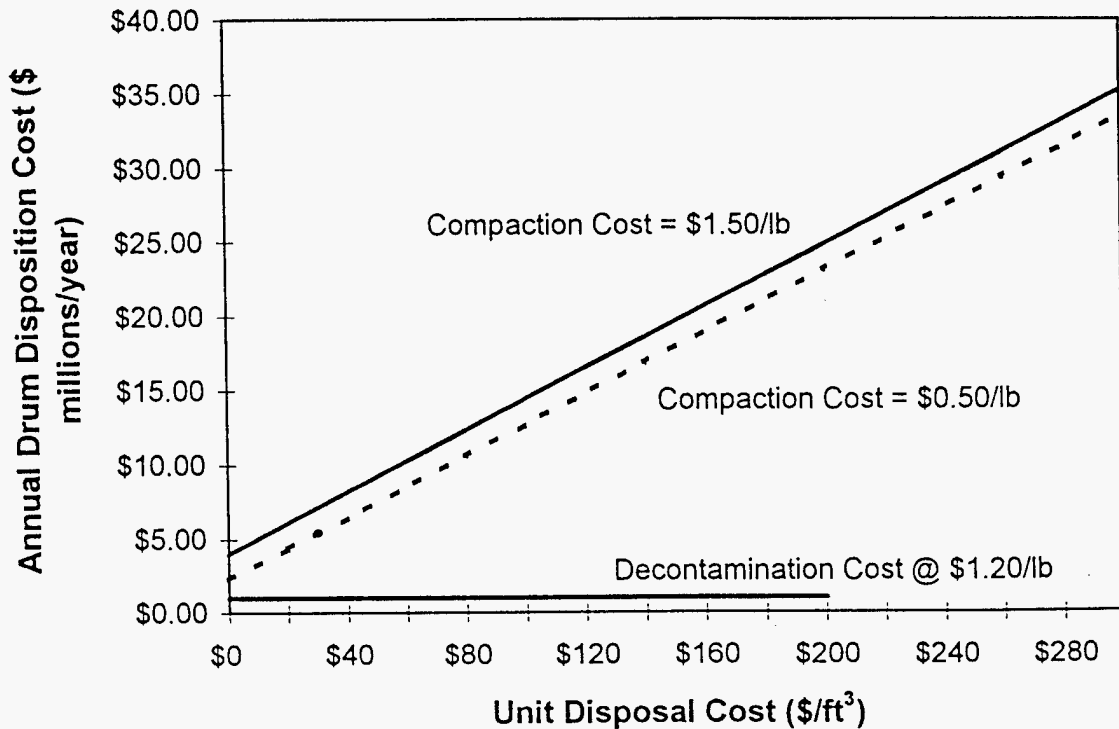


Figure 15. Cost of Compacting and Disposing of Drums. Total cost of drum disposal includes compaction, certification & shipping, and disposal in a 6'x4'x4' Type A box. No decontamination is required.

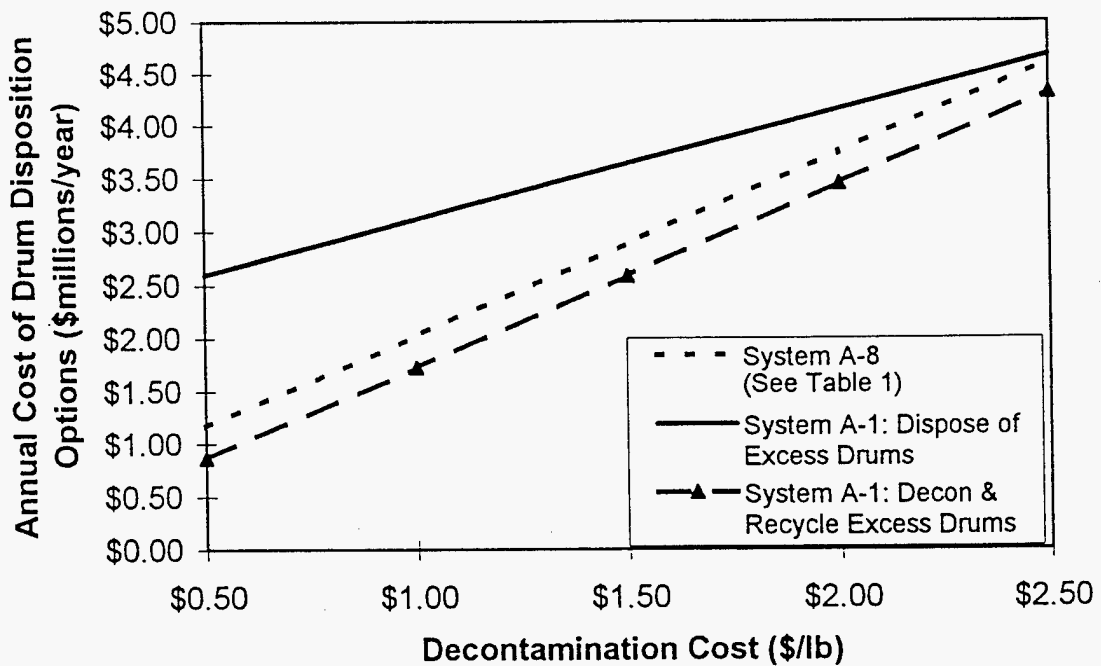


Figure 16. Costs of Drum Recycle versus Disposal for Various Options. Disposal costs are assumed to be \$20/ft³.

Gas volumes may or may not be indicative of contaminant release. Offgas monitors have certain contaminant detection limits and would be more likely to detect contaminants in lower offgas volumes because of higher contaminant concentrations. For the same quantity of contaminants released, the monitors may not be capable of detecting the lower contaminant concentrations in the higher gas volumes. Thus, for technologies that have low offgas emissions the likelihood of detecting contaminants is greater than for technologies that have high offgas emissions even though both technologies emit the same total quantity of contaminant.

Although performance data have been reviewed to estimate partitioning and distribution of radionuclides and heavy metals throughout the APC system(16), more actual performance data and modeling of systems are needed. In the meantime estimates for the decontamination factors through the APC are given in Table 8.

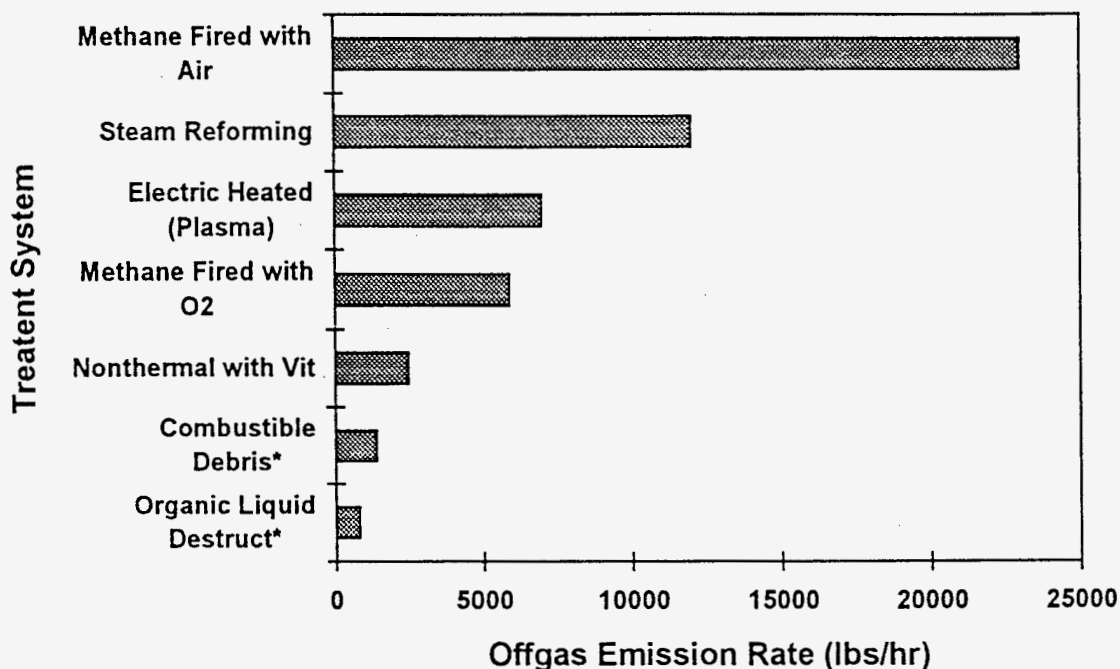


Figure 17. Offgas Emission Rates from Several Types of Treatment Systems. The system described as "Combustible Debris" refers to nonthermal treatment systems that can destroy combustible debris through chemical reactions, the system described as "Organic Liquid Destruct" refers to nonthermal systems that can only destroy organic liquids and cannot treat combustible debris.

Table 8. Estimated Particulate Removal Efficiency of APC Systems

Stage	Removal Efficiency
Quench	10%
Baghouse	99.9%
Activated carbon	10%
HEPA	99.99%
Scrubbers	0%
Total Removal Efficiency	99.999992 %

The amounts of liquid effluent varied considerably as shown in Figure 18. No liquid effluents were produced from the rotary kiln system using grout for stabilization because water was required to form the grout cement, and steam reforming systems emitted all moisture up the stack from the final oxidation step of syngas (hydrogen, methane and carbon monoxide).

Effluents. Gaseous effluents for thermal systems that used combustion heating with air were a factor of 20 higher than nonthermal systems as shown in Figure 17. Water effluents ranged from a net consumption of water in steam reforming and thermal systems that use grout, to a net excess of 900 lbs/hr (1984 kg/hr) for some thermal treatment systems as shown in Figure 18. Stabilized solids sent to disposal ranged from 3500 to 4500 lbs/hr (36 to 42 ft³/hr) [1590 to 2040 kg/hr (1 to 1.2 m³/hr)] for nonthermal systems and from 1700 to 1900 lbs/hr (11.5 to 14.5 ft³/hr) [770 to 860 kg/hr (0.33 to 0.41 m³/hr)] for thermal systems that produce a glass or slag final waste form as shown in Table 9.

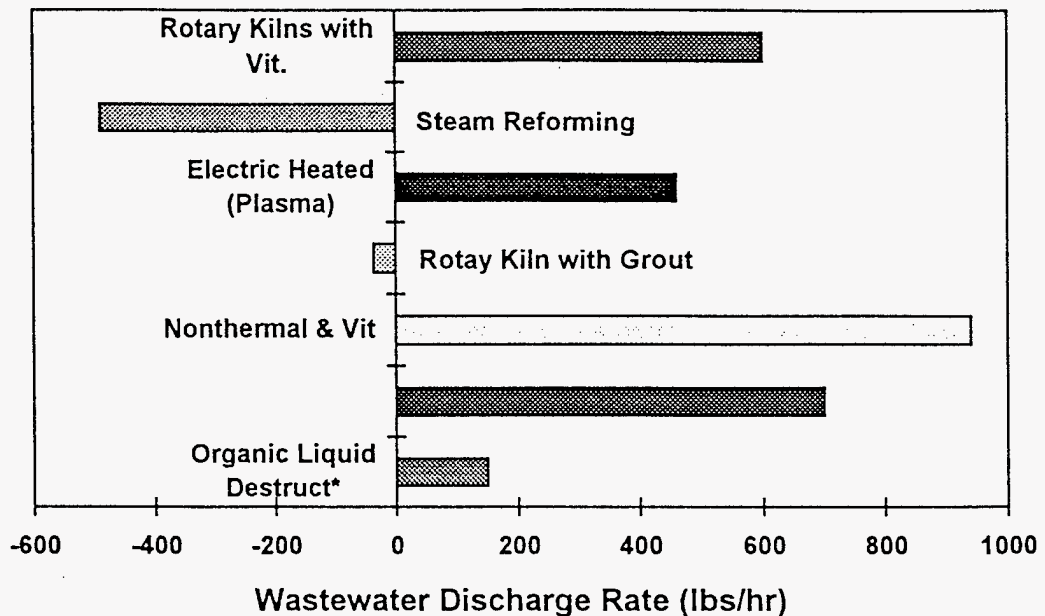


Figure 18. Wastewater Discharge rates from Several Types of Treatment Systems. The system described as "Combustible Debris" refers to nonthermal treatment systems that can destroy combustible debris through chemical reactions, the system described as "Organic Liquid Destruct" refers to nonthermal systems that can only destroy organic liquids and cannot treat combustible debris.

Chemical Reagent. Requirements are minor, even for nonthermal systems. From 80 to 140 lbs/hr (176 to 310 kg/hr) were required principally as sodium hydroxide in offgas scrubbers or to neutralize acids used in nonthermal organic destruction processes.

Transportation. The truck traffic required to bring waste to the facility is 270 trucks/year, and to bring chemicals into the facility ranged from 70 to near 225 trucks/year with the majority of the chemicals being stabilizing agent (e.g., grout, polymer, or glass frit). Hauling waste from the facility took from 230 to 470 trucks/year depending on whether the waste was vitrified or stabilized in grout.

Table 9. Comparison of Effluents of Selected Systems

Selected System	Offgas (lbs/hr)	Waste Water (lbs/hr)	Metal to Recycle (lbs/hr)	Solids to Disposal (lbs/hr)	Solids to Disposal (ft ³ /hr)
Rotary Kiln(RK) w/melter & air combustion (A-1)	20,700	400	620	1930	13.6
RK w/melter, oxygen combustion (A-2)	5,870	890	620	1930	13.6
Slagging RK, air combustion (A-7)	26,400	780	490	2100	14.5
Rotary Kiln w/ grout (A-8)	20,900	-36	620	3670	31.1
Plasma, air combustion (C-1)	6,900	460	660	1860	13.2
Metal Melter, reducing atmosphere (G-1)	11,590	87	640	1790	11.5
Steam Reforming, reducing atmosphere (H-1)	11,650	-490	620	1930	13.6
Thermal Desorption (NT-2)	820	140	450	4620	42.2
Wash (NT-3)	830	180	450	4470	40.8
Catalyzed Wet Oxidation (NT-5)	1430	560	450	3820	36.1

Land Use. Construction of the treatment facility was estimated to require between 50 to 60 acres (20 to 24 hectares) with all of the supporting requirements and buffer zone. The actual treatment building occupies less than 7% of the total site area(7).

The engineered disposal facility consisted of concrete canisters, each containing 8 drums of stabilized waste stacked 2 high in the canister, and the canisters were stacked 3 high to a height of 26 feet (8 meters)(17). The restricted area containing the waste canisters was surrounded by a 1,000 foot (305 meter) buffer zone. The total disposal site, including the buffer zone, required up to 214 acres (87 hectares) for disposal of nonthermally produced waste and 155 acres (63 hectares) for vitrified waste.

Because the waste is stacked essentially 6 drums high, each cubic foot of waste requires approximately 0.426 ft² (0.04 m²) of area within the restricted area for disposal. Increasing the waste volume by a factor of four increases the total area of the disposal site 70% for a site laid out as a square and 77% for a circular site because of the required buffer zone as indicated in Figure19.

RISK REDUCTION

Quantitative indicators of relative risk were used to develop the relative risk between the waste treatment systems so that meaningful comparisons could be made and risk-reduction evaluations performed. This risk-reduction analysis includes risk analyses of normal operations and potential natural and man-made disruptive events during operations, storage, transportation, and disposal of materials. The risk evaluations include risks from both radioactive and hazardous components of the waste.

For this study a simplified risk analysis methodology(18) was used to allow rapid “relative quantitative risk” comparisons of various scenarios, as opposed to the more detailed and rigorous absolute probabilistic risk assessments performed for safety analysis reports and baseline risk assessments. This simplified risk method is based on the fundamental equation of risk assessment (i.e., risk equals the probability that an event will occur multiplied by the consequences from the event). The method develops the equation further into approximately 50 risk elements, including waste contaminant inventories, waste contaminant toxicity, contaminant mobility, confinement barriers, environmental stress on the barriers, operations stress on the barriers, contaminant transport, worker proximity, public proximity, and average time in rest state. The method provides a lookup table containing values for each element. The user selects the most appropriate value for each risk element, then multiplies and adds the values together in accordance with the more detailed equation. The objective of this simplified risk assessment method is to fill the gap between qualitative methods, which may provide quick response but are often so simplified that they are of limited use and reliability, and detailed quantitative methods which may provide more reliable results but require detailed facility and process designs, extensive time for analysis, and major commitments of financial and other resources.

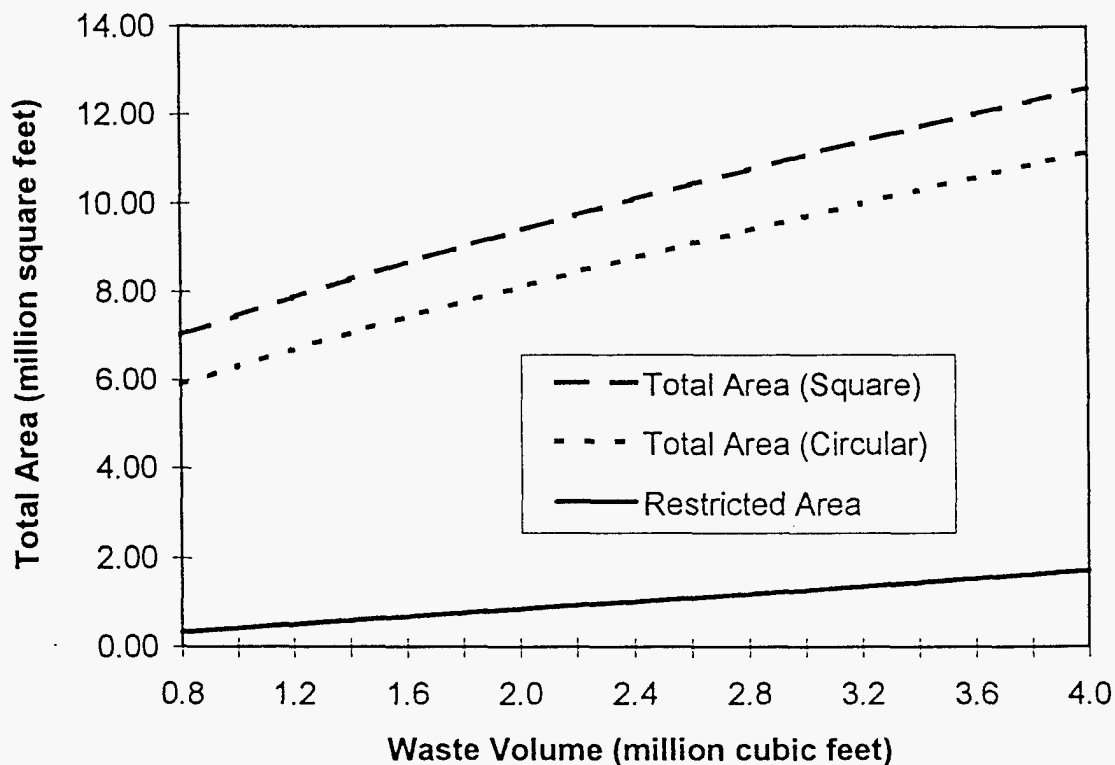


Figure 19. Relationship of an Engineered Disposal Site Area and Waste Volume.

The results of this risk study are summarized in Figure 20. The numbers simply indicate the risk of one system relative to the others and have no physical meaning. Waste management, which includes sorting, segregation, size reduction, material handling, transportation, and other ancillary functions, contributes the most to system risk. Treatment and disposal contribute a relatively small fraction, although stabilizing rotary kiln ash in grout has a higher risk than vitrification or grout stabilization of waste from nonthermal systems. Vitrified waste is more stable than grout and therefore contributes less risk, and most radionuclides from nonthermal treatment are stabilized in

polymer whereas rotary kiln ash contains most of the radionuclides that end up in grout. Polymer is considered a more stable waste form than grout. Even though Figure 20 indicates differences in the relative risk for these systems, this is well within the error bands of the methodology and the differences in risk are small.

RETURN ON INVESTMENT

Insight into the R&D budgets that could be justified by the potential savings can be derived as shown in Table 10. These are savings that can be readily realized by decreasing O&M costs through improvements in equipment or operating efficiency, decrease in volume of waste sent to disposal, improvements in system availability and reliability, etc. This does not include the less definable cost factors such as public acceptability, ease or difficulty (and associated cost) of permitting, decreased risk, decreased effluents, etc.

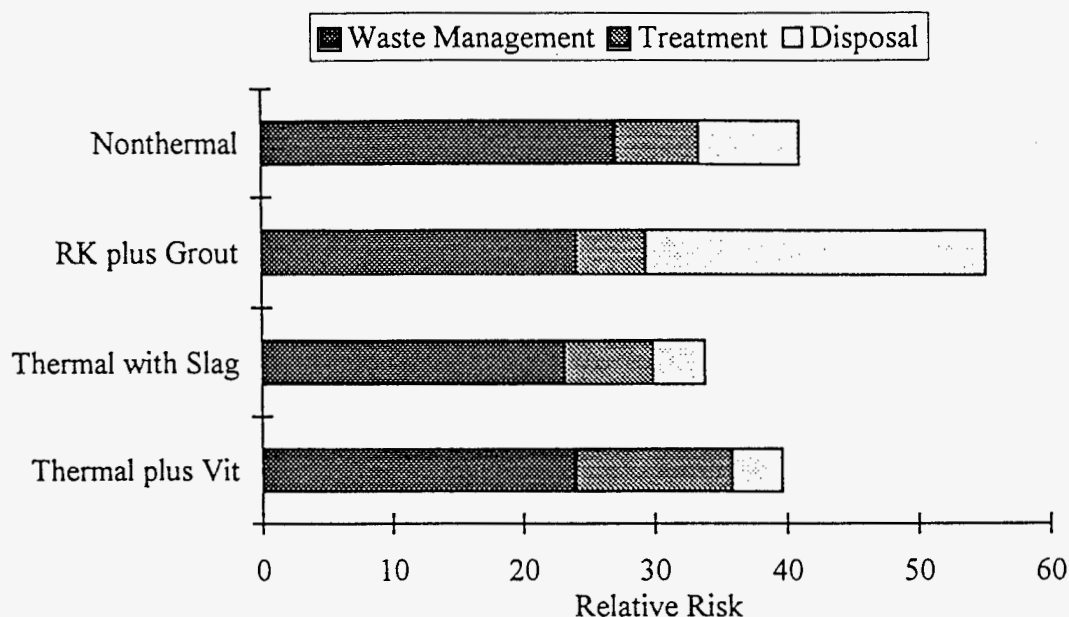


Figure 20. Relative Risk of Several Treatment Systems

Table 10. Guide for R&D Investments from Savings

Potential Savings	R&D Investment Allowed	
	ROI 5/1	ROI 20/1
\$100M	\$ 20M	\$ 5M
\$500M	\$100M	\$ 25M

STAKEHOLDER INVOLVEMENT

Stakeholder involvement in other activities resulted in recommendations that stakeholders should be involved early in planning. Just how early was not clear. Thus, the INTS study used a working group of 20 tribal and stakeholder representatives (Native Americans, state and local government

representatives, citizens, environmental groups, and personnel from private companies). This Tribal and Stakeholder Working Group (TSWG) was organized to provide perspectives on the formulation of the INTS study and to provide comments on the process and results of the INTS and ITTS studies. The TSWG developed a set of principles to reflect their concerns, namely to reduce effluents; to minimize effect on human health and the environment; to minimize waste generation; to address social, cultural, and spiritual concerns; to provide accurate and timely information; and to involve stakeholders in the DOE procurement process when contemplating application of treatment technologies to DOE wastes. These principles were used to guide the evaluation of the treatment systems.

The INTS Study provided tribes and other members of the public an opportunity to participate in an engineering analysis for comparing various technologies at the system level for application to the treatment of DOE mixed low level waste. Participation in development of selection criteria and in the review of technical and non-technical findings of the INTS and ITTS studies allowed the TSWG representatives to understand the issues and trade-offs associated with developing, evaluating, and selecting waste treatment systems. These interactions provided an opportunity for non-technical and technical participants in the INTS study to work together and develop increased understanding and credibility on all sides of the complex issue of waste treatment. The technical members of the INTS study had the opportunity to learn more about tribal and stakeholder issues and how they might apply to the technical tasks associated with technology assessment and selection.

PEER REVIEW

The ITTS and INTS studies were reviewed by an Independent Peer Review Panel (IPRP)(5) consisting of technology and waste treatment experts representing industry and academia. The purpose of this panel was to (1) review and comment on the INTS study and the ITTS/INTS comparison report, (2) make recommendations on the most promising thermal and nonthermal treatment systems, and (3) make recommendations on research and development necessary to prove performance of nonthermal and thermal technologies.

Following are comments from the Independent Peer Review Panel Report(5):

- “The panel was not able to identify any potential advantages of emerging technologies that would outweigh the disadvantages of a significant time delay in treatment of MLLW while these technologies were being developed.”
- “The panel agreed that incineration technology as defined in the ITTS Study is safe and effective for treating the broad range of materials in MLLW.”
- “The panel concluded there are potential critical flaws with nonthermal systems due to their inability to remove enough organic material to insure that nonthermal physical or chemical stabilization will adequately provide long term safe disposal, particularly in grout.”
- “The panel concluded that the potential for a larger quantity and variety of products of incomplete reaction (analogous to products of incomplete combustion) are more likely to result from low temperature reactions than from higher temperature reactions.”

Several development needs for MLLW treatment systems were identified by the peer review panels(3,5) and are summarized as follows:

- Perform treatability studies using bench-scale systems,
- Identify optimum parameters for waste treatment operations by treating surrogate waste,
- Prepare detailed cost/benefit analysis for using oxygen in thermal systems,
- Improve solids-handling for front-end handling and waste feed and discharge,
- Improve air exclusion systems for incineration subsystems,
- Perform field tests to determine the accuracy of partitioning and volatilization models,
- Develop process parameters to prevent ash slagging and for slag management in slagging systems.

Aspects of the APC subsystem that were identified as requiring development to prove the efficacy of various units within the subsystem include:

- Characterize products and concentrations of products of incomplete reaction for thermal and nonthermal systems in the gaseous and liquid phases, including the amount of dioxins/furans formed as offgases from various thermal systems are cooled,
- Improve system designs to minimize formation of dioxins and release of metals and products of incomplete combustion (PICs),
- Identify analytical requirements,
- Improve mercury removal and pre-HEPA filter designs,
- Perform bench-scale or small pilot-scale studies of delayed CO₂ release systems and to assess the feasibility and economics of the concept,
- Develop acceptable alternatives to conventional HEPA filters,
- Develop improved continuous emission monitoring technologies and techniques,
- Determine effectiveness of dry filters and wet scrubbers on capturing radionuclides.

One of the best ways to acquire data on the foregoing is to establish an APC test bed in which designs can be tested, subsystem configurations can be experimented with, and continuous emission monitors can be evaluated.

SUMMARY

This paper summarized the results of a sequence of systems studies that are detailed in the referenced documents. These studies were designed to evaluate thermal and nonthermal systems with respect to costs and performance. Selected systems were compared, and various treatment options were identified where cost savings or cost avoidance could be realized in the treatment of DOE MLLW. Areas requiring R&D were identified that could lead to cost savings, improved performance and/or decreased emissions. The primary results are as follows:

- High temperature vitrification provides a significant savings in post-treatment storage costs relative to grout.
- Reliability, performance, and safety are the most important considerations in selecting equipment for treatment of MLLW.
- System designs should be for maximum efficiency and availability usually achieved by redundancy and readily available spare equipment or improved equipment reliability.
- Disposal costs are affected by a variety of factors including final waste form volume, final waste form type and performance, and waste acceptance criteria.
- At least two types of stabilization media are required, one for primary waste and one for soluble or volatile secondary wastes.

- Several auxiliary processes are required to treat all the MLLW entering a centralized treatment facility.

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