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Integrated Thermal and Nonthermal Treatment Technology and Subsystem Cost Sensitivity Analysis

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EXECUTIVE SUMMARY

The U.S. Department of Energy's (DOE) Environmental Management Office of Science and Technology (EM-50) authorized studies on alternative systems for treating contact-handled DOE mixed low-level radioactive waste (MLLW). The on-going Integrated Thermal Treatment Systems[1] (ITTS) and the Integrated Nonthermal Treatment Systems[2] (INTS) studies satisfy this request. EM-50 further authorized supporting studies including this technology and subsystem cost sensitivity analysis.

This analysis identifies areas where technology development could have the greatest impact on total life cycle system costs. These areas are determined by evaluating the sensitivity of system life cycle costs relative to changes in life cycle component or phase costs, subsystem costs, contingency allowance, facility capacity, operating life, and disposal costs.

For all treatment systems, the most cost sensitive life cycle phase is the operations and maintenance phase and the most cost sensitive subsystem is the receiving and inspection/preparation subsystem. These conclusions were unchanged when the sensitivity analysis was repeated on a present value basis. Opportunity exists for technology development to reduce waste receiving and inspection/preparation costs by effectively minimizing labor costs, the major cost driver, within the maintenance and operations phase of the life cycle.

The capacity analysis demonstrates that life cycle costs are minimized with one large treatment facility for the entire MLLW inventory. In comparison to multiple smaller treatment facilities, the additional transportation costs associated with shipment of the MLLW to a single facility are more than off set by the economies of scale in building and operating a single facility. The analysis further demonstrates that additional life cycle cost savings can be attained by increasing annual facility availability. Although system unavailability is not attributed to a specific cause, it is clear that equipment reliability is a key determinant of availability. This provides incentive for future technology development and/or improvement toward increased equipment availability.

As a potential system discriminator, the sensitivity of life cycle costs to the contingency allowance is evaluated for the less developed technologies. Instead of using the same percent contingency allowance for all systems, as was done in the ITTS and INTS, the contingency allowance in this analysis was varied to account for the maturity of the technology. The results show that the less developed technologies are not as economically desirable when contingency costs are increased to reflect operational uncertainties.

The disposal cost analyses presented in the ITTS and INTS are extended to incorporate varying design capacities for future waste disposal facilities. The fixed and variable components of total disposal costs are calculated to determine the sensitivity of life cycle costs to the disposal volumes resulting from selected treatment systems. As expected, disposal costs decrease with the volume of waste requiring disposal. Maximum cost savings will be realized if the disposal site is designed and sized for the selected treatment technology. If a new RCRA-permitted engineered disposal facility is designed to accommodate a greater waste volume than the selected treatment technology produces, only the variable cost of disposal will be saved. The selection and/or development of treatment technologies, final waste form(s) and disposal site(s) should be coordinated to minimize total life cycle costs. The possibility of delisting certain final waste forms offers the opportunity for additional cost savings.

CONTENTS

FIGURES

TABLES

TABLES (cont'd)

ACRONYMS

DOE	U.S. Department of Energy
EM	(U.S. Department of Energy) Environmental Management
EPA	U.S. Environmental Protection Agency
GOCO	government-owned, contractor-operated
INEL	Idaho National Engineering Laboratory
INTS	Integrated Nonthermal Treatment Systems
ITTS	Integrated Thermal Treatment Systems
LCC	life cycle cost
MK	Morrison Knudsen
MLLW	mixed low-level waste
MWIR	Mixed Waste Inventory Report
NPV	net present value
ORNL	Oak Ridge National Laboratory
RCRA	Resource Conservation and Recovery Act
RFP	Rocky Flats Plant
SRS	Savannah River Site
WBS	work breakdown structure

1.0 INTRODUCTION

1.1 Background and Purpose

The U.S. Department of Energy (DOE) Environmental Management Office of Science and Technology (EM-50) authorized studies on alternative thermal and nonthermal systems for treating contact-handled, alpha and non-alpha DOE mixed low-level radioactive waste (MLLW). The Integrated Thermal Treatment Systems[1] (ITTS) and the Integrated Nonthermal Treatment Systems[2] (INTS) studies satisfy this request. EM-50 further authorized various supporting activities including this technology and subsystem cost sensitivity analysis.

The purpose of this analysis is to identify areas where technology development and/or improvement could have the greatest impact on system life cycle costs. To identify these areas, the sensitivity of life cycle cost to changes in component or phase costs, subsystem costs, contingency allowance, operating life, and disposal cost is evaluated. Facility capacity is varied to determine the effect on treatment life cycle cost for construction and operation of multiple facilities versus a single facility. A present value analysis is included in anticipation of the requirement for all proposed EM projects, as explained in the Ten Year Plan guidance.

1.2 Report Organization

The ITTS and INTS Technology and Subsystem Cost Sensitivity Analysis report is organized into seven sections and three appendices.

Section 1.0 provides the background and purpose, report organization, scope, and major assumptions of the analysis along with a brief introduction to the treatment systems.

Section 2.0 presents the results of the treatment life cycle component and subsystem cost sensitivity analyses along with present value cost comparison for the components or phases of the life cycle. This section lists the life cycle components and the subsystems and identifies those that are most cost sensitive.

Section 3.0 estimates the effect on treatment life cycle costs for multiple versus a single treatment facility. In addition, cost savings is estimated by increasing annual facility availability (i.e., increasing annual operating hours). A present value comparison of the life cycle costs for a reduced operating life is included.

Section 4.0 considers an additional contingency allowance for technologies considered to have more operational uncertainty.

Section 5.0 estimates the cost for disposal as a function of the final waste volume produced by the treatment systems. This disposal cost comparison assumes that a mixed waste disposal facility would be constructed.

Section 6.0 summarizes the major conclusions and recommendations.

Section 7.0 lists the references used in this analysis.

1.3 Analysis Scope

The technology and subsystem cost sensitivity analysis identifies areas where technology development and/or improvements could have the greatest impact on total system life cycle costs. These costs are the system life cycle costs for the twenty-five ITTS and INTS technologies. The cost estimates are based on construction and operation of government-owned contractor-operated (GOCO) facilities. The sensitivity of the system life cycle costs is evaluated relative to changes in life cycle component or phase costs, subsystem costs, contingency allowance, facility capacity, operating life, and disposal costs.

A representative subset of the 20 ITTS and 5 INTS treatment systems is compared in the individual analyses contained in this study. These systems are:

Thermal Treatment Systems

A-1	rotary kiln with air for combustion and vitrification for stabilization,
A-2	rotary kiln with oxygen for combustion and vitrification for stabilization,
A-3	rotary kiln with air for combustion and wet air pollution control system,
A-4	rotary kiln with oxygen for combustion and CO_2 retention,
A-5	rotary kiln with air for combustion and polymer stabilization,
A-6	rotary kiln with air for combustion and maximum recycling,
A-7	slagging rotary kiln with air for combustion,
A-8	rotary kiln with air for combustion and grouting for stabilization,
B-1	indirectly heated pyrolyzer with oxygen and dry/wet air pollution control,
C-1	plasma hearth furnace with air for combustion,
C-2	plasma furnace with oxygen for combustion and CO_2 retention,
C-3	plasma furnace with steam for combustion and dry/wet air pollution control,
D-1	fixed hearth with oxygen and CO_2 retention,
E-1	debris desorption and grouting with rotary kiln for combustibles,
F-1	molten salt oxidation with air for combustion and dry/wet air pollution control,
G-1	molten metal waste destruction with oxygen for combustion,
H-1	steam gasification with steam for combustion and vitrification for stabilization,
J-1	joule heated vitrification with oxygen for combustion and dry/wet air pollution control,
K-1	thermal desorption with starved air for combustion and mediated electrochemical oxidation for organic liquid destruction and dry air pollution control, and
L-1	thermal desorption with starved air for combustion and supercritical water oxidation for organic liquid destruction and dry air pollution control.

Nonthermal Treatment Systems

NT-1	grout debris,
NT-2	vacuum desorption,
NT-3	wash,
NT-4	acid digestion, and
NT-5	catalytic wet oxidation.

1.4 Major Assumptions

The major assumptions in this analysis are summarized as follows:

- The ITTS and INTS facilities are designed and costed to operate three shifts per day, seven days per week, 40 weeks per year at 60% operating efficiency for a total of 4,032 hours per year.
- In the base case, bench scale testing and demonstration begins in year one with a duration of three years; permitting begins in year four with a duration of three years; construction begins in year seven with a duration of two years; one year of preoperations in year eight; operations begin in year nine with a duration of 20 years; disposal operations begin in year nine with a duration of 21 years; decontamination and decommissioning begins in year 29 with a duration of two years.
- The systems are designed for a 20 year operating life.
- The system feed rate calculations are based on a total of 2,927 pounds per hour. This feed rate was derived based on treating the majority of the DOE 1993 MLLW inventory.
- The base case treatment facility will process a portion of the DOE contact-handled, MLLW inventory equal to 236,033,280 pounds (i.e., 2,927 lbs/hr x 4,032 hrs/yr x 20 yrs).
- The physical, chemical, and radiological characteristics of the MLLW inventory, as identified in the ITTS and INTS, are based on the DOE 1993 MLLW inventory.
- The treatment life cycle phases are: bench scale testing, demonstration, construction, preoperations, operations, disposal, and decontamination and decommissioning.
- The cost of transporting the waste to the treatment facility is independent of the treatment system used.
- The cost of transporting the treated waste to the disposal facility is not considered because the ITTS assumes that the residual waste will be disposed at the same location as the treatment facility and therefore, cost is negligible.

2.0 SENSITIVITY TO CHANGE IN COMPONENT AND SUBSYSTEM COSTS

The following sections identify significant system component or phase and subsystem costs. Using parametric comparisons, the life cycle cost sensitivity is examined with respect to change in these cost areas. A present value cost comparison incorporates the time value of money to show the present cost for each life cycle component or phase.

2.1 Sensitivity to Change in Component Costs

Using a representative set of systems, this section identifies major cost components and shows how change to these costs affects treatment life cycle costs. The life cycle components or phases are: bench-scale testing, demonstration, construction, preoperations, operations and maintenance, disposal, and decontamination and decommissioning activities. This analysis combines bench-scale testing and demonstration into one component called demonstration, and construction costs are divided into capital equipment and building cost components. This division maintains consistency with a similar comparison documented in the ITTS and INTS.

The cost sensitivity for each component is determined by doubling and halving the cost of the component or parameter and then measuring the resulting increase and decrease in the total life cycle cost. This cost variation was selected to maintain consistency with the comparison documented in the ITTS. Figure 2-1 illustrates this cost sensitivity. In this analysis, all dependent costs are changed with the parametric comparison; this is referred to as a secondary effect. For example, facility design, inspection, and project management costs are a percentage of construction costs; therefore, if construction costs increase or decrease, these costs also increase or decrease by the given percentage of the construction cost change.

For all systems, the most cost sensitive component is the operations and maintenance phase. When annual operating, utility, material, and maintenance costs are doubled, the total life cycle costs increase by an average of 68% for the technologies. The second and third most cost sensitive components are capital equipment and building expenditures resulting in a 12% and 13% increase, respectively, in total life cycle costs. Table A-1 in Appendix A provides a detailed break out for each of the eighteen systems showing the percentage increase in life cycle costs resulting from a 100% increase in the individual component costs.

As defined in the ITTS and INTS, the cost basis for the operations and maintenance is as follows: operating labor, utilities, consumable materials, maintenance parts and equipment, and maintenance labor. The first three costs are estimated by analyzing the requirements of each facility at the subsystem level. The remaining two costs are estimated as a percentage of the original equipment installed at the facility. That is, annual maintenance spare parts and replacement equipment are estimated to be about 7% of the original equipment purchase cost or 10% for subsystems amenable to corrosion. And lastly, maintenance labor is estimated to cost 250% of the cost of spare parts and replacement equipment on an annual basis.

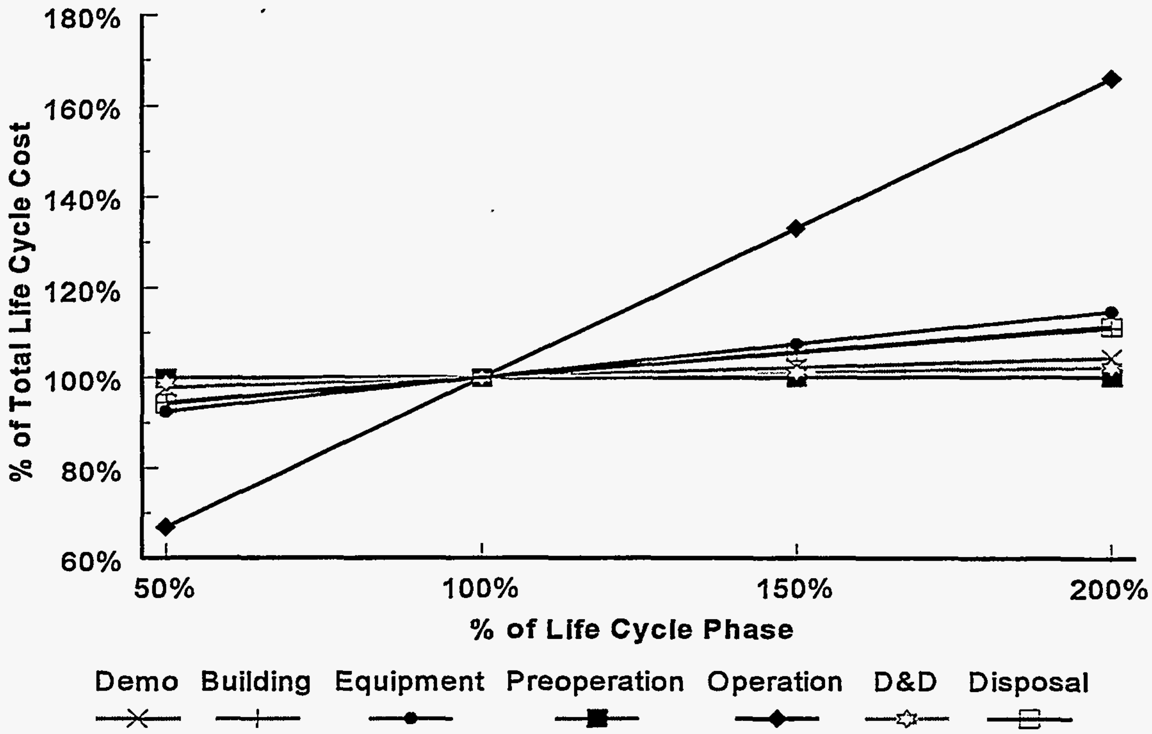

Figure 2-1. Life cycle component cost sensitivity.

Although this analysis focuses exploring cost reductions in the most expensive cost components, it is recognized that a high percentage cost reduction might be achieved in a less expensive cost component, thereby yielding an equivalent overall reduction in treatment life cycle cost.

2.2 Comparison of Component Present Value Costs

Up to this point, the analysis is based on a summation of the costs over the life cycle of the treatment facility. This section of the analysis is included to adhere to guidance from EM via the Ten Year Plans requiring that field offices and sites include present value analyses for all proposed projects whether line item projects or private sector ventures.

The analysis employs the fundamental concept of the time value of money by calculating the present value of costs in order to compensate for differing cash outlays or expenses during the life cycle of selected systems. That is, the value of a given sum of money depends on when the money is received or, as in this analysis, dispersed. The value, economic worth, or purchasing power of money changes over time with the preference being to receive the dollars today rather than at some time in the future or conversely to spend the dollars later rather than earlier. This preference is due to the opportunity cost of money or in other words, the cost of forgoing the opportunity to earn interest, or a return, on investment funds.

The present value of the costs of the life cycle components or phases are compared to the summation of these costs over time. The life cycle phases include building and equipment costs combined to form construction costs, bench scale testing and demonstration split, and disposal costs to form the seven components that are used in the remaining analyses (i.e., bench scale testing, demonstration, construction, preoperations, operations, disposal, and decontamination and decommissioning). This present value comparison is intended to illustrate the time value of money in the absence of inflation or deflation (i.e., constant dollars) using the current Federal Discount Rate of 6%. The time phase for each of the life cycle components and the present value of the costs are included in Appendix A Table A-2 and A-3.

As expected, the results of this analysis show that the present value of the cost for completing the earlier phases of the treatment life cycle is a greater percentage of the total life cycle costs, whereas the present value of the cost for completing the later phases of the treatment life cycle is a smaller percentage of the total life cycle costs. Table 2-1 compares the average total life cycle cost (%) summed over time to the average present value cost (%) for the major cost components.

Table 2-1. Present value life cycle cost comparison.

	Thermal Treatment		Nonthermal Treatment	
Life Cycle Phase	% Life Cycle Cost	% Present Value Cost	% Life Cycle Cost	% Present Value Cost
Operations	55%	44%	53%	44%
Construction	22%	31%	17%	25%
Disposal	13%	10%	20%	16%
Other	10%	15%	10%	15%

When taking into consideration the time value of money, the operating costs remain the most costly life cycle component followed by construction. However, when compared to adding up the life cycle costs over time, the present value comparison shows that the construction costs increase as a percentage of total life cycle costs; whereas, the operating costs decrease as a percentage of total life cycle costs. For the same fundamental concept that money has a time value, the present value of the bench scale testing and demonstration costs becomes a bigger cost component than the present value of the decontamination and decommissioning costs. The present value of the bench scale testing and demonstration costs increases on the average from 4% to 8% of the total life cycle costs; whereas, the present cost of the decontamination and decommissioning costs decreases from 2% to 1% of the total life cycle costs.

In conclusion, this cost comparison demonstrates that cash outlays in the later phases of the life cycle are more economically favorable than cash outlays in the earlier phases of the life cycle. This analysis does not change any previous conclusions and recommendations concerning areas for potential cost savings via technology development or improvement. Furthermore, the overall ranking of technologies and their individual cost components by the present value of the life cycle costs does not differ from the ranking of the technologies and components by summing the life cycle costs. The most costly systems when summing the life cycle costs remain the most costly from a present value perspective, and operations and maintenance costs are still the biggest cost driver for all systems.

2.3 Sensitivity to Change in Subsystem Costs

Using a representative set of systems, this section identifies the most cost sensitive treatment subsystems and examines the treatment life cycle cost sensitivity with respect to changes in subsystem costs. For all systems examined, the most cost sensitive subsystem is the receiving and inspection/preparation subsystem. This cost data is included in Appendix A Tables A-4 and A-5.

As defined in the ITTS and INTS, the function of the receiving and inspection/preparation subsystem is to receive and inspect the incoming waste and prepare the waste for the appropriate treatment subsystems. The receiving and inspection subsystem has cranes and forklift trucks to unload waste containers from incoming vehicles. The physical state of the waste in containers is identified by a real-time radiography unit. A passive/active neutron assay unit determines the level of transuranic contamination of the waste and a gamma scanning unit is used to assay beta and gamma radioactivity. A computer software and bar code scanning unit records and tracks the waste. The wastes are classified either as those requiring sorting or not requiring sorting. Containers of wastes not requiring sorting are moved directly to the appropriate treatment subsystem. The ITTS and INTS assume approximately 50% and 75% of the waste will require sorting, respectively. If sorting is required, the container is decapped by a saw mounted on a gantry robot. After decapping, the container is emptied onto a sorting table equipped with master-slave and hydraulic manipulators used for segregating materials into treatment types. If required, the sorted waste material is size reduced by saw cutting and/or mechanical auger shredders. When ready, the sorted waste is placed in transfer bins and moved to the treatment subsystems.

Opportunity exists for technology development to reduce waste receiving and inspection/preparation costs by effectively minimizing labor costs, the major cost driver, within the maintenance and operations phase of the life cycle. For instance, as defined in the ITTS, the receiving and inspection subsystem requires three 28 person shifts per day or 84 persons per day to process approximately 150 55-gallon drums of waste. If the three shift requirement could be reduced to one 28 person shift per day, then treatment life cycle cost would be reduced by $235 million or 11% of system A-1 costs, rotary kiln with air for combustion. This modification would require that each person process a total of five drums per day at 1.6 hours per drum compared to 1.8 drums per day at 4.4 hours per drum. Time and motion studies on labor intensive subsystems such as the receiving and inspection subsystem are recommended to identify rate limiting steps or other reasons for maintaining three shift operations.

The subsystems that comprise the majority of the life cycle costs are listed in Table 2-2 and graphically presented in Figures 2-2 and 2-3.

Table 2-2. Subsystem cost comparison.

Thermal Subsystem	% Life Cycle Cost	Nonthermal Subsystem	% Life Cycle Cost
Receive and Inspect	33%	Receive and Inspect	31%
Primary Thermal Trtmt	11%	Certify and Ship	15%
Certify and Ship	10%	Polymer Stabilization	8%
Administration	7%	Organic Destruction	7%
Aqueous Waste Trtmt	6%	Administration	6%
Other (11 subsystems)	33%	Other (14 subsystems)	33%

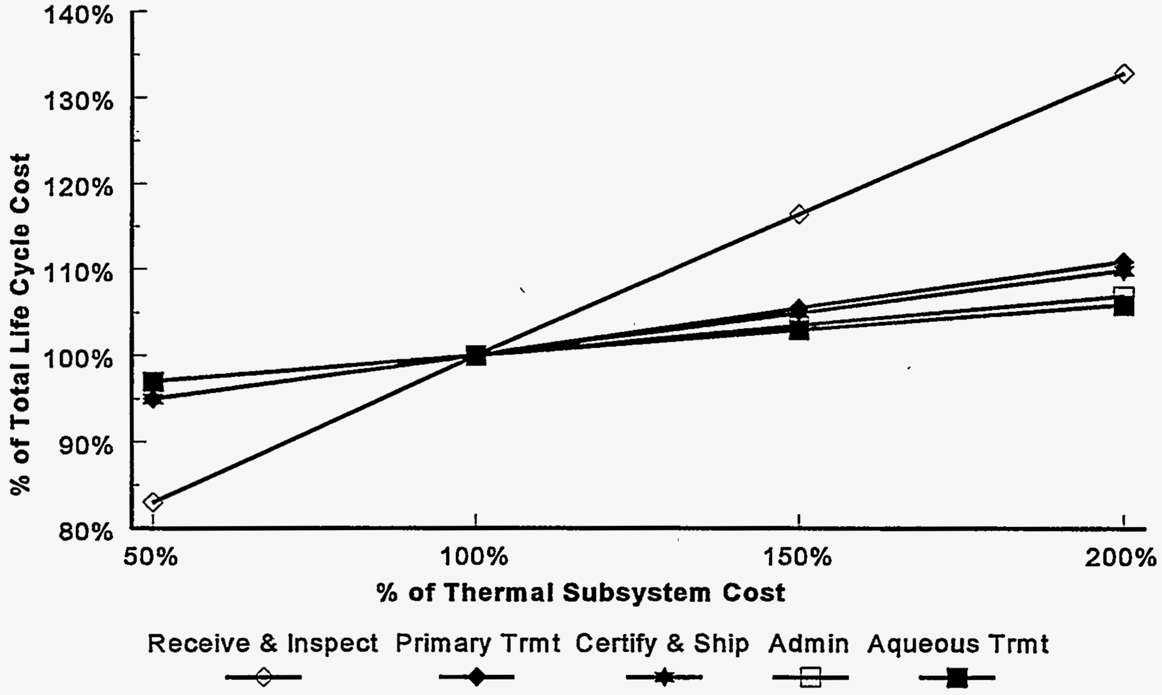

Figure 2-2. Thermal treatment subsystem cost sensitivity.

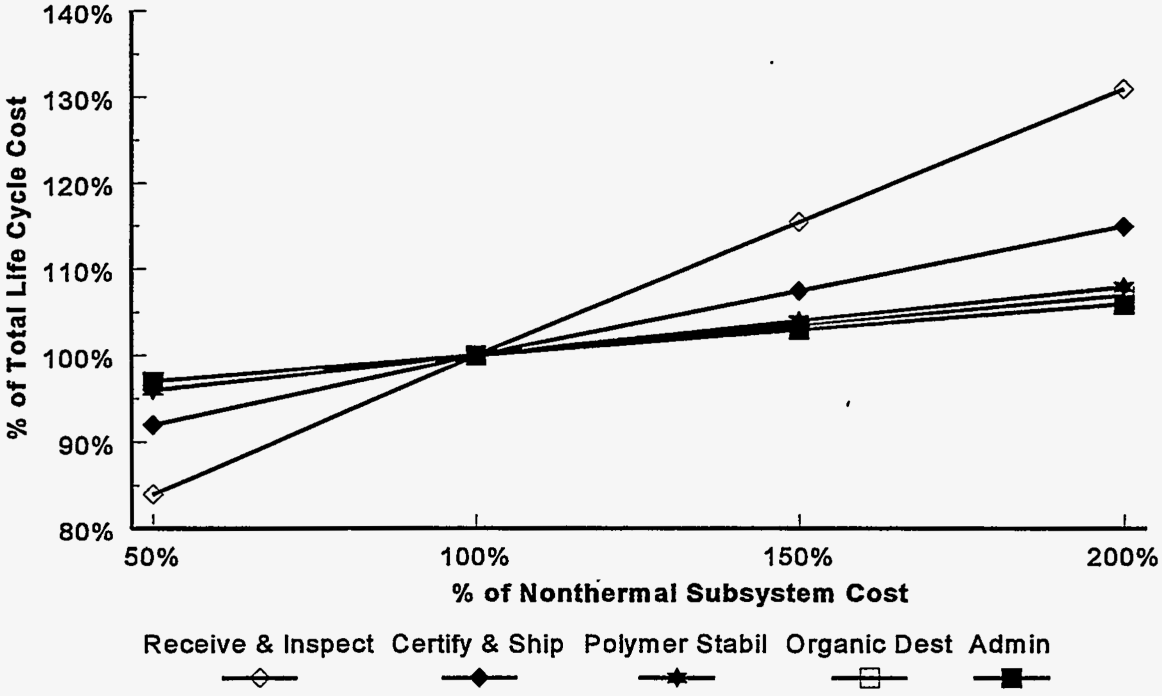

Figure 2-3. Nonthermal treatment subsystem cost sensitivity.

3.0 SENSITIVITY TO SYSTEM CONFIGURATION

Variations in facility capacity are examined in this section to determine the effect of increased or decreased capacity on treatment life cycle costs. Transportation costs to the facility are included because these costs increase as the number of facilities decrease (i.e., tradeoff to transportation cost). The analysis further examines life cycle cost savings that can be attained by increasing annual facility availability.

3.1 Sensitivity to Facility Capacity

The economic scaling applications considered in this section are based on the costs for a baseline thermal treatment facility, system A-1, a system design developed for combustion of the wastes and vitrification of the ash residues. The impact to total treatment life cycle cost is estimated for operating a single facility with increased capacity and multiple facilities to treat the baseline capacity.

3.1.1 Scaling Application Basis and Assumptions

Life cycle costs are scaled up or down to show the cost sensitivity for construction and operation of one larger facility or two or more smaller facilities. Three independent scaling applications are analyzed to determine the change to life cycle cost (i.e., one, two, and five facilities).

The treatment systems described in the INTS and ITTS are sized to a capacity for treating 236 million pounds of MLLW over a 20 year operating life (i.e., 2,927 lbs/hr x 4,032 hrs/yr x 20 yrs). The cost estimates for each of the treatment systems are based on GOCO facility construction and operation. The economics of scaling indicate that treating additional quantities of waste would increase total savings, assuming that extensive design modifications are not required. This analysis uses the throughput rate and cost estimates for the baseline system, A-1, and then, as appropriate for each case, these quantities are scaled upward or downward.

The methodology used to analyze the impact to total life cycle cost for differing facility capacities is based on exponential scaling of the ITTS cost estimates (capacity-ratio exponents)[3]. For example, if the cost of a treatment facility component of capacity q_1 is C_1, then the cost of a similar treatment facility component of capacity q_2 is calculated from $C_2 = C_1(q_2/q_1)^n$ where the value of the exponent n is the scaling factor. The scaling factor, n, is varied from 0 to 1, where scaling factors closer to 0 result in a cost, C_2, that is independent of the size of the facility (i.e., resembles a fixed cost) and, conversely, scaling factors closer to 1 result in a cost, C_2, that is proportional to the change in facility size (i.e., resembles a variable cost). This approach for assessing cost sensitivity is derived from *Perry's Chemical Engineers' Handbook*[3].

Costs are scaled uniformly in this analysis, using a factor of 0.5. The scaled costs are capital equipment, building, operation and maintenance, and decontamination and decommissioning costs. Additional analyses may warrant varying the scaling factor for each individual cost component rather than applying a uniform scaling factor. For instance, although partially dependent on the size of the equipment, the operation and maintenance costs more than likely do not scale to the same magnitude as the equipment costs. The steel industry uses a scaling factor of 0.65 in estimating costs for a processing plant[3]. For this analysis, this industry is compared to the waste processing industry. By comparison, MLLW processing is a much less developed industry than the steel industry and the costs will tend to be more fixed than variable. For example, special equipment used in metal decontamination, mercury amalgamation, special waste processing, etc., will not be easily sized to increase or decrease capacity, and new equipment will have to be designed and manufactured to vary capacity. A factor of 0.5 is used in this analysis to account for the higher percentage of fixed costs for construction and operation of a GOCO treatment facility. In addition, the life cycle cost sensitivity as a function of scaling factor is presented in each case of this analysis to bound any associated uncertainty with the selection of a specific factor. Figure 3-1 summarizes the treatment life cycle cost sensitivity to scaling factor for the applications presented in Sections 3.1.2 and 3.1.3.

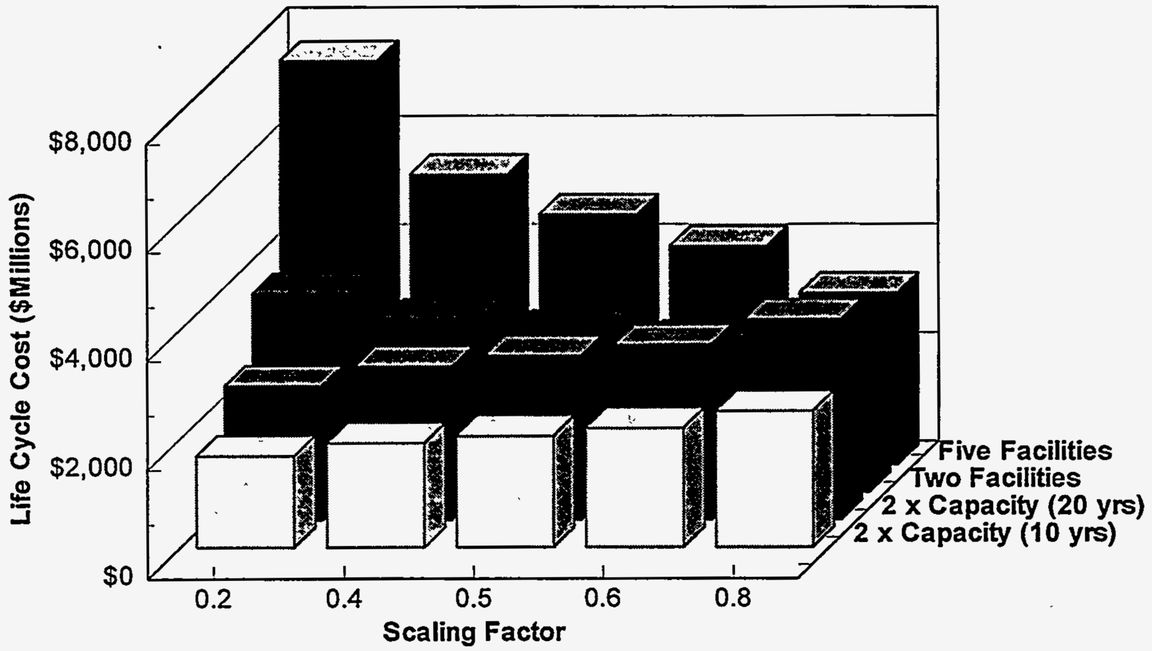

Figure 3-1. Treatment Cost Sensitivity to Scaling Factors.

3.1.2 Single Facility with Double Capacity

Consistent with the INTS and ITTS assumption that the MLLW inventory will be treated in one facility, the following examines the change to life cycle cost as a function of scaling factor, facility capacity, and operating life for a single facility. Section 3.2 examines the change to life cycle cost for a single facility as a function of facility availability without scaling the costs.

This case compares the life cycle cost of a facility sized for twice the capacity of the baseline system to the cost of the baseline system. Doubling the capacity implies doubling the throughput rate; therefore, the same quantity of waste can be treated in half the original time. The operating period is reduced from 20 to 10 years. Alternatively, doubling the capacity of the facility also implies that two times the input waste could be treated over a 20 year operating life, or 472 million pounds.

Doubling the facility capacity, scaling the costs, and reducing the operating period from 20 to 10 years offsets the increased costs for construction, preoperation, and decontamination and decommissioning by reducing operating costs. The total life cycle cost for operating 10 years is approximately the same as the baseline system operating 20 years when using a 0.58 scaling factor. This break-even point is important because it indicates that if costs are scaled using a factor less than 0.58, then the total life cycle cost for operating 10 versus 20 years is less than the life cycle cost of the baseline system.

Alternatively, if the capacity is doubled, two times the input waste could be treated during a 20 year operating life yielding a lower unit cost o $6.75/lb. These costs are shown in Table 3-1, life cycle costs for double capacity.

Table 3-1. Life cycle costs for double capacity ($000).

		Baseline system	2 x capacity	2 x capacity
	Operating life	20 years	10 years	20 years
	Waste treated (lbs)	236M	236M	472M
WBS	Life cycle phase			
1.0	Bench scale testing	$30,525	$30,525	$30,525
2.0	Demonstration	$69,647	$69,647	$69,647
3.0	Construction	$554,377	$784,008	$784,008
4.0	Preoperation	$96,747	$134,087	$134,087
5.0	Operations	$1,361,850	$962,973	$1,925,947
6.0	D&D	$54,171	$76,609	$76,609
Total life cycle cost		$2,167,318	$2,057,850	$3,020,824
Scaling factor = 0.5		$9.18/lb	$8.72/lb	$6.40/lb

Figure 3-2 compares the change to life cycle cost and unit cost as a function of capacity and operating period. Figures 3-3 and 3-4 compare the cost components for operating 10 versus 20 years.

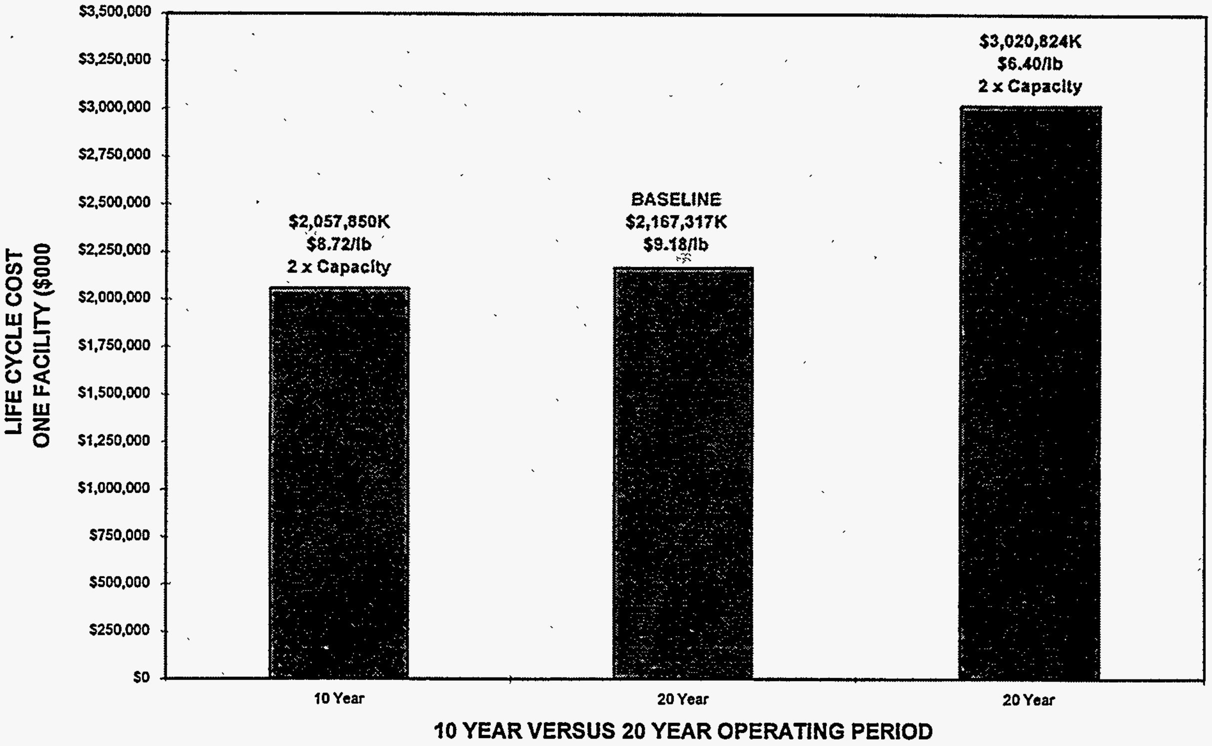

Figure 3-2. Cost sensitivity to increased capacity.

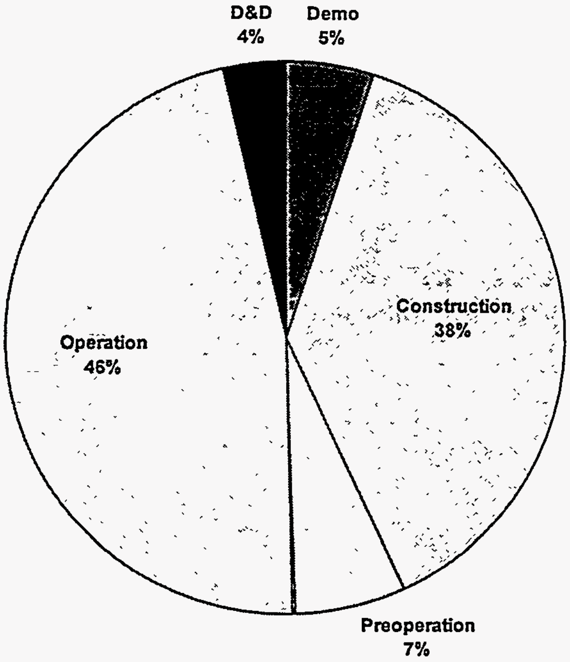

Figure 3-3. Cost comparison
for 10 year operating life.

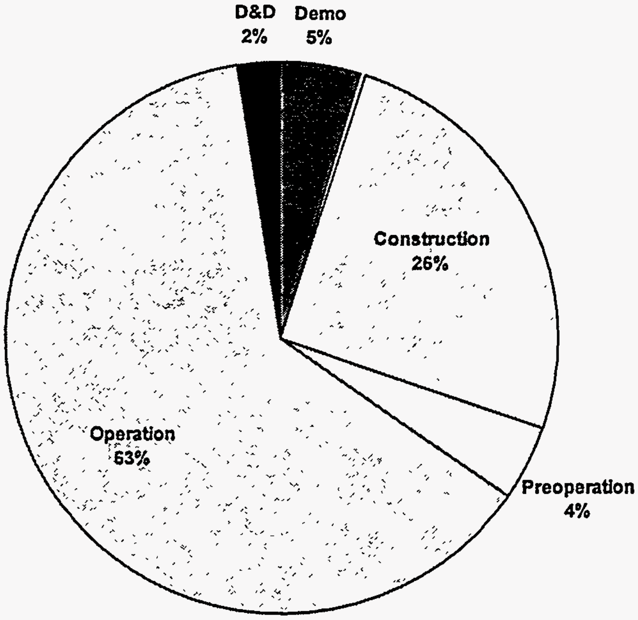

Figure 3-4. Cost comparison
for 20 year operating life (baseline).

In the previous example, capacity is doubled and a scaling factor of 0.5 is used to estimate the resulting increase to cost. Figure 3-5 shows the life cycle cost sensitivity when applying a range of scaling factors to the costs. In this case, the capacity is doubled, allowing treatment of the original quantity of waste in half the time, or a 10 year operating period. As shown, lower scaling factors result in a lower cost per pound. Figure 3-6 shows the life cycle cost sensitivity as a function of scaling factor for treating double the waste quantity over the original 20 year operating period.

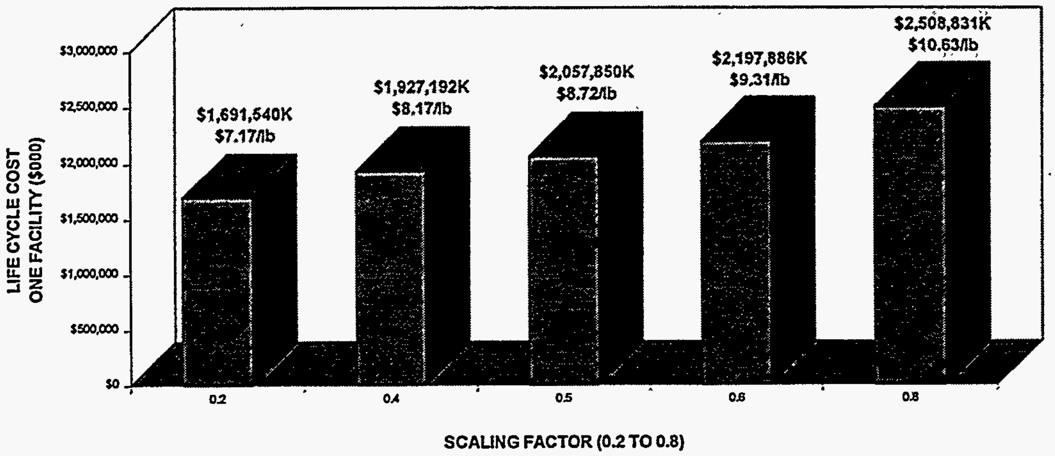

Figure 3-5. Life cycle cost sensitivity to scaling factor when the operating life is reduced from 20 to 10 years.

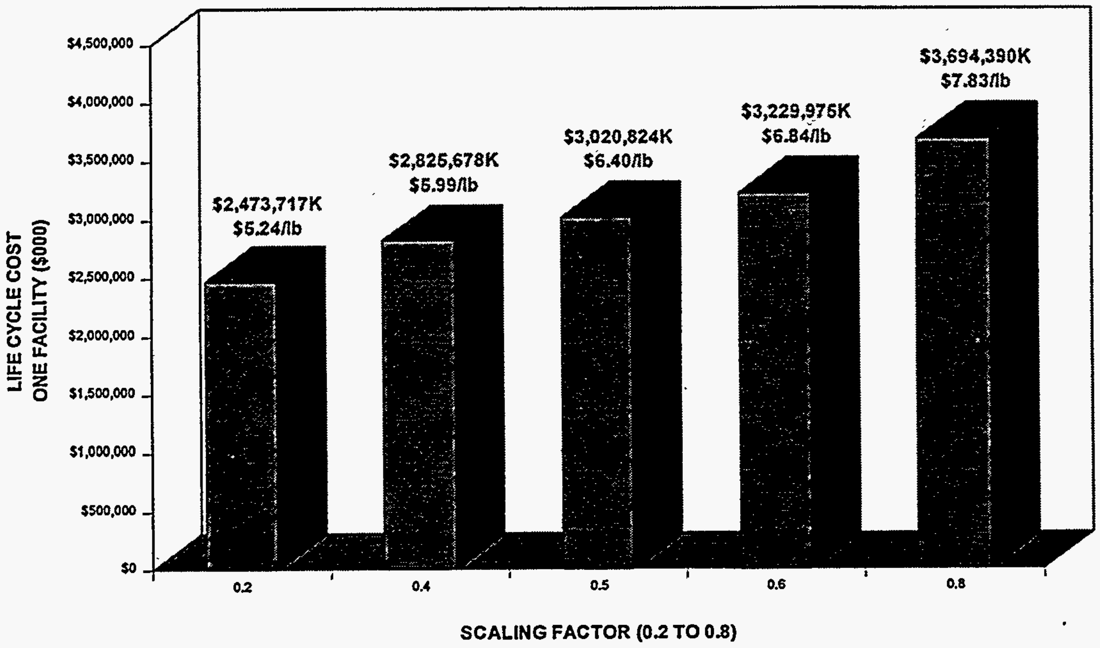

Figure 3-6. Life cycle cost sensitivity to scaling factor when waste quantity treated over 20 years is doubled.

3.1.2.1 Net Present Value Cost Comparison

The time value of money is important in quantifying the cost benefit of early completion given an increased annual investment over the life of the project. As stated in Section 2.2, the value of money changes over time with the preference being to receive the dollars today rather than at some time in the future or conversely to spend the dollars later rather than earlier. The project of construction and operation of a GOCO treatment facility(s) deals with cash outlays without direct revenue to counterbalance the costs. Therefore, the preference, from a present value standpoint, is to postpone the expenditure as long as possible in order to maintain the earning power of the dollars.

As described in the previous section, doubling the facility capacity makes it feasible to treat the MLLW inventory in 10 years rather than 20 years. In this case, the fixed capital costs increase as the facility is scaled upward in size to treat the additional waste. Using a 6% discount rate (i.e., based on the current Federal Discount Rate) and assuming constant dollars (i.e., an inflation rate equal to zero), the present value of the life cycle costs is $1,012,821K for a 20 year operating life and $1,155,801K for a 10 year operating period. Since these are costs rather than revenue, the lower present value of the costs is favorable. As expected, without offsetting revenue flows, cash outlays made later in the project are favorable. Therefore, the 20 year operating life is the preferred alternative from a net present value (NPV) perspective. The difference between these NPVs represents the cost of completing operations sooner, keeping in mind that non-economic benefits may outweigh this cost. The NPV calculations and the time-phased treatment life cycle schedules are included in Appendix B Tables B-1 through B-3.

3.1.3 Multiple Facilities and Baseline Capacity

Deviating from the INTS and ITTS by assuming that more than one facility will be constructed to treat the MLLW inventory, central treatment (two facilities) and regional treatment (five facilities) are compared to the baseline system in this section. Once again, these cases are based on treating 236 million pounds of MLLW over a 20 year operating period.

3.1.3.1 Central Treatment

This analysis assumes two facilities for the central case, one located in the Western U.S. and one located in the Eastern U.S. The target waste stream inventory for each facility is assumed to be representative of the entire inventory; therefore, the two facilities are assumed to be duplicated in design, demonstration, and testing. For this reason, these costs are not included in construction of the second facility.

The central case considers treatment facilities located at the Oak Ridge National Laboratory (ORNL) and the Idaho National Engineering Laboratory (INEL), the sites with the largest MLLW inventories, 33% and 19% of the current national inventory, respectively[4]. These facility locations are chosen for this study only to represent central locations with respect to the Western U.S. and the Eastern U.S. This selection does not in any way imply a Department of Energy (DOE) decision for siting such facilities at these locations. Based on the proportion of the waste currently stored at DOE sites located in the East and West, the 236 million pounds of input waste is split 66% to be treated at the eastern location and 34% to be treated at the western location. Table 3-2 breaks down the costs for each of the two facilities using a 0.5 scaling factor and shows the relative distribution of these costs compared to the baseline system. Figure 3-7 presents the life cycle cost and unit costs for two facilities as a percentage of the baseline system cost for a range of scaling factors.

This analysis indicates that constructing and operating two treatment facilities will result in a 14% to 69% increase, based on a 0.8 to 0.2 range of scaling factors, in overall life cycle cost when compared to the baseline system. Because transportation costs will likely be less for shipping the waste to multiple facilities compared to transport to a single facility, transportation is considered as a discriminating factor in Section 3.6 Tradeoff to Transportation Cost, of this report.

Table 3-2. Life cycle costs for centralized facilities ($000).

		Baseline Facility	66% Capacity Facility	34% Capacity Facility	Total
	Waste qty (lbs)	236M	156M	80M	236M
WBS	Life cycle phase				
1.0	Bench scale testing	$30,525	$30,525	$0	$30,525
2.0	Demonstration	$69,647	$69,647	$0	$69,647
3.0	Construction	$554,377	$450,378	$323,255	$773,633
4.0	Preoperation	$96,747	$79,836	$59,164	$139,000
5.0	Operations	$1,361,850	$1,106,372	$794,088	$1,900,460
6.0	D&D	$54,171	$44,009	$31,587	$75,596
Total life cycle cost		$2,167,318	$1,780,767	$1,208,094	$2,988,861
*Scaling factor		$9.18/lb	$11.42/lb	$15.10/lb	$12.66/lb Weighted Avg.

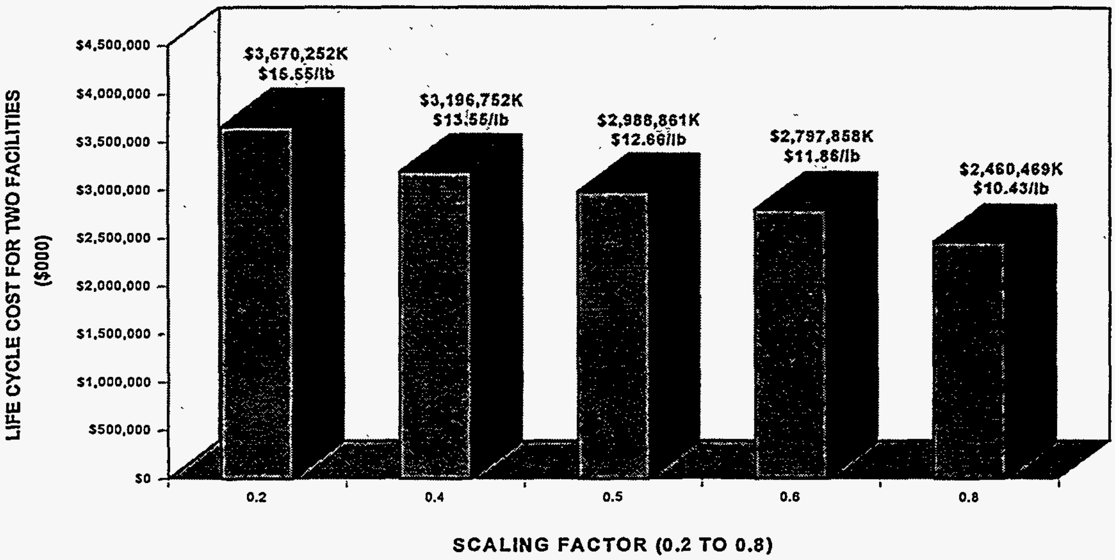

Figure 3-7. Life cycle cost sensitivity to scaling factor for centralized treatment (66% Eastern U.S. and 34% Western U.S.).

3.1.3.2 Regional Treatment

The regional case considers five facilities located at the larger DOE sites where greater than 5,000 m^3 of MLLW is in storage: Hanford, Idaho National Engineering Laboratory, Rocky Flats Plant, Savannah River Site, and Oak Ridge National Laboratory[4]. These sites are selected only for comparative purposes within this analysis. This selection does not in any way imply a DOE decision for siting such facilities at these locations. For the regional option, the potential waste stream inventory for treatment at each of the facilities will not be representative of the entire inventory; therefore, the design, demonstration, and testing phase will be required for all five facilities.

Once again, the proportion of the waste currently in storage at the DOE sites was used to apportion the 236 million pounds of input waste among the five treatment facilities. As shown in the following graphic, ORNL will treat 60% of the waste, INEL 20%, Rocky Flats Plant (RFP) 10%, Hanford 5%, and Savannah River Site (SRS) 5%.

Depending on the scaling factor applied, operating five treatment facilities results in a 46% to 244% increase in total life cycle cost when compared to the baseline system. This increase translates to a range of unit costs from $13.45 per pound to $31.57 per pound compared to $9.18 per pound for the baseline system. Table 3-3 breaks down the costs for each of the five facilities using a 0.5 scaling factor and shows the relative distribution of these costs compared to the baseline system. Figure 3-8 shows the range of life cycle cost and unit costs as a function of scaling factor.

Table 3-3. Life cycle costs for regional facilities ($000).

	Baseline system	60% Capacity	20% Capacity	10% Capacity	2 @ 5% Capacity	Total ($000)
Waste treated (lbs)	236M	141M	47M	24M	24M	236M
Life cycle phase						
Bench scale testing	$30,525	$30,525	$30,525	$30,525	$61,050	$152,625
Demonstration	$69,647	$69,647	$69,647	$69,647	$139,294	$348,235
Construction	$554,377	$429,419	$247,925	$175,310	$247,926	$1,100,580
Preoperation	$96,747	$76,428	$46,915	$35,107	$53,516	$211,966
Operations	$1,361,850	$1,054,884	$609,038	$430,655	$609,038	$2,703,615
D&D	$54,171	$41,961	$24,226	$17,130	$24,226	$107,543
Total life cycle cost	$2,167,318	$1,702,864	$1,028,276	$758,374	$1,135,048	$4,624,562
Scaling factor = 0.5	$9.18/lb	$12.00/lb	$21.80/lb	$32.10/lb	$48.10/lb	$19.60/lb Weighted Avg.

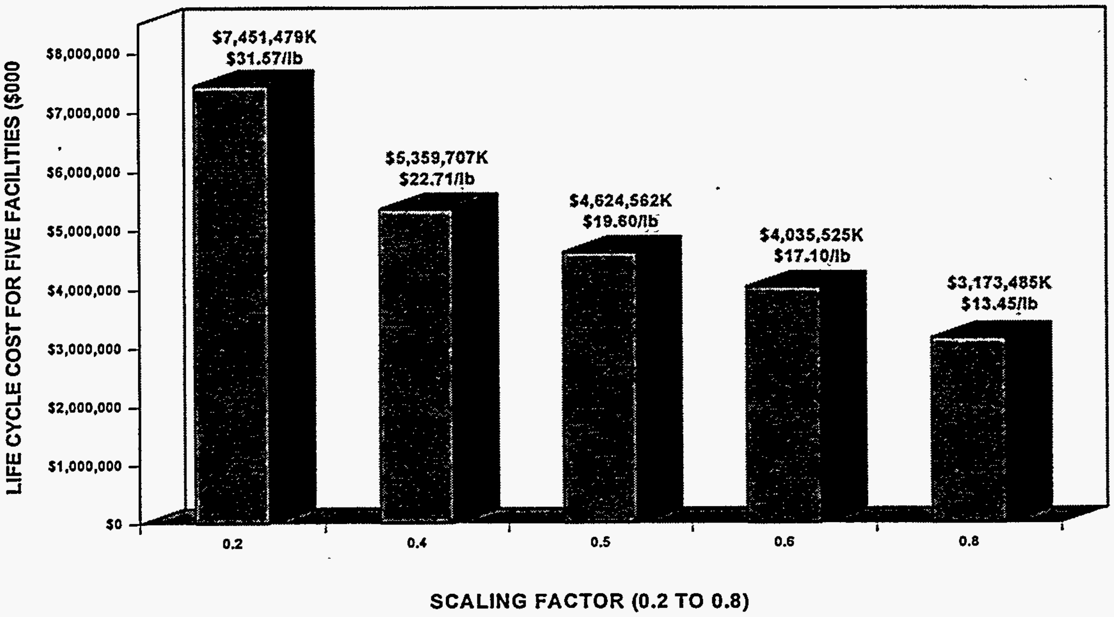

Figure 3-8. Life cycle cost sensitivity to scaling factor for regional treatment (five facilities).

The results demonstrate that larger facilities can treat greater quantities of waste at a lower cost per pound than smaller facilities, as illustrated in Figures 3-9 and 3-10. For example, 60% of the waste can be treated at $12.00 per pound compared to treating 20% of the waste at $21.80 per pound.

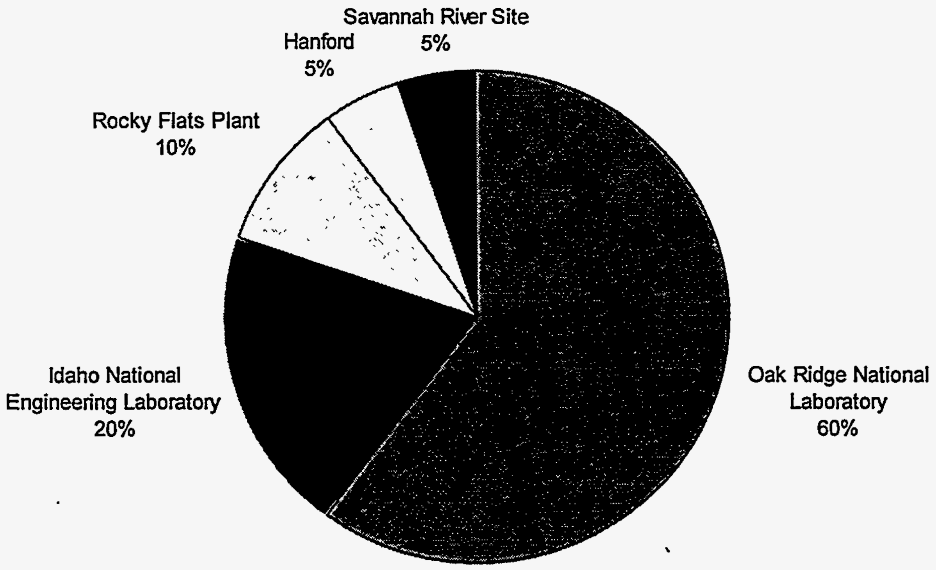

Figure 3-9. Volume % for regional treatment of MLLW (based on 1995 MWIR).

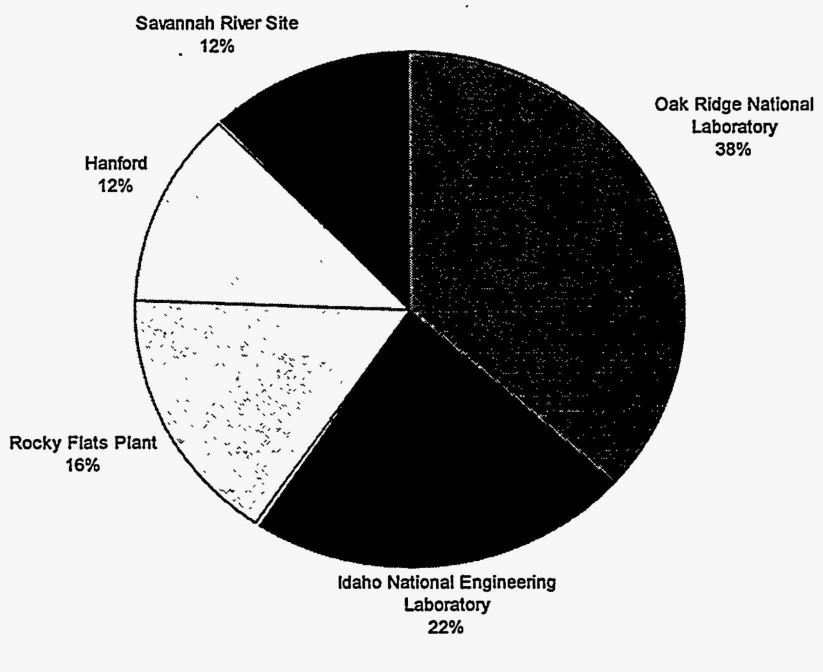

Figure 3-10. Life cycle cost % for regional treatment of MLLW.

3.1.4 Tradeoff to Transportation Cost

To be more complete, this section factors in transportation costs for shipping MLLW to a single large treatment facility and to multiple smaller treatment facilities. Transportation cost from the treatment facility to the disposal location is not included. The assumption made in the ITTS and INTS is that final waste output from the treatment process will be disposed at the same location as the treatment facility and therefore, the cost will be negligible.

The ORNL has approximately 33% of the national MLLW inventory in storage. The second largest inventory, approximately 19%, is located at the INEL[4]. Based on this information, the location for treating all the waste in one facility is assumed to be at Oak Ridge, Tennessee. Transportation costs for shipping the waste inventories from all DOE sites to ORNL are calculated based on a methodology used for truck shipment[5]. To be conservative, truck shipment costs are used because they are slightly greater than rail shipment costs.

The amount of waste shipped from each site to ORNL is determined by applying the current percentage of the national inventory stored at each location[4] to the input waste quantity, 236M pounds. The number of shipments is based on 44,000 pounds of waste per shipment. Variable transportation cost is $4.00 per mile if transport is more than 200 miles and $4.98 per mile for less than 200 miles. The variable carrier costs include tractor, fuel, labor, insurance, security escort, taxes, tools, permit fees, and related costs incurred while the waste is in transport. Fixed transportation cost is $880.00 per shipment to account for demurrage costs of the carrier and the hardware used in the shipment. A breakdown of the transportation cost data is included in Appendix B, Table B-4 and Table B-6.

As expected, the results indicate that transportation cost to a single large treatment facility is the greatest but, still relatively small, at <1% of the baseline system life cycle cost. This analysis demonstrates that transportation cost is relatively low and provides little incentive by itself for selecting one versus multiple facilities. However, non-economic drivers such as the ability to transport across state boundaries may favor multiple facility locations. Table 3-4 and Figure 3-11 present the life cycle cost comparison for a single facility, two facilities, and five facilities including the cost to transport the MLLW to the facilities.

Table 3-4. Transportation cost data.

	Quantity (lbs)	# Shipments	Transport $	Life cycle $	Total $
One Facility	236M	3,581	$18,846,540	$2,167,318K	$2,186,165K
Two Facilities*	236M	2,578	$7,104,960	$2,988,861K*	$2,995,966K*
Five Facilities*	236M	1,521	$4,040,300	$4,624,562K*	$4,628,603K*

* Scaling factor = 0.5

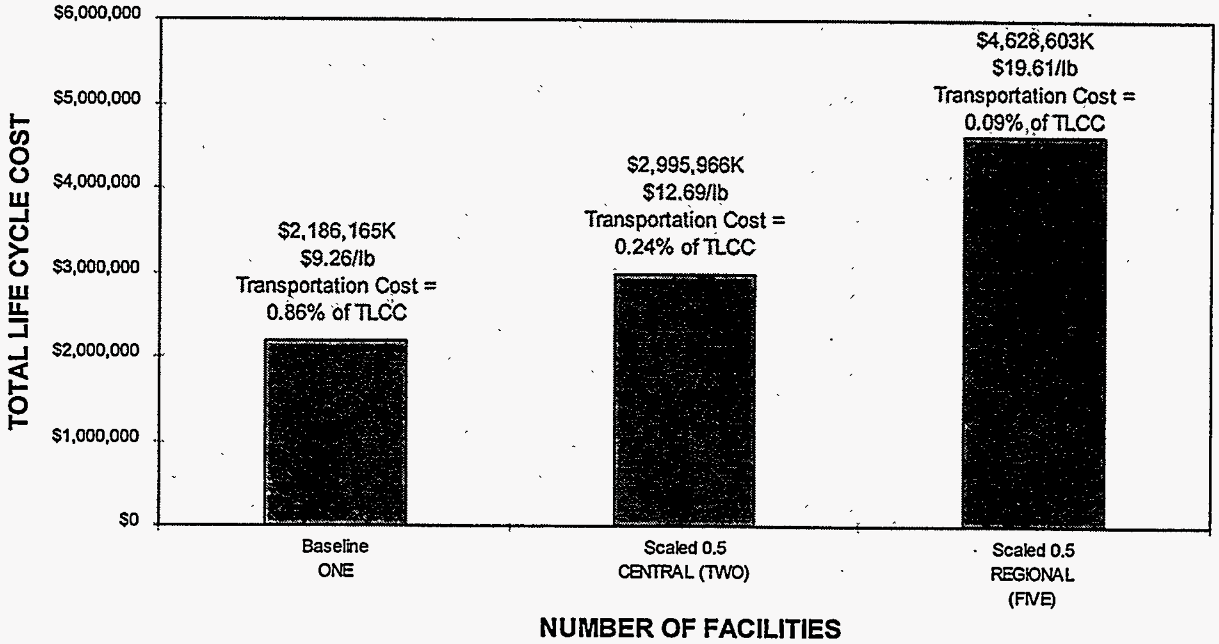

Figure 3-11. Total life cycle cost comparison $000 (including transportation).

3.2 Sensitivity to Increased Availability of Treatment

Another means for reducing the operating period or increasing the volume of waste treated is to increase the availability of treatment (i.e., increase the operating hours of the plant). The INTS and ITTS are based on operating 4,032 hours per year (280 days/year x 24 hours/day x .60 availability). In comparison, if treatment is fully functional 325 days per year at 75% availability, then total operating hours per year are 5,850 hours, a 45% increase. At this rate, the 236 million pounds of input waste (i.e., 2,927 pounds per hour) could be processed in 14 rather than 20 years resulting in a net decrease in operating and maintenance costs of $377M, a reduction of $1.58 per pound of input waste. This assumes that annual labor costs remain constant (i.e., as documented in the studies labor is based on 365 days/year; 4 shifts/week; 7 days/week; 24 hours/day) and material and utility costs increase to treat the additional volume of waste.

Alternatively, at the throughput rate of 2,927 pounds per hour, 343 million pounds of input waste can be processed over 20 years operating 5,850 hours per year. The cost per pound to treat the additional quantity of waste is $6.53 per pound or $2.65 less than the cost per pound for the baseline system.

The costs for increased availability of treatment, compared to the baseline system costs, are presented in Table 3-5.

Table 3-5. Increased availability of treatment ($000).

		Baseline system	5,850 hours/year	5,850 hours/year
	Operating life	20 years	14 years	20 years
	Waste treated (lbs)	236M	236M	343M
WBS	Life cycle phase			
1.0	Bench scale testing	$30,525	$30,525	$30,525
2.0	Demonstration	$69,647	$69,647	$69,647
3.0	Construction	$554,377	$554,377	$554,377
4.0	Preoperation	$96,747	$100,471	$100,471
5.0	Operations	$1,361,850	$985,161	$1,429,564
6.0	D&D	$54,171	$54,171	$54,171
Total life cycle cost		$2,167,318	$1,794,352	$2,238,755
		$9.18/lb	$7.60/lb	$6.53/lb

Figure 3-12 compares the baseline system to the baseline system operating 5,850 hours per year (i.e., 45% increase) as a function of operating period (i.e., 14 versus 20 years).

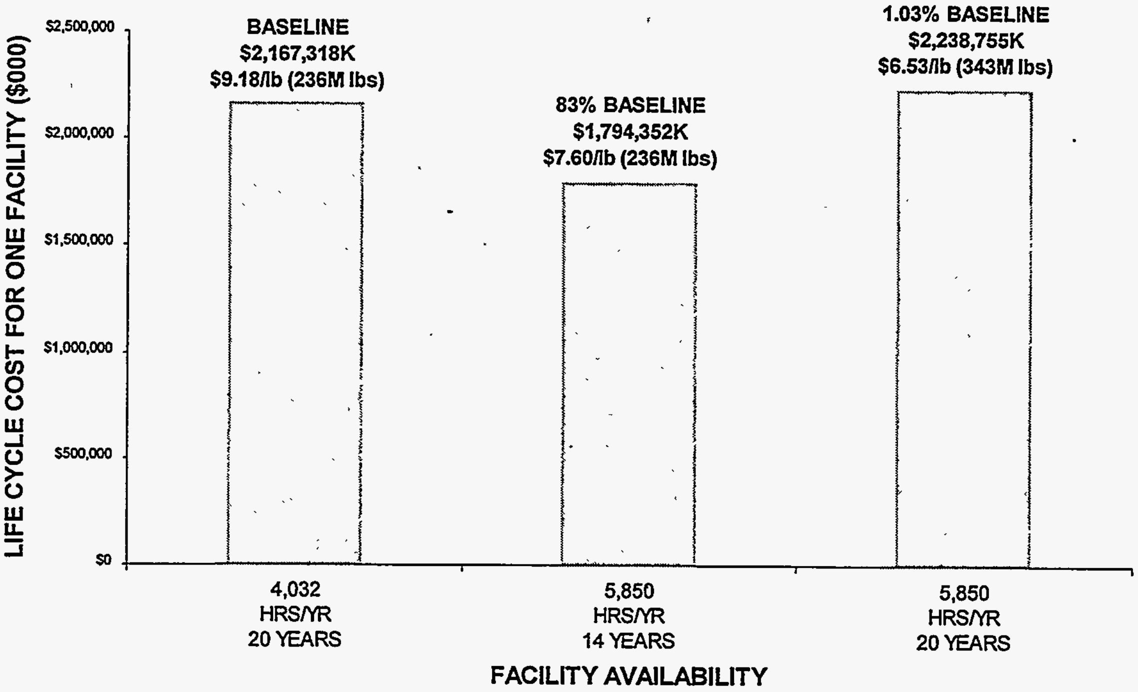

Figure 3-12. Sensitivity to availability.

4.0 ADDITIONAL TREATMENT COST SENSITIVITIES

4.1 Sensitivity to Contingency Cost

When developing the ITTS and INTS life cycle costs, a standard contingency percentage of 25% was applied to cost components: studies and bench scale testing, demonstration, construction, and operating and maintenance. This contingency was defined as an allowance for scoping and costing inaccuracies. In reality, the systems are not equal in the degree of risk associated with the technology development state.

This section measures the sensitivity to contingency cost using a baseline of 25% for the more developed technologies and increasing this percentage for technologies that carry a greater degree of operational uncertainty. Based on the information provided in the ITTS and INTS studies, the systems considered more developed include: A-1 rotary kiln with air for combustion and vitrification for stabilization, A-2 rotary kiln with oxygen for combustion and vitrification for stabilization, A-7 slagging rotary kiln with air for combustion, and A-8 rotary kiln with air for combustion and grouting for stabilization. Systems considered less developed include: C-1 plasma hearth furnace with air for combustion, G-1 molten metal waste destruction with oxygen for combustion, H-1 steam gasification with steam for combustion , NT-3 wash, NT-4 acid digestion, and NT-5 catalytic wet oxidation.

An increase in contingency percentage from 25% to 35%, 45%, and 50% for the less-developed technologies results in a 7%, 15%, and 18% increase in the total life cycle costs, respectively. This increase indicates that the operational uncertainty for the three thermal treatment systems, G-1, C-1, and H-1, lessens the economic desirability for these technologies. The nonthermal treatment systems maintain the same economic ranking with higher contingency costs. Table 4-1 shows the ranking of the technologies by treatment life cycle cost as a function of contingency cost percentage.

Table 4-1. Total life cycle cost as a function of contingency allowance ($million).

	Total treatment cost	Rank	Total treatment cost	Rank	Total treatment cost	Rank	Total treatment cost	Rank
Contingency		25%		35%		45%		50%
G-1	$1,894	1	$2,032	4	$2,171	12	$2,241	14
A-7	$1,914	2		1		1		1
J-1	$1,922	3		2		2		2
C-3	$1,929	4		3		3		3
C-1	$1,981	5	$2,126	8	$2,272	16	$2,345	19
A-5	$2,083	6		5		4		4
C-2	$2,096	7		6		5		5
L-1	$2,098	8		7		6		6
K-1	$2,144	9		9		7		7
A-3	$2,144	10		10		8		8
A-8	$2,144	11		11		9		9
A-2	$2,166	12		12		10		10
A-1	$2,167	13		13		11		11
E-1	$2,191	14		14		13		12
H-1	$2,193	15	$2,354	20	$2,515	20	$2,596	20
A-6	$2,236	16		15		14		13
B-1	$2,242	17		16		15		15
F-1	$2,275	18		17		17		16
A-4	$2,282	19		18		18		17
D-1	$2,338	20		19		19		18

Table 4-1, Cont'd.

	Total treatment cost	Rank	Total treatment cost	Rank	Total treatment cost	Rank	Total treatment cost	Rank
Contingency		25%		35%		45%		50%
NT-2	$2,846	21		21		21		21
NT-1	$2,883	22		22		22		22
NT-3	$2,990	23	$3,210	23	$3,429	23	$3,539	23
NT-5	$3,118	24	$3,348	24	$3,577	24	$3,692	24
NT-4	$3,135	25	$3,365	25	$3,596	25	$3,711	25

A methodology for assigning individual contingency cost has been developed by personnel at Morrison Knudsen (MK) Corporation. Using the MK methodology, contingencies are estimated for each phase of the life cycle based on a combination of engineering judgement, standard industrial contingency values, and facility scope certainties. The ITTS system A-1, rotary kiln with air for combustion was studied initially and the result lead to a 2% overall reduction in life cycle costs using the revised contingencies. Future work scope includes applying this methodology to additional systems so comparisons can be made across technologies.

5.0 SENSITIVITY TO DISPOSAL COST

The ITTS and INTS studies assume a variable disposal cost of \$243 per ft^3 based on a facility sized to accommodate disposal for all systems. Applying a single unit cost assumes that disposal cost is directly proportional to the volume of waste disposed. In contrast, the life cycle costs for constructing and operating a disposal facility include both fixed and variable components. To be more accurate and complete, this analysis takes into account the split between fixed and variable costs when calculating the cost for disposal.

This analysis compares disposal costs for all systems and assesses the overall impact to life cycle costs when incorporating the fixed and variable cost components for disposal. A separate comparison between systems using vitrification versus grouting for stabilization is examined to determine the effect final waste form has on disposal cost and total life cycle cost. In addition, the analysis looks at potential delisting of the vitrified waste form, making it possible to dispose of the stabilized waste in a low-level radioactive waste disposal facility.

The organization of the disposal section is as follows:

Section 5.1 identifies the fixed and variable cost components for constructing and operating two different sized disposal facilities (i.e., small- and medium-size facilities).

Section 5.2 compares the disposal cost for each of the systems as calculated using the applicable fixed and variable costs based on the final waste volume. This section also looks at disposal cost sensitivity as a function of the size of the facility.

Section 5.3 identifies potential disposal cost savings based on a reduced final waste volume by comparing disposal costs between a technology using vitrification and a technology using grout for stabilization.

Section 5.4 further expands on the potential cost savings for systems employing vitrification by reducing the disposal cost for the vitrified portion of the final waste volume assuming delisting of the waste form.

5.1 Fixed Versus Variable Disposal Costs

The cost estimates used in this analysis are based on construction and operation of a Government-Owned, Contractor-Operated (GOCO) Resource Conservation and Recovery Act (RCRA)-permitted disposal facility[6]. These cost estimates are also the basis for the unit cost of \$243 used in ITTS and INTS.

The disposal cost estimates consist of two major cost modules: disposal administration and above-ground disposal. The above-ground disposal cost module is derived from costs for construction and operation of engineered disposal units that are based on the proposed Illinois low-level waste disposal facility design using an earth-mound concrete-cell concept with modifications to the leachate collection system for RCRA compliance. The disposal administration cost module provides the necessary disposal support functions such as truck loading and unloading areas, administrative offices, analytical laboratory facilities, and truck inspection and wash-down[6]. For each of the modules, the disposal life cycle costs are subdivided into phases of the life cycle: bench scale testing, demonstration, construction, preoperations, operations, and postoperations.

Certain costs are fixed with the size of the facility and certain costs vary with the volume of waste disposed; these costs are referred to as fixed and variable costs, respectively. The fixed costs are recovered on a per unit basis by allocating a percentage of the cost to an expected waste quantity. The unit cost is comprised of this fixed cost percentage and the variable cost per ft^3. If the expected quantity of waste is not disposed, then the fixed costs incurred are not recovered unless the unit cost is increased to accomodate the smaller volume of waste disposed.

On examination, the total costs were logically divided between fixed and variable. Fixed costs include: capital construction costs, preoperating costs including permitting and contingency for any delays in start up operations, a percentage of the annual operating labor costs, annual maintenance costs, and postoperating costs. Variable costs include: a percentage of the annual operating labor costs, annual material costs, and annual utility costs. A comparison of the total life cycle costs for small- and medium-size facilities is graphically illustrated in Figure 5-1 and Table 5-1 provides the life cycle cost breakdown for small- and medium-size disposal facilities.

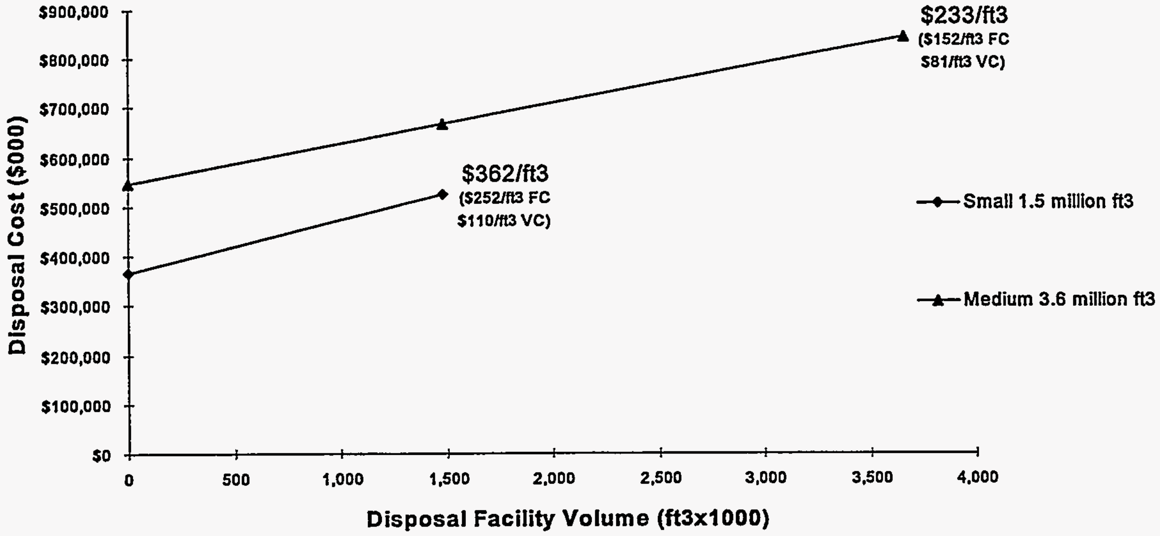

Figure 5-1. Disposal cost for small- and medium-size facilities at design capacity.

Table 5-1. Disposal life cycle costs for small- and medium-size facilities.

	Small-size facility (1,451,488 ft3) Total $525,184K; $362/ft3				**Medium-size facility (3,628,809 ft3) Total $845,276K; $233/ft3**			
	Disposal Administration		Above-ground Disposal		Disposal Administration		Above-ground Disposal	
	Fixed ($000)	Variable ($000)	Fixed ($000)	Variable ($000)	Fixed ($000)	Variable ($000)	Fixed ($000)	Variable ($000)
Test & demo	$0	$0	$0	$0	$0	$0	$0	$0
Construction	$11,565	$0	$99,561	$0	$18,565	$0	$221,303	$0
Preoperations	$7,095	$0	$13,495	$0	$10,327	$0	$22,568	$0
Operations	$13,225	$110,000	$145,450	$50,125	$19,450	$159,025	$163,575	$136,100
Postoperations	$4,163	$0	$70,505	$0	$7,763	$0	$86,600	$0
Total fixed/variable	$36,048	$110,000	$329,011	$50,125	$56,105	$159,025	$494,046	$136,100
% fixed/variable	25%	75%	87%	13%	26%	74%	78%	22%
Total by cost module	**Administration $146,048**		**Disposal $379,136**		**Administration $215,130**		**Disposal $630,146**	
Total disposal life cycle costs	**70% Fixed $365,059 30% Variable $160,125 or $110/ft^3 Total $525,184K; $362/ft3**				**65% Fixed $550,151 35% Variable $295,125 or $81/ft^3 Total $845,276K; $233/ft3**			

5.2 ITTS AND INTS DISPOSAL COST ESTIMATES

Disposal costs, including both fixed and variable cost components, are presented in this section for each of the twenty thermal treatment systems and 5 nonthermal treatment systems. These revised disposal costs are used in the remainder of the analysis.

5.2.1 Disposal Cost Comparison for All Technologies

Depending on the final waste volume, disposal costs for a small- or medium-size facility as identified in the previous section, are calculated for each of the treatment systems. The greatest waste volume considered within the capacity of a small-size facility is 1,585K ft^3 which is produced by system A-4, rotary kiln with oxygen. All final volumes greater than 1,585K ft^3 are assumed to require a medium-size facility for disposal. This revised disposal cost is greater than the disposal cost estimated in the ITTS and INTS for all systems. In fact, the disposal cost has increased on the average by 35%, and as a result, the system ranking by total life cycle cost has changed, as shown in Table 5-2. For example, system A-6, rotary kiln with maximum recycle, produces the least amount of final waste, 864K ft^3, and ranks ninth in total life cycle cost when assuming that all costs are variable as estimated in the ITTS and INTS. However, after applying the revised disposal cost, system A-6 ranks eleventh in total life cycle cost.

Table 5-2. Systems ranked by total life cycle cost including revised disposal costs.

	Final waste volume (ft^3x1000)	Total treatment cost ($million)	Revised* disposal cost ($million)	Total LCC ($million)	Rank	% LCC	Disposal cost \$243/ft^3 ($million)	Total LCC ($million)	Rank	% LCC
G-1	929	$1,894	$468	$2,361	1	20%	$226	$2,119	1	11%
J-1	1,095	$1,922	$486	$2,408	2	20%	$266	$2,188	2	12%
A-7	1,171	$1,914	$494	$2,408	3	21%	$284	$2,198	4	13%
C-3	1,067	$1,929	$483	$2,412	4	20%	$259	$2,189	3	12%
C-1	1,067	$1,981	$483	$2,464	5	20%	$259	$2,240	5	12%
C-2	1,220	$2,096	$500	$2,595	6	19%	$297	$2,392	6	12%
A-2	1,096	$2,166	$486	$2,652	7	18%	$266	$2,432	7	11%
A-1	1,096	$2,167	$486	$2,653	8	18%	$266	$2,434	8	11%
A-3	1,369	$2,144	$516	$2,660	9	19%	$333	$2,476	11	13%
H-1	1,095	$2,193	$486	$2,679	10	18%	$266	$2,459	10	11%
A-6	864	$2,236	$460	$2,697	11	17%	$210	$2,446	9	9%
B-1	1,096	$2,242	$486	$2,728	12	18%	$266	$2,509	12	11%
F-1	1,176	$2,275	$495	$2,770	13	18%	$286	$2,561	13	11%
A-5	2,301	$2,083	$737	$2,821	14	26%	$559	$2,642	15	21%
A-4	1,585	$2,282	$540	$2,822	15	19%	$385	$2,667	16	14%
D-1	1,226	$2,338	$500	$2,839	16	18%	$298	$2,636	14	11%
A-8	2,508	$2,144	$754	$2,898	17	26%	$609	$2,754	17	22%
L-1	3,270	$2,098	$816	$2,914	18	28%	$795	$2,893	19	27%

Table 5-2., Cont'd.

	Final waste volume (ft^3x1000)	Total treatment cost ($million)	Revised* disposal cost ($million)	Total LCC ($million)	Rank	% LCC	Disposal cost $243/$ft^3$ ($million)	Total LCC ($million)	Rank	% LCC
E-1	2,482	$2,191	$752	$2,943	19	26%	$603	$2,794	18	22%
K-1	3,435	$2,144	$830	$2,973	20	28%	$835	$2,978	20	28%
NT-2	3,306	$2,846	$820	$3,665	21	22%	$803	$3,649	21	22%
NT-1	3,347	$2,883	$822	$3,706	22	22%	$813	$3,697	22	22%
NT-3	3,411	$2,990	$828	$3,817	23	22%	$829	$3,819	25	22%
NT-5	2,782	$3,118	$776	$3,895	24	20%	$676	$3,794	24	18%
NT-4	2,710	$3,135	$771	$3,905	25	20%	$658	$3,793	23	17%

* Revised disposal cost includes fixed and variable cost components.

On the average disposal costs increase from 16% to 21% of total life cycle costs. The higher cost for disposal indicates that total life cycle costs are slightly more sensitive to an increase or decrease in disposal costs. This sensitivity is illustrated in Figure 5-2 by showing the average percentage change in the total life cycle costs when cost components, including the higher disposal cost, are increased by 100% and decreased by 50%.

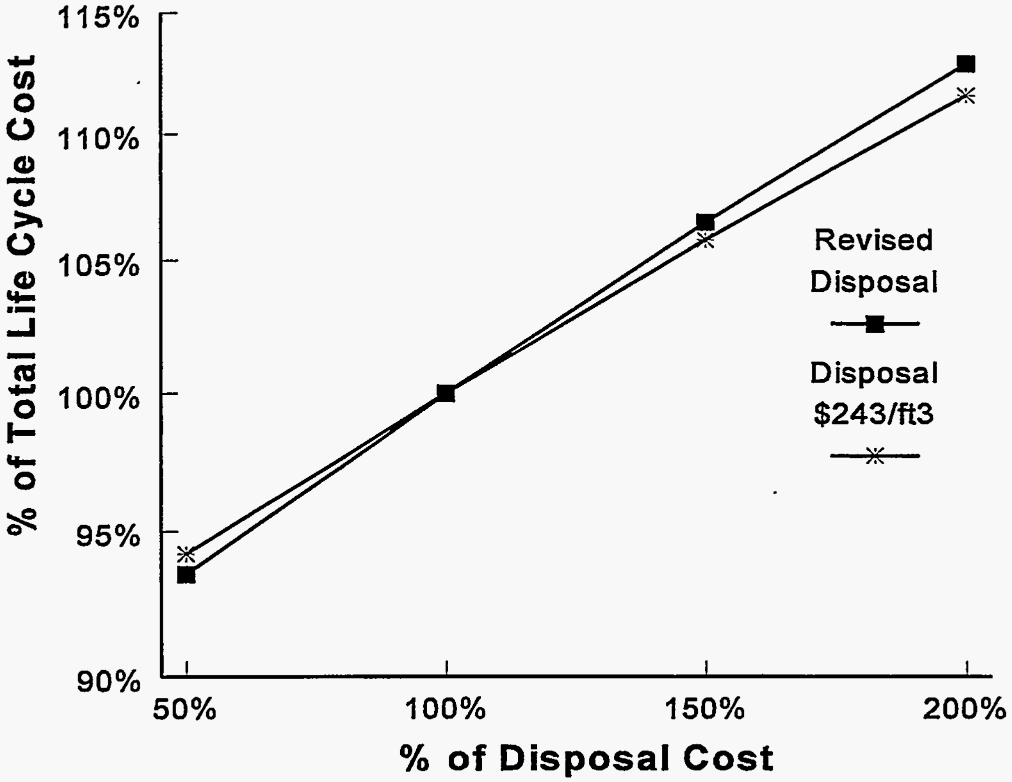

Figure 5-2. Life cycle component cost sensitivity with increased disposal cost.

5.2.2 Disposal Cost Sensitivity as a Function of Facility Size

To determine the disposal cost sensitivity as a function of the facility size, both the small- and medium-size facility cost estimates are applied to each system. The range of disposal costs across all the systems is illustrated in Figure 5-3. A breakdown of the cost estimates for small- and medium-size facilities is included in Appendix C Table C-1.

The data points for each system, as shown in Figure 5-3, represent the total cost for disposal in a small- and medium-size facility. Because costs are very close for several systems, distinguishing all 25 systems on the chart is difficult. The cost per ft^3 is identified for various systems (i.e., $533 on the small-size facility cost curve and $718 on the medium facility cost curve represents the cost per ft^3 for disposal of the final waste volume, 864K ft^3, for technology A-6, rotary kiln with air for combustion and maximum recycling). The results show that the total cost for disposal in a small-size facility is less than the cost for disposal in a medium-size facility as long as the waste quantity does not exceed the design capacity of the small-size facility (i.e., 1.5 million ft^3).

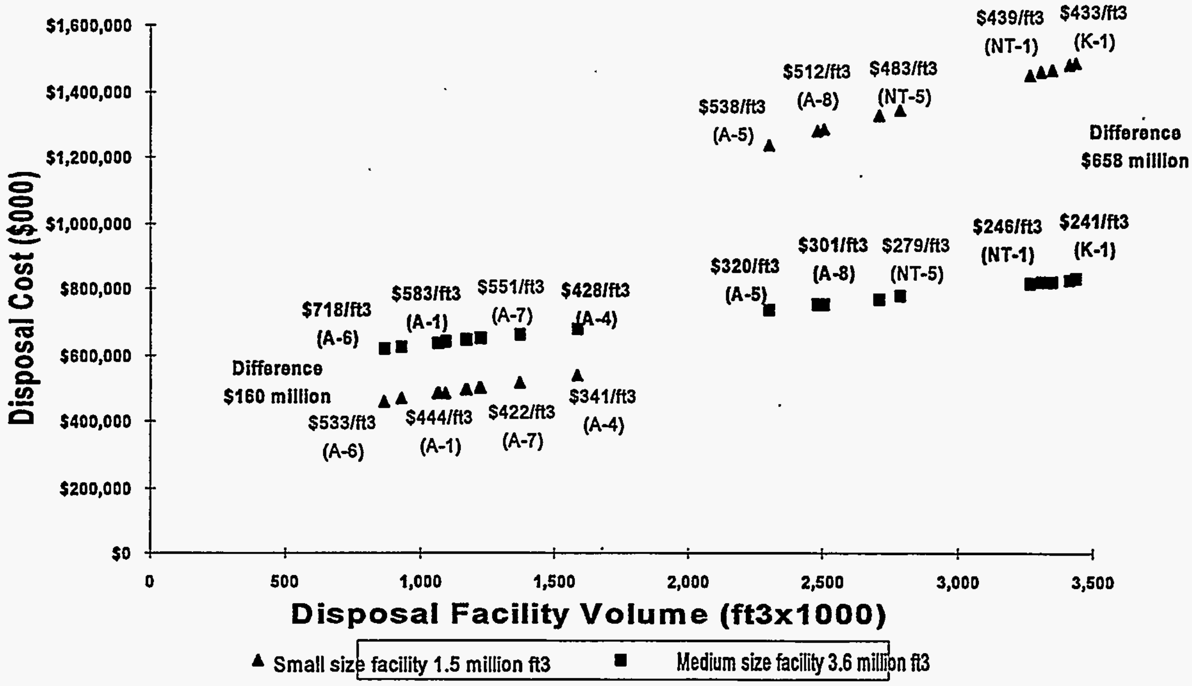

Figure 5-3. Disposal cost comparison for systems.

For example, suppose a small-size facility is constructed, and unexpectedly, waste quantity exceeds the design capacity. In this case, it is assumed that a second disposal facility would have to be built to accomodate the additional waste. Fixed costs for constructing and operating a second facility would be incurred as a result. To illustrate, if two small-size facilities are constructed to dispose of 2.3 million ft^3, or the output volume for system A-5 rotary kiln utilizing air for combustion and polymer for stabilization, the total disposal cost increases by $500 million (i.e., $320 to $538 per ft^3).

As shown in Figure 5-3, the cost difference of $160 million represents the cost risk for constructing a medium-size facility and disposing of the minimum waste volume. In comparison, the cost difference of $658 million represents the cost risk for construction of two small-size facilities and disposing of the maximum waste volume. Based on these examples, it is advisable to construct a slightly larger facility at the risk of having excess disposal capacity.

These results demonstrate the importance of estimating the final waste volume with as much accuracy as possible before the disposal facility is designed and constructed. Selection of the waste treatment technology in advance is critical in determining disposal requirements because the output volume and final waste form are used to calculate capacity requirements.

5.3 Disposal Cost Comparison for Grout vs. Vitrification

When comparing treatment technology A-1, a technology that uses vitrification for stabilization, to A-8, a technology that uses grout for stabilization, a cost savings of $268 million could be realized if a smaller disposal facility is constructed compared to the cost of constructing a medium-size facility to dispose of the grout waste form (i.e., $754 million less $486 million). This is the maximum cost savings over the life of the facility assuming the disposal site is sized for and meets the expected waste quantity.

Realistically, the disposal facility can be sized for the estimated final waste volume only if the treatment technology and final waste forms are known prior to construction of the disposal facility. Once the disposal facility is constructed and the fixed costs are incurred, the cost for disposal will vary directly with the volume of waste disposed. Therefore, systems producing less immobilized waste volume are preferred over systems producing greater final waste volume. For example, to be conservative assume that a medium-size facility is constructed to accomodate output waste volume from all treatment systems. If ultimately the waste is vitrified, disposal of a smaller quantity of vitrified waste will still cost less because the variable cost per ft^3 disposed will be saved. This is illustrated in Figure 5-4, $114 million is saved by disposing of the lower quantity of vitrified waste form in a medium-size facility (i.e., $754 million less $640 million).

These results are illustrated in Figure 5-4. Throughout this section, caution should be taken when comparing the unit costs to avoid misinterpretation of the costs. That is, for a given facility, as waste volume increases so does total disposal cost even though unit cost decreases.

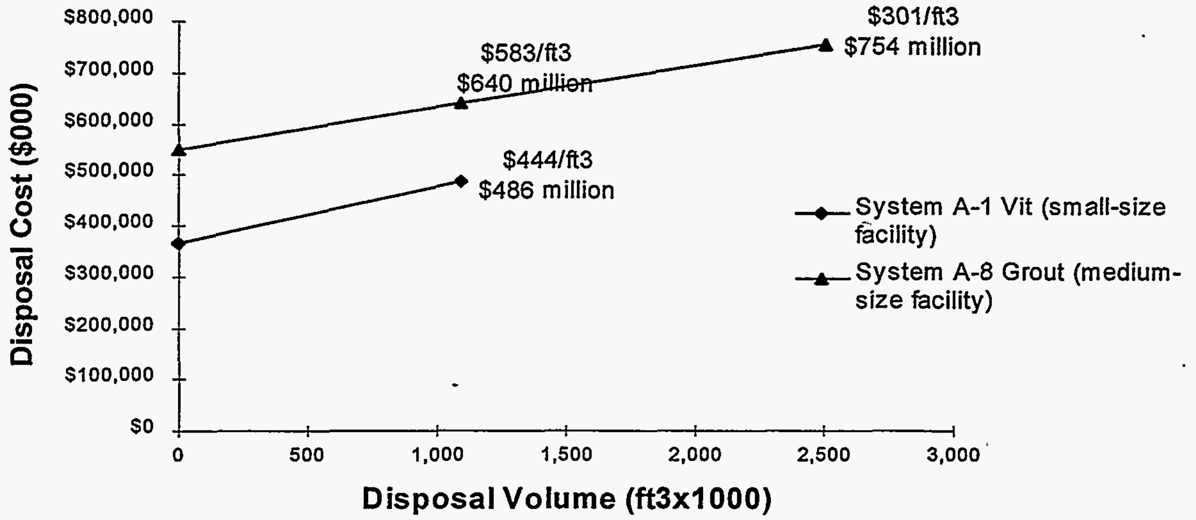

Figure 5-4. Disposal cost comparison for grout versus vitrified waste form (revised disposal costs).

For comparison, using the variable cost of $243 per ft^3 for disposal, the ITTS and INTS studies show a $343 million cost savings for disposal of the smaller waste volume from system A-1 (i.e., $609 million less $266 million) as illustrated in Figure 5-5. However, as previously mentioned, applying a single unit cost assumes that disposal cost is directly proportional to the volume of waste disposed. In contrast, as defined in this analysis, the life cycle costs for constructing and operating a disposal facility include both fixed and variable components. It is the variable cost component only that is saved when disposing of a smaller waste volume. This accounts for the difference in projected cost savings for vitrification versus grout in this analysis and the ITTS and INTS studies (i.e., $268 million versus $343 million).

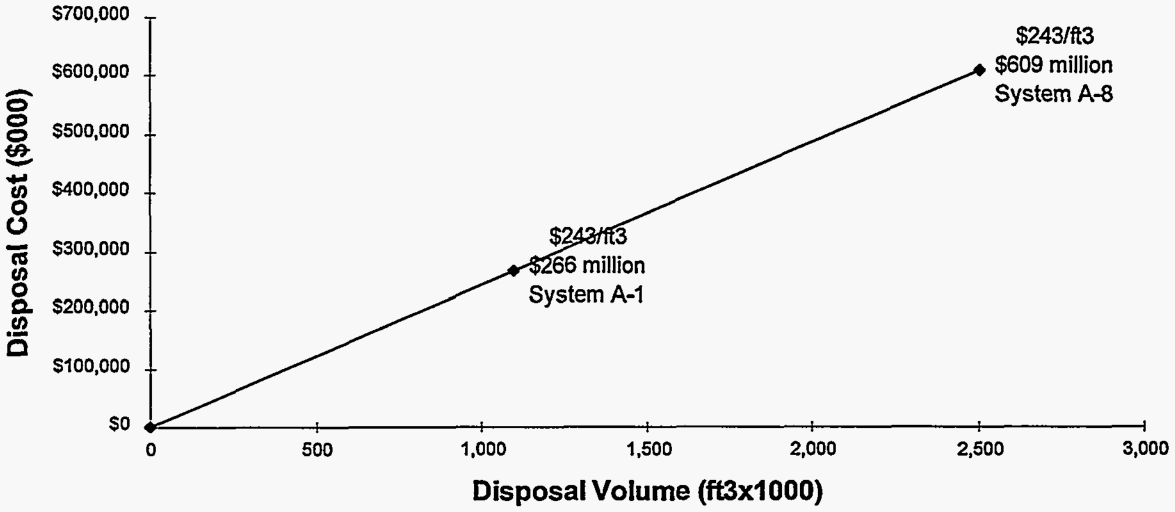

Figure 5-5. Disposal cost comparison for grout versus vitrified waste form ($243 per ft^3).

5.4 Economic Impact of Delisting Vitrified Waste Form

Currently, petitions to the U.S. Environmental Protection Agency (EPA) have been drafted within the DOE for exclusion of vitrified treatment residues from the lists of hazardous wastes[7]. Listed MLLW, as identified in the Resource Conservation and Recovery Act (RCRA) regulation 40 CFR Part 261.3, would be treated by a vitrification process and the resultant treatment residues would be regulated by 40 CFR 261.3(c)(2)(I) until delisted. When delisting for the RCRA hazardous constituents is complete, the stabilized waste form would be managed and disposed in a manner consistent with the requirements of the Atomic Energy Act of 1954 as implemented by the DOE Order 5820.2A Radioactive Waste Management. In order to delist the waste, the petitioner must demonstrate that the waste does not meet any of the criteria under which the waste was listed as a hazardous waste and that there are no factors other than those for which the waste was listed that could cause the waste to be a hazardous waste.

Delisting the vitrified waste form would be economically advantageous because the cost to dispose of low-level radioactive waste at existing shallow land disposal facilities is reported to be less than the cost for disposal in a RCRA-permitted engineered disposal facility, as estimated. For example, assume that a disposal facility such as the Richland shallow land disposal facility could accommodate the additional delisted vitrified waste volume without increasing their estimated cost of \$40 per ft^3 for disposal[8]. This cost per ft^3 is substantially less than the costs calculated in this analysis which range from \$241 to \$718 per ft^3 for constructing and operating a medium-size RCRA-permitted facility, as shown in Appendix C, Table C-1.

This section estimates the potential cost savings that would result for each of the thermal treatment technologies using vitrification for primary stabilization if the vitrified waste form is delisted and disposed of at \$40 per ft^3. The thermal treatment technologies using vitrification for primary stabilization include:

A-1 rotary kiln with air for combustion and dry/wet air pollution control,
A-2 rotary kiln with oxygen for combustion and dry/wet air pollution control,
A-3 rotary kiln with air for combustion and wet air pollution control,
A-4 rotary kiln with oxygen for combustion and CO_2 retention,
A-6 rotary kiln with air for combustion and maximum recycling,
D-1 fixed hearth with oxygen and CO_2 retention,
E-1 debris desorption and grouting with rotary kiln for combustion,
F-1 molten salt oxidation with air for combustion and dry/wet air pollution control, and
H-1 steam gasification with steam for combustion.

Applying the shallow land disposal cost of \$40 per ft^3 to the volume of slag output from the vitrification process [9], and the applicable disposal cost for the remaining output volume of waste, the total estimated disposal cost for the systems employing vitrification for stabilization is reduced by as much as \$45 million, or 2% of the total life cycle costs. These disposal estimates are summarized in Table 5-3 . However, even after reducing the disposal cost by assuming delisting of the slag output volume, the overall ranking of systems by total life cycle cost including disposal remains the same as presented in Table 5-2. A breakdown of the vitrified and solid output volume and disposal cost for each system is provided in Appendix C, Table C-2.

Table 5-3. Disposal cost assuming delisting of vitrified waste form.

	Final waste volume (ft^3x1000)	Total treatment cost ($million)	Revised* disposal cost ($million)	Total LCC ($million)	Disposal cost assuming delisting ($million)	Total LCC assuming delisting ($million)
A-2	1,096	$2,166	$486	$2,652	$440	$2,606
A-1	1,096	$2,167	$486	$2,653	$440	$2,607
A-3	1,369	$2,144	$516	$2,660	$482	$2,625
H-1	1,095	$2,193	$486	$2,679	$440	$2,633
A-6	864	$2,236	$460	$2,697	$414	$2,651
F-1	1,176	$2,275	$495	$2,770	$449	$2,724
A-4	1,585	$2,282	$540	$2,822	$494	$2,776
D-1	1,226	$2,338	$500	$2,839	$454	$2,793
E-1	2,482	$2,191	$752	$2,943	$749	$2,940

*Revised disposal cost includes fixed and variable cost components.

6.0 CONCLUSIONS AND RECOMMENDATIONS

For all systems, the most cost sensitive life cycle component is the operations and maintenance phase and the most cost sensitive subsystem component is the receiving and inspection/preparation subsystem. These conclusions were unchanged when the sensitivity analysis was repeated on a present value basis. Opportunity exists for technology development to reduce waste receiving and inspection/preparation costs by effectively minimizing labor costs, the major cost driver, within the maintenance and operations phase of the life cycle.

The capacity analysis demonstrates that treatment of the MLLW inventory in one facility is the most economically advantageous alternative. The economic scaling alternatives explored in this analysis show that even when factoring in the greater transportation costs associated with shipment of the MLLW to a single facility, the life cycle costs are still approximately 27% less for constructing and operating one facility versus two facilities, assuming a 0.5 scaling factor. If a single facility is sized to double the throughput capacity and treat the same quantity of waste in half the time, the life cycle cost will be less than the baseline system costs for any scaling factor less than 0.58. However, from an NPV perspective, the higher cash outlays in the earlier years, due to the reduced operating period, are not preferred unless there is a non-economic driver to treat the waste sooner, such as the Federal Facility Compliance Act.

If feasible, the most economically favorable alternative would be one facility capable of operating more available hours. As shown in this analysis, if the facility is fully operational 5,850 hours per year, the operating period is reduced from 20 to 14 years and the total life cycle cost are 17% less than baseline system life cycle cost. Alternatively, rather than reducing the operating period, a 45% increase in the quantity of waste processed results in a cost of $6.75 per pound versus $9.18 per pound or net decrease of $2.65 per pound over a 20 year operating life. Although system unavailability is not attributed to any specific cause, it is clear that reliable operating equipment is a key factor to increasing system availability. Therefore, a recommended area of focus is on improving equipment availability.

To further support treatment in a single facility, a recommended area for technology development and/or technology improvement is to ensure that the facility is capable of accepting and treating greater volumes of heterogenous waste streams. The increased technical risk associated with engineering a single large-scale process to accept heterogeneous waste streams with complex physical and chemical characteristics needs to be addressed. Treatment systems operate on tight controls in order to achieve organic destruction of the contaminants and produce a specific final waste form while insuring that no damage is done physically to the system itself. Therefore, there are normally restrictions on the chemical, physical, and radiological characteristics of the waste input to the treatment process. If input waste streams do not fit the input specifications of the treatment process, then only the portion of the mixed waste inventory that fits within the narrow specifications of the treatment system will undergo treatment in that given process. The challenge that remains is to treat waste streams that vary widely in physical, chemical, and radiological form (i.e., heterogeneous waste streams).

As a potential technology discriminator, the sensitivity of life cycle costs to contingency allowance was evaluated for the less-developed technologies. An increase in contingency percentage from 25% to 35%, 45%, and 50% for the less developed technologies results in a 7%, 15%, and 18% increase in the total life cycle costs, respectively. These results show that the less developed technologies are not as economically desirable when the contingency costs are increased to reflect operational uncertainties.

The disposal cost analyses presented in the ITTS and INTS were extended to incorporate varying design capacities for future waste disposal facilities. The fixed and variable components of total disposal costs were calculated to determine the sensitivity of life cycle costs to final waste volume. Disposal costs increased an average of 35% above the cost derived using \$243 per ft^3, as documented in the ITTS and INTS.

If a new RCRA-permitted engineered disposal facility is designed to accomodate a greater waste volume than the selected treatment system produces, only the variable cost of disposal will be saved. As expected, disposal costs will decrease with the volume of waste requiring disposal due to the variable cost component savings. Maximum cost savings will be realized if the disposal site is designed and sized for the selected treatment system. The selection and/or development of treatment technologies, final waste form(s) and disposal site(s) should be coordinated to minimize total life cycle costs. The possibility of delisting certain final waste forms offers the opportunity for additional cost savings.

7.0 REFERENCES

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Appendix A

Life Cycle Component and Subsystem Cost Data

Table A-1. Life cycle cost sensitivity to 100% increase in component cost.

		Life Cycle Cost ($000)	Studies, Test, & Demo.	Building	Equipment	Ops. funded activities	Ops. & Maint.	D&D
Rotary kiln, air/vit.	A-1	$2,167,318	5%	11%	15%	0.3%	66%	3%
Rotary kiln, oxygen	A-2	$2,165,709	5%	11%	14%	0.3%	66%	3%
Slagging rotary kiln	A-7	$1,913,812	5%	11%	14%	0.3%	66%	3%
Rotary kiln, air/grouut	A-8	$2,144,205	4%	12%	13%	0.3%	68%	3%
Plasma furnace	C-1	$1,980,756	5%	11%	13%	0.3%	68%	3%
Plasma furnace, CO2 ret.	C-2	$2,095,782	5%	11%	14%	0.3%	67%	2%
Plasma gasification	C-3	$1,929,110	4%	11%	15%	0.3%	66%	3%
Molten salt oxidation	F-1	$2,275,209	3%	11%	15%	0.3%	68%	2%
Molten metal waste destruction	G-1	$1,893,481	5%	13%	10%	0.3%	68%	3%
Steam gasification	H-1	$2,193,160	3%	11%	16%	0.3%	67%	1%
Joule heated vitrification	J-1	$1,921,590	4%	12%	14%	0.3%	68%	3%
Thermal desorption and MEO	K-1	$2,143,501	3%	10%	14%	0.3%	70%	3%
Thermal desorption and SCWO	L-1	$2,098,135	3%	11%	13%	0.3%	70%	3%
Grout debris	NT-1	$2,883,364	5%	13%	9%	0.3%	71%	3%
Desorption	NT-2	$2,845,686	5%	13%	9%	0.3%	71%	3%
Wash	NT-3	$2,989,775	5%	13%	9%	0.3%	71%	3%
Acid digestion	NT-4	$3,134,475	7%	13%	9%	0.3%	68%	3%
Catalyzed wet oxidation	NT-5	$3,118,337	6%	13%	9%	0.3%	69%	3%

Table A-2. Time phased life cycle costs for baseline system A-1 rotary kiln with air combustion ($000).

Cost Category	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Bench scale testing	$30,525									
Capital demonstration		$20,000								
Annual demonstration		$24,824	$24,824							
Permitting				$2,000	$2,000	$2,000				
Capital construction							$205,745			
Annual construction							$174,316	$174,316		
Other preoperations								$90,747		
Annual operations & maintenance									$68,093	$68,093
Decontamination & decommissioning										
Disposal									$6,656	$13,312
TOTAL COST	($30,525)	($44,824)	($24,824)	($2,000)	($2,000)	($2,000)	($380,061)	($265,063)	($68,093)	($68,093)

Cost Category	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Bench scale testing										
Capital demonstration										
Annual demonstration										
Permitting										
Capital construction										
Annual construction										
Other preoperations										
Annual operations & maintenance	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093
Decontamination & decommissioning										
Disposal	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312
TOTAL COST	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)

Cost Category	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	TOTAL $
Bench scale testing											$30,525
Capital demonstration											$20,000
Annual demonstration											$49,647
Permitting											$6,000
Capital construction											$205,745
Annual construction											$348,632
Other preoperations											$90,747
Annual operations & maintenance	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093			$1,361,850
Decontamination & decommissioning									$27,086	$27,086	$54,171
Disposal	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$6,656		$266,242
TOTAL COST	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($27,086)	($27,086)	**$2,433,560**

Table A-3. Present value life cycle cost (LCC) comparison ($000).

	A-1 rotary kiln, air/vitrification				A-2 rotary kiln, oxygen				A-7 slagging rotary kiln			
	LCC $		PV $		LCC $		PV $		LCC $		PV $	
Bench scale test	$30,525	1%	$28,797	3%	$30,525	1%	$28,797	3%	$25,575	1%	$24,127	2%
Demonstration	$69,647	3%	$60,735	5%	$69,647	3%	$60,735	6%	$73,858	3%	$64,415	6%
Construction	$554,377	23%	$362,131	33%	$535,818	22%	$350,007	32%	$474,302	22%	$309,824	31%
Preoperations	$96,747	4%	$61,424	6%	$97,168	4%	$61,689	6%	$85,913	4%	$54,627	5%
Operations	$1,361,850	56%	$490,019	44%	$1,378,775	57%	$496,109	45%	$1,204,908	55%	$433,548	44%
Disposal	$266,242	11%	$93,088	8%	$266,242	11%	$93,088	8%	$284,423	13%	$99,444	10%
D&D	$54,171	2%	$9,715	1%	$53,776	2%	$9,644	1%	$49,256	2%	$8,833	1%
Total	$2,433,560	100%	$1,105,909	100%	$2,431,952	100%	$994,818	100%	$2,198,235	100%	$994,818	100%

	A-8 rotary kiln, air/grout				C-1 plasma arc furnace				G-1 molten metal melter			
	LCC $		PV $		LCC $		PV $		LCC $		PV $	
Bench scale test	$25,575	1%	$24,127	2%	$29,288	1%	$27,630	3%	$25,369	1%	$23,933	3%
Demonstration	$69,647	3%	$60,735	5%	$69,647	3%	$60,735	6%	$62,248	3%	$54,303	6%
Construction	$513,656	19%	$335,530	28%	$458,639	20%	$299,592	30%	$449,457	21%	$293,595	31%
Preoperations	$96,785	4%	$61,448	5%	$89,796	4%	$57,063	6%	$86,064	4%	$54,722	6%
Operations	$1,382,900	49%	$497,593	41%	$1,283,333	57%	$461,767	46%	$1,220,078	58%	$439,006	46%
Disposal	$609,421	22%	$213,075	18%	$259,168	12%	$90,614	9%	$225,780	11%	$78,940	8%
D&D	$55,642	2%	$9,978	1%	$50,053	2%	$8,976	1%	$50,266	2%	$9,014	1%
Total	$2,753,626	100%	$1,202,488	100%	$2,239,924	100%	$1,006,378	100%	$2,119,261	100%	$953,514	100%

Table A-3. Present value life cycle cost (LCC) comparison ($000) (continued).

	H-1 steam gasification				NT-1 grout debris				NT-2 desorption			
	LCC $		PV $		LCC $		PV $		LCC $		PV $	
Bench scale test	$33,138	1%	$31,262	3%	$41,085	1%	$38,759	2%	$41,085	1%	$38,759	2%
Demonstration	$29,302	1%	$25,545	2%	$92,039	2%	$80,178	5%	$100,466	3%	$87,516	6%
Construction	$587,587	24%	$383,824	35%	$603,341	16%	$394,115	25%	$583,034	16%	$380,850	24%
Preoperations	$99,217	4%	$62,974	6%	$131,006	4%	$83,040	5%	$129,339	4%	$81,994	5%
Operations	$1,390,160	57%	$500,205	45%	$1,940,260	52%	$698,141	44%	$1,920,100	53%	$690,888	44%
Disposal	$266,033	11%	$93,014	8%	$813,214	22%	$284,328	18%	$803,416	22%	$280,902	18%
D&D	$53,756	2%	$9,640	1%	$75,633	2%	$13,564	1%	$71,662	2%	$12,851	1%
Total	$2,459,193	100%	$1,105,909	100%	$3,696,578	100%	$1,592,125	100%	$3,649,102	100%	$1,573,760	100%

	NT-3 wash				NT-4 acid digestion				NT-5 catalyzed wet oxidation			
	LCC $		PV $		LCC $		PV $		LCC $		PV $	
Bench scale test	$41,635	1%	$39,278	2%	$58,341	2%	$55,039	3%	$47,685	1%	$44,986	3%
Demonstration	$100,090	3%	$87,196	5%	$157,389	4%	$137,111	8%	$127,055	3%	$110,682	7%
Construction	$638,231	17%	$416,905	25%	$670,985	18%	$438,301	26%	$677,764	18%	$442,729	26%
Preoperations	$135,101	4%	$85,609	5%	$137,781	4%	$87,290	5%	$138,954	4%	$88,026	5%
Operations	$1,997,280	52%	$718,658	44%	$2,029,600	54%	$730,288	43%	$2,047,560	54%	$736,750	44%
Disposal	$828,891	22%	$289,809	18%	$658,409	17%	$230,203	14%	$676,045	18%	$236,369	14%
D&D	$77,438	2%	$13,887	1%	$80,379	2%	$14,415	1%	$79,319	2%	$14,225	1%
Total	$3,818,666	100%	$1,651,343	100%	$3,792,884	100%	$1,692,647	100%	$3,794,382	100%	$1,673,767	100%

Table A-4. Thermal subsystem component cost sensitivity ($000).

Thermal Subsystems	Rotary kiln, air, vit.	Rotary kiln, oxygen, vit.	Slagging rotary kiln	Rotary kiln, grout	Plasma hearth, air	Molten metal	Steam gasification	Average % Life Cycle $
System Abbreviation	A-1	A-2	A-7	A-8	C-1	G-1	H-1	
Receive & Inspect	$666,796	$666,796	$660,054	$666,765	$660,012	$636,881	$783,367	33%
Primary Thermal Treatment	$161,490	$199,288	$245,835	$161,459	$201,833	$364,365	$184,938	11%
Certifiy & Ship	$193,049	$193,049	$193,173	$325,947	$193,085	$193,223	$193,094	10%
Administration	$139,037	$139,037	$139,125	$139,006	$139,074	$139,175	$139,047	7%
Aqueous Waste Treatment	$149,186	$149,186	$147,494	$149,154	$149,222	$120,263	$53,685	6%
Primary Stabilization	$243,688	$243,688	$0	$0	$150,592	$0	$243,656	6%
Support	$101,200	$101,200	$110,012	$101,169	$101,236	$110,063	$109,934	5%
Air Pollution Control	$115,219	$76,224	$113,658	$115,187	$79,977	$85,395	$87,864	5%
Lead Recovery	$81,130	$81,129	$81,207	$81,098	$81,166	$81,257	$81,129	4%
Secondary Stabil.	$80,942	$81,148	$79,560	$80,911	$80,978	$81,027	$80,898	4%
Mercury Amalgam.	$52,244	$51,625	$52,302	$52,212	$52,280	$52,352	$52,224	2%
Metal Decon	$61,878	$61,878	$61,963	$61,846	$61,914	$0	$61,884	2%
Metal Melting	$92,110	$92,110	$0	$92,079	$0	$0	$92,089	2%
Special Waste	$29,350	$29,351	$29,429	$29,319	$29,387	$29,479	$29,351	1%
Grout Stabilization	$0	$0	$0	$87,613	$0	$0	$0	1%
Total Life Cycle $	$2,167,318	$2,165,709	$1,913,812	$2,144,205	$1,980,756	$1,893,480	$2,193,160	

Table A-5. Nonthermal subsystem component cost sensitivity ($000).

Nonthermal Subsystems	Grout debris	Vacuum desorption	Wash	Acid digestion	Catalytic wet oxid.	Average % Life Cycle $
System Abbrev.	NT-1	NT-2	NT-3	NT-4	NT-5	
Receive & Inspect	$940,494	$940,494	$940,494	$940,494	$940,494	31%
Certify & Ship	$480,507	$472,550	$495,277	$401,899	$405,490	15%
Polymer Stabilization	$289,200	$289,200	$291,101	$95,995	$289,200	8%
Organic Destruction	$245,695	$195,695	$245,695	$181,074	$176,979	7%
Administration	$169,917	$169,917	$169,917	$169,917	$169,917	6%
Aqueous Waste Treatment	$149,655	$149,655	$149,655	$146,285	$146,285	5%
Process Residue & Sludge	$134,292	$156,658	$84,882	$126,717	$126,717	4%
Grout Stabilization	$119,186	$120,011	$119,073	$75,907	$120,011	4%
Soft Debris Treatment	$0	$0	$0	$209,380	$219,317	3%
Support	$84,388	$77,086	$81,203	$82,982	$80,649	3%
Air Pollution Control	$70,896	$70,896	$90,694	$70,896	$70,896	3%
Metal Decon	$69,323	$69,323	$69,323	$69,003	$69,003	2%
Phosphate Stabilization	$0	$0	$0	$273,259	$0	2%
Special Waste	$53,990	$58,388	$53,990	$51,474	$51,474	2%
Lead Recovery	$41,123	$41,123	$54,954	$41,123	$54,954	2%
Open Debris	$0	$0	$0	$97,896	$97,896	1%
Mercury Amalgamation	$34,707	$34,707	$34,707	$34,707	$34,707	1%
Bulk Soil Treatment	$0	$0	$0	$64,365	$64,365	1%
Complex Debris	$0	$0	$108,840	$0	$0	1%
Total Life Cycle $	$2,883,373	$2,845,703	$2,989,805	$3,133,373	$3,118,354	

Appendix B

Time Phased Life Cycle Costs and Transportation Data

Figure B-1. Time phased life cycle costs for baseline system A-1 rotary kiln with air combustion ($000).

Cost Category	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Bench scale testing	$30,525									
Capital demonstration		$20,000								
Annual demonstration		$24,824	$24,824							
Permitting				$2,000	$2,000	$2,000				
Capital construction							$205,745			
Annual construction							$174,316	$174,316		
Other preoperations								$90,747		
Annual operations & maintenance									$68,093	$68,093
Decontamination & decommissioning										
Disposal									$6,656	$13,312
TOTAL COST	($30,525)	($44,824)	($24,824)	($2,000)	($2,000)	($2,000)	($380,061)	($265,063)	($68,093)	($68,093)

Cost Category	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Bench scale testing										
Capital demonstration										
Annual demonstration										
Permitting										
Capital construction										
Annual construction										
Other preoperations										
Annual operations & maintenance	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093
Decontamination & decommissioning										
Disposal	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312
TOTAL COST	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)

Cost Category	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	TOTAL $
Bench scale testing											$30,525
Capital demonstration											$20,000
Annual demonstration											$49,647
Permitting											$6,000
Capital construction											$205,745
Annual construction											$348,632
Other preoperations											$90,747
Annual operations & maintenance	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093	$68,093			$1,361,850
Decontamination & decommissioning									$27,086	$27,086	$54,171
Disposal	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$13,312	$6,656		$266,242
TOTAL COST	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($27,086)	($27,086)	**$2,433,560**

Table B-2. Time phased life cycle costs ($000) for 10 year operating life (scaling factor 0.5).

Cost Category	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Bench scale testing	$30,525									
Capital demonstration		$20,000								
Annual demonstration		$24,824	$24,824							
Permitting				$2,000	$2,000	$2,000				
Capital construction							$290,967			
Annual construction							$246,521	$246,521		
Other preoperations								$128,087		
Annual operations & maintenance									$96,297	$96,297
Decontamination & decommissioning										
TOTAL COST	($30,525)	($44,824)	($24,824)	($2,000)	($2,000)	($2,000)	($537,488)	($374,608)	($96,297)	($96,297)

Cost Category	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	TOTAL $
Bench scale testing											$30,525
Capital demonstration											$20,000
Annual demonstration											$49,647
Permitting											$6,000
Capital construction											$290,967
Annual construction											$493,041
Other preoperations											$128,087
Annual operations & maintenance	$96,297	$96,297	$96,297	$96,297	$96,297	$96,297	$96,297	$96,297			$962,973
Decontamination & decommissioning									$38,305	$38,305	$76,609
TOTAL COST	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($38,305)	($38,305)	($2,057,850)

Table B-3. Net present value comparison for operating 20 versus 10 years ($000; discount rate = 0.06, constant $).

	Net Present Value (NPV) Total LCC ($000)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Baseline A-1 Rotary Kiln 20 Year Operating Life	($1,012,821)	($30,525)	($44,824)	($24,824)	($2,000)	($2,000)	($2,000)	($380,061)	($265,063)	($68,093)	($68,093)
2xCapacity Scaled 0.5 10 Year Operating Life	($1,155,801)	($30,525)	($44,824)	($24,824)	($2,000)	($2,000)	($2,000)	($537,488)	($374,608)	($96,297)	($96,297)

	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21
Baseline A-1 Rotary Kiln 20 Year Operating Life	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)
2xCapacity Scaled 0.5 10 Year Operating Life	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($96,297)	($38,305)	($38,305)	$0

	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	TOTAL LCC ($000)	
Baseline A-1 Rotary Kiln 20 Year Operating Life	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($68,093)	($27,086)	($27,086)	($2,167,318)	**20 Year**
2xCapacity Scaled 0.5 10 Year Operating Life	$0	$0	$0	$0	$0	$0	$0	$0	$0	($2,057,850)	**10 Year**

Table B-4. Transportation cost data for shipment to one facility.

	MILES	LBS	#SHIPMENTS	VARIABLE $	FIXED $	TOTAL $
California	2,400	922,536	21	$201,600	$18,480	$220,080
Colorado	1,300	23,150,520	526	$2,735,200	$462,880	$3,198,080
Idaho	1,850	44,129,665	1,003	$7,422,200	$882,640	$8,304,840
Illinois	455	58,086	1	$1,820	$880	$2,700
Kentucky	260	1,763,068	40	$41,600	$35,200	$76,800
Maine	845	1,708	1	$3,380	$880	$4,260
Missouri	450	3,456,092	79	$142,200	$69,520	$211,720
Nevada	2,010	509,103	12	$96,480	$10,560	$107,040
New Jersey	520	41,821,617	950	$1,976,000	$836,000	$2,812,000
New Mexico	1,300	1,160,003	26	$135,200	$22,880	$158,080
New York	620	239,176	5	$12,400	$4,400	$16,800
Ohio	260	16,721,813	380	$395,200	$334,400	$729,600
Pennsylvania	455	64,919	1	$1,820	$880	$2,700
South Carolina	230	12,303,892	280	$257,600	$246,400	$504,000
Tennessee	0	78,475,326	0	$0	$0	$0
Texas	1,050	218,675	5	$21,000	$4,400	$25,400
Virginia	390	8,542	1	$1,560	$880	$2,440
Washington	2,250	10,995,258	250	$2,250,000	$220,000	$2,470,000
	16,645	236,000,000	3,581	$15,695,260	$3,151,280	$18,846,540

TOTAL TRANSPORTATION COST TO ORNL $18,846,540 1% BASELINE LCC

Table B-5. Transportation cost data for shipment to two facilities.

	MILES	LBS	SHIPMENT	VARIABLE $	FIXED $	TOTAL $		
Illinois	455	58,086	1	$1,820	$880	$2,700		
Kentucky	260	1,763,068	40	$41,600	$35,200	$76,800		
Maine	845	1,708	1	$3,380	$880	$4,260		
Missouri	450	3,456,092	79	$142,200	$69,520	$211,720		
New Jersey	520	41,821,617	950	$1,976,000	$836,000	$2,812,000		
New York	620	239,176	5	$12,400	$4,400	$16,800		
Ohio	260	16,721,813	380	$395,200	$334,400	$729,600		
Pennsylvania	455	64,919	1	$1,820	$880	$2,700		
South Carolina	230	12,303,892	280	$257,600	$246,400	$504,000		
Tennessee	0	78,475,326	0	$0	$0	$0		
Virginia	390	8,542	1	$1,560	$880	$2,440	$4,363,020	EAST
California	845	922,536	21	$70,980	$18,480	$89,460		
Colorado	600	23,150,520	526	$1,262,400	$462,880	$1,725,280		
Idaho	0	44,129,665	0	$0	$0	$0		
Nevada	615	509,103	12	$29,520	$10,560	$40,080		
New Mexico	810	1,160,003	26	$84,240	$22,880	$107,120		
Texas	780	218,675	5	$15,600	$4,400	$20,000		
Washington	540	10,995,258	250	$540,000	$220,000	$760,000	$2,741,940	WEST
	8,675	236,000,000	2,578	$4,836,320	$2,268,640	$7,104,960	$7,104,960	

TOTAL TRANSPORTATION COST TO INEL & ORNL $7,104,960 .3% BASELINE LCC

Table B-6. Transportation cost data for shipment to five facilities.

	MILES	LBS	# SHIPMENTS	VARIABLE $	FIXED $	TOTAL $		
California	620	922,536	21	$52,080	$18,480	$70,560		
Nevada	715	509,103	12	$34,320	$10,560	$44,880		
Washington	0	10,995,258	0	$0	$0	$0	$115,440	Hanford
Idaho	0	44,129,665	0	$0	$0	$0	$0	INEL
Illinois	455	58,086	1	$1,820	$880	$2,700		
Kentucky	260	1,763,068	40	$41,600	$35,200	$76,800		
Maine	845	1,708	1	$3,380	$880	$4,260		
Missouri	450	3,456,092	79	$142,200	$69,520	$211,720		
New Jersey	520	41,821,617	950	$1,976,000	$836,000	$2,812,000		
New York	620	239,176	5	$12,400	$4,400	$16,800		
Ohio	260	16,721,813	380	$395,200	$334,400	$729,600		
Pennsylvania	455	64,919	1	$1,820	$880	$2,700		
Tennessee	0	78,475,326	0	$0	$0	$0		
Virginia	390	8,542	0	$0	$0	$0	$3,856,580	ORNL
Colorado	0	23,150,520	0	$0	$0	$0		
New Mexico	325	1,160,003	26	$33,800	$22,880	$56,680		
Texas	360	218,675	5	$7,200	$4,400	$11,600	$68,280	RFP
South Carolina	0	12,303,892	0	$0	$0	$0	$0	SRS
	6,275	236,000,000	1,521	$2,701,820	$1,338,480	$4,040,300	$4,040,300	

TOTAL TRANSPORTATION COST TO 5 SITES $4,040,300 0.2% BASELINE LC

Appendix C

Disposal Cost Data

Table C-1. Revised disposal cost estimates for small- and medium-size facilities.

Treatment System	Final Waste Volume (ft^3)	Small (1.5 million ft^3) ($000)	\$/ft^3	Medium (3.6 million ft^3) ($000)	\$/ft^3
A-1 Rotary kiln, air	1,095,648	$485,920	$444	$639,260	$583
A-2 Rotary kiln, oxygen	1,095,648	$485,920	$444	$639,260	$583
A-3 Rotary kiln, air, wet APC	1,369,325	$516,109	$377	$661,518	$483
A-4 Rotary kiln, oxygen, CO_2 retention	1,585,118	$539,913	$341	$679,069	$428
A-5 Rotary kiln, air, polymer stabil.	2,300,532	$1,237,661	$538	$737,253	$320
A-6 Rotary kiln, air, maximum recycling	864,018	$460,369	$533	$620,422	$718
A-7 Slagging rotary kiln	1,170,466	$494,173	$422	$645,345	$551
A-8 Rotary kiln, grout stabilization	2,507,904	$1,283,412	$512	$754,119	$301
B-1 Indirectly heated pyrolyzer	1,095,648	$485,920	$444	$639,260	$583
C-1 Plasma furnace	1,066,540	$482,709	$453	$636,893	$597
C-2 Plasma furnace, CO_2 retention	1,220,080	$499,646	$410	$649,380	$532
C-3 Plasma gasification	1,067,403	$482,804	$452	$636,963	$597
D-1 Fixed hearth pyrolyzer, CO_2 retent.	1,226,221	$500,323	$408	$649,880	$530
E-1 Rotary kiln, air, thermal desorption	2,482,376	$1,277,780	$515	$752,043	$303
F-1 Molten salt oxidation	1,176,428	$494,831	$421	$645,830	$549
G-1 Molten metal waste destruction	929,131	$467,551	$503	$625,717	$673
H-1 Steam gasification	1,094,786	$485,825	$444	$639,190	$584
J-1 Joule-heated vitrification	1,095,217	$485,872	$444	$639,225	$584
K-1 Thermal desorption and MEO	3,435,031	$1,487,955	$433	$829,522	$241
L-1 Thermal desorption and SCWO	3,269,719	$1,451,483	$444	$816,077	$250
NT-1 Grout debris	3,346,560	$1,468,436	$439	$822,327	$246
NT-2 Desorption	3,306,240	$1,459,541	$441	$819,047	$248
NT-3 Wash	3,411,072	$1,482,669	$435	$827,573	$243
NT-4 Acid digestion	2,709,504	$1,327,889	$490	$770,515	$284
NT-5 Catalyzed wet oxidation	2,782,080	$1,343,900	$483	$776,418	$279

Table C-2. Vitrified and solid waste output and revised disposal cost.

Treatment System	Final waste volume (ft^3x1000)	Vitrified waste output (ft^3x1000)	Other waste to disposal (ft^3x1000)	Disposal cost for delisted vitrified waste ($million)	Other disposal cost ($million)	Total disposal cost assuming delisting	Total disposal cost without delisting
A-1 Rotary kiln, air	1,096	653	442	$26,127	$413,867	$439,995	$485,920
A-2 Rotary kiln, oxygen	1,096	653	442	$26,127	$413,867	$439,995	$485,920
A-3 Rotary kiln, air, wet APC	1,369	492	877	$19,676	$461,847	$481,523	$516,109
A-4 Rotary kiln	1,585	653	932	$26,127	$467,861	$493,988	$539,913
A-5 Rotary kiln, air, polymer stabil.	2,301	0	2,301	$0	$737,253	$737,253	$737,253
A-6 Rotary kiln, air, maximum recycling	864	653	211	$26,127	$388,316	$414,443	$460,369
A-7 Slagging rotary kiln	1,170	0	1,170	$0	$494,173	$494,173	$494,173
A-8 Rotary kiln, grout stabilization	2,508	0	2,508	$0	$754,119	$754,119	$754,119
B-1 Indirectly heated pyrolyzer	1,096	0	1,096	$0	$485,920	$485,920	$485,920
C-1 Plasma furnace	1,067	0	1,067	$0	$482,709	$482,709	$482,709
C-2 Plasma furnace, CO_2 retention	1,220	0	1,220	$0	$499,646	$499,646	$499,646
C-3 Plasma gasification	1,067	0	1,067	$0	$482,804	$482,804	$482,804
D-1 Fixed hearth pyrolyzer, CO_2 retent.	1,226	653	573	$26,127	$428,271	$454,398	$500,323
E-1 Rotary kiln, air, thermal desorption	2,482	81	2,402	$3,226	$745,484	$748,710	$752,043
F-1 Molten salt oxidation	1,176	653	523	$26,127	$422,778	$448,905	$494,831
G-1 Molten metal waste destruction	929	0	929	$0	$467,551	$467,551	$467,551

Table C-2., Cont'd.

Treatment Technology	Final waste volume (ft^3x1000)	Vitrified waste output (ft^3x1000)	Other waste to disposal (ft^3x1000)	Disposal cost for delisted vitrified waste ($million)	Other disposal cost ($million)	Total disposal cost assuming delisting	Total disposal cost without delisting
H-1 Steam gasification	1,095	653	442	$26,127	$413,772	$439,899	$485,825
J-1 Joule-heated vitrification	1,095	0	1,095	$0	$485,872	$485,872	$485,872
K-1 Thermal desorption and MEO	3,435	0	3,435	$0	$829,522	$829,522	$829,522
L-1 Thermal desorption and SCWO	3,270	0	3,270	$0	$816,077	$816,077	$816,077
NT-1 Grout debris	3,347	0	3,347	$0	$822,327	$822,327	$822,327
NT-2 Desorption	3,306	0	3,306	$0	$819,047	$819,047	$819,047
NT-3 Wash	3,411	0	3,411	$0	$827,573	$827,573	$827,573
NT-4 Acid digestion	2,710	0	2,710	$0	$770,515	$770,515	$770,515
NT-5 Catalyzed wet oxidation	2,782	0	2,782	$0	$776,418	$776,418	$776,418