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Decision Document for Transuranic Tank Waste Disposal

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U.S. Department of Energy Contract DE-AC06-87RL10930

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Abstract: During the Tank Waste Remediation System systems requirements review, an issue was raised regarding the disposal of potentially transuranic tank waste. This report documents the decision analysis process to resolve this issue. A decision was made to blend the Hanford Site transuranic tank waste with high-level waste for disposal in an offsite repository. In the interim, the transuranic tank waste will remain stored consistent with the existing safety authorization basis and waste compatibility requirements. The transuranic tank waste will not be sent to the Waste Isolation Pilot Plant for disposal.

The decision is justified based on several decision criteria including cost, volume of waste produced, operability, safety, and technical maturity. There is no cost incentive to segregate transuranic tank waste for disposal at Waste Isolation Pilot Plant. The additional operating and capital costs required to immobilize segregated transuranic tank waste outweigh the savings gained in disposal cost.

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DECISION DOCUMENT FOR TRANSURANIC TANK WASTE DISPOSAL

July 1996

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U.S. Department of Energy
Richland, Washington

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DOE	U.S. Department of Energy
DST	Double-shell tank
HLW	High-level waste
IRT	Independent Review Team
LAW	Low-activity waste
OCRWM	Office of Civilian Radioactive Waste Management
PNNL	Pacific Northwest National Laboratory
RH	Remote handled
RL	U.S. Department of Energy-Richland Operations Office
SRR	Systems requirements review
SST	Single-shell tank
TRU	Transuranic
TWRS	Tank Waste Remediation System
WHC	Westinghouse Hanford Company
WIPP	Waste Isolation Pilot Plant

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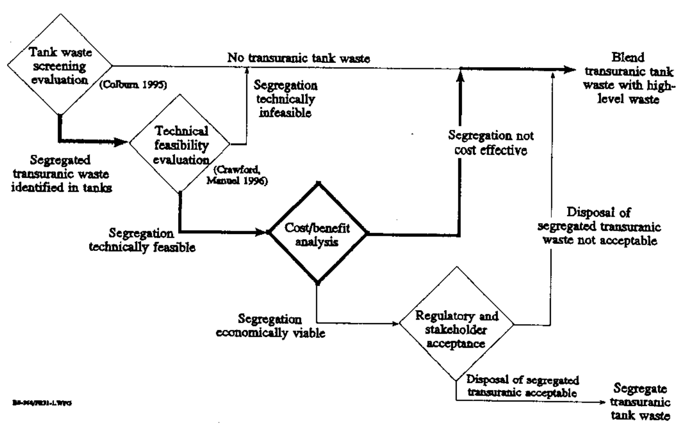
DECISION DOCUMENT FOR TRANSURANIC TANK WASTE DISPOSAL

1.0 INTRODUCTION

During the Tank Waste Remediation System (TWRS) systems requirements review (SRR) conducted during November 1994, an issue was raised regarding the disposal of potentially transuranic (TRU) tank waste. Westinghouse Hanford Company (WHC) prepared an action plan that identified a need to resolve this issue, recorded as *SRR Finding 2.2.4.5* (Bacon 1996). A decision memorandum addressing *SRR Finding 2.2.4.5* as *Program Issue #6* was issued by WHC and approved by the U.S. Department of Energy-Richland Operations Office (RL) (Kinzer 1995). The decision memorandum provided near term program guidance and maintained the potential TRU waste remain segregated from high-level waste (HLW) until disposal options are evaluated (e.g., technical feasibility, cost effectiveness, and regulatory acceptability).

Figure 1 shows the decision logic for disposal of TRU tank waste. Seven single-shell tanks (SSTs) and three double-shell tanks (DSTs) have been identified as potentially containing TRU waste, based on a conservative interpretation of the definitions of HLW and TRU wastes (Colburn 1995). The technical feasibility of immobilizing insoluble TRU tank waste in a HLW vitrification facility has been confirmed (Crawford and Manuel 1996). This report summarizes the TRU waste cost/benefit analysis.

Figure 1. Decision Logic for Disposal of Transuranic Tank Waste.



2.0 STATEMENT OF THE DECISION

The current TWRS program baseline (WHC 1995) assumes TRU tank waste will be blended with tank HLW, immobilized by vitrification, and disposed of in a geologic repository. Alternatively, it has been proposed that the TRU tank waste remain segregated and be disposed of as remote-handled transuranic (RH-TRU) waste in the WIPP if it is determined to be technically feasible, economically beneficial, and compliant with regulations governing WIPP and TRU wastes. This study evaluates the costs/benefits of these two alternatives to aid the U.S. Department of Energy in determining the disposition of TRU tank wastes.

This decision does not include final resolution of the following U.S. Department of Energy (DOE) policy issues:

1. Formal designation of TRU tank waste

2. WIPP acceptance of TRU tank waste or DOE Office of Civilian Radioactive Waste Management (OCRWM) acceptance of TRU tank waste blended with HLW.

3.0 DECISION MAKER

J. O. Honeyman is the responsible decision maker.

4.0 DECISION ACTION OFFICER

J. S. Garfield is the decision action officer.

5.0 ALTERNATIVE SELECTED

The Hanford Site TRU tank waste will be blended with HLW for treatment and disposal in an offsite geologic repository. In the interim, the TRU tank waste will remain stored consistent with the existing safety authorization basis and waste compatibility requirements. The immobilized TRU tank waste will not be sent to WIPP for disposal.

6.0 DATE OF SELECTION

This decision document satisfies RL milestone T36-96-116, "TRU Waste Disposal Options Cost-Benefit Analysis and Draft Recommendation". The milestone commitment consists of performing a "cost/benefit analysis for TRU waste segregation assessing the impact on retrieval, pretreatment and vitrification plant operation versus the alternative of blending with HLW for repository disposal" (WHC 1995). WHC requests RL concurrence on this decision by August 1, 1996. Concurrence is necessary by this date to incorporate this decision into the tank waste retrieval sequence document, which is a deliverable defined in the *Hanford Federal Facility Agreement and Consent Order* (referred to as the Tri-Party Agreement) (Ecology et al. 1994) as Milestone M-45-02A, "Initial Single-shell Tank Retrieval Sequence Document," due September 30, 1996.

7.0 ALTERNATIVES CONSIDERED

The Hanford Site TRU tank waste is currently segregated from the other tank HLW. Two alternatives exist for disposal of the Hanford Site TRU tank waste:

1. Blend the TRU waste with the tank HLW for disposal in an offsite repository.

2. Maintain TRU tank waste segregation, and dispose of TRU waste at WIPP.

Four case studies were chosen to evaluate the two alternatives. All four case studies are based on conditions assumed by the *TWRS Process Flowsheet* (Orme 1995), with the exceptions listed in Table 1. All cases assume minimized capital costs and, therefore, no excess processing capacity. Alternative 1 assumes the TRU waste and other tank HLW will be blended prior to immobilization. Case 1 represents Alternative 1 listed above and matches the *TWRS Process Flowsheet* (Orme 1995) conditions (i.e., uniform blending of all 177 tanks and Hanford Waste Vitrification Plant (HWVP) glass oxide limits in addition to a 10 MT/day vitrification capacity).

Table 1. Case Study Variables.

Case study variables	Case 1, *TWRS Process Flowsheet*, (Orme 1995)	Case 2a, Segregated TRU waste	Case 2b, Segregated TRU waste, crystalline TRU waste form	Case 2c, Segregated TRU waste, 10.7 MT/day melter
High-Level and TRU waste blending	Blend	Segregate	Segregate	Segregate
Melter size	10 MT/day	10 MT/day	10 MT/day	10.7 MT/day
TRU waste form	Non-crystalline glass	Non-crystalline glass	Crystalline	Non-crystalline glass

TRU = Transuranic
TWRS = Tank Waste Remediation System.

Alternative 2 assumes TRU waste segregation will be maintained during the pretreatment and immobilization processes. Cases 2a, 2b, and 2c are variations of Alternative 2 and segregate the TRU tank waste from the HLW. The segregated TRU waste inventory is comprised of approximately 7,600 m^3 sludge contained in seven SSTs: 241-T-201, 241-T-202, 241-T-203, 241-T-204, 241-T-110, 241-T-111, 241-T-112, and three DSTs: 241-SY-102, 241-AW-103, 241-AW-105 (Colburn 1995). The segregated TRU tank waste represents approximately 3 percent of the total liquid and sludge/solids inventory in the 177 SSTs and DSTs. Case 2a matches the *TWRS Process Flowsheet* (Orme 1995) with the exception of segregating the TRU tank waste from the HLW. Case 2b assumes the same conditions as Case 2a with the exception of waste oxide limits for a crystalline, non-homogeneous, TRU waste form. Case 2c assumes the same conditions as Case 2a but with increased vitrification and canister handling capacity to match the operating duration of Case 1.

Since WIPP does not require glass as a waste form, alternative waste forms were considered including grout and polyethylene (Boomer et al. 1993). It is estimated these alternative waste forms would produce from two to five times more waste volume than borosilicate glass. In addition to increased volume, a separate facility with adequate radiation shielding would need to be constructed for the alternative immobilization process. A new facility would increase the capital cost of treating segregated TRU tank waste. A facility is already planned to produce HLW glass. Construction of a new facility to produce an alternative waste form for segregated TRU waste would not be economically justified. Therefore, TRU waste forms other than glass or glass-like material were excluded from further consideration in this analysis.

8.0 DECISION CRITERIA

The four cases are evaluated based on the following decision criteria:

1. Life-cycle cost (including disposal costs)
2. Life-cycle cost (excluding disposal costs)
3. Process duration (years)
4. Volume of immobilized HLW produced
5. Volume of immobilized TRU waste produced
6. Volume and radioactivity of immobilized low-activity waste (LAW) left onsite
7. Operability (a measure of the difficulties encountered while conducting treatment facility operations)
8. Safety
9. Technical Maturity (a measure of the development required to implement the technologies necessary to accomplish each alternative).

The first six decision criteria (1 through 6) are based on the values of governments and constituencies with a stake in the future of the Hanford Site (PNNL 1996). The last three decision criteria (7 through 9) are selected specifically to facilitate the TRU waste segregation decision analysis. The decision criteria 7 through 9 reflect concerns designers and facility operators would have with regard to selecting technologies and processes to treat the TRU wastes.

9.0 RATIONALE FOR THE SELECTION

Blending TRU tank waste with HLW for disposal in an offsite repository is justified based on several decision criteria including cost, volume of waste produced, operability, safety, and technical maturity. An evaluation summary shown in Table 2 indicates there is no cost incentive to segregate TRU tank waste for disposal at WIPP. A summary of the significant differences among the cases (Table 3) shows the operating cost and capital cost of producing segregated TRU waste outweigh the potential savings gained in disposal cost.

In general, blending of TRU waste with HLW produces less waste volume and fewer canisters of glass. Fewer canisters decrease the safety risk during transportation to offsite repositories. Blending of the two waste types would also decrease the operations complexity for retrieval, pretreatment, and immobilization. Blending of TRU and HLW tank waste could use mature technologies. The only situation where a minor cost savings could be found (Case 2b), requires technology development to produce a crystalline form which would offset at least a portion of the potential savings. Several sources of uncertainty and programmatic risks also support the decision as shown in Sections 9.2 and 9.3.

Table 2. Case Study Evaluation Summary. (2 sheets)

Decision criteria	Blended HLW and TRU Waste	Segregated TRU Waste		
	Case 1, TWRS Process Flowsheet (Orme 1995)	Case 2a, TWRS Process Flowsheet (Orme 1995) Conditions	Case 2b, Crystalline TRU waste form	Case 2c, 10.7 MT/day melter
Cost (Millions of 1995 dollars)				
Labor[a]	790	932	829	870
Consumables[a]	365	389	363	389
Canisters[a]	71	79	73	79
DST retrieval operations[a]	864	1,008	912	864
Startup training[a]	180	180	180	198
Decontamination and decommissioning[a]	742	743	743	791
Total expense cost[a,c]	**3,012**	**3,331**	**3,100**	**3,190**
Facility capital cost[a]	1,873	1,875	1,875	1,975
Replacement melters[a]	195	234	195	195
Interim storage[a]	636	530	530	530
Total capital cost[a,c]	**2,705**	**2,640**	**2,600**	**2,700**
Life-cycle cost excluding disposal cost[a,b,c]	**5,717 uncertainty range: 5,500 - 6,600**	**5,970 uncertainty range: 5,800 - 6,900**	**5,699 uncertainty range: 5,600 - 6,700**	**5,891 uncertainty range: 5,800 - 6,900**
Repository disposal cost[a]	2,788	2,565	2,565	2,565
WIPP disposal cost[a]	N/A	55	28	55
Total disposal cost[a]	**2,788**	**2,620**	**2,593**	**2,620**
Life-cycle cost including disposal cost[a,b,c]	**8,505 uncertainty range: 8,300 - 9,900**	**8,591 uncertainty range: 8,500 - 10,100**	**8,292 uncertainty range: 8,200 - 9,800**	**8,511 uncertainty range: 8,500 - 10,200**
Immobilized Waste Volume				
HLW (m^3)[a]	8,970	8,250	8,250	8,250
TRU waste (m^3)[a]	0	1,310	660	1,310
TRU+HLW (m^3)[a]	8,970	9,560	8,910	9,560
HLW canisters (1.26 m^3)[a,d]	7,120	6,550	6,550	6,550
TRU waste canisters (0.71 m^3)[a,e]	0	1,850	925	1,850
TRU+HLW canisters[a,d,e]	7,120	8,400	7,475	8,400
Low-activity waste (m^3)	Same for all cases, not a discriminator.			

Table 2. Case Study Evaluation Summary. (2 sheets)

Decision criteria	Blended HLW and TRU Waste	Segregated TRU Waste		
	Case 1, TWRS Process Flowsheet (Orme 1995)	Case 2a, TWRS Process Flowsheet (Orme 1995) Conditions	Case 2b, Crystalline TRU waste form	Case 2c, 10.7 MT/day melter
Process Duration				
Process duration (years)[a,b]	13 uncertainty range: 11.5 - 18	16 uncertainty range: 14.5 - 21	14 uncertainty range: 13 - 19	13 uncertainty range: 12 - 18
Tri-Party Agreement schedule impacts	Allows deferral of HLW processing for early SST closure[h]	WIPP closure drives HLW processing to compete with SST closure and precludes sequential processing alternatives for LAW and HLW.[f,h]		
	90 percent probability of meeting Tri-Party Agreement completion date[g]	75 percent probability of meeting Tri-Party Agreement completion date[g]	80 percent probability of meeting Tri-Party Agreement completion date[g]	90 percent probability of meeting Tri-Party Agreement completion date[g]
Other Decision Criteria				
Operability		Segregating the TRU waste from the HLW would increase operations complexity for retrieval, pretreatment, and vitrification.		
Safety		Increased safety risks due to increased number of canisters and offsite shipments.		
Technical maturity	Uses proven technology	Uses proven technology	Requires melter and glass form development which is not included in the life-cycle cost estimate.	Uses proven technology

HLW = High-level waste
RH = Remote handled
SST = Single-shell tank
TRU = Transuranic
WIPP = Waste Isolation Pilot Plant

[a]Single values reported for cost, volume, and duration represent "base case" values calculated by the INSIGHT Model. Algorithms and references for each input value are reported in Crawford and McConville 1996, Appendix A. Due to rounding, totals may not equal sum of numbers shown.

[b]Uncertainty ranges reported for life-cycle cost and duration represent cumulative probabilities of 20 percent and 80 percent (Crawford and McConville 1996, Appendix A).

[c]Cost values represent HLW and TRU waste processing only. The total life-cycle cost does not include SST retrieval, pretreatment, or low-activity waste processing.

[d]HLW canister being evaluated for acceptance by DOE-OCRWM.

[e]RH-TRU waste canister currently accepted by DOE-WIPP.

[f]TRU tank waste must be immobilized by 2021 to meet the RH-TRU waste emplacement window at WIPP.

[g]Assuming the HLW/TRU waste process begins in 2009, the process duration must be 19 years or less to meet the Tri-Party Agreement mandated HLW/TRU waste immobilization completion date of 2028 (Milestone M-51-00).

[h]SST closure to be completed by September 2024 (Tri-Party Agreement Milestone M-45-00).

Table 3. Transuranic Waste Segregation Savings and Additions Compared to Blending. Reference Case: *TWRS Process Flowsheet* (Orme 1995) Case 1

	Case 2a, *TWRS Process Flowsheet* (Orme 1995) Conditions		Case 2b, Crystalline TRU waste form		Case 2c, 10.7 MT/day melter	
	Savings	Additions	Savings	Additions	savings	additions
Cost (Millions of 1995 dollars)						
Labor		+142		+39		+80
Consumables		+24	-2			+24
Canisters		+8		+2		+8
DST retrieval operations		+144		+48		0
Startup training	0	0	0	0		+18
Decontamination and decommissioning		+1		+1		+49
Total expense cost		+319		+88		+178
Facility capital cost		+2		+2		+102
Replacement melters		+39	0	0	0	0
Interim storage	-106		-106		-106	
Total capital cost	-65		-105		-5	
Life-cycle cost excluding disposal cost		+253	-18			+174
Repository disposal cost	-223		-223		-223	
WIPP disposal cost		+55		+28		+55
Total disposal cost	-168		-195		-168	
Life-cycle cost including disposal cost		+86	-213			+7
Immobilized Waste Volume						
TRU+HLW (m^3)		+590	-60			+590
TRU+HLW canisters		+1,280		+355		+1,280
Low-activity waste (m^3)	0	0	0	0	0	0
Process Duration						
Process duration (years)		+3		+1	0	0

DST = Double-shell tank
HLW = High-level waste
TRU = Transuranic
TWRS = Tank Waste Remediation System

Note: The values shown were determined by subtracting the Case 1 values in Table 2 from the Case 2 values in Table 2. The shaded values identify significant savings or additions.

9.1 ANALYSIS OF ALTERNATIVES

The INSIGHT Model is used with a decision analysis software, Supertree[1] (McConville and Johnson 1995), to perform deterministic and probabilistic evaluations for the first five decision criteria listed in Section 8.0: (1) total life-cycle cost, (2) life-cycle cost excluding disposal costs, (3) process duration, (4) volume of immobilized HLW produced, and (5) volume of immobilized TRU waste produced. Appendix A describes the input variables and algorithms constructed to calculate values for each of these five decision criteria. The sixth criterion, volume of immobilized LAW produced, is determined to be the same for all cases and is not included in the deterministic and probabilistic evaluations. The last three decision criteria (operability, safety, technical maturity) are evaluated qualitatively. Table 2 summarizes the case study evaluation results for each of the decision criteria. Table 3 summarizes the cost, volume, and duration differences among the cases. The details of the deterministic and probabilistic evaluations are provided in Appendix A.

The INSIGHT Model, coupled with decision analysis software, evaluates the decision criteria in two steps: (1) deterministic sensitivity analysis, and (2) probabilistic analysis. More than 100 variables are assessed in each sensitivity analysis, with each variable input as a range of high, mid, and low values. (The applicable variables for this study are defined in Section A3.0 of Appendix A). The deterministic sensitivity analysis identifies which input variables have the most significant effect on the decision criterion being evaluated (e.g., life-cycle cost, HLW volume, process duration). These significant variables provide the frame for the subsequent probabilistic analysis. Probabilities of 25 percent, 50 percent, and 25 percent are assigned to the high, mid, and low values of the top five significantvariables identified in each sensitivity analysis. The decision criterion is calculated for all possible combinations of the framing variables based on their ranges and assigned probabilities. The result is a cumulative probability distribution over the full range of the decision criterion.

The point values reported in Table 2 for cost, volume, and duration were determined by the INSIGHT Model with all input variables set to their "base case" value (e.g., mid-range value). The range of life-cycle cost and process duration values reported in Table 2 were determined from cumulative probability distribution charts, with the low value representing a 20 percent probability and the high value representing an 80 percent probability (see Appendix A, Section A5.0). Table 3 subtracts the Case 1 values in Table 2 from the Case 2 values in Table 2 to show the savings (-) and additions (+) required to segregate the TRU tank waste.

Segregation of TRU waste increases the total non-crystalline glass volume produced by approximately 600 m^3 as shown by Cases 2a and 2c. The segregated TRU waste has a high zirconium concentration and the immobilized TRU waste volume is therefore sensitive to the achievable zirconium oxide concentration in non-crystalline glass. Case 2b produces a

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[1]Supertree is a registered trademark of Strategic Decisions Group.

crystalline TRU waste form with a higher zirconium oxide concentration limit that reduces the immobilized TRU waste volume.

Variations in life-cycle cost including disposal cost among the four case studies are negligible. In addition, variations in life-cycle cost excluding life-cycle cost are very small and well within the range of uncertainty. Comparison of the evaluation results for the two decision criteria (i.e., life-cycle cost including disposal cost and life-cycle cost excluding disposal cost) shows that uncertainties associated with disposal costs cause the variations among the cases to become less distinctive. Although Case 2b shows a potential of saving a few hundred million dollars, the incremental cost of developing, constructing, and operating a steep-sloped bottom-pour melter required to produce the crystalline waste form is not included in the estimate and would be expected to offset a portion of the potential savings. See Appendix B for a more detailed life-cycle cost summary.

Cases 1 and 2c have the greatest probability of meeting the Tri-Party Agreement completion date for HLW/TRU waste immobilization. Assuming the HLW/TRU waste process begins in 2009, the process duration must be 19 years or less to meet the Tri-Party Agreement mandated completion date of 2028. The cumulative probability of meeting the completion date is approximately 90 percent for Cases 1 and 2c, 80 percent for Case 2b, and 75 percent for Case 2a.

9.2 SOURCES OF UNCERTAINTY

There are seven major sources of uncertainty that impact cost, volume, and duration: (1) tank waste inventory, (2) heel remaining in tanks, (3) blending factor, (4) pretreatment efficiencies, (5) oxide limits in immobilized waste form, (6) regulatory acceptance, and (7) complexity of interfaces. Table 4 summarizes the uncertainties favoring blending the TRU waste with HLW or segregating TRU waste.

Table 4. Sources of Uncertainty.

Uncertainties	Favors blending transuranic waste with high-level waste	Favors segregation of transuranic waste
1. Tank waste inventory	X	
2. Heel remaining in tanks	X	
3. Blending factor		X
4. Pretreatment efficiencies	X	
5. Oxide limits in immobilized waste form	X	
6. Regulatory acceptance	X	
7. Complexity of interfaces	X	

1. **Tank Waste Inventory**. An important uncertainty factor in making this decision is the proposed revision in the Hanford Site tank composition inventories. (Draft C of the *Best-Basis Inventories of Chemicals and Radionuclides in Hanford Site Tank Waste* [Kupfer et al., 1996] documents the "Best-Basis" inventories to date). The provisional "Best-Basis" inventories substantially changes the estimated inventories for several key components that affect waste loading in a HLW glass. For the provisional "Best-Basis" inventory, the chromium inventory increases by more than a factor of two making it the probable limiting glass component. Waste in the TRU tanks collectively have a low concentration of chromium. Due to the low chromium concentration, segregating TRU tank waste from HLW may not decrease the volume of HLW. The net result would be the same cost for immobilization and disposal of HLW plus the additional cost of immobilization and disposal of segregated TRU waste.

2. **Heel Remaining in Tanks**. The *TWRS Process Flowsheet* (Orme 1995) assumes that 100 percent of the waste in the tanks would be retrieved. Given the refractory nature of some of material in the tank, it is not clear that this will be achieved. If it is not, then the calculated amount of HLW and TRU waste will be overestimated. The INSIGHT model takes this uncertainty into account by using ranges of retrieval efficiencies for both SSTs and DSTs. Decreased retrieval efficiency lowers the volumes of HLW and TRU waste produced. A smaller HLW volume increases the impact of TRU tank waste processing, thereby making segregation of TRU tank waste less attractive.

3. **Blending Factor.** The INSIGHT Model cost, volume, and duration calculations assume that all tank waste is perfectly blended. In practice, it is unlikely that perfect blending of the insoluble HLW would be achieved. A blending factor of 1.2 applied to HLW only, is suggested as a reasonable upper bound by an independent review team which was assembled by DOE to estimate a range of HLW glass volume for the TWRS EIS (Taylor and Lang 1996). A blending factor is not required for the segregated TRU waste. Blending the TRU waste is not perceived as a problem since the TRU waste volume is small (approximately 7,600 m^3). A blending factor of 1.2 applied to HLW would increase the HLW glass volume, processing duration, operating cost, and disposal cost by about 20 percent. In general, increasing the volume of HLW decreases the impact of processing segregated TRU tank waste, thereby making segregation of TRU tank waste more attractive.

4. **Pretreatment Efficiencies.** Pretreatment of tank sludge will be performed to remove selected materials and reduce the volume of product HLW glass. The *TWRS Process Flowsheet* (Orme 1995) is based on a water wash to remove soluble species, followed by caustic leaching of the insoluble species. The separation efficiencies assumed in the flowsheet reflect the best judgement based on available experimental work. However, all tank waste groups have not been

sampled and analyzed. Thus, the pretreatment efficiencies constitute a potentially significant source of uncertainty. Uncertainty in separation efficiencies have been incorporated into the probabilistic assessment of the HLW and TRU waste volume.

5. **Oxide Limits in Immobilized Waste Form.** The *TWRS Process Flowsheet* (Orme 1995) assumes a set of waste oxide loading limits based on the HWVP glass composition. Two factors have changed since the design of HWVP that add uncertainty to these waste oxide limits and their impact on the volume of HLW. The two factors are the inclusion of SSTs in the feed inventory and advances in glass formulations. The INSIGHT model takes the oxide limit uncertainty into account by using ranges of limits for each critical oxide component. For the limiting waste oxide component, sodium, an increased waste oxide limit from 12.5 wt% to 20 wt% decreases the volume of HLW produced by 1,300 to 1,600 m^3. A smaller HLW volume increases the impact of TRU tank waste processing, thereby making segregation of TRU tank waste less attractive.

6. **Regulatory Acceptance.** Acceptability of a unique waste form (i.e., Hanford TRU tank waste) by WIPP and the state of New Mexico is uncertain. In addition, it is uncertain whether WIPP could receive RH-TRU tank waste and remain within the legal waste volume limit. WIPP has the capacity to accept a total RH-TRU waste volume of 7,080 m^3, according to the *Agreement for Consultation and Cooperation Between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant* (DOE and the State of New Mexico 1981). Other DOE sites have estimated a total inventory of approximately 5,000 m^3 for shipment to WIPP (DOE 1995). The Hanford Site has estimated an inventory of approximately 3,000 m^3, excluding TRU tank waste (Kosiancic 1996). The total projected inventories from the Hanford Site and other DOE sites exceed WIPP's legally mandated capacity.

7. **Complexity of Interfaces.** Blending the TRU waste with HLW would require interfacing with only one repository. Segregating the TRU tank waste for disposal at WIPP would require interfacing with two separate repositories for certification and disposal of tank waste. The additional repository interface would increase the complexity of meeting applicable customer requirements, transportation arrangements, documentation, etc.

9.3 PROGRAMMATIC RISKS AND BENEFITS

The major programmatic benefits and risks associated with the two TRU waste disposal alternatives are summarized in Table 5.

Table 5. Programmatic Benefits and Risks.

	Benefit	Risk
Blending TRU waste with HLW	Less total volume of immobilized waste. Blending the TRU waste with HLW for disposal results in a smaller total volume than segregating the two waste types.	DOE Order Interpretation. There is a risk that a DOE interpretation of DOE Order 5820.2a would not allow mixing of TRU tank waste with HLW for disposition at the geologic repository. A strict interpretation could require TRU waste to be stored and treated as a segregated waste stream and disposed of at WIPP. This risk is small since a precedent has been set at Savannah River Site for blending these waste types in underground storage tanks.
	Less Complexity. Blending the TRU waste with HLW for disposal is simpler than segregating and sending to separate disposal facilities.	
Segregating TRU waste	Less Waste Stored Onsite if WIPP Opens and Geologic Repository Does Not Open. If WIPP opens and accepts Hanford's immobilized TRU tank waste, and if the federal geologic repository is delayed or does not open, about 720 m^3 (approximately 8 percent) less waste would be stored onsite. However, the TRU tank waste to be sent to WIPP contains less than one percent of the total curies from TRU radionuclides in the tank waste.	WIPP May Not Have Sufficient Capacity for RH-TRU waste. It is uncertain whether WIPP could receive RH-TRU tank waste and remain within the legal waste volume limit. WIPP has the capacity to accept a total RH-TRU waste volume of 7,080 m^3, according to the *Agreement for Consultation and Cooperation Between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant* (DOE and the State of New Mexico 1981). Other DOE sites have estimated a total inventory of approximately 5,000 m^3 for shipment to WIPP (DOE 1995). The Hanford Site has estimated an inventory of approximately 3,000 m^3, excluding TRU tank waste (Kosiancic 1996). The total projected inventories from the Hanford Site and other DOE sites exceed WIPP's capacity.
		Increased Cost If WIPP Does Not Open Or Rejects RH-TRU Tank Waste. If segregated TRU waste is immobilized, and if WIPP does not open or cannot accept Hanford TRU tank waste, then: (a) another interim storage facility would be required at a capital cost of about $100 million, (b) annual interim storage operating costs would increase by about 20 percent, and (c) disposal costs at the geologic repository would increase by an additional $500 million.
		Schedule Slippage. Completion of retrieval and immobilization of TRU tank waste within the WIPP waste emplacement window may not occur due to schedule interferences. This study assumes there is no impact on vitrification operations to immobilize TRU waste by 2021 to meet the RH-TRU waste emplacement window at WIPP. Also assumed is that there is no impact on retrieval to retrieve 10 TRU tanks before 2019.
		Increased Retrieval Complexity. Retrieval complexity may increase to maintain a segregated TRU waste stream. The TRU waste cannot be commingled with HLW and still retain TRU classification. Retrieval and transfer of TRU waste tanks may need to occur first in the schedule to prevent cross contamination with HLW.

DOE = U.S. Department of Energy
HLW = High-level waste
RH = Remote handled
TRU = Transuranic
WIPP = Waste Isolation Pilot Plant

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10.0 ASSUMPTIONS

The key assumptions related to the disposal of TRU tank waste are discussed below:

Meeting RH-TRU Waste Criteria. It is assumed that vitrified tank waste would meet WIPP's waste acceptance criteria with respect to waste form and other criteria. The TRU waste does meet the criteria of being greater than 100 nCi per gram of transuranic radionuclides. Also, it meets the radiation dose rate criteria to be remote handled waste instead of contact handled waste (Crawford and Manuel 1996).

Classification of TRU Waste Tanks. The ability to treat segregated TRU tank waste assumes DOE classifies the waste in at least the 10 underground storage tanks identified as TRU waste (Colburn 1995).

Negligible Impact On Current TWRS Operations. It is assumed there is a negligible impact on current TWRS operations to maintain segregated TRU insoluble waste stream. Based on this assumption it is permissible to transfer and store non-complexed supernatant waste on top of TRU sludge which mitigates most waste volume management and waste compatibility issues. This assumption defines the lower bound cost of TWRS Operations before retrieval. Any deviations from this assumption necessary to maintain TRU waste segregated will only increase TWRS Operations complexity and cost.

No Impact On Waste Retrieval Project. For this analysis it is assumed there is no impact on the Waste Retrieval Project resulting from segregating TRU waste. Although it is clear this is an oversimplification, conclusions can be drawn from the analysis without quantifying retrieval impacts (see Section 6.5.1.2.4). This assumption defines the lower bound cost of the Waste Retrieval Project. Any deviations from this assumption necessary to retrieve TRU waste while maintaining segregation will only increase retrieval complexity and cost. Qualitatively, retrieval of segregated TRU waste would cause some impact on retrieval complexity and cost due to segregation requirements, early scheduling needs of TRU waste, and retrieval inefficiencies.

No Physical Impacts On Blending. It is assumed segregation of TRU waste will not require additional equipment for blending. However, TRU segregation does impact blended waste compositions and glass compositions resulting in increased glass volume.

No Impacts On Pretreatment Of HLW/TRU Sludge. The pretreatment of HLW/TRU sludge is not expected to be impacted by the segregation of TRU waste. In general, the sludge washing process is independent of tank blending or segregation.

No Impacts On LAW Treatment. This analysis assumes there is no impact on LAW treatment since there is a negligible difference in LAW volume and composition if TRU waste is segregated.

HLW And TRU Waste Vitrified In Same Facility. It is assumed that HLW and TRU waste can be vitrified in the same facility with only minor modifications (Crawford and Manuel 1996). The two waste types would be processed in campaigns to minimize cross contamination. The optimal case would be to process the TRU waste first to prevent contaminating the TRU waste with HLW.

Negligible Cost Difference To Meet Disposal Criteria. This analysis assumes there is a negligible cost difference to meet waste acceptance requirements for WIPP (WIPP-WAC) and the geologic repository. Although an additional set of documentation would be required for TRU waste bound for WIPP, this type of documentation is not unique to the Hanford site

Immobilization of TRU Waste in HLW Facility. It is assumed that immobilization of TRU waste in the planned HLW vitrification facility would be more cost effective than to perform the immobilization process in a facility designed, built, and operated exclusively for TRU wastes. This assumption is based upon a sunk capital cost including infrastructure and the experience base of borosilicate glass as an acceptable waste form.

Schedule Impact To Meet RH-TRU Waste Emplacement Window At WIPP. This study assumes there is no impact on vitrification operations to immobilize TRU waste by 2021 to meet the RH-TRU waste emplacement window at WIPP. It is assumed that there is no impact associated with retrieval of 10 TRU tanks before 2019.

No Additional Interim Storage For RH-TRU Glass Canisters. Interim storage for RH-TRU glass canisters is not explicitly included in the interim storage cost. TRU waste is assumed to be shipped within one year of its immobilization and therefore does not require dedicated interim storage.

No Additional Cost to Produce Crystalline TRU Waste Form (Case 2b). It is assumed that to produce a TRU crystalline waste form there is no additional development, operation, or capital costs associated with using a steep sloped wall, bottom pour melter necessary to remove the two-phase glass. Although this assumption is not very likely, it does define the lower bounds of the immobilization facility expense and capital costs. Any deviations from this assumption necessary to immobilize segregated TRU waste as a crystalline waste form will only increase the complexity and costs associated with that option.

No Excess Processing Capacity. All cases assume no excess processing capacity to minimize capital costs.

11.0 DECISION ACCEPTANCE

The Hanford Site TRU tank waste will be blended with HLW for disposal in an offsite geologic repository. In the interim, the TRU tank waste will remain stored consistent with the existing safety authorization basis and waste compatibility requirements. The TRU tank waste will not be sent to WIPP for disposal.

The decision is justified based on several decision criteria including cost, volume of waste produced, operability, safety, and technical maturity. There is no cost incentive to segregate TRU tank waste for disposal at WIPP. The additional operating and capital costs required to retrieve, treat, and immobilize segregated TRU tank waste outweigh the savings gained in disposal cost.

Responsible Decision Maker: [signature] J. O. Honeyman — Date: 4/22/96

DOE Concurrence: W. J. Taylor — Date:

Decision Action Officer: [signature] J. S. Garfield — Date: 4-19-96

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APPENDIX A

CASE STUDY EVALUATION

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APPENDIX A

CASE STUDY EVALUATION

This appendix describes how each of the four cases were evaluated against five of the nine decision criteria listed in Section 8.0: (1) total life-cycle cost, (2) life-cycle cost excluding disposal costs, (3) process duration, (4) volume of immobilized HLW produced, and (5) volume of immobilized TRU waste produced. The INSIGHT Model was used with a decision analysis software, Supertree (McConville and Johnson 1995), to perform deterministic and probabilistic evaluations.

The INSIGHT Model case study definitions are discussed in Section A1.0. The algorithms for calculating life-cycle cost, process duration, and immobilized waste volume for the HLW/TRU waste treatment process are presented in Section A2.0. The INSIGHT Model input variables are listed in Section A3.0. The methods for evaluation (i.e., deterministic sensitivity analysis and probabilistic analysis) are described in Section A4.0. The deterministic and probabilistic results of the four case study evaluations are presented in Section A5.0.

A1.0 CASE STUDY DEFINITION

The user of the INSIGHT Model chooses among options for tank waste inventory, retrieval system, pretreatment process, pretreatment facility, HLW/TRU waste treatment process, HLW/TRU waste form, container size, and LAW form to define the waste treatment strategy to be analyzed. Table A-1 lists the user specified parameters that are common to each of the four cases evaluated. Table A-2 lists the user specified parameters that vary among the four cases.

Table A-1. INSIGHT Model Case Study Fixed Parameters.

User Specified Parameters	Cases 1, 2a, 2b, and 2c Fixed Parameters
Tank Waste Inventory	Inventory specified in *TWRS Process Flowsheet,* (Orme 1995)
Primary SST Retrieval System	30 Sluicers
Secondary SST Retrieval System	2 Mechanical Arms
DST Retrieval System	2 Mixer Pumps per DST
Pretreatment Process	Enhanced Sludge Wash, Cesium Ion Exchange, Selective Strontium TRU Element Precipitation
Pretreatment Facility	New Enhanced Sludge Wash Pretreatment Facility
HLW Form	Low-Temperature/Non-Crystalline Glass
TRU Waste Container volume	0.71 m^3
HLW Container volume	1.26 m^3
LAW Form	Glass-in-Sulfur

DST = Double-shell tank
HLW = High-level waste
LAW = Low-activity waste
SST = Single-shell tank
TRU = Transuranic
TWRS = Tank Waste Remediation System.

Table A-2. INSIGHT Model Case Study Variable Parameters.

User specified parameters	Case 1, *TWRS Process Flowsheet* (Orme 1995)	Case 2a, Segregated TRU Waste	Case 2b, Segregated TRU Waste, Crystalline Transuranic Waste Form	Case 2c, Segregated TRU Waste, 10.7 MT/day Melter
High-Level and TRU Waste Blending	Blend	Segregate	Segregate	Segregate
Melter Size	10 MT/day	10 MT/day	10 MT/day	10.7 MT/day
TRU Waste Form	Non-Crystalline Glass	Non-Crystalline Glass	Crystalline	Non-Crystalline Glass

TRU = Transuranic
TWRS = Tank Waste Remediation System.

A2.0 INSIGHT MODEL ALGORITHMS

This section discusses the input variable relationships for calculating life-cycle cost, process duration, and immobilized waste volume for the HLW/TRU waste treatment process. Some of the original INSIGHT Model algorithms required modification to support the segregation of TRU waste from HLW. The algorithms relevant to the HLW/TRU waste treatment process are listed below, with the modified algorithms marked with an asterisk. The remaining algorithms can be found in *Decision Analysis Model for Assessment of Tank Waste Remediation System Waste Treatment Strategies* (McConville and Johnson 1995).

The INSIGHT Model cost and volume algorithms have been verified via independent calculations. The volume algorithms for Case 1 were verified by comparing the immobilized HLW and TRU waste volumes with volumes reported in the *TWRS Process Flowsheet* (Orme 1995). The HLW and TRU waste volume algorithms for Case 2a were verified against a modified version of the *TWRS Process Flowsheet* (Orme 1995) that segregated the TRU waste from the HLW (Crawford and Manuel 1996). Cases 2b and 2c used the same HLW and TRU waste volume algorithms as Case 2a, but different input variables (see Table A-2).

A2.1 Life-Cycle Cost Algorithms

The life-cycle cost calculated for this study does not represent the complete TWRS program costs. The calculated life-cycle cost includes only the HLW/TRU waste disposal elements of the TWRS Program. Costs for SST retrieval, pretreatment, and LAW processing remain the same for all four cases and, therefore, are not included in the life-cycle cost evaluation. The HLW/TRU waste life-cycle cost is a total of the HLW/TRU waste expense, capital, and disposal costs.

The HLW/TRU waste total expense cost includes costs for labor, startup training, consumables, DST retrieval operations, canisters, and facility D&D, as shown in Table A-3. Case 2c assumes a slightly larger melter than the other cases and therefore requires a greater labor operating cost than Cases 1, 2a, and 2b (see Section A3.0, Table A-8). The DST retrieval duration also affects the HLW/TRU waste total expense cost. DST retrieval begins once SST retrieval commences and ends when immobilization of the HLW and TRU waste is complete. The consumable cost is based on metric tons of immobilized HLW and TRU waste produced. The same consumable cost per metric ton is used for all four cases.

The HLW and TRU waste canisters differ in volume and cost. The HLW canister holds approximately 1.26 m^3 of immobilized waste and costs approximately $10,000 (1995 dollars) per canister (Crawford 1995). The WIPP requires the TRU waste to be packaged in a smaller canister that is estimated to hold 0.71 m^3 of immobilized waste (Crawford and Manuel 1996) and costs approximately $7,000 (1995 dollars) per canister.

Table A-3. High-Level Waste/Transuranic Waste Expense Cost Algorithms.

Calculated Parameter	Algorithm
*Expense Cost	labor cost + startup training cost + consumables + HLW container cost + TRU waste container cost + DST retrieval operating cost + HLW/TRU waste facility D&D
Labor cost	(HLW/TRU waste process duration) x (HLW/TRU waste facility labor cost per year)
Startup training cost	3 years x HLW/TRU waste labor cost per year
*Consumables cost	(consumables cost per MT glass produced) x (MT HLW glass + MT TRU waste glass)
HLW container cost	(cost per 1.26 m^3 container) x (number of 1.26 m^3 containers produced)
*TRU waste container cost	(cost per 0.71 m^3 container) x (number of 0.71 m^3 containers produced)
DST retrieval operating cost	(DST retrieval operating cost per year) x (HLW completion date - SST retrieval start date)
HLW/TRU waste facility D&D cost	(0.3) x (HLW/TRU waste facility construction cost) + (3 years) x (HLW/TRU waste facility labor cost per year)

*Indicates a modification of algorithms reported in *Decision Analysis Model for Assessment of Tank Waste Remediation System Waste Treatment Strategies*, (McConville and Johnson 1995)

D&D = Decontamination and Decommissioning
DST = Double-shell tank
HLW = High-level waste
TRU = Transuranic.

The HLW/TRU waste total capital cost includes costs for construction of the process facility, construction of interim storage buildings, and melter replacements, as shown in Table A-4. The number of interim storage buildings required are based on a building capacity of 1,330 containers with a volume of 1.26 m^3. The interim storage building costs apply to the HLW only. The TRU waste segregation cases assume the TRU waste is processed before the HLW, and shipped within one year of its immobilization. Before shipment, the TRU waste containers would be stored in the HLW interim storage buildings. The total melter replacement cost is based on the melter life and the required process duration excluding down time for replacement. The melter life is assumed to be two years with a five month replacement period, based on HWVP and Defense Waste Processing Facility assumptions (WHC 1992 and WSRC 1995).

Table A-4. High-Level Waste/Transuranic Waste Capital Cost Algorithms.

Calculated parameter	Algorithm
*Capital cost	HLW/TRU waste facility construction cost + interim storage + melter replacement cost
Interim storage building construction cost	[Round up to nearest whole number: (number of HLW containers produced)/(number of HLW containers per interim storage building)] x (Construction cost per interim storage building)
*Melter replacement cost	[Round to nearest whole number: (HLW/TRU waste process duration excluding melter replacements)/(melter life)] x (cost per melter replacement)

*Indicates modification of algorithms reported in *Decision Analysis Model for Assessment of Tank Waste Remediation System Waste Treatment Strategies* (McConville and Johnson 1995).

HLW = High-level waste
TRU = Transuranic.

The HLW and TRU waste disposal costs are based on the number of canisters produced, as shown in Table A-5. The HLW disposal cost is estimated at $356,000 per 0.62 m^3 canister (1995 dollars) by the DOE OCRWM (DOE-RW 1995). This study assumes a HLW container volume of 1.26 m^3 (Crawford 1995). Based on previous HLW disposal cost estimates by DOE (DOE-RW 1993), this study assumes the disposal cost for 1.26-m^3 canisters is 10 percent greater than the 0.62-m^3 canister disposal cost.

Table A-5. High-Level Waste/Transuranic Waste Disposal Cost Algorithms.

Calculated parameter	Algorithm
High-level waste disposal cost	(disposal cost per 1.26-m^3 high-level waste canister) x (number of 1.26-m^3 containers produced)
*Transuranic waste disposal cost	(disposal cost per 0.71-m^3 container) x (number of 0.71-m^3 containers produced)

*Indicates modification of algorithms reported in *Decision Analysis Model for Assessment of Tank Waste Remediation System Waste Treatment Strategies* (McConville and Johnson 1995).

A2.2 Process Duration Algorithms

The HLW/TRU waste immobilization process may not begin before pretreatment begins and the facility operates until all wastes have been treated. The HLW process startup date is calculated as the maximum of the HLW availability date or the pretreatment startup date. The HLW/TRU waste process facility availability date reflects the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1994) date of December 2009 (Tri-Party Agreement Milestone M-51-03) for startup of HLW/TRU waste hot operations.

The HLW/TRU waste process duration is derived from the total mass throughput, total operating efficiency, duration required for melter replacement, and the quantity of waste treated, as shown below in Table A-6. The parameter "percent operating time" represents the percentage of the process duration when the melter is actually in operation.

Table A-6. High-Level Waste/Transuranic Process Duration Algorithms.

Calculated parameter	Equation
HLW/TRU waste process startup date	Maximum of HLW/TRU waste vitrification facility availability date or Pretreatment startup date
*percent operating time	melter life/(melter life + melter replacement duration)
*HLW/TRU waste process duration	Cases 1, 2a, 2b (quantity of HLW containers + quantity of TRU waste containers)/[(% operating time)x(total operating efficiency)x(container per year facility throughput)]
	Case 2c (mass of HLW glass + mass of TRU waste glass)/[(% operating time)x(total operating efficiency)x(mass per year melter throughput)]
HLW/TRU waste process completion date	HLW/TRU waste process startup date + HLW/TRU waste duration

*Indicates modification of algorithms reported in *Decision Analysis Model for Assessment of Tank Waste Remediation System Waste Treatment Strategies* (McConville and Johnson 1995).

HLW = High-level waste
TRU = Transuranic.

The HLW/TRU waste process duration was calculated using an annual container throughput for Cases 1, 2a, and 2b, and an annual mass throughput for Case 2c. For Case 1, the annual mass throughput is equal to the annual container throughput. The segregated TRU waste Cases (2a, 2b, 2c) require a separate, smaller volume container for the TRU waste. Cases 2a and 2b assume the TRU waste annual canister throughput is the same as the HLW annual canister throughput (i.e., Cases 2a and 2b are limited by canister handling). The Case 2c process duration algorithm is based on annual mass throughput and assumes increased canister handling to accommodate the mass throughput.

A.2.3 Immobilized Waste Volume Algorithms

The composition of the immobilized HLW/TRU waste form must meet several criteria such as durability, minimization of radionuclide leaching, thermal output, etc. The quantity of waste oxides incorporated into the immobilized HLW/TRU waste form, along with the immobilizing materials, will influence the ability to meet these criteria. Cases 1, 2a, and 2c assume non-crystalline glass as the immobilized HLW/TRU waste form. Case 2b assumes a crystalline TRU waste form and non-crystalline glass as the HLW form. The crystalline and non-crystalline waste forms have different waste oxide concentration limits. The volume of HLW produced is a function of the total mass of oxides in the pretreated HLW, and waste oxide limits for individual components, as shown in Table A-7.

Table A-7. Immobilized Waste Volume Algorithms.

Calculated Parameter	Equation
Waste oxide loading limit	100 percent - minimum SiO_2 concentration limit - minimum B_2O_3 concentration limit - minimum Li_2O concentration limit
Number of 1.26 m^3 HLW containers produced	Maximum of [sum of(mass of component i oxide in pretreated HLW)/(component i concentration limit)x(HLW mass per container)] or [(total mass of oxides in pretreated HLW)/(waste oxide loading limit)x(HLW mass per container)]
*Number of 0.71 m^3 TRU waste containers produced	Maximum of [sum of(mass of component i oxide in pretreated TRU waste)/(component i waste concentration limit)x(TRU waste mass per container)] or [(total mass of oxides in pretreated TRU waste)/(waste oxide loading limit)x(TRU waste glass per container)]
Volume (m^3) of immobilized HLW glass produced	(Quantity of HLW containers produced)x(1.26 m^3 glass per container)
*Volume (m^3) of immobilized TRU glass produced	(Quantity of TRU waste containers produced)x(0.71 m^3 glass per container)

*Indicates modification of algorithms reported in McConville and Johnson (1995)
HLW = High-level waste
TRU = Transuranic.

A3.0 INSIGHT MODEL INPUT VARIABLES

The INSIGHT Model includes values with specified uncertainty ranges for variables such as facility construction and operation costs; process start-up and completion dates; and the fraction of waste components separated and sent to LLW and HLW treatment. Each variable range is defined in terms of a base condition (i.e., mid value) and a high and low modifier that represent the range of the technical uncertainty. The variable ranges are estimates based on evaluation of available engineering information by knowledgeable technical personnel (e.g., contingency included in architectural engineering conceptual designs, cost estimates for facilities, range of tank waste sludge components dissolved by caustic).

The original list of input variables reported in *Decision Analysis Model for Assessment of Tank Waste Remediation System Waste Treatment Strategies* (McConville and Johnson 1995) has been specifically modified to support the evaluation of waste treatment alternatives which maintain the segregation of TRU waste from HLW. The uncertainty ranges for each input variable relevant to the HLW/TRU waste treatment process are listed in Tables A-8, A-9, and A-10, with the modified variables marked with an asterisk.

Table A-8. Life-Cycle Cost Input Variables. (2 Sheets)

Technical uncertainties	Description	Range of solution for technical uncertainty			Spreadsheet variable name
		Low-range value	Mid-range value	High-range value	
HLW/TRU waste facility construction cost (Millions of 1995 dollars)	10 MT/day Joule-heated melter facility construction cost from WHC-SD-WM-ES-295, page 75 (Boomer et al. 1994). The base estimate was determined from Kaiser Interactive Estimating (IEST) job #436302 and assumes a 40 percent contingency. The high-range value is 25 percent greater than the base estimate and the low-range value assumes a 25 percent contingency.	1673	1873	2342	hlwconstcost
	10.7 MT/day Joule-heated melter facility construction cost determined from Kaiser IEST job #E11523/Z395. The 10.7 MT/day facility cost base estimate assumes a 40 percent contingency, and is $100 million (1995 dollars) greater than the 10 MT/day facility base estimate. The $100 million difference is based on the difference between Kaiser IEST job #E11523/Z395 and job #436302. The high-range value is 25 percent greater than the base estimate and the low-range value assumes a 25 percent contingency.	*1762	*1973	*2467	
Facility Modification Cost (Millions of 1995 dollars)	Facility Modification Cost to process TRU waste separately from HLW is an additional cost to the HLW facility construction cost and is only applicable if TRU waste is segregated from HLW (Crawford and Manuel 1996).	*2.1	*2.1	*2.1	trumodcost
Interim storage building construction cost (Millions of 1995 dollars per building)	Construction cost per interim storage building from WHC-EP-0616, p. R-250 (Boomer et al. 1993). Cost per building assumes 1330 HLW canisters (1.26 m^3) per storage building and no additional interim storage required for TRU waste canisters (0.71 m^3).	106.1	106.1	106.1	interimstor
HLW/TRU waste facility labor cost per year (Millions of 1995 dollars/yr)	10 MT/day facility: The low-range value represents the staffing cost for one facility from WHC-SD-WM-ES-295, page 77 (Boomer et al. 1994) escalated to 1995 dollars. The high-range value represents the staffing cost for the HWVP Joule-heated melter from WHC-EP-0616, page R-378 (Boomer et al. 1993) escalated to 1995 dollars. The mid-range value is the midpoint between the low and high values.	*47	*60	*73	hlwopcost
	10.7 MT/day facility: The base estimate staffing costs are assumed to be 10 percent greater than the 10 MT/day facility. The high-range value is 25 percent greater than the base estimate and the low-range value assumes a 25 percent contingency.	*59	*66	*83	

Table A-8. Life-Cycle Cost Input Variables. (2 Sheets)

Technical uncertainties	Description	Range of solution for technical uncertainty			Spreadsheet variable name
		Low-range value	Mid-range value	High-range value	
DST retrieval operating cost (millions of 1995 dollars per year)	Annual operating cost for mixer pump retrieval is $48 million (1995 dollars) from FY 1996 TWRS MYPP, WHC-SP-1101, Rev.1. The high-range value is 10 percent greater than the base estimate, and the low-range value is 10 percent less than the base estimate. DST retrieval continues throughout the HLW/TRU waste immobilization process.	*43	*48	*53	dstopcost
Consumables cost per MT immobilized waste (1995 dollars per MT immobilized waste)	The consumable operating cost is based on the mid-point of annual consumable operating costs for a 10 MT/day Joule-heated melter (Boomer et al. 1994, page 77, escalated to 1995 dollars) and the HWVP melter (Boomer et al. 1993, page R-378, excluding errors identified in utility costs and escalated to 1995 dollars). The consumable cost per MT of glass produced was determined by multiplying the mid-point consumable cost per year and the TWRS Process Flowsheet Rev. 1 Case HLW process duration then dividing by the total mass of HLW glass produced (i.e., $28M/year x 13 years/23,860 MT glass = $15,300/MT glass produced). The high-range value is 25 percent greater than the base estimate, and the low-range value assumes a 25 percent contingency.	*13,660	*15,300	*19,125	hlwchemcost
Melter Replacement Cost (millions of 1995 dollars per melter replaced)	Cost per melter replaced is $39 million (1995 dollars). The life span of a melter is estimated to be 2 years (WSRC 1995, page 54).	39	39	39	meltrep
Canister Costs	HLW Canister cost for 1.26 m^3 canister.	10	10	10	hlwconcost
(thousands of 1995 dollars per canister)	Transuranic (TRU) Waste Canister cost for 0.71 m^3 canister from (Crawford and Manuel 1996). Low and mid-range values do not include overpack and concrete shielding for pad storage. High-range value includes overpack and concrete shielding.	*7.2	*7.2	*8.6	truconcost
Disposal Cost (thousands of 1995 dollars per canister)	HLW Disposal Cost: The disposal cost for a 1.26 m^3 HLW canister is assumed to be 10 percent greater than the disposal cost for a 0.62 m^3 canister (DOE/RW 1993). The disposal cost for the 0.62 m^3 canister is $356,000 per canister (DOE/RW 1995)	*392	*392	*392	candis
	TRU Waste Disposal Cost: The low and mid-range disposal cost per 0.71 m^3 canister is estimated from a July 1995 WIPP presentation, (DOE-EM 1995). The high-range value is 20 percent greater than the mid-range value.	*30	*30	*36	trudis

*Indicates a modification of variables reported in McConville and Johnson (1995). Shaded cells indicate "Base Case" values.

Table A-9. Process Duration Input Variables.

Technical uncertainties	Description	Range of solution for technical uncertainty			Spreadsheet variable name
		Low-range value	Mid-range value	High-range value	
High-level waste (HLW) melter throughput (kg/h)	10 MT/day melter throughput in kg/hour. The high-range estimate is 15 percent greater than the base estimate. The low-range estimate is 15 percent less than the base estimate.	354	417	479	hlwthput
	10.7 MT/day melter throughput in kg/hour. The high-range estimate is 15 percent greater than the base estimate. The low-range estimate is 15 percent less than the base estimate.	*377	*444	*511	
HLW facility total operating efficiency (TOE)	Total operating efficiency (TOE) for 10 MT/day facility and 10.7 MT/day facility	50%	60%	70%	capfac
Melter life (years)	The life span of 10 MT/day or 10.7 MT/day Joule-heated melter is estimated to be 2 years in the Savannah River Site HLW System Plan, Rev.5, page 54 (WSRC 1995) and the HWVP Technical Data Package, Volume 2 (WHC 1992).	*1	*2	*3	hlwunitlife
Melter replacement duration (months)	Duration required to allow for melter replacement at end of melter life. Five months for replacement and restart is assumed (WSRC 1995).	*5	*5	*5	outagedur
HLW/TRU waste availability date	Availability date for 10 MT/day facility and 10+ MT/day facility. Tri-Party Agreement Milestone M-51-03 (HLW process start date) is December 2009.	2008	2009	2010	hlwyear
SST retrieval start date	Year SST retrieval begins is based on Tri-Party Agreement Milestone M-45-05-T01 which specifies initiating tank waste retrieval from one SST 12/31/2003. INSIGHT Model assumes DST retrieval operations begin when SST retrieval begins, and end when HLW processing ends.	2004	2005	2006	vSSTretstart
Pretreatment start date	Pretreatment is assumed to begin one year after retrieval operations begin.	2005	2007	2009	preyear

*Indicates a modification of variables reported in McConville and Johnson (1995).
Shaded cells indicate "Base Case" values.

Table A-10. Immobilized Waste Volume Input Variables. (2 Sheets)

Technical uncertainties	Description	Range of solution for technical uncertainty			Spreadsheet variable name
		Low-range value	Mid-range value	High-range value	
SiO_2 minimum immobilized HLW/TRU waste concentration limit	Crystalline HLW/TRU waste form minimum SiO_2 concentration limit. (Glass Chemistry Workshop 1995)	37%	40%	45%	vSiO2
	Non-crystalline low temperature HLW/TRU waste glass minimum SiO_2 concentration limit. (Glass Chemistry Workshop 1995)	37%	42%	47%	
B_2O_3 minimum immobilized HLW/TRU waste concentration limit	Crystalline HLW/TRU waste form minimum Boron concentration limit. (Glass Chemistry Workshop 1995)	0%	3%	5%	vBoron
	Non-crystalline low temperature HLW/TRU waste glass minimum Boron concentration limit (Glass Chemistry Workshop 1995).	0%	3%	5%	
Li_2O minimum immobilized HLW/TRU waste concentration limit	Minimum Li_2O concentration limit for crystalline or non-crystalline HLW/TRU waste form (Orme 1995).	2%	2%	2%	
Al_2O_3 Maximum immobilized HLW/TRU waste concentration limit	Crystalline HLW/TRU waste form maximum Al_2O_3 concentration limit (Glass Chemistry Workshop 1995).	20%	25%	35%	valhlwlim
	HWVP Non-crystalline low-temperature HLW/TRU waste glass maximum Al_2O_3 concentration limit (Orme 1995).	10%	11%	15%	
Cr_2O_3 Maximum immobilized HLW/TRU waste concentration limit	Crystalline HLW/TRU waste form maximum Cr_2O_3 concentration limit (Glass Chemistry Workshop 1995).	2%	5%	8%	vcrhlwlim
	Hanford waste vitrification plant (HWVP) Non-crystalline low-temperature HLW/TRU waste glass maximum Cr_2O_3 concentration limit (Orme 1995).	0.3%	0.5%	0.7%	
Na_2O Maximum immobilized HLW/TRU waste concentration limit	Crystalline HLW/TRU waste form maximum Na_2O concentration limit (Glass Chemistry Workshop 1995).	16%	20%	25%	vnahlwlim
	HWVP Non-crystalline low-temperature HLW/TRU waste glass maximum Na_2O concentration limit (Orme 1995).	10%	12.5%	16%	

Table A-10. Immobilized Waste Volume Input Variables. (2 Sheets)

Technical uncertainties	Description	Range of solution for technical uncertainty			Spreadsheet variable name
		Low-range value	Mid-range value	High-range value	
NiO Maximum immobilized HLW/TRU waste concentration limit	Crystalline HLW/TRU waste form maximum NiO concentration limit (Glass Chemistry Workshop 1995).	2%	6%	10%	vnihlwlim
	Non-crystalline low-temperature HLW/TRU waste glass maximum NiO concentration limit (Glass Chemistry Workshop 1995).	1%	2%	3%	
ZrO_2 Maximum immobilized HLW/TRU waste concentration limit	Crystalline HLW/TRU waste form maximum ZrO_2 concentration limit (Glass Chemistry Workshop 1995).	10%	20%	30%	vzrhlwlim
	HWVP Non-crystalline low-temperature HLW/TRU waste glass maximum ZrO_2 concentration limit (Orme 1995).	9%	10%	11%	
Double-shell tank heel	Percentage of waste left behind is DSTs after sluicing	*0%	10%	15%	dstheel
Single-shell tank heel	Percentage of waste left behind by the primary sluicer and secondary mechanical arm retrieval system.	0%	0.001%	0.05%	sstheel

*Indicates a modification of variables reported in McConville and Johnson (1995).

[a]Only the maximum concentration limits with a significant effect on cost, duration or volume are shown (see Figures A-1 through A-21). See WHC-EP-0874, Appendix D (McConville and Johnson 1995) for a complete listing of maximum concentration limits for immobilized HLW/TRU waste.

Shaded cells indicates "Base Case" values.

A4.0 METHODS FOR EVALUATION

The evaluation of the decision criteria for each of the four cases is conducted in two steps: (1) deterministic sensitivity analysis, and (2) probabilistic analysis. The INSIGHT Model communicates with a decision analysis software, Supertree[1], to perform both analyses.

The deterministic sensitivity analysis is performed first to identify which input variable uncertainties have the most significant effect on the performance measure being evaluated. The result is a bar chart, known as a tornado chart, that ranks the input variables in descending order according to their influence on the performance measure calculation. Each of the significant input variables are assigned probabilities to the high, mid, and low values of their uncertainty ranges. The performance measure is calculated for all possible combinations of the significant variable ranges and assigned probabilities. The result is a cumulative probability distribution over the full range of a performance measure.

A4.1 DETERMINISTIC SENSITIVITY ANALYSIS

The INSIGHT Model communicates with the decision analysis software, Supertree®, to perform the deterministic sensitivity analysis. Supertree® calculates the deterministic sensitivity of input variable uncertainties with respect to a performance measure in four successive steps:

1. A base case value is selected from the range of each input uncertainty and the resulting performance measure is calculated. This base case performance measure value is only one possible combination of the many possible from the input variables. The base case value shown in the lower right corner of the tornado charts is the value calculated by the INSIGHT Model with all variables set to their base case values. All base case values included in the INSIGHT Model are listed in Section A3.0, Tables A-8 through A-10, and are indicated by a shaded cell.

2. An input variable is selected for evaluation.

   a. The value of the input variable is changed from its base case value to its high value, leaving all the other input variables in the INSIGHT Model at their base case values.

   b. The performance measure is calculated for the set of inputs described in (a).

[1]Supertree is a registered trademark of Strategic Decisions Group.

c. The value of the selected input variable is then changed to its low value, leaving all the other input variables at their base case values.

d. The performance measure is calculated for the set of inputs described in (c).

e. The swing around the base case value of the performance measure is recorded.

f. All input variables are then reset to their base case values.

3. Another input variable is chosen for evaluation and the procedure in Step 2 is repeated until all input variables have been evaluated. Approximately 100 input variables are included in the INSIGHT Model and are evaluated for each deterministic sensitivity analysis.

4. The input variables are ranked in descending order on a bar chart according to their influence on the performance measure calculation.

The product of the deterministic sensitivity analysis is a tornado chart. The tornado chart is a bar chart that is wide at the top and narrow at the bottom, suggesting the form of a tornado. Hence, its informal name "tornado chart" is often used. The input variables that significantly affect the calculation of a performance measure are those at the top of the tornado chart. Only the most significant variables are used in the subsequent probabilistic analysis. The deterministic sensitivity analysis step simplifies the probabilistic analysis by eliminating those variables having little or no effect on the calculation of the performance measures.

A4.2 PROBABILISTIC ANALYSIS

The probabilistic analysis is also performed by linking the decision analysis software, Supertree®, to the INSIGHT Model. Each of the significant input variables identified by inspection of the tornado chart are assigned probabilities over the range of their possible values. For this report, the low and high values for each of the significant variables identified in the deterministic sensitivity analysis were assigned a probability of 0.25, whereas the nominal value for each significant variable was assigned a probability of 0.5.

The INSIGHT Model, in conjunction with the Supertree® software is used to calculate a probabilistic distribution for a specified performance measure and waste treatment strategy. A decision tree is constructed using the Supertree® software to relate each of the variables according to their influence on a performance measure. The Supertree® software executes a series of commands that calculate the performance measure for each of the paths in the decision tree using the INSIGHT Model. The performance measure is calculated for all possible combinations of the significant variable ranges and assigned probabilities. The result is a cumulative probability distribution over the full range of the performance measure.

A5.0 CASE STUDY RESULTS

This section presents the deterministic and probabilistic results of the four case study evaluations for five of the six decision criteria: (1) total life-cycle cost, (2) life-cycle cost excluding disposal costs, (3) process duration, (4) volume of immobilized HLW produced, and (5) volume of immobilized TRU waste produced. The criterion, "volume and radioactivity of immobilized LAW produced," was determined to be the same for all cases and, therefore, was not included in the deterministic and probabilistic evaluations. The evaluations were performed using the algorithms discussed in Section A2.0, the associated variable uncertainty ranges listed in Section A3.0 and the evaluation method described in Section A4.0.

A5.1 LIFE-CYCLE COST INCLUDING DISPOSAL

The results of the life-cycle cost including disposal cost deterministic sensitivity and probabilistic analyses for the four case studies are shown in Figures A-1 through A-5. The life-cycle cost is determined as net present worth in 1995 dollars and includes only the HLW/TRU waste treatment elements of the TWRS Program (see Tables A-3, A-4, and A-5). The DST retrieval operating cost is included in the HLW/TRU waste life-cycle cost since DST retrieval operations continue throughout the HLW/TRU waste process duration. Costs for SST retrieval, pretreatment, and LAW processing remain the same for all four cases, and, therefore, are not included in the life-cycle cost evaluation.

The tornado charts resulting from the deterministic sensitivity analyses (Figures A-1 through A-4) indicate the sodium oxide and chromium oxide concentration limits in the immobilized waste form, aluminum separation efficiency, and facility construction cost are areas of great uncertainty for all four case studies. The uncertainty ranges for each of these variables are listed in Table A-8. A comparison of the "base case life-cycle cost" values shown on Figures A-1 through A-4, indicates only a slight variation among the case studies. The INSIGHT Model calculates a "base case life-cycle cost" of approximately $8.5 billion (1995 dollars) for all four cases.

Figure A-5 shows the cumulative probability distributions resulting from the probabilistic evaluation of the top five input variables of each tornado chart. The cumulative probability distribution curves confirm the tornado chart interpretation that the variations in life-cycle cost among the four case studies are negligible. Figure A-5 also indicates the HLW/TRU waste life-cycle cost including disposal could actually range from $7 billion (1995 dollars) to $11 billion (1995 dollars). The "base case life-cycle cost" of $8.5 billion (1995 dollars) represents a cumulative probability of only 20 to 30 percent for the four case studies. At 80 percent cumulative probability, the life-cycle cost is approximately $10 billion (1995 dollars) or less for all four cases.

Figure A-1. Case 1 Life-Cycle Cost Tornado Chart.

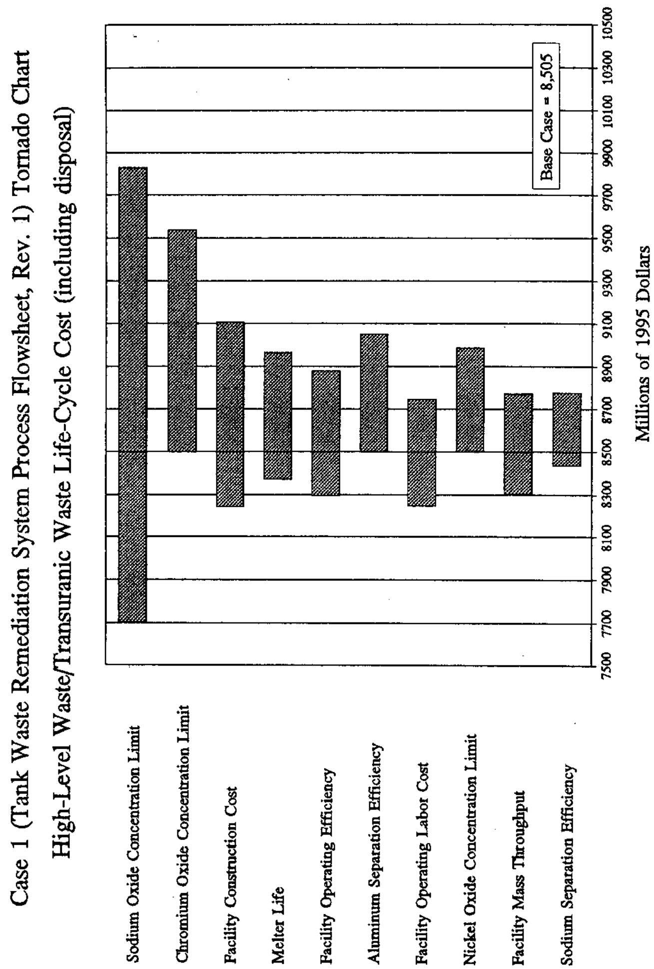


Figure A-2. Case 2a Life-Cycle Cost Tornado Chart.

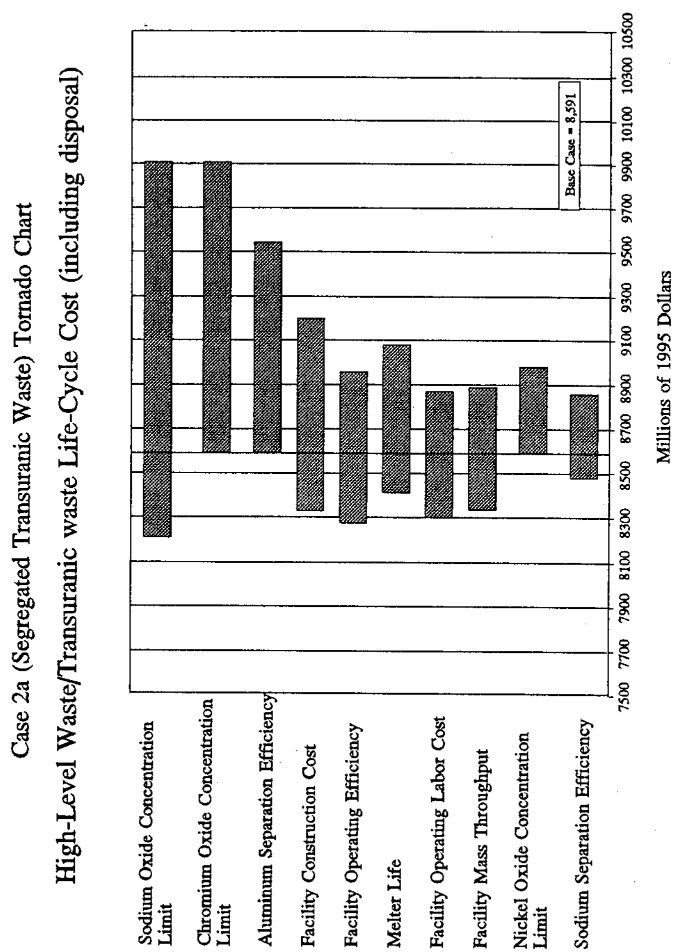


Figure A-3. Case 2b Life-Cycle Cost Tornado Chart.

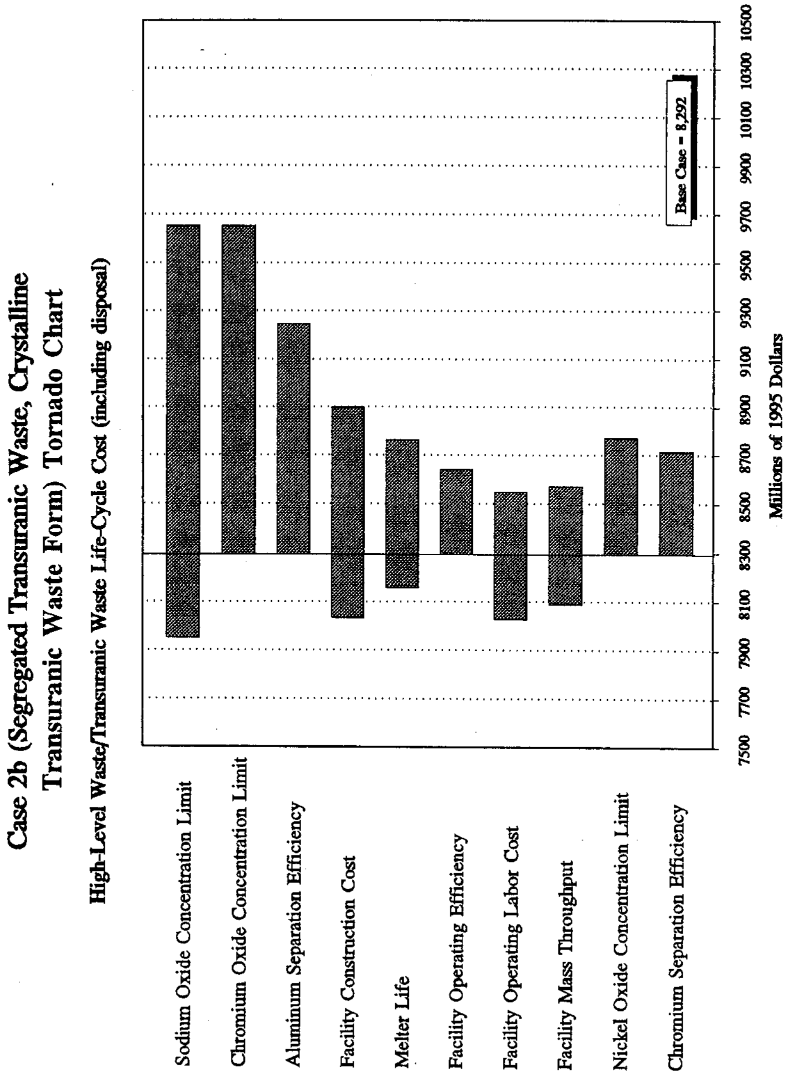


Figure A-4. Case 2c Life-Cycle Cost Tornado Chart.

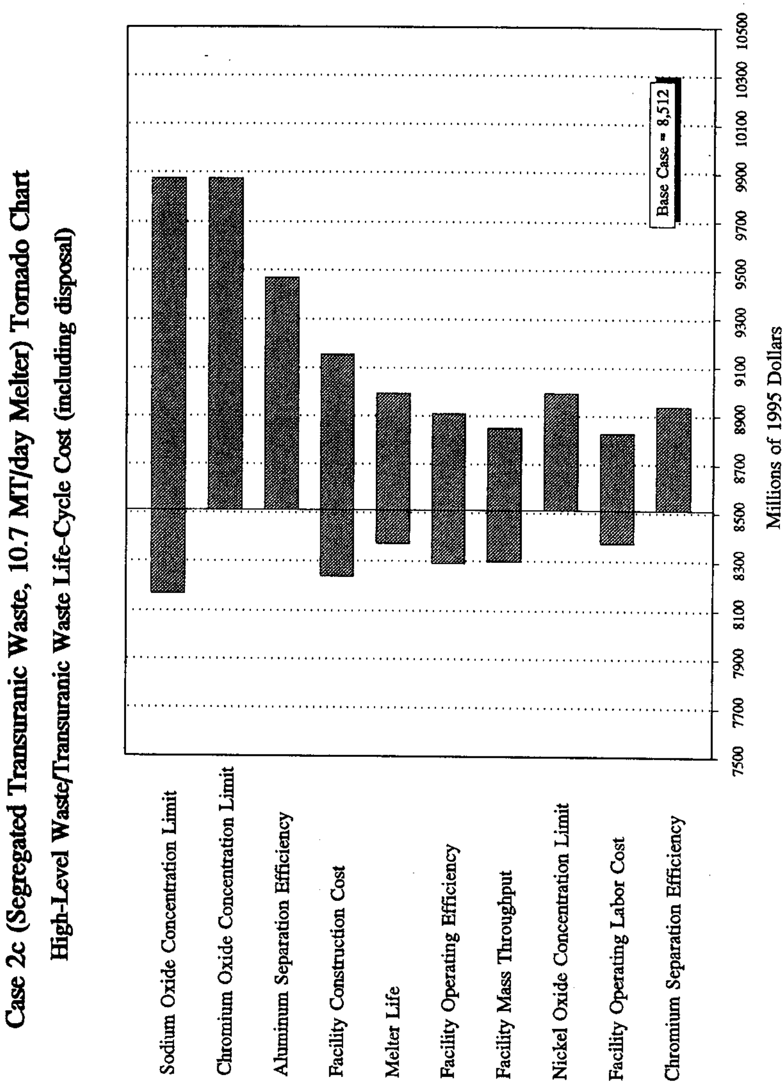
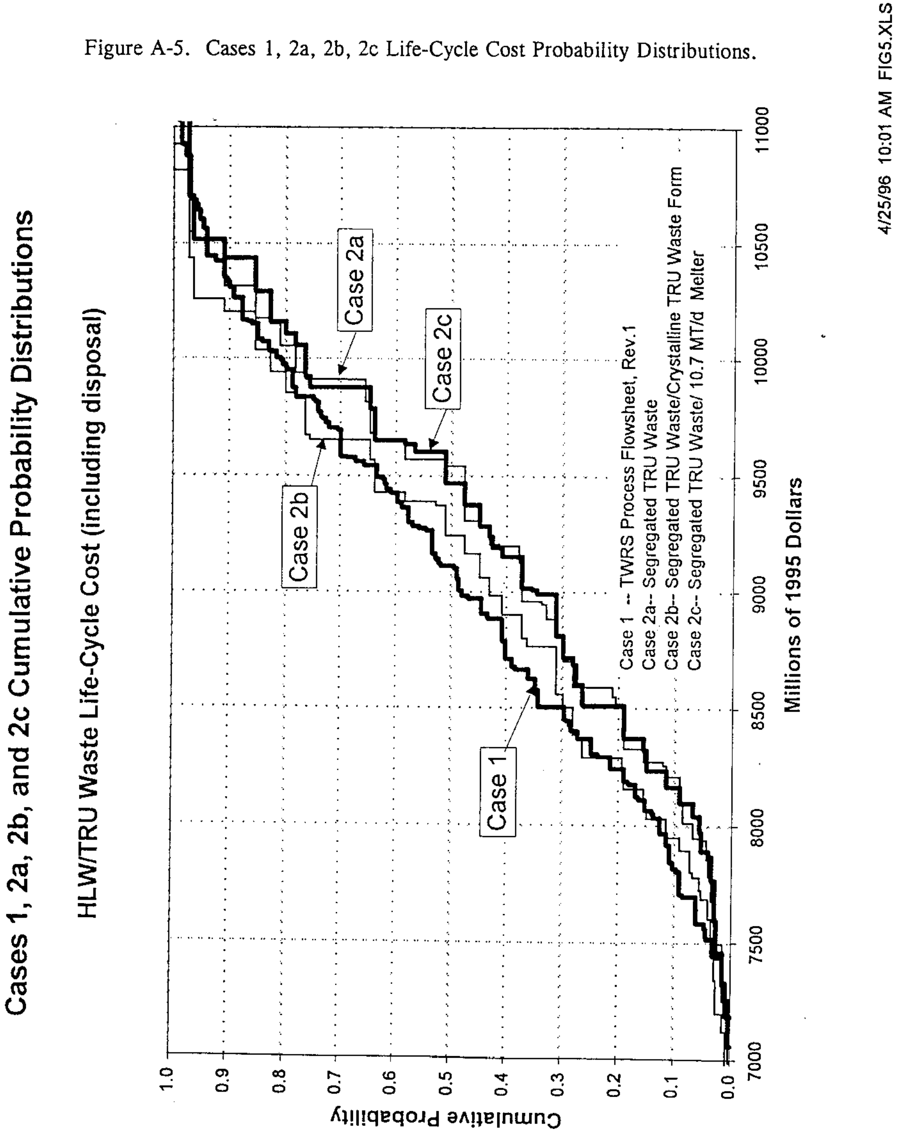


Figure A-5. Cases 1, 2a, 2b, 2c Life-Cycle Cost Probability Distributions.



A5.2 LIFE-CYCLE COST EXCLUDING DISPOSAL COST

The results of the life-cycle cost, excluding disposal cost, deterministic sensitivity and probabilistic analyses for the four case studies are shown in Figures A-6 through A-10. The life-cycle cost excluding disposal cost is determined as net present worth in 1995 dollars. The life-cycle cost excluding disposal cost includes only the HLW/TRU waste treatment elements of the TWRS Program but excludes costs for disposing of HLW and TRU waste (see Tables A-3, A-4, and A-5). The DST retrieval operating cost is included in the HLW/TRU waste life-cycle cost since DST retrieval operations continue throughout the HLW/TRU waste process duration. Costs for SST retrieval, pretreatment, and LAW processing remain the same for all four cases and, therefore, are not included in the life-cycle cost evaluation.

The tornado charts resulting from the deterministic sensitivity analyses (Figures A-6 through A-9) indicate the sodium oxide and chromium oxide concentration limits in the immobilized waste form, facility construction cost, melter life, and facility operating efficiency are areas of great uncertainty for all four case studies. The uncertainty ranges for each of these variables are listed in Table A-8. A comparison of the "base case life-cycle cost excluding disposal cost" values shown on Figures A-6 through A-9, indicates only a slight variation among the case studies. The INSIGHT Model calculates a "base case life-cycle cost excluding disposal cost" of approximately $6 billion (1995 dollars) for all four cases.

Figure A-10 shows the cumulative probability distributions resulting from the probabilistic evaluation of the top five input variables of each life-cycle cost excluding disposal cost tornado chart (Figures A-6 through A-9). The cumulative probability distribution curves for life-cycle cost excluding disposal costs show that cost differences between Cases 1 and 2b are negligible, and cost differences between Cases 2a and 2c are negligible. The chart also shows a constant variation between the two groups (i.e., Cases 1 and 2b compared to Cases 2a and 2c), with Cases 1 and 2b always costing less than Cases 2a and 2c. When compared to the cumulative probability distribution curves for life-cycle cost including disposal costs (Figure A-5), it can be seen that the uncertainties associated with disposal costs cause the variations among the cases to become less distinctive.

Figure A-10 also indicates the HLW/TRU waste life-cycle cost excluding disposal could actually range from $5 billion to $8 billion for all four cases. The "base case life-cycle cost excluding disposal cost" of $6 billion (1995 dollars) represents a cumulative probability of only 30 percent for Cases 2a and 2c, and a cumulative probability of approximately 40 percent for cases 1 and 2b. At 80 percent cumulative probability, the life-cycle cost excluding disposal cost is approximately $6.7 billion (1995 dollars) or less for Cases 1 and 2b, and $6.9 billion (1995 dollars) or less for Cases 2a and 2c.

Figure A-6. Case 1 Life-Cycle Cost (Excluding Disposal) Tornado Chart.

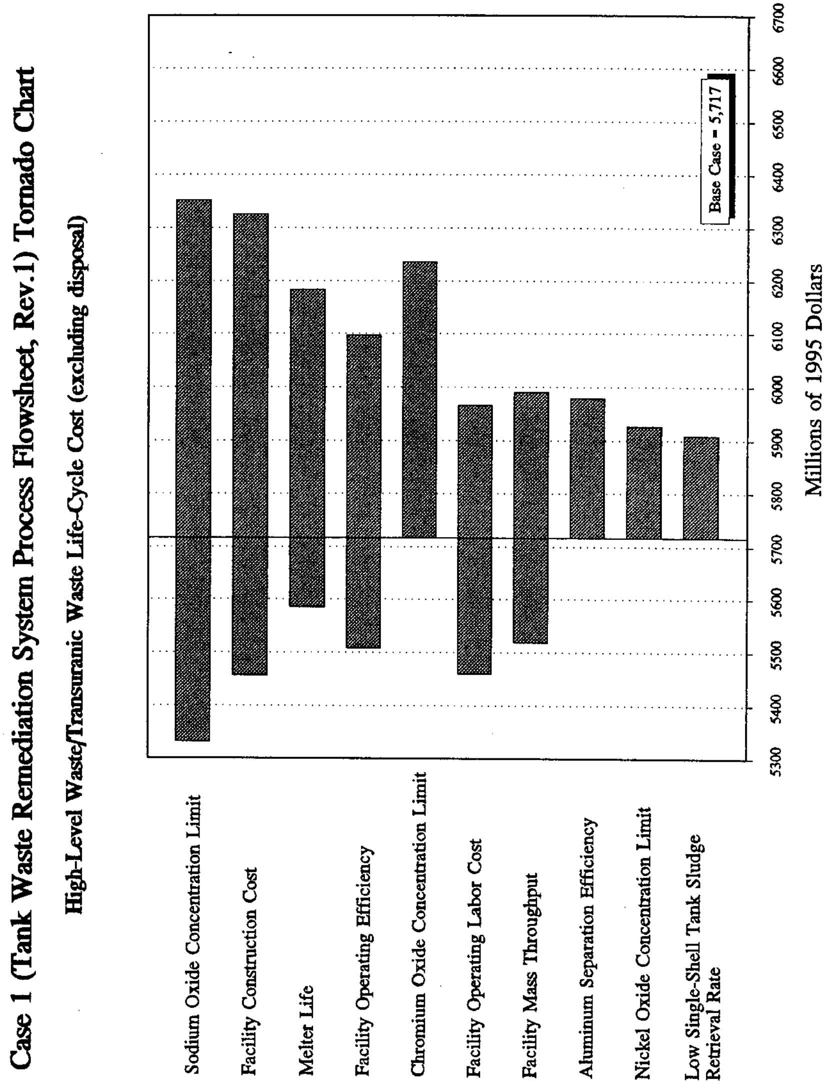


Figure A-7. Case 2a Life-Cycle Cost (Excluding Disposal) Tornado Chart.

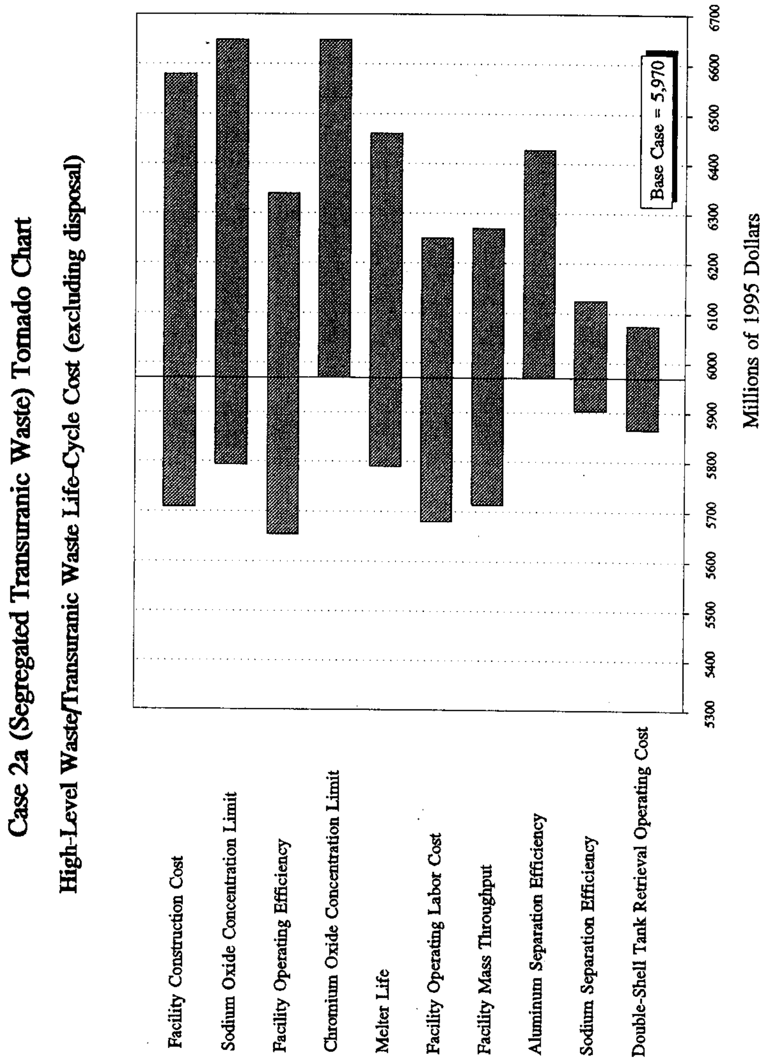


Figure A-8. Case 2b Life-Cycle Cost (Excluding Disposal) Tornado Chart.

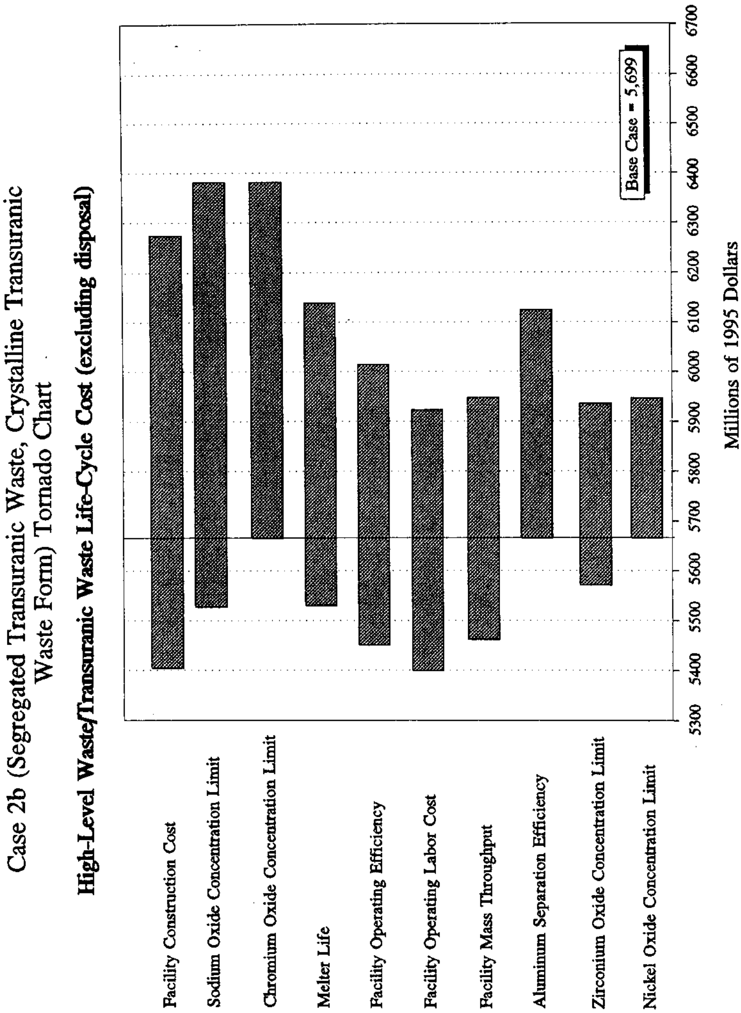


Figure A-9. Case 2c Life-Cycle Cost (Excluding Disposal) Tornado Chart.

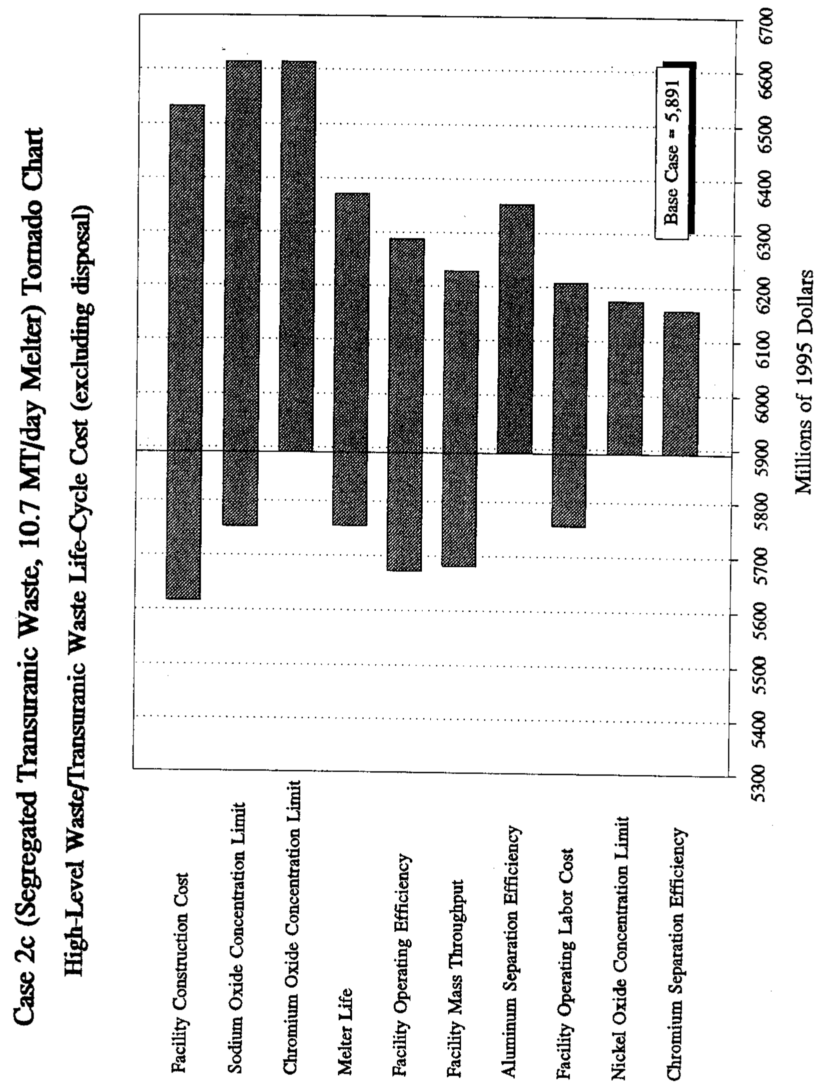
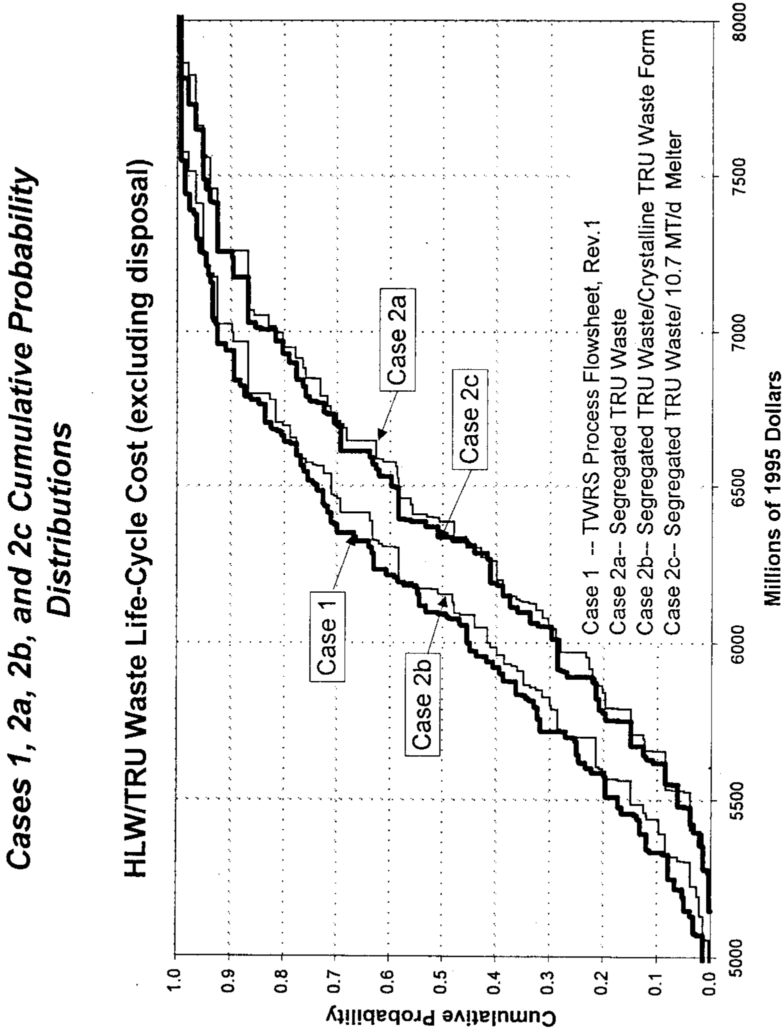


Figure A-10. Cases 1, 2a, 2b, 2c Process Duration Probability Distributions.



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A5.3 PROCESS DURATION

The results for the process duration deterministic sensitivity and probabilistic analyses for the four case studies are shown in Figures A-11 through A-15. The HLW/TRU waste process duration is determined as the time period (years) necessary to complete immobilization of the HLW and TRU tank wastes once tank waste retrieval has commenced (see Table A-6). The pretreatment and LAW process durations remain the same for all four cases and, therefore, are not included in the process duration evaluation.

The tornado charts resulting from the deterministic sensitivity analyses (Figures A-11 through 14) indicate that facility operating efficiency, facility mass throughput, melter life, sodium oxide and chromium oxide concentration limits in the immobilized waste form are areas of great uncertainty for all four case studies. The uncertainty ranges for each of these variables are listed in Table A-9. A comparison of the base case process duration values shown on Figures A-11 through A-15 indicates a variation of approximately three years among the case studies. The INSIGHT Model calculates a "base case process duration" of 13 years for Cases 1 and 2c, 16 years for Case 2a, and 14 years for Case 2b.

Figure A-15 shows the cumulative probability distributions resulting from the probabilistic evaluation of the top five input variables of each process duration tornado chart (Figures A-11 through A-14). Figure A-15 shows distinctive variations among the case studies. Cases 1 and 2c overlap and follow approximately the same curve. The two cases process the HLW and TRU waste in the shortest duration. The variation between Case 2b and Cases 1 and 2c is distinct, but very small. Case 2a requires the longest process duration.

Figure A-15 indicates the HLW/TRU waste process duration could actually range from 8 to 26 years. Assuming the HLW/TRU waste process begins in 2009, the process duration must be 19 years or less to meet the Tri-Party Agreement mandated completion date of 2028. The cumulative probability of meeting the Tri-Party Agreement completion date is approximately 90 percent for Cases 1 and 2c, 80 percent for Case 2b, and 75 percent for Case 2a.

The variation in process duration is expected since segregating the TRU waste from the HLW ultimately produces more immobilized waste, extending the process duration. The segregated TRU waste has a high zirconium concentration and the TRU waste volume is sensitive to the zirconium oxide concentration limit. Case 2b produces a crystalline TRU waste form with a higher zirconium oxide concentration limit that reduces the immobilized TRU waste volume. Case 2c has a larger melter and canister handling capacity to accommodate the larger waste throughput in the same duration as Case 1.

Figure A-11. Case 1 Process Duration Tornado Chart.

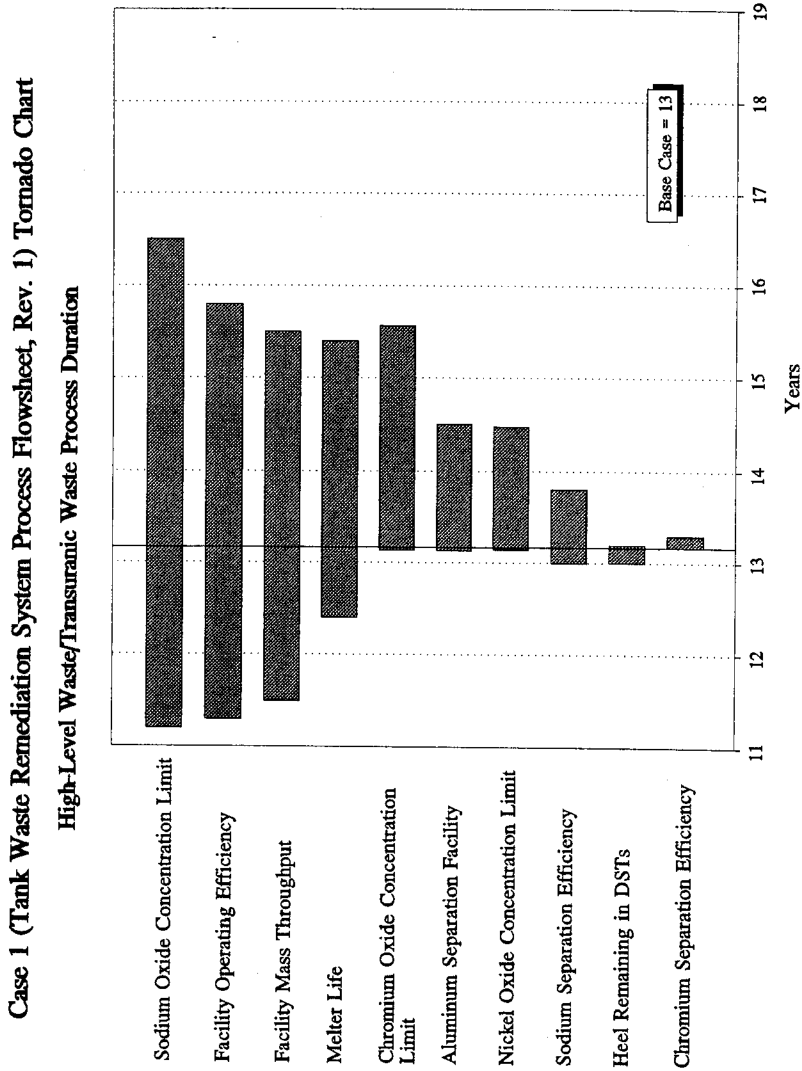


Figure A-12. Case 2a Process Duration Tornado Chart.

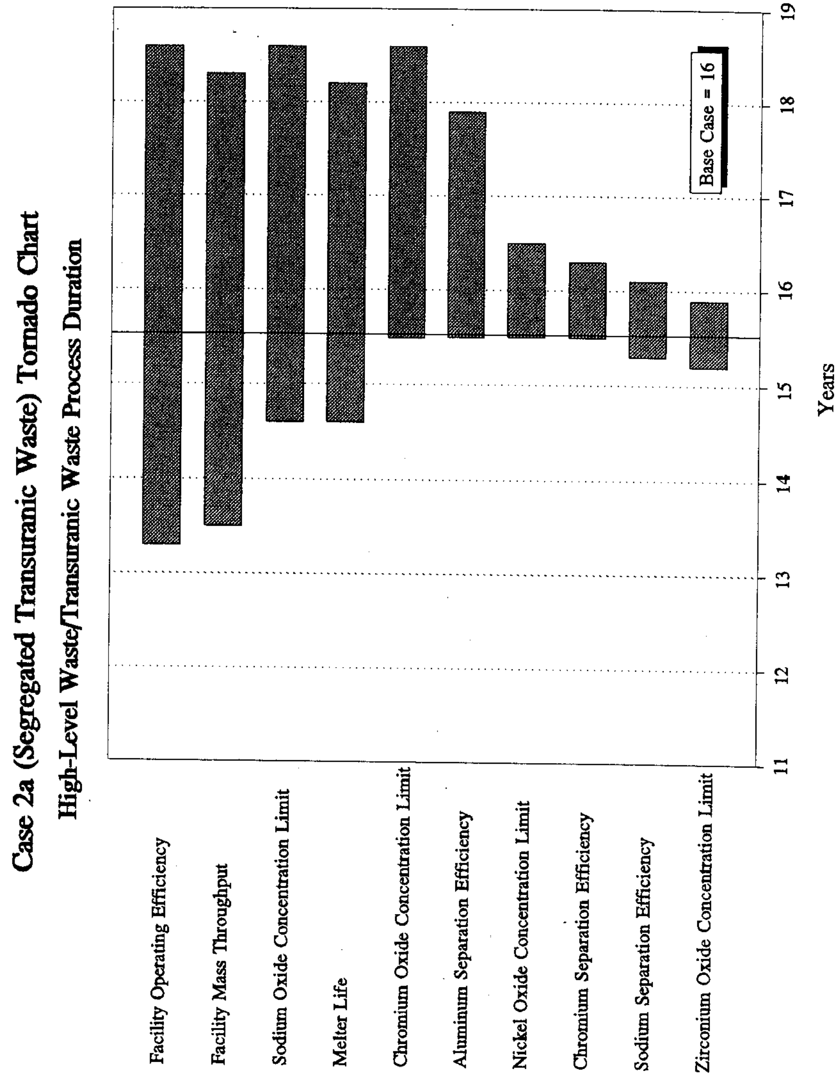


Figure A-13. Case 2b Process Duration Tornado Chart.

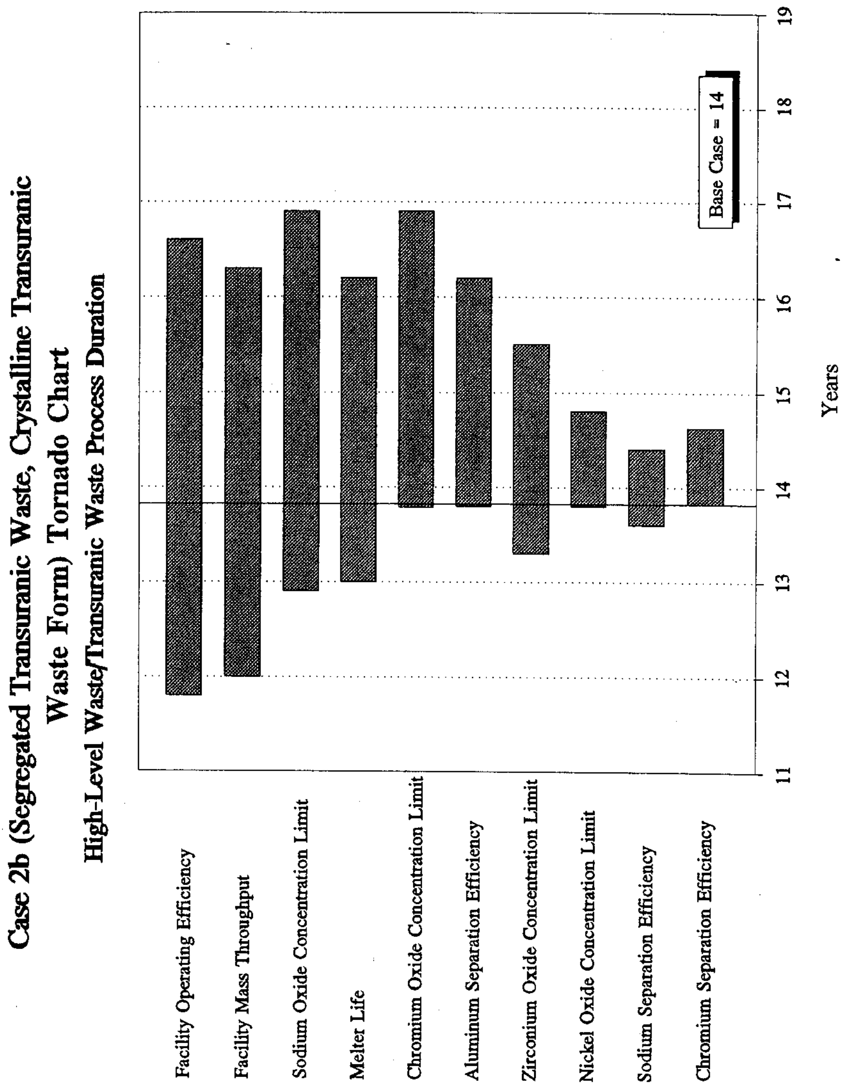


Figure A-14. Case 2c Process Duration Tornado Chart.

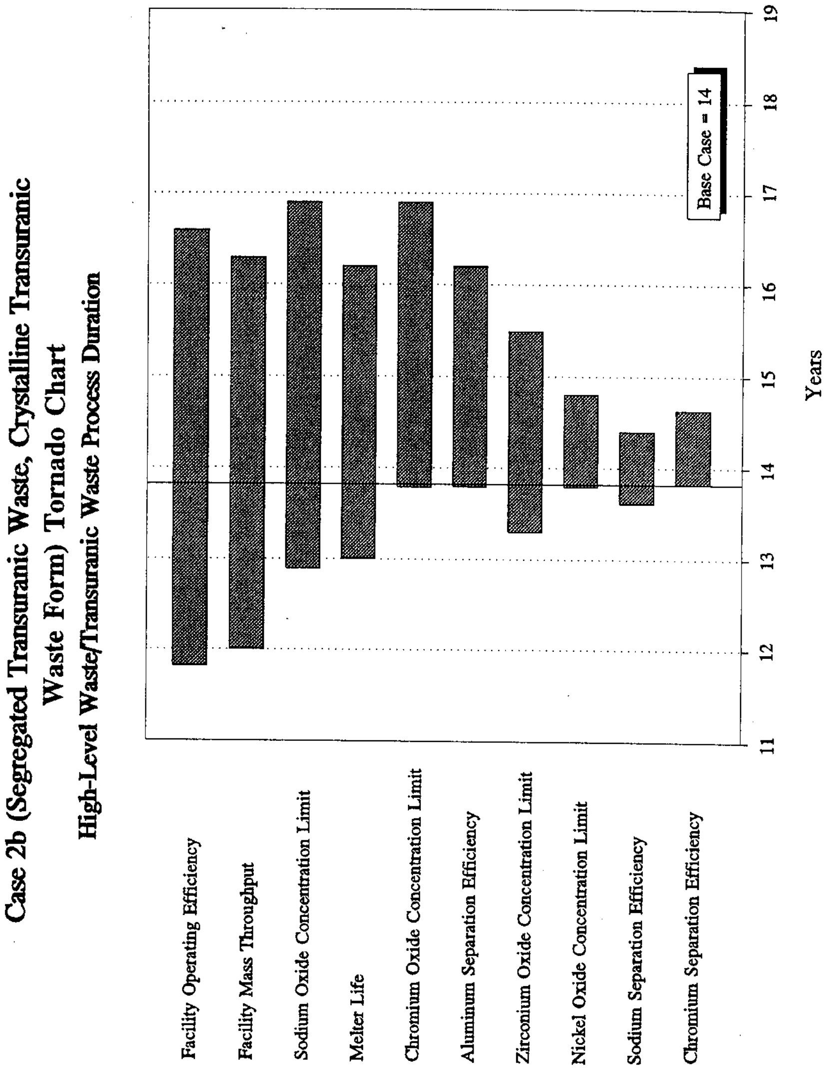
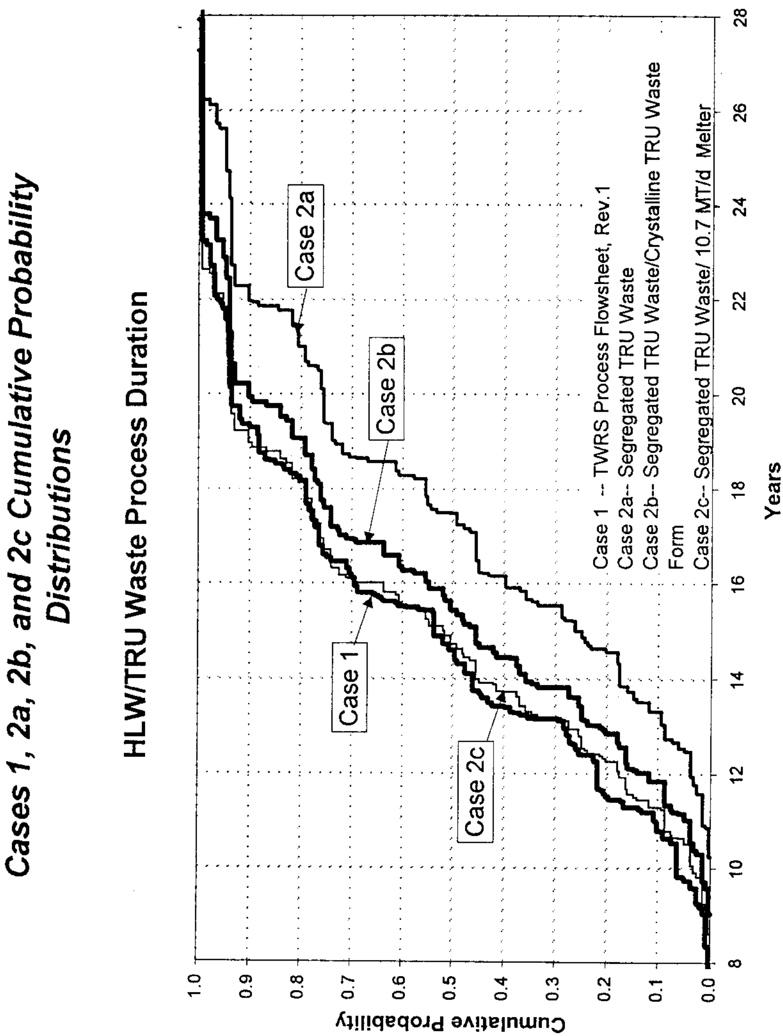


Figure A-15. Cases 1, 2a, 2b, 2c Process Duration Probability Distributions.



4/25/96 10:15 AM FIG15.XLS

A5.4 VOLUME OF IMMOBILIZED HIGH-LEVEL WASTE PRODUCED

The results of the immobilized HLW volume deterministic sensitivity and probabilistic analyses for the four case studies are shown in Figures A-16 through A-18. The immobilized HLW volume is determined as the number of 1.26 m^3 containers produced for disposal in an offsite HLW repository (see Table A-7).

The tornado charts resulting from the deterministic sensitivity analyses (Figures A-16 and A-17) indicate the sodium oxide, chromium oxide, and nickel oxide concentration limits in the immobilized waste form, and the aluminum separation efficiency are areas of great uncertainty for all four case studies. The uncertainty ranges for each of these variables are listed in Table A-10. Figure A-16 shows the "base case" number of 1.26 m^3 HLW containers produced is approximately 7,100 for blended HLW and TRU waste (Case 1). Figure A-17 shows the "base case" number of 1.26 m^3 HLW containers is approximately 6,550 for the three segregated TRU waste Cases 2a, 2b, and 2c.

Figure A-18 shows the cumulative probability distributions resulting from the probabilistic evaluation of the top five input variables of the two HLW volume tornado charts (Figures A-16 and A-17). The cumulative probability distribution curves for HLW volume indicate the number of 1.26 m^3 HLW containers produced could range from approximately 5,700 to 11,700 containers for blended HLW and TRU waste, and from 5,100 to 9,300 containers for segregated HLW and TRU waste. The segregated cases always produce fewer HLW canisters than the blended case. However, it is important to keep in mind the overall volume of immobilized HLW and TRU waste produced.

Figure A-16. Case 1 High-Level Waste Volume Tornado Chart.

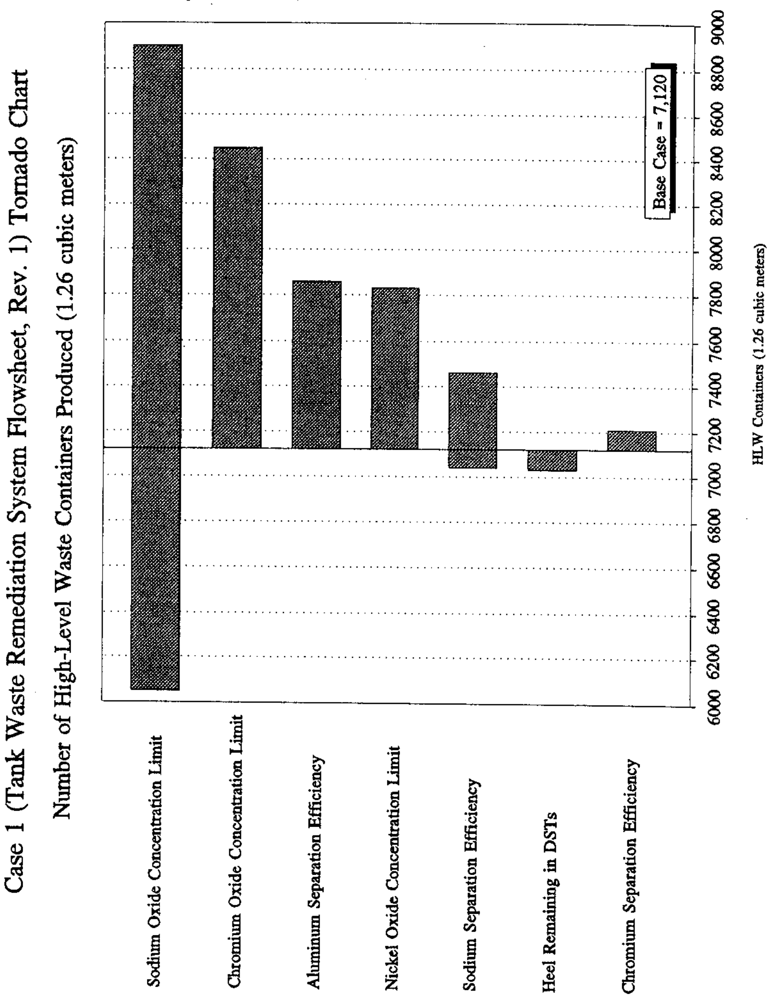


Figure A-17. Cases 2a, 2b, 2c High-Level Waste Volume Tornado Chart.

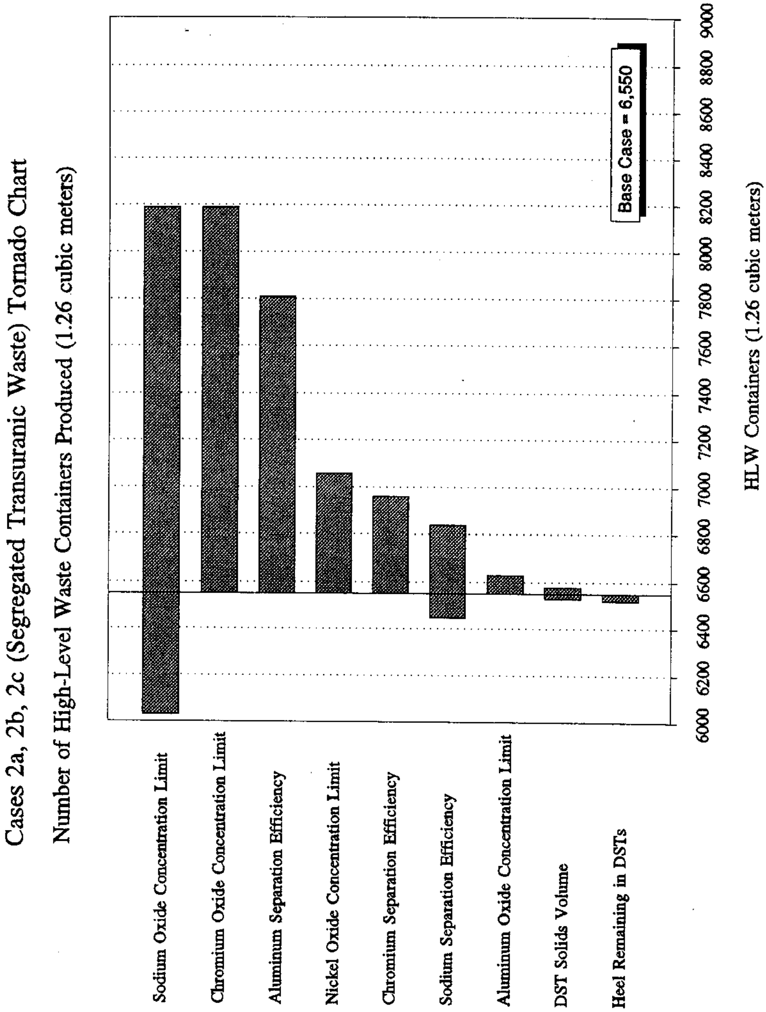
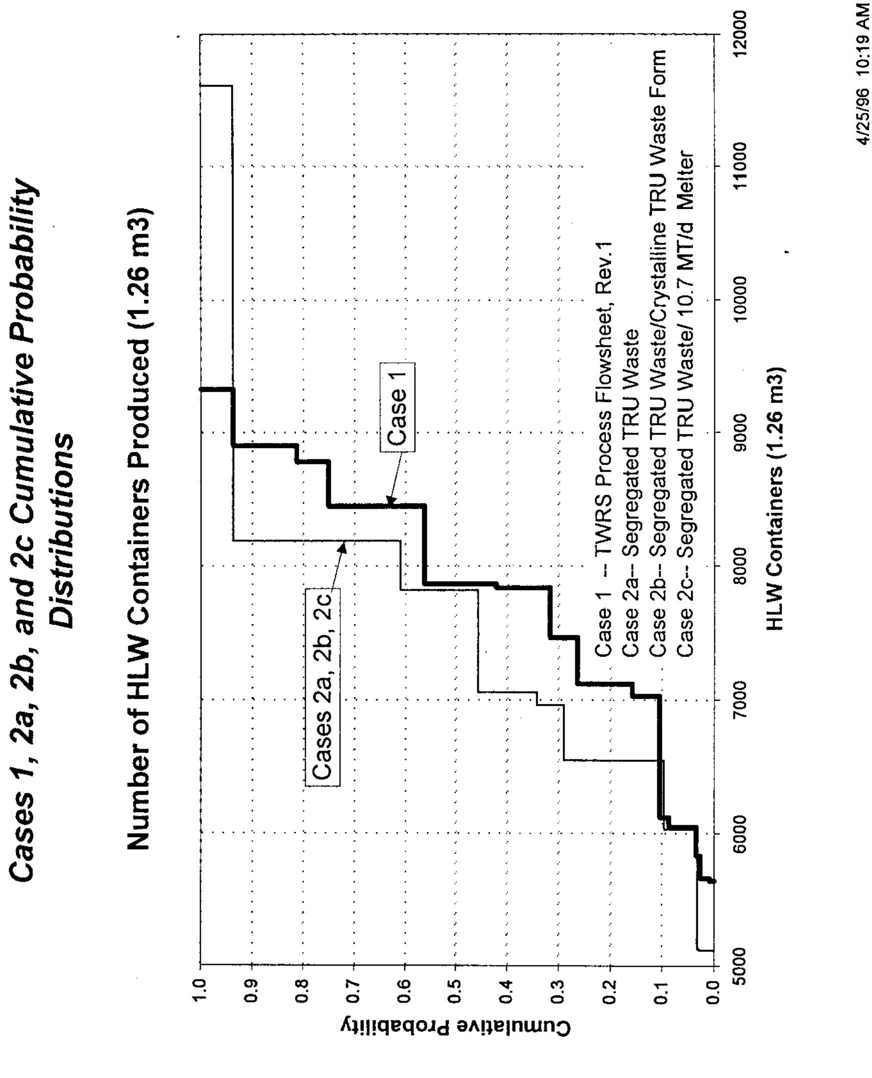


Figure A-18. Cases 1, 2a, 2b, 2c High-Level Waste Volume Probability Distributions.



A5.5 VOLUME OF IMMOBILIZED TRANSURANIC WASTE PRODUCED

The results of the immobilized TRU waste volume deterministic sensitivity and probabilistic analyses for the three segregated TRU waste case studies (2a, 2b, 2c) are shown in Figures A-19 through A-21. The immobilized TRU waste volume is determined as the number of 0.71 m^3 containers produced for disposal at WIPP (see Table A-7).

The tornado charts resulting from the deterministic sensitivity analyses (Figures A-19 and 20) indicate the zirconium oxide concentration limit in the immobilized waste form, and the heel remaining in the DSTs are areas of great uncertainty for the three segregated TRU waste Cases (2a, 2b, 2c). The uncertainty ranges for each of these variables are listed in Table A-10. Figure A-19 shows the "base case" number of 0.71 m^3 TRU waste containers produced is approximately 1,850 for the non-crystalline glass cases (2a and 2c). Figure A-20 shows the "base case" number of 0.71 m^3 TRU waste containers is approximately 925 for Case 2b, crystalline TRU waste form.

Figure A-21 shows the cumulative probability distributions resulting from the probabilistic evaluation of the two input variables of the TRU waste volume tornado charts (Figures A-19 and A-20). The cumulative probability distribution curves for TRU waste volume indicate the number of 0.71 m^3 TRU waste containers produced could range from approximately 1,400 to 2,050 containers for non-crystalline TRU glass (cases 2a, 2c), and from approximately 520 to 1,850 containers for a crystalline TRU waste form (case 2b). Since the segregated TRU waste has a high zirconium concentration, the immobilized TRU waste volume is sensitive to the zirconium oxide concentration limit. Case 2b produces a crystalline TRU waste form with a higher zirconium oxide concentration limit that reduces the immobilized TRU waste volume.

Figure A-19. Cases 2a and 2c Transuranic Waste Volume Tornado Chart.

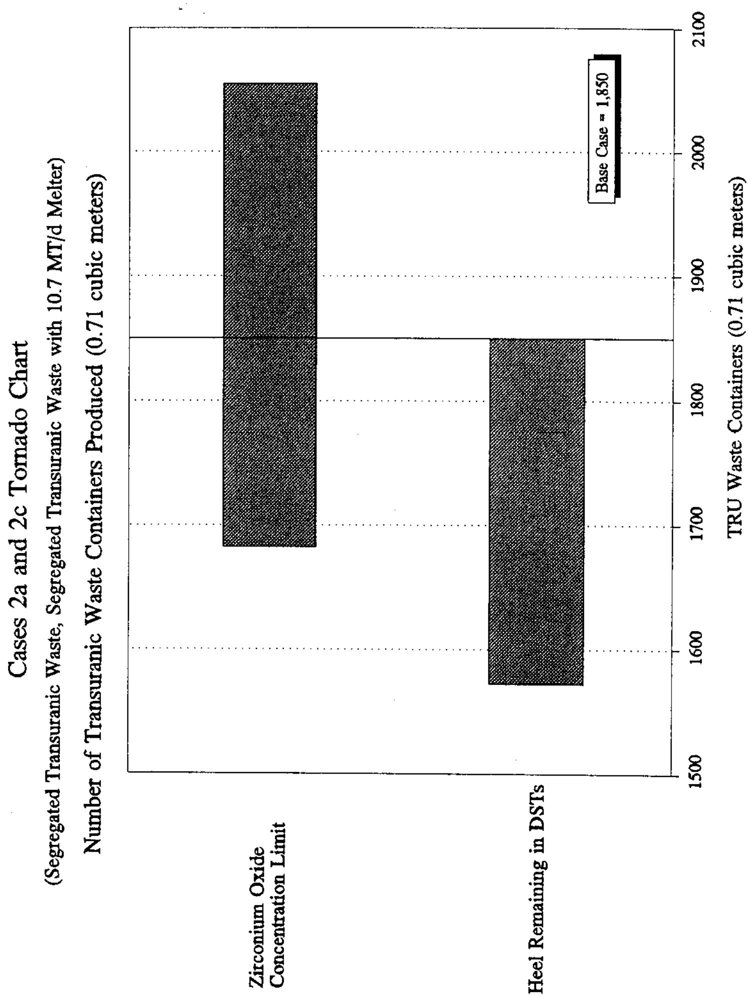


Figure A-20. Case 2b Transuranic Waste Volume Tornado Chart.

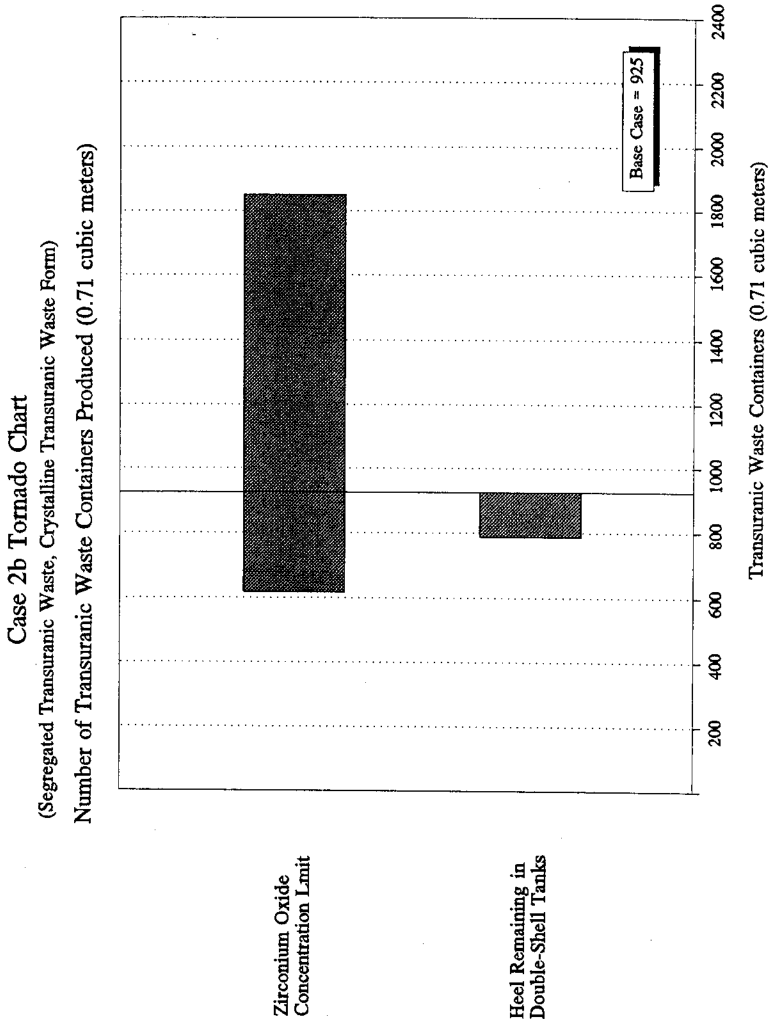
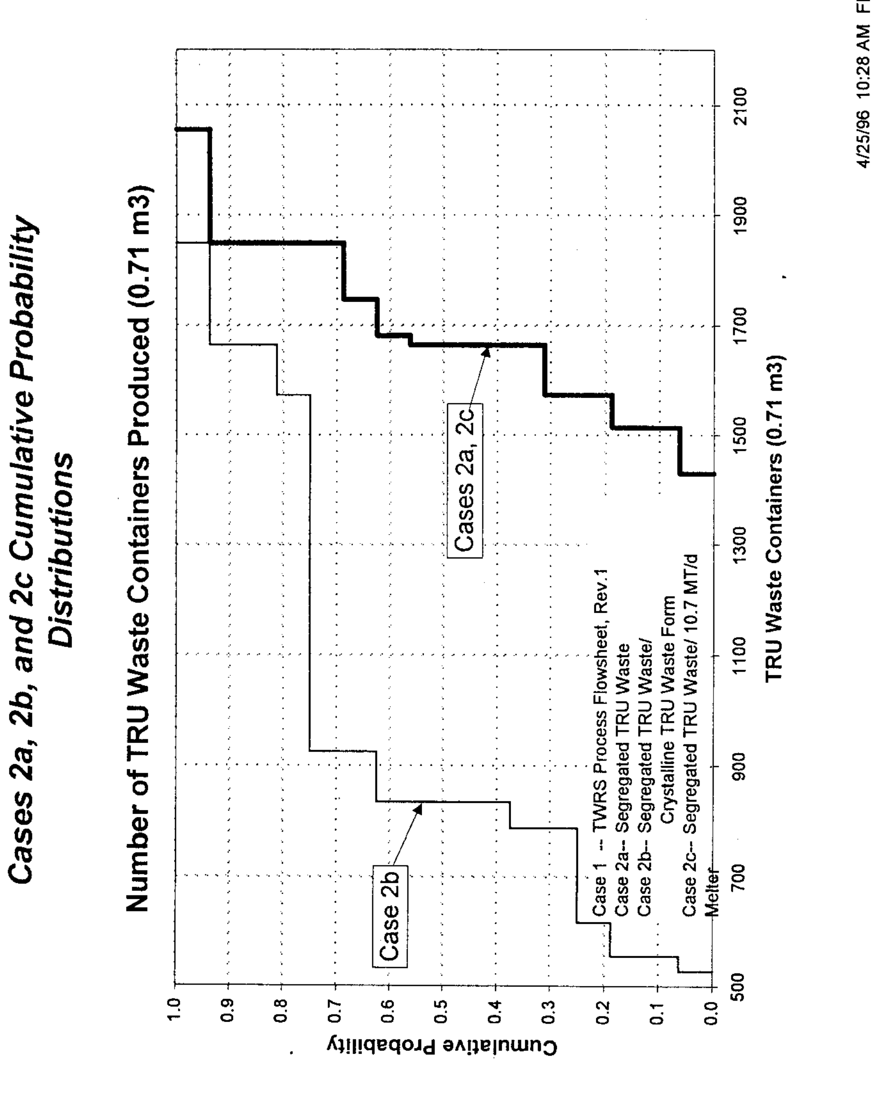


Figure A-21. Cases 2a, 2b, 2c Transuranic Waste Volume Probability Distributions.



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APPENDIX B

DETAILED LIFE-CYCLE COST SUMMARY

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APPENDIX B

DETAILED LIFE-CYCLE COST SUMMARY

Given user specified input parameters such as tank waste inventories, process conditions (e.g. glass waste form, crystalline or non-crystalline, etc.), and cost basis, the INSIGHT model calculates "base case" values for several performance measures. During the calculation of individual "base case" values, the factors that influence cost differences between the reference case 1, and all other cases are as follows. For cases 2a and 2c, segregation of TRU waste increases the total glass volume as shown in Table B-1. The volume of blended TRU glass is limited by the zirconium oxide limit. The total glass volume increases due to the limited volume of other TRU tank waste available to dilute the large quantity of zirconium in neutralized cladding removal waste stored in tanks 241-AW-103 and 241-AW-105. The number of canisters increase due to the increased glass volume and since the RH-TRU canister volume is about 44 percent less than the HLW canister. In case 2b, the TRU glass volume is half that of cases 2a and 2c since the TRU crystalline waste form can accommodate a larger quantity of zirconium.

Table B-1. Immobilized High-Level Waste and Transuranic Waste Volumes

		Case 1 TWRS Process Flowsheet, Rev. 1	Case 2a Segregated TRU Waste	Case 2b Segregated TRU Waste, Crystalline TRU Waste Form	Case 2c Segregated TRU Waste, 10.7 MT/d Melter
High-level waste	Containers (1.26m^3)	7,120	6,550	6,550	6,550
	Volume (m^3)	8,970	8,250	8,250	8,250
Transuranic waste	Containers (0.71 m^3)	N/A	1,850	925	1,850
	Volume (m^3)	N/A	1,310	660	1,310
Total HLW/TRU waste volume	Volume (m^3)	8,970	9,560	8,910	9,560

The increased number of canisters increases the vitrification and retrieval operating duration in cases 2a, b, and c as indicated by higher operating costs shown in Table B-2. The HLW facility capital cost increases about $100 million (1995 dollars) for Case 2c to account for the increase plant capacity as shown in Table B-3. The HLW facility capital cost increases about $2 million (1995 dollars) for Cases 2a, 2b, 2c to account for two different canister sizes (Crawford 1996). A longer operating duration results in increased replacement melters and their associated cost. Interim storage costs decrease with segregated TRU waste because no dedicated interim storage is provided for TRU waste. The RH-TRU waste canisters would be temporarily stored in HLW interim storage space since the TRU is assumed to be shipped to WIPP within a year of immobilization.

Table B-2. Expense Cost Breakdown (Millions of 1995 Dollars).

	Case 1, *TWRS Process Flowsheet* (Orme 1995)	Case 2a, Segregated TRU Waste	Case 2b Segregated TRU Waste, Crystalline Waste Form	Case 2c Segregated TRU Waste, 10.7 MT/d Melter
Operating expense	2,090	2,408	2,177	2,202
Labor	790	932	829	870
Consumables	365	389	363	389
Containers	71	79	73	79
Double-shell tank retrieval operations	864	1,008	912	864
Startup training	180	180	180	198
Decontamination and decommissioning	742	743	743	791
Total expense cost	3,012	3,331	3,100	3,190

TRU = Transuranic
TWRS = Tank Waste Remediation System

Table B-3. Capital Cost Breakdown (Millions of 1995 Dollars).

	Case 1 TWRS Process Flowsheet, Rev. 1	Case 2a Segregated TRU Waste	Case 2b Segregated TRU Waste, Crystalline TRU Waste Form	Case 2c Segregated TRU Waste, 10.7 MT/d Melter
Facility Capital Cost	1,873	1,875[a]	1,875[a]	1,975[a]
Replacement Melters	195	234	195	195
Interim Storage	636	530	530	530
Total Capital Cost	2,705	2,640	2,600	2,700

[a]The HLW facility capital cost increases about $2 million (1995 dollars) for cases 2a, 2b, 2c to account for two different canister sizes (Crawford 1996).

HLW disposal costs decrease proportionally with the amount of TRU waste sent to WIPP as shown in Table B-4. TRU disposal costs are very minor compared to the total life cycle cost. The total life cycle cost differences between cases 1 and 2a or 2c are negligible. Cost savings in disposal costs are offset by additional operating costs (case 2a) or capital cost (case 2c). Total life cycle costs excluding disposal cost (Table B-5) indicate a $200 million (1995 dollars) penalty for segregating TRU waste under the conditions of cases 2a and 2c. Although case 2b has potential of saving a few hundred million dollars, the incremental cost of developing, constructing, and operating a steep sloped bottom pour melter required to produce the crystalline waste form is not included in the estimate and would be expected to offset a portion of the potential savings.

Table B-4. Disposal Cost Breakdown (Millions of 1995 Dollars)

	Case 1, *TWRS Process Flowsheet* (Orme 1995)	Case 2a, Segregated TRU Waste	Case 2b, Segregated TRU Waste, Crystalline TRU Waste Form	Case 2c Segregated TRU Waste, 10.7 MT/d Melter
Repository disposal cost	2,788	2,565	2,565	2,565
WIPP disposal cost	N/A	55	28	55
Total disposal cost	2,788	2,620	2,593	2,620

TRU = Transuranic
TWRS = Tank Waste Remediation System

Table B-5. Life-Cycle Cost Breakdown (Millions of 1995 Dollars)[a]

	Case 1, *TWRS Process Flowsheet* (Orme 1995)	Case 2a, Segregated TRU Waste	Case 2b,[b] Segregated TRU Waste, Crystalline TRU Waste Form	Case 2c, Segregated TRU Waste, 10.7 MT/d Melter
Expense cost	3,012	3,331	3,100	3,190
Capital cost	2,705	2,640	2,600	2,700
Life-cycle cost excluding disposal	5,717	5,970	5,699	5,891
Disposal cost	2,788	2,620	2,593	2,620
Total life-cycle cost	8,505	8,591	8,292	8,512

TRU = Transuranic
TWRS = Tank Waste Remediation System

[a]Costs shown here represent high-level and transuranic waste processing only. The total life-cycle cost does not include single-shell tank retrieval, pretreatment, or low-activity waste processing.

[b]Case 2b requires melter and glass form development which is not included in the life-cycle cost estimate.

Table B-6 summarizes the results of the life-cycle cost probabilistic evaluation. Life-cycle cost values are reported as a range, with the low value representing a 20 percent probability and the high value representing an 80 percent probability. The values were determined from the life-cycle cost probability distribution charts, Figures A-5 and A-10. It can be seen from Table B-6 and Figure A-5 that the variations in life-cycle cost including disposal cost among the four case studies are negligible. The probability distribution chart for life-cycle cost excluding life-cycle cost (Figure A-10) shows a constant variation between cases 1 and 2b and cases 2a and 2c, with cases 1 and 2b always costing less. However, when compared to the cumulative probability distribution curves for life-cycle cost including disposal cost (Figure A-5), it can be seen that the uncertainties associated with disposal costs cause the variations among the cases to become less distinctive.

Table B-6. Life-Cycle Cost Probabilistic Summary (Millions of 1995 Dollars).[a]

	Life-cycle cost including disposal cost[b]		Life-cycle cost excluding disposal cost[c]	
	20% cumulative probability	80% cumulative probability	20% cumulative probability	80% cumulative probability
Case 1, *TWRS Process Flowsheet* (Orme 1995)	8,250	9,900	5,500	6,600
Case 2a, Segregated TRU Waste	8,500	10,100	5,800	6,900
Case 2b,[c] Segregated TRU Waste, Crystalline TRU Waste Form	8,250	9,800	5,600	6,700
Case 2c, Segregated TRU Waste, 10.7 MT/d Melter	8,500	10,200	5,750	6,900

TRU = Transuranic
TWRS = Tank Waste Remediation System

[a]The life-cycle costs shown here represent high-level and transuranic waste processing only. The costs do not include single-shell tank retrieval, pretreatment, or low-activity waste processing.

[b]Cumulative probabilities of 20 and 80 percent are representative of the range shown on the life-cycle cost including disposal probability distribution chart Figure A-5.

[c]Cumulative probabilities of 20 and 80 percent are representative of the range shown on the life-cycle cost excluding disposal probability distribution chart Figure A-10.

[d]Case 2b requires melter and glass form development which is not included in the life-cycle cost estimate.

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