Accession #: D196054896

Document #: SD-WM-ER-502

Title/Desc:

DOCUMENTATION OF DECISION FRAMEWORK TO SUPPORT ENHANCED SLUDGE WASHING

9/29/95 Sta. 37 35

ENGINEERING DATA TRANSMITTAL

1. EDT № 612833

2. To: (Receiving Organization) 73510	3. From: (Originating Organization) OM570	4. Related EDT No.:
5. Proj./Prog./Dept./Div.: TWRS Pretreatment Program	6. Cog. Engr.: DG Sutherland	7. Purchase Order No.:
8. Originator Remarks: Previously submitted on Information Release Request dated 4-28-95 as WHC-EP-0838 Rev 0.		9. Equip./Component No.:
		10. System/Bldg./Facility:
11. Receiver Remarks:		12. Major Assm. Dwg. No.:
		13. Permit/Permit Application No.:
		14. Required Response Date: 9-22-95

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Approval Designator	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	WHC-SD-WM-ER-502	N/A	0	Documentation of Decision Framework to Support Enhanced Sludge Washing	N/A		1	

16. KEY

Approval Designator (F)	Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)	1. Approval 2. Release 3. Information	4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment	4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)

(G) Reason	(H) Disp.	(J) Name (K) Signature (L) Date (M) MSIN	(J) Name (K) Signature (L) Date (M) MSIN	(G) Reason	(H) Disp.
1	1	Cog. Eng. DG Sutherland 9/12/95 L5-31			
1	1	Cog. Mgr. [signature] 9/22/95 H5-27			
		QA			
		Safety			
		Env.			

18. [signature] 9-29-95 Signature of EDT Originator Date	19. Authorized Representative Date for Receiving Organization	20. [signature] 9/22/95 Cognizant Manager Date	21. DOE APPROVAL (if required) Ctrl. No. [] Approved [] Approved w/comments [] Disapproved w/comments

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RELEASE AUTHORIZATION

Document Number:	WHC-SD-WM-ER-502, Rev. 0
Document Title:	Documentation of a Decision Framework to Support Enhanced Sludge Washing
Release Date:	September 29, 1995

This document was reviewed following the procedures described in WHC-CM-3-4 and is:

APPROVED FOR PUBLIC RELEASE

WHC Information Release Administration Specialist:

T.L. Ontiveros — September 29, 1995

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SUPPORTING DOCUMENT

1. Total Pages ~~80~~ 77

2. Title

Documentation of a Decision Framework to Support Enhanced Sludge Washing

3. Number

WHC-SD-WM-ER-502

4. Rev No.

0

5. Key Words

Sludge Washing Decision Model (SWDM)
multi-attribute utility (MAU)
decision model
sludge washing
risk analysis

6. Author

Name: A. J. Brothers

Signature

Organization/Charge Code D7H21/BE1131

7. Abstract

This document describes a proposed decision model that, if developed to its fullest, can provide a wide range of analysis options and insights to pretreatment/sludge washing alternatives. A recent decision has been made to terminate this work.

8. RELEASE STAMP

OFFICIAL RELEASE BY WHC DATE 9/29/95 Sta. 37 35

A-6400-073 (08/94) WEF124

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DOCUMENTATION OF A DECISION FRAMEWORK TO SUPPORT ENHANCED SLUDGE WASHING

EXECUTIVE SUMMARY

In FY1994, a decision model was developed for evaluating pretreatment process alternatives. This document describes a proposed refinement of the model so as to be more sensitive to specific variations of sludge washing strategies. This redevelopment was proposed to support the 1998 sludge washing decision. The strawman decision model developed during FY 1994 is described in Status Report on the Development of a Decision Analysis Model for Evaluating Pretreatment Decision Alternatives (Sutherland et al. 1994).

The purpose of this model is to aid in the selection of an optimal pretreatment/sludge washing strategy, to make explicit the basis for this selection, to promote consensus within the technical community, to enhance public understanding of pretreatment technical decisions, to clearly demonstrate the impacts of alternatives on stakeholder values, and to determine the value of technology development and characterization needs.

The model is a user friendly computer-based decision support tool. It is designed with a spreadsheet interface that drives a decision modeling software package. Simply "clicking" on buttons allows one to navigate to input and output fields, perform analysis, and view model structures.

Design and development was guided by a principle of transparent modeling and open discussion both within the scientific community and among stakeholders. Influence diagram representations of algorithms make it possible to quickly understand how impacts on stakeholder values are calculated. This facilitates discussions among the scientific community and enhances lay person understanding. A multi-objective utility model insures the consideration of all stakeholder concerns. Objective weights can be changed in real time to see the impacts of different stakeholder perspectives on values. Major uncertainties are modeled using decision trees. This ensures their correct multiplicative impact on overall value. A formal process is specified for developing model inputs. This ensures consistent and fair evaluation of all alternatives.

The outputs from model analysis are easily understood graphical representations of results. The model can determine the best pretreatment process based upon specific evaluation criteria, such as cost or high-level waste volume, and can determine which uncertainties are the most important. It provides an analysis of the risk of different alternatives and what it is worth in dollars for additional technology development. The model developed to its fullest can provide a wide range of analysis options and insights to pretreatment/sludge washing alternatives.

The model currently evaluates entire pretreatment/sludge washing strategies. The proposed extension would allow individual technology decisions to be evaluated. This would make it possible to examine new combinations of technologies without requiring new inputs to be developed.

A decision has been made to terminate this work (Washenfelder, 1995).

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LIST OF ACRONYMS

CC	Complexant Concentrate (Waste)
CST	crystalline silicotitanates
DOE	U.S. Department of Energy
DPL	Decision Programming Language
DST	double-shell tank
EIS	Environmental Impact Statement
FY	fiscal year
HLW	high-level waste
LLW	low-level waste
MAU	multi–attribute utility
NCAW	Neutralized Current Acid Waste
NCRW	Neutralized Claddng Removal Waste
PDM	Pretreatment Decision Model
PFP	Plutonium Finishing Plant (Waste)
PNL	Pacific Northwest Laboratories
RL	U.S. Department of Energy, Richland Operations Office
SST	single-shell tank
SWDM	Sludge Washing Decision Model
Tri-Party Agreement	Hanford Federal Facility Agreement and Consent Order
TRU	transuranic
TRUEX	transuranic extraction
TWRS	Tank Waste Remediation System

1. INTRODUCTION

Enhanced sludge washing has been chosen as the baseline process for separating Hanford Site tank waste sludge into high-level waste (HLW) and low-level waste (LLW) fractions to facilitate waste disposal as directed by the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Amendment Four (Ecology, EPA and DOE 1994). During Fiscal Year (FY) 1994, the *Enhanced Sludge Washing Evaluation Plan* (Jensen, 1994) was prepared to define a rational, comprehensive evaluation process to determine in March 1998 if enhanced sludge washing performs satisfactorily, or whether advanced separation processes are required. The purpose of this report is to describe the decision framework that was considered to support the sludge washing plan.

Section 1.0 of this document briefly discusses the developments that led to the need for evaluation of enhanced sludge washing and the motivation for selecting decision analysis as the methodology to assist the evaluation. Section 2.0 provides a summary of the sludge washing baseline and backup processes relevant to the 1998 decision. Section 3.0 briefly reviews the Pretreatment Decision Model (PDM), a decision analytic model that was developed during FY 1994 to support the evaluation of candidate pretreatment technologies and was intended to serve as the basis for developing a new Sludge Washing Decision Model (SWMD). Section 4.0 explains the nature and operation of the SWDM and is composed of two main subsections. Subsection 4.1 describes extension of the PDM to construct the SWDM. Subsection 4.2 illustrates how a specific pretreatment issue related to the sludge washing decision could be investigated using the SWDM. Section 5.0 describes how the development and use of the SWDM would interact with the key milestones leading to the 1998 sludge washing decision, as detailed in the *Enhanced Sludge Washing Evaluation Plan.* The work plan that was intended for the SWDM development and use during FY 1995 is outlined in Section 6.0. Section 7.0 provides a list of references. Subsequent to the activity status reported herein, a decision was made to cancel this work package (Washenfelder, 1995).

1.1 BACKGROUND

The Tank Waste Remediation System (TWRS) Program mission is to store, treat, and immobilize highly radioactive Hanford Site waste in an environmentally sound, safe, and cost-effective manner. The scope of the TWRS Waste Pretreatment Program is to separate tank waste into HLW and LLW fractions suitable for feed to immobilization facilities.

As a result of significant changes to plans for disposal of Hanford Site tank waste subsequent to the original signing of the Tri-Party Agreement in 1989, the tank waste disposal program was redefined. During the negotiations in 1993 leading to the Fourth Amendment to the Tri-Party Agreement, three basic pretreatment methods for waste tank sludge pretreatment were considered: (1) simple sludge washing, (2) enhanced sludge washing, and (3) advanced separations. Simple sludge washing consists of washing the sludge with corrosion-inhibited water in existing double-shell tanks (DST). Enhanced sludge washing consists of simple washing followed by leaching of chemical constituents with caustic and other chemicals either in existing DSTs, if possible, or in new specially designed processing equipment. Advanced separations consists of dissolution in acid followed by extensive chemical and radionuclide separations.

The pretreatment program approach selected, as defined in The Fourth Amendment to the Tri-Party Agreement, specifies the use of existing technologies as much as possible. A simple pretreatment process that can be done within tanks or in relatively simple new facilities and requires only limited development is preferred over processes requiring complex facilities and extensive technology development. The idea of getting on with the cleanup was more important to the public stakeholders than minimizing the volume of waste to be sent to the Federal repository (Armacost et al., 1994). The level of radioactivity in the LLW planned for near-surface storage at the Hanford Site was felt to be adequately controlled with retrievable storage of an improved waste form.

To support the schedule of the disposal program it was agreed that determination of the adequacy of the enhanced sludge washing processes to meet program requirements should occur by mid-1998. Consequently, the Tri-Party Agreement Milestone M-50-03, *Complete Evaluation of Enhanced Sludge Washing to Determine Whether Advanced Sludge Separation Processes are Required,* was established and scheduled for completion on March 31, 1998. The *Enhanced Sludge Washing Evaluation Plan* was prepared to establish an orderly progression toward this decision.

1.2 MOTIVATION FOR DECISION MODELING

As pressure on the DOE budget increases, TWRS is being challenged to do more and more with less and less. As a result, TWRS does not have the luxury of resolving all uncertainties prior to adopting a HLW volume reduction strategy. What strategy should be chosen in the face of the inevitable uncertainty? Where should research be focused to resolve particularly important uncertainties? Decision analysis (Clemen 1991) (Keeney et al., 1976) (Winterfeldt et al., 1986) provides a means to make such critical decisions that are essential to meet this challenge.

Because of its ability to address such critical issues, decision analysis has been chosen as the method for evaluating enhanced sludge washing. Decision analysis is an iterative, structured process that can deal effectively with complex systems. It provides a methodology for rational choice when facing uncertainty in policy issues, costs, technical information, and stakeholder values. Decision analysis is an integral aspect of the Systems Engineering approach being used by TWRS to evaluate and implement Hanford Site tank waste cleanup technologies. The following two subsections describe the general advantages of decision analysis for dealing with the difficult decisions and the specific advantages of using decision analysis as a tool for risk management.

1.2.1 Advantages of Decision Analysis.

The development of a decision model for the sludge washing decision serves a variety of needs. Key among them is the analysis and management of uncertainty. In addition, a decision model will provide documentation and justification of the decision rationale, will increase the likelihood of identifying alternatives that optimize achievement of objectives, and will provide a quantitative method of determining what additional technology development and characterization is needed and how much can justifiably be spent on such research.

Decision analysis is a valuable tool for documenting the rationale for a decision. It shows explicitly what values are considered in making a decision, how those values are weighted and what the expected impacts of the decision alternatives are on the values. Sensitivity analysis can be used to show the impact of changes in importance for specific values and the effect of different sets of value judgments for different stakeholders. This type of analysis is especially valuable for the sludge washing decision in which there are multiple, conflicting values to be considered. Decision analysis integrates scientific and engineering judgments about the expected performance of alternatives with stakeholder values regarding the relative importance of objectives. Thus, decision analysis completely documents the decision basis and the performance of alternatives.

Decision analysis often can promote creativity in the identification of alternatives. The explicit consideration of values and the identification of what is important in a decision provide leverage that can be used to create a broad range of alternatives. This increases the chances that an optimal alternative will be identified.

Decision analysis promotes clarity of thought. This clarity is a result of a well-defined theoretically based methodology as well as the insistence that all concepts used in the analysis are clearly defined. Thus, decision analysis enhances the likelihood that differences of opinion concerning what is the best alternative will be resolved by eliminating any differences that are due to miscommunication or failure to share information. Decision analysis promotes win-win strategies over zero-sum games.

All these advantages of decision analysis apply even in the special circumstance where uncertainty is not a critical factor in the decision process. However, the full power of decision analysis is realized when uncertainty is an issue. Decision analysis provides a methodology for identifying potential programmatic risks and evaluating alternatives for managing those risks. It also provides for a quantifiable method for valuing information needs and technology development.

1.2.2 Decision Analysis for Risk Management

There is much confusion and misunderstanding on the Hanford site about what constitutes risk management. One major source of confusion is due to the fact that "risk" is used to refer to uncertain impacts on public and worker health and safety, as well as to uncertainties in technical or programmatic performance. Public and worker safety cannot be compromised. However, the technical risks regarding pretreatment system performance need to be systematically considered using an appropriate methodology, so that those risks that are unacceptable can be separated from those that pose no real threat. By focusing effort on the significant programmatic risks it will be possible for TWRS to accomplish its mission in a timely and cost effective manner.

Decision analysis under conditions of uncertainty provides a risk analysis methodology that can be used to identify potential issues that pose a threat to the TWRS program. Risk analysis can distinguish those concerns that present an unacceptable risk to the program from those issues for which, while initially seeming to pose a risk, are determined upon further analysis to pose no real threat. Most planning and analysis within TWRS makes use of point estimates for key parameters and does not consider the range over which these parameters may vary. In fact, the decision analysis literature supports the fact that scientists and engineers have a bias towards overconfidence in that they tend to place much narrower error bands around their estimates of uncertain parameters than is justified by their degree of uncertainty (Kahneman et al, 1982).

Risk analysis consists of performing sensitivity analysis to determine the key parameters that impact the objectives or values that the program is trying to achieve. The specific parameters that have the potential to have a negative impact on the program outcomes then can be identified. Once identified, these variables are modeled probalistically to determine whether the expected program outcomes are desirable and whether the risk is within acceptable limits. If the risk is acceptable the issue can be put to rest; otherwise, risk management alternatives need to be identified and evaluated.

Decision analysis has a variety of tools that can be used to analyze risks, and can aid in understanding their magnitude and the actions that can be taken to mitigate them. These tools are described in Sections 3.0 and 4.0.

2. SLUDGE WASHING DECISION

Enhanced sludge washing has been selected as the baseline method for pretreating tank waste with the expectation it will result in a reasonable volume of HLW, a sufficiently low LLW radionuclide content, and pretreatment product streams that will serve as acceptable feeds for HLW and LLW vitrification. This process also is expected to be relatively simple, to avoid the need for extensive technology development, to expedite schedule, and to minimize cost.

Many details of the enhanced sludge washing process must still be defined, including the choice of specific technologies to implement the process, and the determination of what functions the process must perform. What volume of HLW is acceptable, and can enhanced sludge washing produce this small volume or is acidic processing required? Should strontium be removed from LLW? As a result of current uncertainties in process details, development and testing of select technologies to enhance the simple sludge washing process are being continued as the major thrust of the technical baseline. In parallel, a limited amount of technology development on other activities such as acid dissolution of sludges, advanced radionuclide removal, and organic destruction are continuing as contingencies. Some of the contingencies may prove necessary, or may at least be found to result in significant cost reductions or schedule improvements.

2.1 BASELINE PROCESS

The three principle operations of the enhanced sludge washing process are (1) solid–liquid separations, (2) alkaline leach, and (3) dilute caustic washes. The TWRS baseline pretreatment process, Case Beta, includes an enhanced sludge washing and the additional operations of cesium removal and LLW evaporation, as indicated in Figure 2–1. This report generally assumes that enhanced sludge washing takes place within the process envelope represented by Figure 2–1. However, the decision modeling described in this report is intended to be adaptable to other potential variations of pretreatment.

The enhanced sludge washing baseline is an in–tank sludge processing operation that accomplishes multiple stages of washing and blending to produce sludges that are suitable for vitrification (*TWRS Process Flowsheet,* Orme 1994a). The initial washing and blend stage is concurrent with retrieval, and is followed by an enhanced caustic wash. Three dilute caustic washes are then performed. Figure 2–2 depicts a typical DST configuration that may be used for enhanced sludge washing. As an alternative or supplement to in–tank processing, the use of filtration devices external to the waste tanks for solid–liquid separations also is being considered.

Figure 2–1. Waste Pretreatment Block Diagram

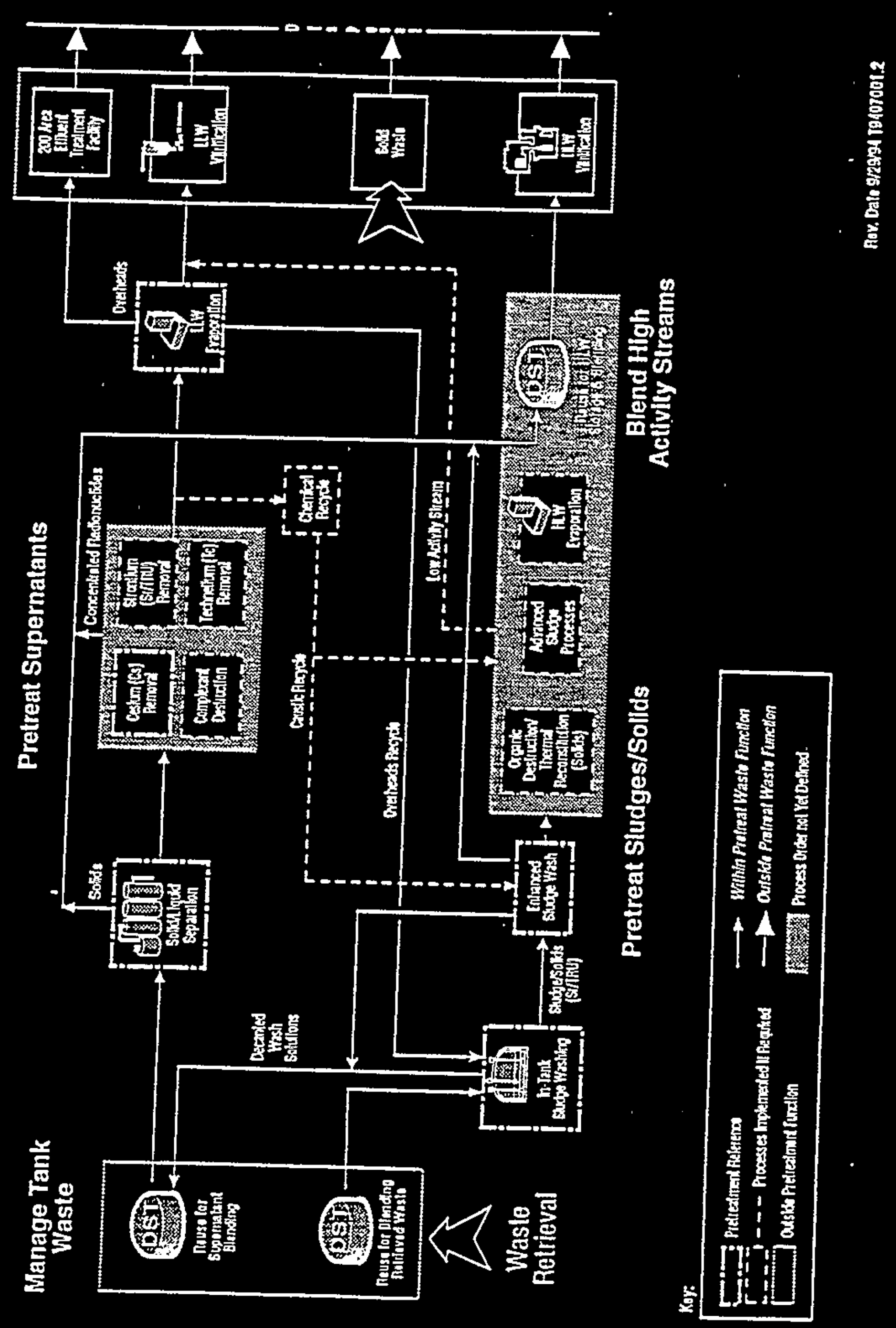
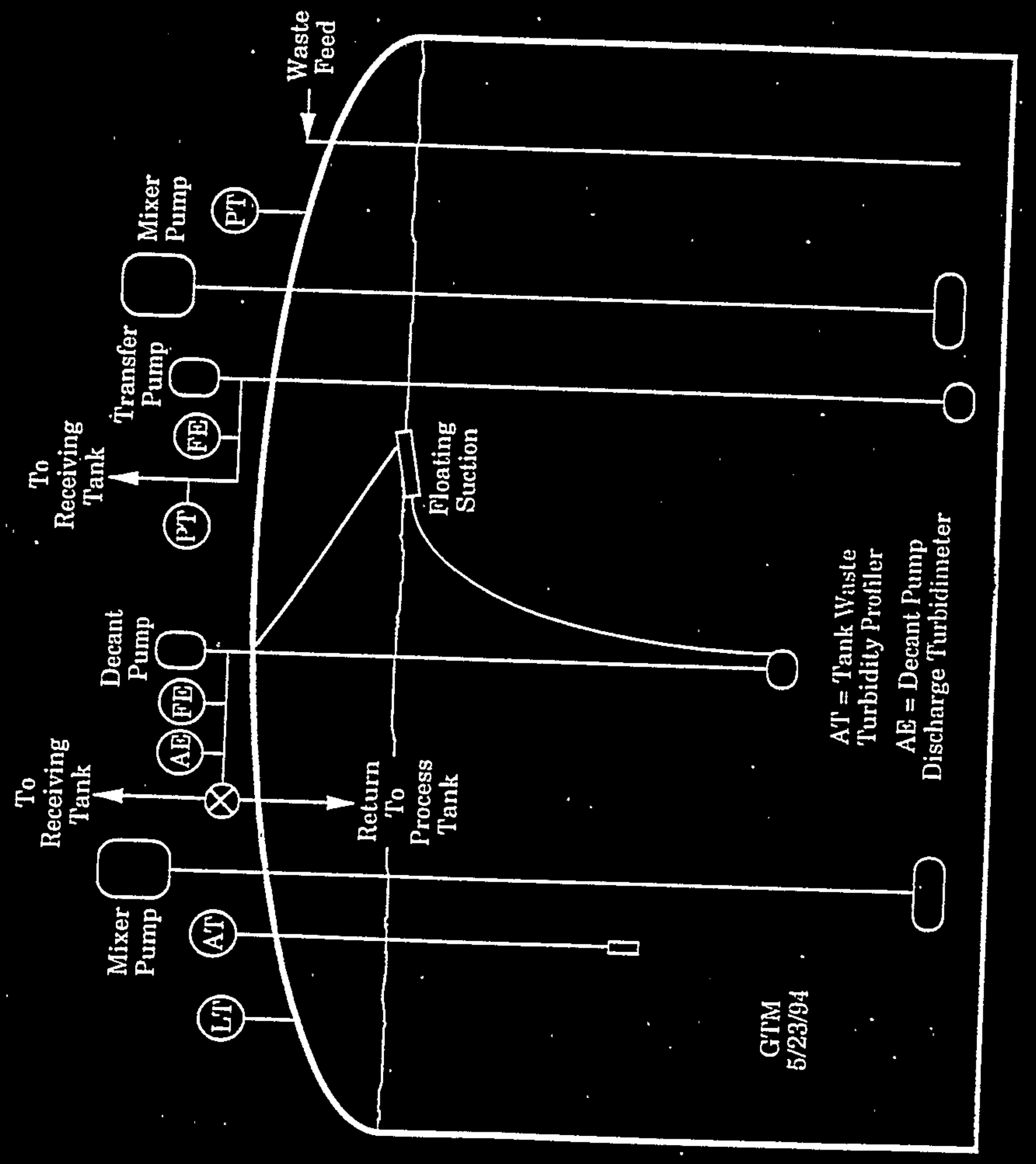


Figure 2-2. In-Tank Processing Equipment and Instruments



2.1.1 Water Wash

A primary purpose of pretreatment is to separate tank waste into a high–volume, low–activity stream and a low–volume, high–activity stream. For this purpose and to simplify the overall processing requirement, the first pretreatment operation performed on saltcakes and sludges is a simple wash with dilute caustic. The caustic solution is essentially a water wash with enough chemical addition to ensure that the wash solution is not corrosive to the carbon steel tanks and ancillary equipment. The primary constituents of saltcakes and sludges, non–radioactive sodium nitrate and other sodium salts, are dissolved in the wash solution and pumped to the LLW portion of the pretreatment facility.

The retrieval of waste from different tanks with dilute caustic solutions, and accumulation of this waste, constitutes the initial wash and blending function. This wash effectively occurs during retrieval as salts are dissolved and insoluble solids are slurried together. Blending occurs when slurries from different sources are combined in a single accumulation tank. This takes place when the contents of different tanks from the same tank farm are collected together, or when waste from different tank farms are combined.

The majority of the radionuclides are insoluble in the dilute wash and stay behind with the relatively low volume of insoluble solids. An exception is ^{137}Cs, which is soluble in the wash solution. Cesium is known to be a major nuclear constituent of the waste and therefore must be removed from LLW and returned to a HLW stream. ^{99}Tc is also soluble in the dilute wash, but is presumed not to be present in quantities sufficient to justify provisions for its removal.

Some waste tanks contain large quantities of organic complexants, which could complex strontium and transuranics (TRU) and thereby solubilize them from HLW sludges into LLW supernates. The complexants also may interfere with pretreatment processes intended to remove strontium and TRUs from LLW. If the concentration of strontium or TRU exceeds the acceptance criteria of the LLW vitrification plant, in–tank measures may be employed to reduce the level of contamination. The current leading candidate for organic complexant destruction is heat and digest, although the optimum combination of elevated temperature and pH is yet to be determined. In waste tanks where strontium and TRUs appear to be in solution, it is generally believed these materials are complexed, but the extent to which they exist as colloids or as dissolved species is unknown.

2.1.2 Alkaline Leach

When certain chemical elements (aluminum, chromium, and phosphorous) are present in waste sludges in high enough concentrations, they interfere with the vitrification process. In order to prevent a lowering of the amount of waste oxides that can be loaded into vitrified HLW, an excess in any of these three elements must first be removed. Simple sludge washing will not remove the chemical compounds containing these elements adequately because of the low solubility of the compounds in typical water–wash solutions.

Leaching and/or metathesis steps are necessary to solubilize the aluminum, chromium and phosphorus. The enhanced sludge washing process uses a strong sodium hydroxide solution to remove these materials by converting them to more soluble forms. Typical examples are the conversion of insoluble aluminum hydroxide to soluble sodium aluminate by reaction with caustic, the use of caustic solutions to convert insoluble chromium (III) hydroxide to soluble Cr (VI) species, and the metathesis of insoluble phosphates to soluble hydroxides (or carbonates).

The current flowsheet, based on data available at this time, reflects solubilities of aluminum, chromium, and phosphorus sufficiently high that a second alkaline leach is not planned. These solubilities, using a 3 M sodium hydroxide leach solution, are 85 wt% for aluminum, 75 wt% for chromium, and 70 wt% for phosphorus. As uncertainties concerning the need for leaching processes are resolved, future decisions will be made as to the advisability of adding a second leaching cycle for specific wastes. Subsequent leaching, if required and identified early in the design phase, can be added with little impact to the pretreatment process.

2.1.3 Solid–Liquid Separation

The separation of solids and liquids takes place during each of the three principle operations of enhanced sludge washing. In all cases, the purpose of solid-liquid separations is to separate highly radioactive solids destined for HLW from the LLW liquids. Solids that are in solution go with the liquid LLW stream and thus reduce the volume of HLW; however, solids that are in suspension in the liquids need to be allowed to settle out so as to minimize interference during subsequent processing.

In the first-stage settling tanks, slurries settle to a solids layer containing 20 wt% solids. After a one–month settling period, the supernate is decanted by use of a floating suction decant pump to a second stage settling tank. Decantation of supernate is not expected to yield a perfect solid–liquid separation. Some entrained solids are expected from less–than–complete settling, or there may be inadvertent entrainment at the solid–liquid interface during decanting. An additional polishing separation downstream from the settle and decant operation using filtration technology is anticipated.

Flocculating agents may be used to accelerate settling rates. At the current early stage of flowsheet development, because the effectiveness of flocculants with Hanford Site tank solids has not been demonstrated, it is unknown if they will be used. Conservatively, the current flowsheet assumes the addition of flocculants to the first-stage settling tanks, second-stage settling tanks, first wash tank, second wash tank, and third wash tank. If future experience shows this conservatism to be unnecessary, a decision to consolidate the entire enhanced sludge washing process into a single tank may be considered. This would reduce the number of tanks required for in–tank processing, eliminate several tank–to–tank transfers, and free additional DSTs for pretreated waste storage.

During the caustic leach operation the solution is brought into close contact with HLW solids, and the mixture is held in–tank while the solids gravity settle. The majority of the particulates settle within the first several days, but some require a significantly longer period and others do not settle at all. The purpose of this settling is to compact the HLW solids to reduce the interstitial spaces between particles, thereby displacing the caustic solution into the supernate region. Dilute caustic is added to the first wash tank to mobilize and wash the solids, and the resulting slurry is transferred to the second wash tank. After gravity settling the supernate is decanted, and the wash is repeated two more times. Three stages of washing are planned because the settled solids layer, being only 20 wt% solids, is mostly interstitial liquor. The washed solids are then transferred to a HLW accumulation tank.

The separation of solids and liquids by gravity settling is considered a suitable primary separation technique, but may not be capable of meeting overall separation requirements. Uncertainties of concern are that overall efficiencies may not be sufficiently high to ensure the LLW product does not exceed NRC Class C for TRU, and/or the effect of feed solids loading on cesium ion exchange performance. Cross-flow microfiltration is considered capable of meeting the overall separation requirement either as a single system or as a secondary filter. Other alternatives being considered include combination processes such as settling plus filtration or centrifugation plus filtration.

2.2 BACKUP PROCESSES

Alternatives to enhanced sludge washing are being developed in the event that further reduction in HLW volume is required, or some other need develops for which the baseline process is inappropriate. A potential alternative being investigated during FY 1995 is acid dissolution of sludges followed by radionuclide removals. The radionuclide separation processes of primary interest as backup for enhanced sludge washing are acid-side solvent extraction and ion exchange. Laboratory testing of batch solvent extraction during FY 1995 using test-tube quantities of actual tank waste will determine preliminary separation coefficients for strontium and the transuranics. Results from these tests will be used to confirm the generic Transuranic Extraction (TRUEX) Model or to update the model. Additionally, continuous bench testing of an integrated solvent extraction using 2-centimeter contractors will be conducted using simulated waste. Improved separation coefficients for strontium and transuranics will be determined as part of this activity. Acid dissolution and subsequent radionuclide removals will be pursued during FY 1996 and FY 1997 only if the simpler, more mature alkaline pretreatment processes under investigation are unsuccessful.

2.2.1 Acid Dissolution

A more aggressive approach to minimizing the volume of HLW glass resulting from pretreatment of the tank wastes (compared to sludge leaching/metathesis and washing) would be to dissolve the sludge in acid, and process the acidic solutions to separate the radionuclides from inert chemical components. The small-mass radionuclide fraction would be vitrified as HLW and the large-mass inert chemical fraction would be vitrified as LLW. This method of pretreatment could be applied either after leaching and/or metathesis of the sludge or following only simple sludge washing. In either case, the approach would require the development and implementation of acidic processes for radionuclide separation.

Dissolution data are now available for sludges from three types of DST waste and from four different SSTs. High percentages of dissolution were observed in over half of the cases. In the cases where the percentage of total sludge dissolution was low, the percentage of radionuclide dissolution was high. Depending on yet-to-be-defined LLW vitrification feed criteria, it is possible that the residual sludge solids remaining after dissolution could go to LLW. Although this would substantially reduce the HLW glass volume, insufficient data exists to assume the approach is realistic.

Batch dissolution testing will be conducted during FY 1995 on test-tube quantities of actual tank waste under a wide range of time and temperature conditions using nitric acid, nitric/oxalic acid mixtures, and nitric/hydrofluoric acid mixtures. Component material balances will be determined so that better projections of the assumed HLW undissolved sludge and resulting glass volume can be made.

2.2.2 Acidic Processing

Several technologies have been studied for the removal of TRUs from acidic waste, including solvent extraction, extraction chromatography, solid sorbents, and precipitation. Of these technologies, the most promising appears to be solvent extraction using the TRUEX process. This process selectively extracts the TRU elements into a solvent phase, while leaving most of the inert chemical components in the aqueous phase. Lanthanide elements, however, also are extracted. TRUEX has been extensively demonstrated in laboratory testing using simulated solutions, and to a limited extent on actual wastes. A computer program has been prepared for modeling performance of the TRUEX process for many of the key elements.

Approaches for the removal of strontium from dissolved sludge solutions have been tested, but the technologies are not advanced. Solvent extraction using crown ethers (the SREX process), either alone, as mixed TRUEX/SREX, or as mixed PUREX/SREX solvents, shows promise in laboratory tests with simulated waste. Solvent extraction using a cobalt-dicarbollide-based solvent is being used on a large scale in Russia, but the solvent used may not be acceptable for use in the United States.

Removing cesium from acidic solutions produced during sludge dissolution may be required to meet LLW vitrification feed requirements. The amounts of cesium remaining in the sludge following wash and enhanced leach steps is unknown, but is expected to be higher than the limit for LLW vitrification. While relatively well-developed technologies exist for removing cesium from alkaline solutions, only less developed acidic processes are available. The acidic technologies include precipitation, ion exchange, and solvent extraction. Of these, only precipitation has been used on a large scale. Precipitation processes have inherent disadvantages, such as batch operation and the need for using solid-liquid separation techniques. Solid sorbents such as crystalline silicotitanates (CST) have a high affinity for cesium, but cannot be eluted and presently are not available for column operation. Removal of cesium by solvent extraction with a cobalt dicarbollide-based solvent is being practiced on a large scale in Russia, but the solvent used may not be acceptable for use in the United States.

Although it is currently believed that technetium is not present in tank waste in sufficient quantity to justify its removal, a future requirement to do so is possible. Technetium can be removed using several of the solvent extraction processes that could also be used for removing TRUs and strontium, as well as other extraction processes. Anion exchange processes also could be used. If the dissolved sludge solution is neutralized after removing most radionuclides of concern, the technetium that remains in the liquid phase could be removed by alkaline processes.

3. CURRENT STATUS OF THE MODEL

As a result of significant work in fiscal years 1994, a "strawman" PDM has been developed to aid in decisions regarding pretreatment of Hanford tank wastes. The plans for extension of this model in FY 1995 as described in this document are designed to build on the foregoing work. This section briefly summarizes the current status of the PDM in order to provide relevant background for the subsequent sections of this report. A more detailed description of the current PDM is contained in the document *Status Report on the Development of a Decision Analysis Model for Evaluating Pretreatment Alternatives* (Sutherland, et al. 1994), subsequently referred to simply as the *Status Report.*

3.1 BASIC OPERATION OF THE MODEL

The current PDM is designed to aid in the evaluation of "pretreatment strategies," where a strategy is a complete, internally consistent operating scenario for pretreatment. Defining a pretreatment strategy requires specifying a large number of individual decisions about how each stage in pretreatment will be conducted, what technologies will be employed, etc. Example strategies that might be evaluated using the existing PDM are no separations, treatment to an intermediate form and extensive separations, as well as the current reference, enhanced sludge washing. For each strategy to be evaluated, a number of "technical" model inputs must be developed describing how the strategy performs. In evaluating the impacts of a pretreatment strategy, the model takes a system–wide perspective, explicitly quantifying the impacts of pretreatment decisions on the other components of the TWRS. In addition to a technical description of the performance of a pretreatment strategy, the model requires value judgment inputs describing how trade–offs should be made between achieving different pretreatment objectives (e.g., minimizing project cost, minimizing project duration, and minimizing LLW volume). Based on the technical inputs generated for several strategies and the value judgment inputs, the model can generate numerous outputs useful for comparing candidate strategies.

The PDM is implemented as a decision support system that can be run on an IBM or compatible personal computer. It is designed to be both easy to use and powerful. To ensure ease of use, the user interface or "front end" of the model is based on the widely used Excel[1] spreadsheet software. Excel is used to organize and store the model's data inputs as well as to create graphical outputs. The decision analytic power of the model comes from its use of Decision Programming Language[2] (DPL) decision analysis software to represent the structure of decisions and uncertainties in the model and to perform probabilistic calculations.

[1] Excel is a trademark of Microsoft Corporation, Redmond, Washington.
[2] DPL is a trademark of ADA Decision Systems, Menlo Park, CA.

3.2 MODEL DESIGN PHILOSOPHY

The PDM was initially designed to be used in a process that allows decision makers to quickly and cost–effectively evaluate new pretreatment strategies, and to compare new strategies with current reference strategies. To be useful in this role, it was determined that the model must facilitate the development and communication of an explicit decision rationale for pretreatment decisions. It also was determined that model inputs and outputs must be open to technical peer review to promote technical consensus. To ensure the model could be developed rapidly, the model was designed to make maximum use of prior work on decision and value modeling relevant to TWRS decisions. Finally, it was decided that the model should help facilitate public involvement in pretreatment decisions. To this end, the model was designed to provide a clear role for value judgments and to allow the impact of alternative value judgments to be investigated.

3.3 MODEL COMPONENTS

The current PDM is implemented as a computer–based decision support tool that is designed to quantitatively analyze pretreatment decisions based on the impact of these decisions on relevant uncertainties and pretreatment performance criteria. The major components of the model are:

1. ***A decision tree***, which identifies key decisions and uncertainties relevant to the evaluation of a pretreatment strategy;

2. ***A value model***, which identifies what criteria are of interest in evaluating a pretreatment strategy, and which provides a basis for quantifying the "value" associated with a pretreatment strategy based on these criteria; and

3. ***A set of submodels***, which are used to calculate the impact of different pretreatment strategies on the criteria of interest for evaluating pretreatment decisions.

The following sections briefly describe each of these model components.

3.3.1 Decision Tree

The PDM is structured around a "decision tree," which explicitly identifies the key decisions and uncertainties that the model addresses. A decision tree is a graphical representation of the interrelationships among the factors bearing on a decision or group of related decisions. The decision tree for the PDM is depicted in Figure 3–1 below.

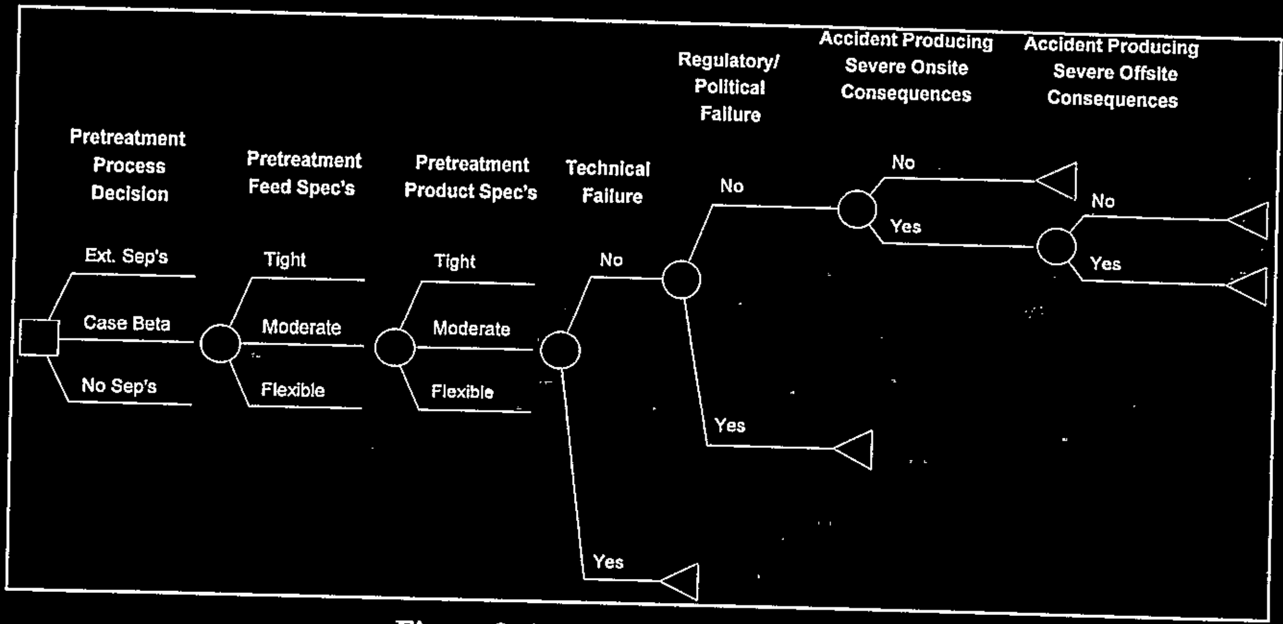


Figure 3–1. Decision Tree for PDM

The decision tree in Figure 3–1 is read from left to right. Boxes in the tree represent decisions, while circles represent uncertainties. Boxes and circles are collectively referred to as "nodes" in a decision tree. The order of decision and uncertainty nodes from left to right indicates the order in which decisions are made and uncertainties are resolved. The lines emanating from each box or circle in the decision tree represent the possible decision options or outcome states associated with each decision or uncertainty. These lines are referred to as "branches" in a decision tree.

The model assumes that an initial decision must be made regarding which pretreatment process to pursue prior to the finalization of decisions regarding pretreatment feed specifications and pretreatment product specifications. Pretreatment feed and product specifications are treated as uncertainties in the model. The model requires a separate evaluation of each pretreatment process for each combination of possible feed and product specifications.

Following the selection of a pretreatment process and the determination of feed and product specifications, the model assumes that several key uncertainties will be resolved. First, the model assumes that there is some chance that the pretreatment process will not "work" (i.e., technical failure). In the model, it is assumed that this likelihood is dependent on the selection of a process as well as on the feed and product specifications. A process is defined to "work" if it is technically possible for the process to produce product within specifications given feed within specifications. Furthermore, the process fails to work if the process must be "significantly" altered in order to achieve the desired input and output specifications.

Even if a pretreatment process is technically successful, there is still a chance that the process may fail to be implemented due to a lack of regulatory and/or political acceptability. Thus, the likelihood of regulatory/political failure is the next key uncertainty in the decision tree.

As with the likelihood of technical failure, a process fails to meet regulatory/political approval if the process must be significantly altered in order to be approved.

The final key uncertainties considered in the model involve the likelihood of accidents generating severe onsite or offsite consequences. The model requires two specific assessments: (1) the likelihood that an accident will occur during the lifetime of the pretreatment process and result in "severe onsite consequences," and (2) the conditional likelihood that an accident that results in "severe onsite consequences" also will result in "severe offsite consequences."

For each choice of pretreatment option and feed and product specifications, the model assigns a value to each of the five possible outcomes (corresponding to the five triangles on the right hand side of the decision tree in Figure 3–1), based on their desirability. The basis for assigning a value to each outcome is summarized in Section 3.3.2 below.

3.3.2 Value Model

The value model component of the PDM provides the means for converting knowledge about the consequences of a pretreatment strategy (e.g., its cost, schedule, and risk implications) into a measure of the overall value or benefit associated with choosing that strategy. The current PDM uses a "strawman" value model developed in a three step process: (1) identification of the criteria by which pretreatment strategies should be evaluated, (2) identification of appropriate quantitative measures for each criterion, and (3) development of an equation for combining these measures into a single measure of pretreatment benefit. The development of a "strawman" value model through each of these three steps is described briefly below.

To construct the strawman value model, a set of fundamental criteria by which to evaluate pretreatment options was first developed. The criteria identified for the PDM value model were chosen explicitly to be comprehensive and also to ensure compatibility with previous work on identifying appropriate evaluation criteria for TWRS decisions. In particular, all the major criteria identified by the TWRS program Leadership Council and staff (Johnson et al, 1993) were included in the PDM, either as part of the value model (e.g., schedule and cost) or as uncertainties in the decision tree (e.g., likelihood of technical success and of regulatory success). Figure 3–2 illustrates the criteria included in the PDM value model in a hierarchy.

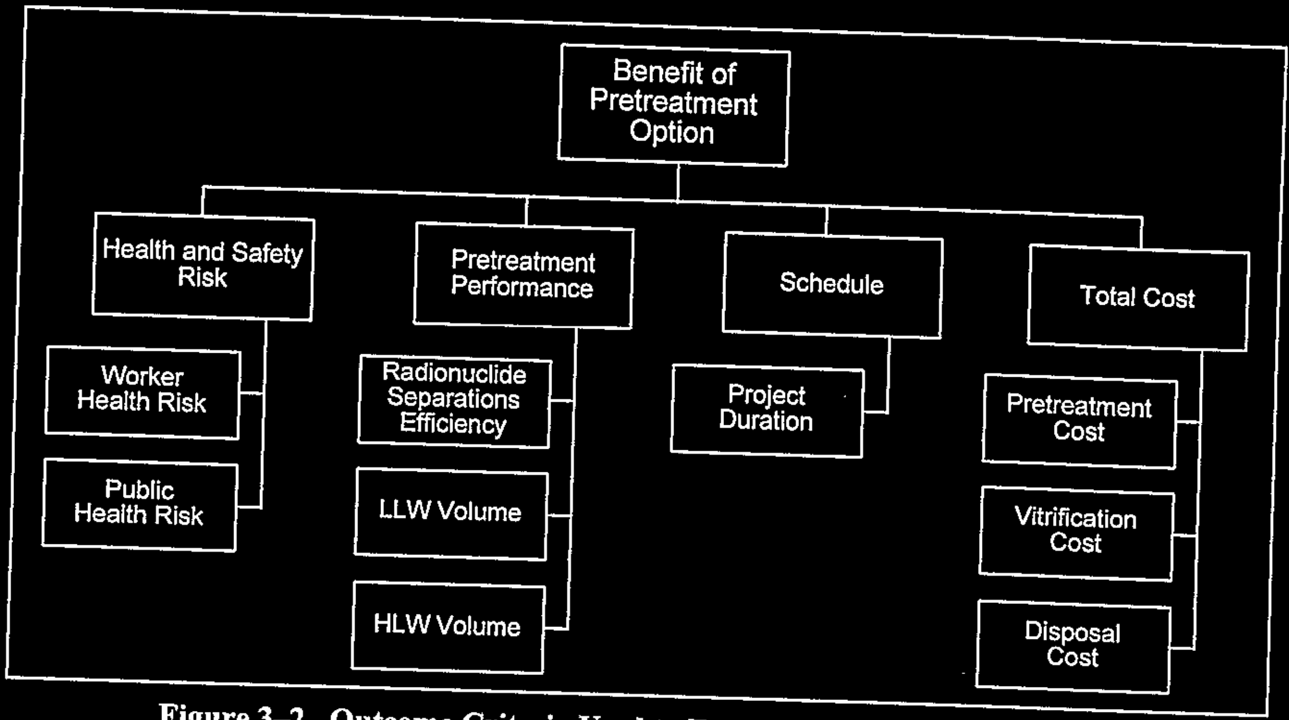


Figure 3–2. Outcome Criteria Used to Evaluate Pretreatment Options

In order to estimate how well alternative pretreatment options perform against these criteria, it is necessary to quantify that performance. Thus, the second major step in developing the strawman PDM value model was to identify quantitative performance measures for each criterion. Table 3–1 lists the criteria and the performance measure used for each.

Table 3–1. Criteria and Performance Measures

Criterion	Performance Measure
Worker Health Risk	1 if health effects occur; 0 otherwise
Public Health Risk	1 if health effects occur; 0 otherwise
Radionuclide Separations Efficiency	Percent curies to HLW
LLW Volume	Volume in m^3
HLW Volume	Volume in m^3
Schedule	Project Duration in Years
Total Cost	Millions of 1994 dollars

Finally, an equation for combining these measures (a "utility function") was determined based on a rigorous approach for making multi–criteria decisions known as multi–attribute utility theory (MAU) (Keeney, et al., 1976). A general additive function was determined to be appropriate to convert a specification of performance on all performance measures into a single measure of benefit, as shown below.

$$U(C_{k,j}) = w_{wr}U_{wr}(S_{wr}) + w_{pr}U_{pr}(S_{pr}) + w_{se}U_{se}(S_{se})$$
$$+w_{lv}U_{lv}(S_{lv}) + w_{hv}U_{hv}(S_{hv})$$
$$+w_{sc}U_{sc}(S_{sc}) + w_{tc}U_{tc}(S_{tc})$$

where:

W's		represent the "weights" for each criterion
U's		represent "single attribute utility functions" for each criterion
S's		represent the score or performance level for each performance measure
wr	=	worker risk
pr	=	public risk
se	=	separations efficiency
lv	=	low–level waste volume
hv	=	high–level waste volume
sc	=	schedule
tc	=	total cost

The utility function is designed to be flexible enough to allow a wide variety of different value judgments to be expressed. Different value judgments are expressed through the determination of "weights" (reflecting the relative importance of achieving specific levels of performance across different criteria) and of "single attribute utility functions" (reflecting the relative importance of different levels of performance on a single criterion). Strawman value judgments were developed to form a preliminary set of weights and single attribute utility functions. The strawman value judgments are described in detail in the *Status Report*.

3.3.3 Submodels

To evaluate a pretreatment strategy, the PDM requires an assessment of the performance of that strategy on each of the performance measures listed in Table 3–1 above. Because many of the required performance assessments are very difficult to make directly, the PDM provides submodels that can calculate the value of performance measures based on a set of more easily determined inputs. The PDM includes a quantitative submodel for each of the criteria highlighted in Figure 3–3 below.

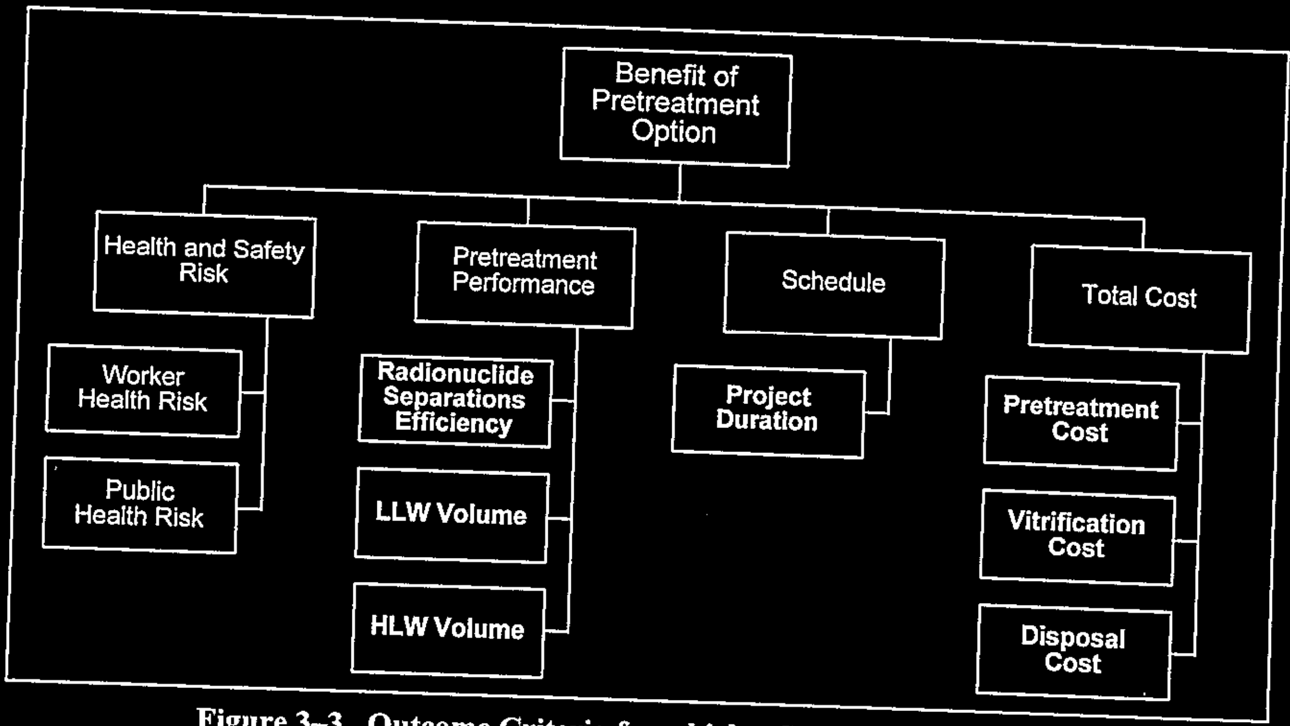


Figure 3–3. Outcome Criteria for which a Submodel is Provided

The basic concept of a submodel is illustrated in Figure 3–4 below, which depicts a submodel for calculating the volume of HLW produced by a pretreatment strategy based on a number of inputs.

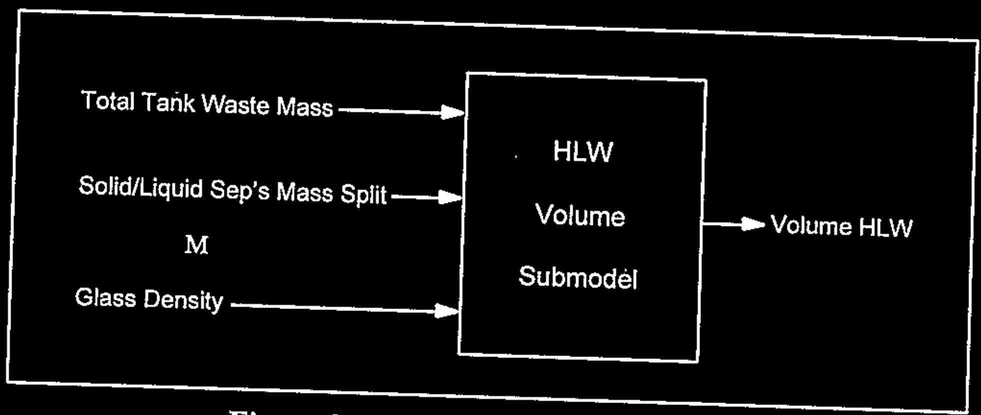


Figure 3–4. Example PDM Submodel

The purpose of this submodel is to break down the assessment of the volume of HLW generated into a number of lower–level assessments (e.g., the total mass of tank waste, the mass split between HLW and LLW during solid/liquid separations, and the density of HLW glass), corresponding to the submodel's inputs. It is assumed that more accurate results can be obtained by assessing individual submodel inputs (and then logically combining the inputs using the submodel) than could be obtained by a direct assessment of the submodel output.

Submodels are represented in the PDM using a decision–analytic tool known as influence diagrams. An influence diagram model has been constructed for each criterion highlighted in Figure 3–3 above. An example influence diagram for the calculation of the volume of high level waste glass produced under a particular pretreatment process is illustrated in Figure 3–5 below.

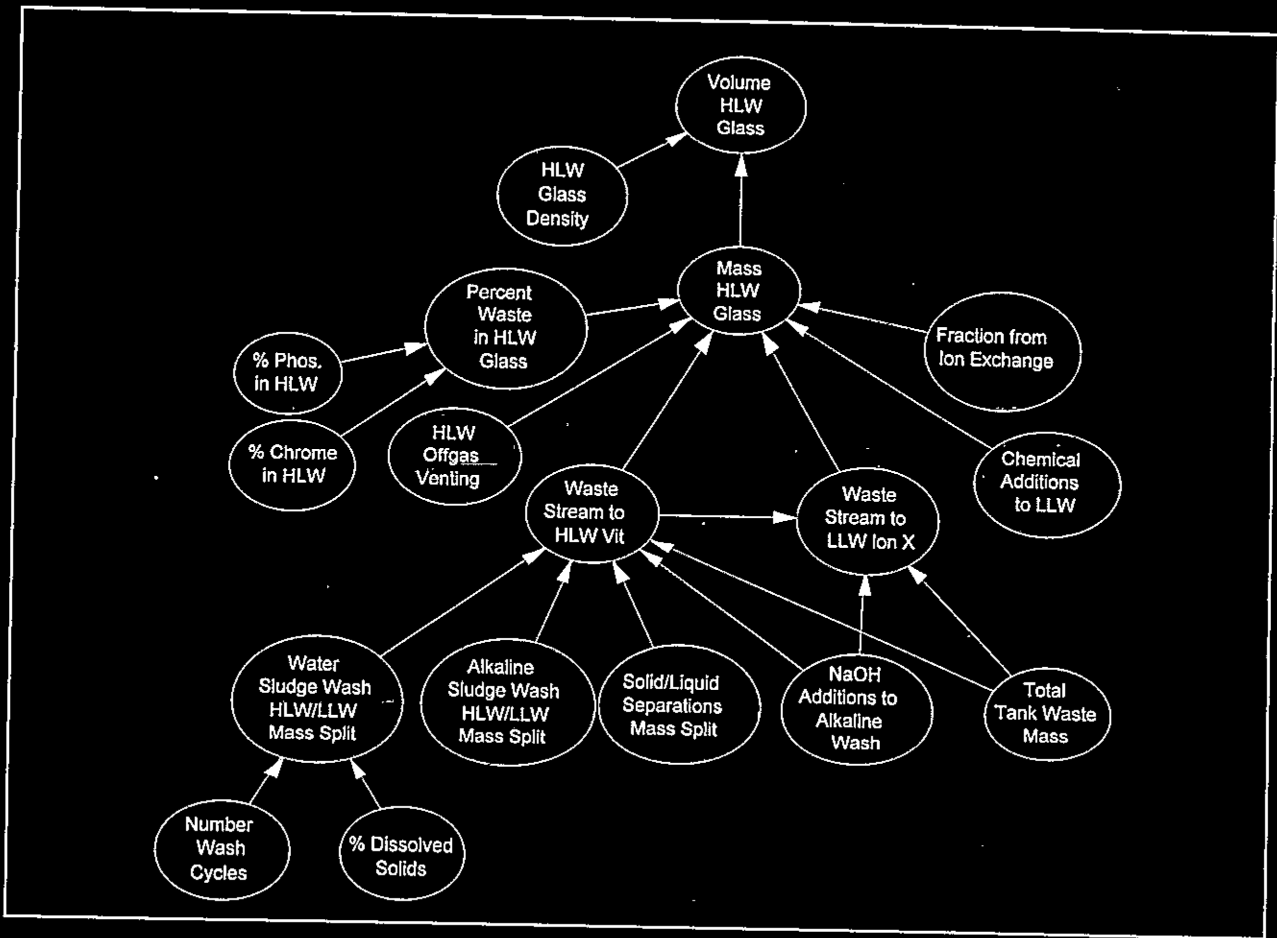


Figure 3–5. Influence Diagram for HLW Volume

The ovals in an influence diagram indicate uncertain quantities, while arrows from one oval to a second oval indicate that the quantity represented by the second oval is dependent upon the quantity represented by the first. Thus, the influence diagram in Figure 3–5 indicates that the total volume of HLW glass produced is determined by the mass and the density of the HLW glass produced. The mass of HLW glass is, in turn, determined by the percentage of waste in the glass produced, the mass of tank waste that goes to HLW vitrification, the mass of waste that goes to LLW ion exchange, the fraction of waste from ion exchange that goes to the HLW stream, the mass of chemical additions to LLW, and the mass lost through offgas venting.

In Figure 3–5, ten ovals are shown shaded, indicating the quantities that are required as inputs to the submodel. Thus, for example, the quantity "Percent Waste in HLW Glass" is shaded and is required as a submodel input. The other factors shown in the diagram as having influences on this quantity ("% Phosphorous in HLW" and "% Chrome in HLW") have been identified to aid those providing inputs to the model in thinking about all the relevant issues, but are not explicit inputs to the submodel.

The final component of each submodel is a set of equations which represent the relationships between the model inputs and outputs. For example, the equations used to combine the assessed quantities shown shaded in Figure 3–5 above into an estimate of HLW glass volume are as follows:

$$HLWVol = \frac{HLWMass}{HLWGlassRo}$$

$$HLWMass = \frac{HLWVit + (LLWIonX + ChemAdd) * IonXFrac - HLWGas}{HLWGlass\%}$$

$$LLWIonX = TankMass + NaOHAdd - HLWVit$$

$$HLWVit = (TankMass * SolMS + NaOHAdd) * AlkMS * H2OMS$$

where:

HLWVol	=	High–level waste glass volume
HLWMass	=	High–level waste glass mass
HLWGlassRo	=	High–level waste glass density
HLWVit	=	Waste stream to HLW vitrification
LLWIonX	=	Waste stream to LLW ion exchange
ChemAdd	=	Chemical additions to LLW
IonXFrac	=	Fraction from ion exchange
HLWGas	=	High–level waste offgas venting
HLWGlass%	=	Percent high–level waste in glass
TankMass	=	Total tank waste mass
NaOHAdd	=	NaOH additions to alkaline wash
SolMS	=	Solid/liquid mass split
AlkMS	=	Alkaline sludge wash HLW/LLW mass split
H2OMS	=	Water sludge wash HLW/LLW mass split

A detailed description of each PDM submodel is provided in the *Status Report.*

3.4 MODEL ANALYSIS CAPABILITIES

The model is designed to produce a number of useful outputs to aid decisions regarding pretreatment. This section provides an explanation of a small number of example outputs that can be generated using the current PDM. The *Status Report* contains a more complete treatment of model outputs and illustrates each output graphically. Primary PDM outputs include the following:

1. **Comparison of pretreatment options.** Graphs can be produced comparing the expected performance of pretreatment options based on a single criterion (e.g., total cost) as well as on overall pretreatment benefit (across all criteria).
2. **Comparison of probability distributions for utility of pretreatment options.** Probability distribution graphs can be produced to aid in understanding the degree of certainty associated with the estimated benefit of different pretreatment options.
3. **Value of information.** Graphs can be generated depicting the potential value of reducing or resolving the uncertainties considered by the model. These outputs are useful for determining where research funds can usefully be directed.
4. **Sensitivity analysis.** The model can produce numerous graphs depicting how model recommendations change with changes in both technical and value judgment inputs. This type of output is useful for examining the robustness of model recommendations, as well as for determining the implications of alternative views about model inputs.

4. MODEL EXTENSION FOR THE SLUDGE WASHING DECISION

The sludge washing decision involves many complexities, including: (1) numerous lower–level decisions with potentially complex interactions, (2) significant uncertainties which cannot be completely resolved before a course of action is chosen, (3) multiple conflicting objectives, and (4) a need to develop both technical and public consensus regarding the appropriate course of action. Decision analysis has been chosen as the basis for evaluating the sludge washing decision because it provides defensible tools for dealing with all of these problem complexities.

This section provides a detailed description of how decision analysis techniques can be applied to aid in the sludge washing decision. The general approach involves extending the current PDM to facilitate analysis of the sludge washing decision as well as analysis of specific technology alternatives related to this decision. The extended model is referred to in this document as the SWDM. This section is divided into two subsections. The first subsection describes the proposed extension of the PDM to support the sludge washing decision, and describes the general process for using the resulting SWDM model to aid in decision–making. The second subsection provides detail on how the impacts of low–level technology decisions can be modeled and analyzed.

4.1 GENERAL APPROACH FOR MODEL EXTENSION

As described in the previous section, the current PDM is designed to aid in the evaluation of high–level pretreatment strategies, where each strategy is defined by a large number of low–level technology decisions. The relationship between a pretreatment strategy and individual technology decisions is illustrated in a "strategy table" in Figure 4–1 below. In the figure, example pretreatment technology decisions regarding solid/liquid separations, cesium removal, and TRU removal technologies are listed from left to right. For each technology, a simplified list of technology options is provided (e.g., centrifugation and filtration for solid/liquid separations). Specification of a pretreatment strategy (e.g., Case Beta) requires a choice from each list of technology options. Thus, the connected circles in the figure represent one possible pretreatment strategy.

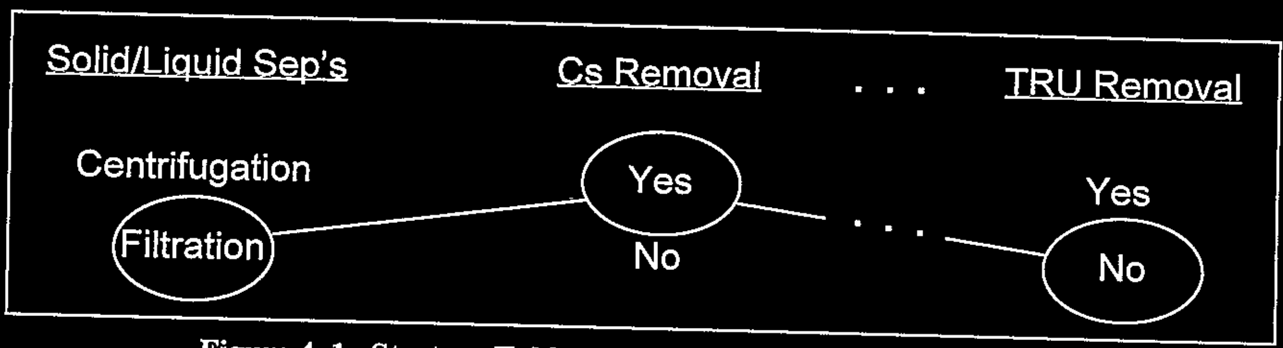


Figure 4–1. Strategy Table Illustrating Pretreatment Decisions

Since the current PDM evaluates pretreatment strategies (as illustrated in the block diagram in Figure 4–2) rather than individual technologies, a complete new set of inputs must be developed each time a new strategy is to be evaluated. Additionally, the impacts of individual technology decisions cannot be evaluated directly.

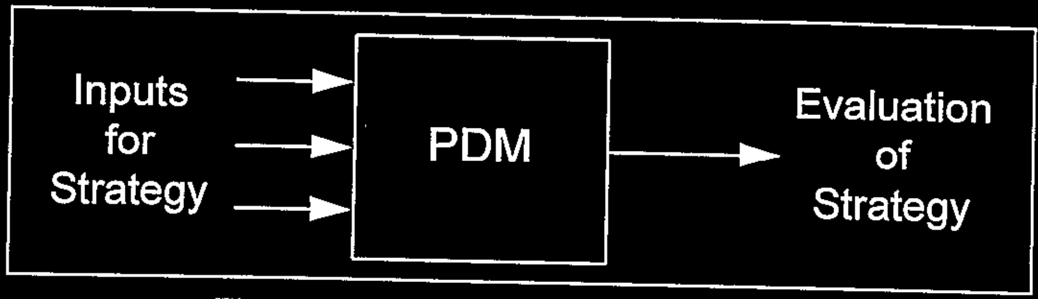


Figure 4–2. Block Diagram of Current PDM

It has become evident that the utility of the PDM to support the sludge washing decision and related decisions would be increased greatly if it were extended to allow a more direct evaluation of lower–level technology decisions. The envisioned revised model formulation is depicted as a block diagram in Figure 4–3. The revised model is referred to in this document as the SWDM to distinguish it from the existing PDM.

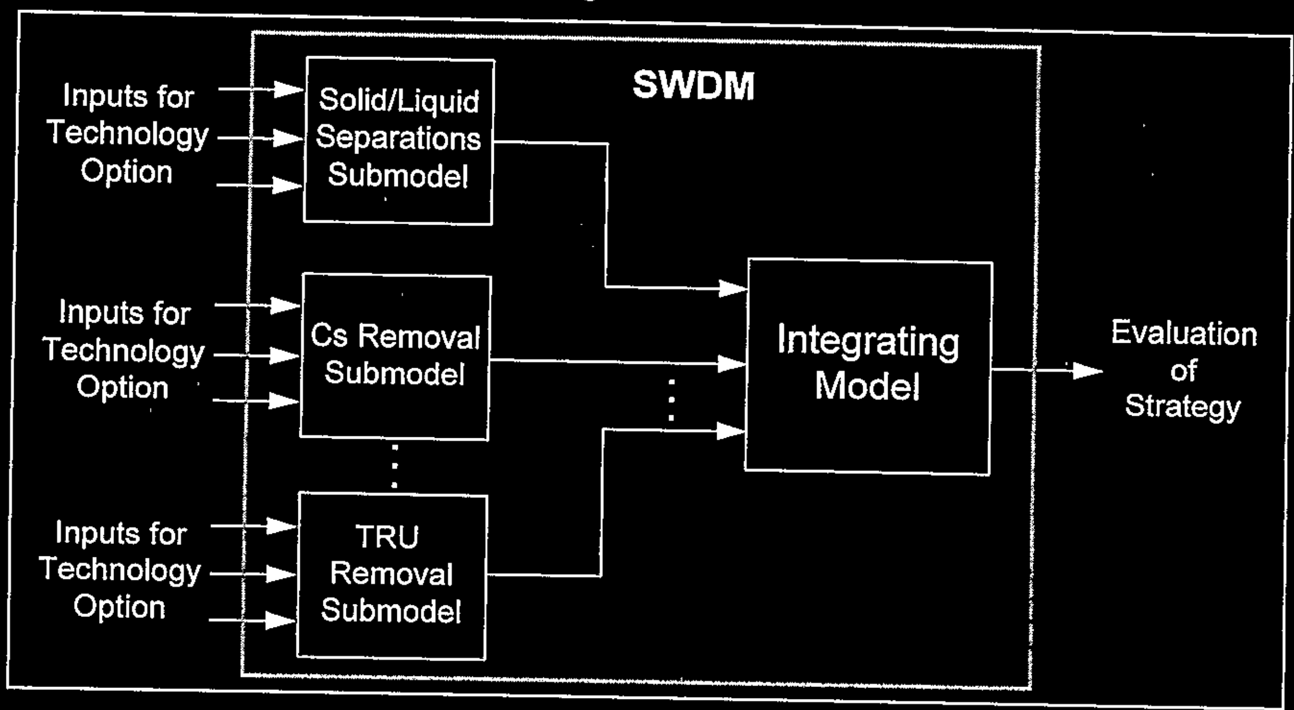


Figure 4–3. Block Diagram of SWDM

This section describes work to date and the proposed future work for developing the SWDM by extending the PDM to facilitate evaluation of individual technology decisions related to the sludge washing decision. The section is organized into five major subsections. The first subsection describes the vision for the SWDM, including a summary of the needs that motivate model revision, the questions that the revised model is designed to help answer, and the revisions to the model necessary to ensure that these questions can be answered. The second through the fourth subsections describe in detail the planned revisions to PDM components (decision tree, submodels, and value model, respectively) necessary to develop the SWDM. Finally, the fifth subsection describes the envisioned analysis capabilities of the SWDM.

4.1.1 New Model Vision

The primary goal of the SWDM is to aid DOE, WHC and other stakeholders in developing an understanding of and ultimately making the sludge washing decision. To this end, planned extensions to the PDM are based on a set of key questions that the SWDM must be able to help answer in order for the model to aid in the sludge washing decision process. This section lists these key questions, describes model requirements derived from the need to answer these questions, and summarizes the corresponding planned model revisions.

4.1.1.1 Questions the SWDM Should Help Answer

The design of the SWDM is based on the assumption that the model should aid in answering all of the key questions surrounding the sludge washing decision. Thus, to develop an appropriate model design, it was first necessary to identify a comprehensive list of such questions. The following list provides the key questions identified to date that serve as the basis for the SWDM design:

1. ***Does enhanced sludge washing perform satisfactorily, or should advanced separations processes be used? What are the relative advantages and disadvantages of the two alternatives?*** These are the fundamental questions that must be answered for the sludge washing decision. As described in the Enhanced Sludge Washing Evaluation Plan, these questions will be posed on an annual basis between now and FY 1998. Each year, the question would be answered based on current best available information and the answers would be used to help guide pretreatment research in the most promising directions.
2. ***Are the remaining uncertainties in the performance of enhanced sludge washing and advanced separations processes sufficiently small that a final choice between the two approaches is justified?*** This is an additional key question that should be asked on an annual basis to determine whether research to resolve uncertainties should be continued or whether enough is known to commit to a course of action.
3. ***What are the costs and benefits of resolving specific residual uncertainties before choosing between enhanced sludge washing and advanced separations processes?*** This question must be answered to guide the direction of specific research efforts between now and the sludge washing decision point.

4. ***What specific technologies should be used if enhanced sludge washing or some minor variation is implemented? What are the relative advantages and disadvantages of alternative technology choices?*** Within the general rubric of enhanced sludge washing, there are many low–level decisions that must be made regarding which alternative technologies are implemented.

5. ***What specific technologies should be used if advanced separations processes must be implemented? What are the relative advantages and disadvantages of alternative technology choices?*** As with enhanced sludge washing, there are many low–level decisions to be made.

6. ***What is the value of continuing development of individual technologies?*** At every point in the pretreatment decision process, there is some set of favored technologies. However, there is value to continuing development of technologies that are currently out of favor in order to maintain flexibility, particularly when there are large uncertainties in technology performance.

7. ***How sensitive are the answers to all of the above questions to alternative views about the technical performance of individual technologies or of entire pretreatment strategies?*** It is possible that technical consensus will not be reached regarding the relative merits of enhanced sludge washing and advanced separations processes or regarding the relative merits of candidate technologies for implementing these processes. To this extent, it is important to be able to investigate the extent to which alternative technical judgments impact decisions.

8. ***How sensitive are the answers to all of the above questions to alternative views about the relative importance of achieving conflicting pretreatment objectives?*** Just as with technical judgments, it likely will be important to be able to easily investigate the implications of alternative value judgments for pretreatment decisions.

The capabilities of the SWDM must be tailored to facilitate answering these questions. Thus, for example, the revised model must be designed to explicitly model the sludge washing decision and associated uncertainties to ensure that questions 1 through 3 above can be appropriately addressed. The model also must allow direct evaluation of individual technologies based on their costs (development and implementation), their benefits, and key uncertainties in technology performance so that questions 4 through 6 can be addressed. To help answer questions 2, 3, and 6, the model must be designed to allow the value of information from resolving various uncertainties to be calculated. Additionally, the model must be able to perform various types of sensitivity analyses to address questions 7 and 8. Finally, the model must be flexible enough that model inputs and even model structure can be changed as the understanding of the pretreatment decision problem evolves. This flexibility is crucial to maintaining the relevance of the model over time.

4.1.1.2 Summary of Necessary Extensions to the PDM to Develop the SWDM

As described in the section on the current status of the PDM, the current model consists of three primary components: a decision tree, a set of submodels, and a value model. Each of these three components of the PDM must be extended and/or updated to develop an SWDM capable of answering the aforementioned questions. The process of model revision and application will proceed through the five steps depicted in Figure 4–4 below.

Extend decision tree to represent key technology decisions and alternatives

⇩

Add low–level scales/submodels relating technology decisions to outcomes of concern

⇩

Revise and develop inputs for value model

⇩

Develop inputs for individual technologies for SWDM

⇩

Perform analysis of technology decisions using SWDM

Figure 4–4. Approach for Evaluating the Sludge Washing Decision

As illustrated in Figure 4–4, the first step in developing the SWDM is to develop a comprehensive list of pretreatment technologies that should be considered, then to extend the PDM decision tree to include the associated technology decisions. Once technology decisions have been identified, the model will be extended through the development of low–level scales and additional submodels designed to allow the relationships between technology choices and outcomes of concern to be quantified. In parallel, the PDM value model will be revised to ensure sensitivity to impacts of individual technologies, and new value weights will be assessed. Finally, model inputs will be developed for individual technologies to be evaluated, and the model will be exercised to perform analysis of the implications of alternative technology decisions. The sections below provide details on how each step in this process would be performed.

4.1.2 Extension of the PDM Decision Tree

The current PDM model evaluates high–level pretreatment strategies rather than low–level technologies. Thus, the decision tree in the current PDM (shown in Figure 3–1) contains a single decision about what pretreatment strategy to choose from a set of several candidate strategies. The decision tree for the SWDM must account not just for a single decision but for the many decisions corresponding to the many different technology choices that define a pretreatment strategy. This section describes current and planned work to extend the PDM decision tree to represent a complete set of technology decisions and alternatives related to the sludge washing decision. As described in detail below, the extension of the PDM decision tree involves first developing a list of pretreatment technologies, then structuring the list into technology decisions and alternatives, and finally developing a complete decision tree representing the sludge washing decision.

4.1.2.1 Developing a List of Pretreatment Technologies

Before the revised decision tree for the SWDM can be constructed, a comprehensive list of pretreatment technologies first must be developed. The primary goal of this step in the process to identify all technologies that are *currently proposed or under development,* which could be used as part of the pretreatment process.

Efforts currently are under way to develop a list of technologies relevant to pretreatment. This list initially is being developed through review and integration of information from various recent and relevant TWRS documents, including *Technology Development in Support of the TWRS Process Flowsheet* (Orme 1994b), the *Integrated Technology Plan* (DOE 1994), and the *Enhanced Sludge Washing Evaluation Plan* (Jensen 1994). Once a preliminary list of technologies has been developed through literature review, the list will be circulated for review and comment by relevant experts at Westinghouse Hanford Company (WHC) and Pacific Northwest Laboratories (PNL). Finally, relevant experts will be invited to a workshop to verify the appropriateness of the items on the initial list and to augment the list with additional technologies if warranted. An excerpt from a preliminary list of technologies is illustrated in Table 4–1 below. This list is for illustrative purposes only and is not intended to be complete.

Table 4–1. Example Partial List of Technologies

#	Technology
1	Destroy Complexants Using Heat and Digest
2	Destroy Complexants Using Calcination
3	Destroy Complexants Using Steam Reforming
4	Destroy Complexants Using Hydrothermal Processes
5	Destroy Complexants Using Electrochemical Processes
6	Solid/Liquid Separation Using Gravity Settling
7	Solid/Liquid Separation Using Gravity Incline Tube
8	Solid/Liquid Separation Using Filtration
9	Solid/Liquid Separation Using Flocculant Assisted Settling
10	Solid/Liquid Separation Using Centrifugation
11	Dissolve Sludge in Nitric Acid
12	Dissolve Sludge in Nitric and Hydrofluoric Acid
13	Dissolve Sludge in Nitric and Oxalic Acid
14	Remove Cs Using Solvent Extraction
15	Remove Cs Using Ion Exchange
16	Remove Cs Using Precipitation
	...

As can be seen in the table, for a given "technology need" (e.g., solid/liquid separation), the list may include several alternative technologies that could meet that need. Before this list is finalized, it will be necessary to consider both the range of technology alternatives that should be evaluated (or conversely, which technologies can be screened out) and the appropriate level of detail at which to define technologies for evaluation.

4.1.2.2 Structuring Technologies into Decisions and Alternatives

Once a comprehensive list of technologies has been identified, it will be necessary to structure the list in a way that explicitly represents the interdependencies among technologies. As a first cut, it is anticipated that technologies can be organized in terms of general "technology needs" such that, at most, one technology would be chosen to serve each need. Table 4–2 illustrates the correspondence between needs and technologies for the example technologies listed in Table 4–1 above. Again, the list of technologies and of technology needs is for illustrative purposes and is not intended to be exhaustive.

Table 4–2. Correspondence Between Technology Needs and Technologies

Technology Needs (Decisions)	Technologies (Alternatives)
Complexant Destruction	Heat and Digest
	Calcination
	Steam Reforming
	Hydrothermal
	Electrochemical
Solid/Liquid Separation	Gravity Settling
	Gravity Incline Tube
	Filtration
	Flocculant Assisted Settling
	Centrifugation
Acid Dissolution	Nitric Acid
	Nitric and Hydrofluoric Acid
	Nitric and Oxalic Acid
Remove Cs	Solvent Extraction
	Ion Exchange
	Precipitation

The groupings of technologies into needs can be translated easily into a decision tree format that explicitly represents all technology alternatives. For example, a decision tree corresponding to the groupings of technologies in Table 4–2 is shown in Figure 4–5 below.

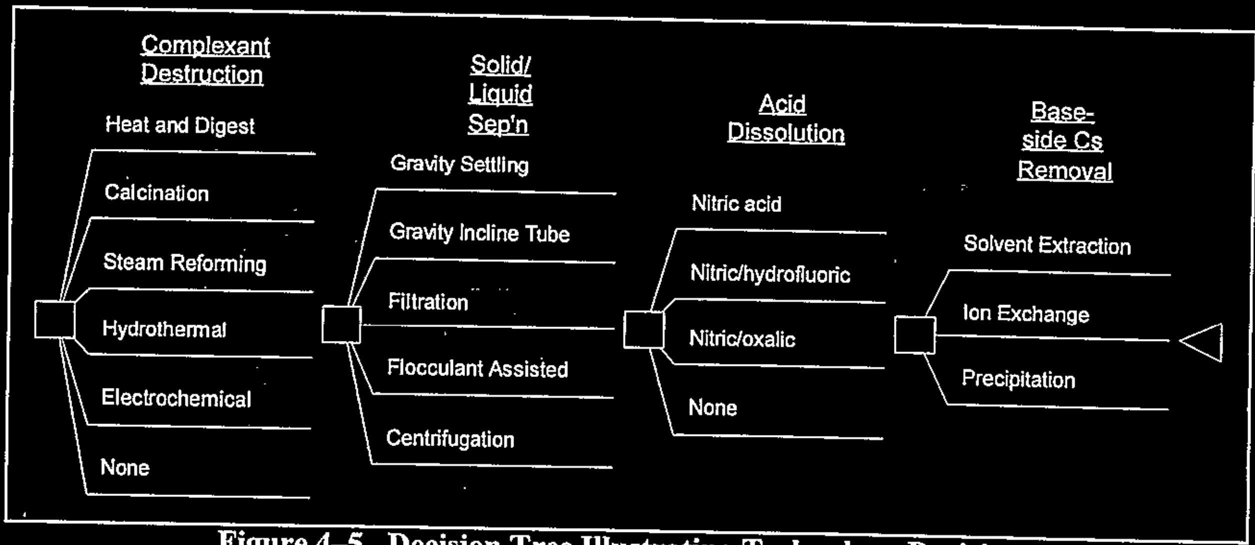


Figure 4–5. Decision Tree Illustrating Technology Decisions

Note that the decision tree in Figure 4–5 adds additional information beyond that in Table 4–2 regarding which technology needs can simply be left unserved. For example, the decision entitled "Complexant Destruction" has one option called "None," which corresponds to no complexant destruction technology being implemented. Note also that the decision tree in Figure 4–5 is only an illustrative fragment as it represents only a few sample pretreatment decisions rather than the entire set of technology decisions relevant to the high-level sludge washing decision. Section 4.1.2.3 describes the development of a complete decision tree appropriate for analysis of the sludge washing decision.

4.1.2.3 Developing a Complete Decision Tree Representing the Sludge Washing Decision

The existing PDM is designed to evaluate entire pretreatment strategies and thus its decision tree contains a single decision, as illustrated in Figure 3–1. The SWDM will allow the technologies comprising a pretreatment strategy to be evaluated separately. Thus, the decision tree for the SWDM must include a decision node for each technology decision. The new decision tree also must be structured so as to explicitly represent the high-level sludge washing decision.

A preliminary decision tree for the SWDM representing the sludge washing decision is shown in Figure 4–6. As depicted in this decision tree, a decision first must be made regarding whether enhanced sludge washing is adequate or whether advanced separations processes will be needed. Note that this is precisely the sludge washing decision. Since there are many detailed decisions that can still be made at this point regarding what exactly is meant by "enhanced sludge washing" and what exactly is meant by "advanced separations," the choice of one of these two options does not end the decision process. Instead, this initial choice determines which "track" of decisions follows. If enhanced sludge washing is deemed adequate, there are a number of subsequent decisions that must be made regarding whether and how such technologies as

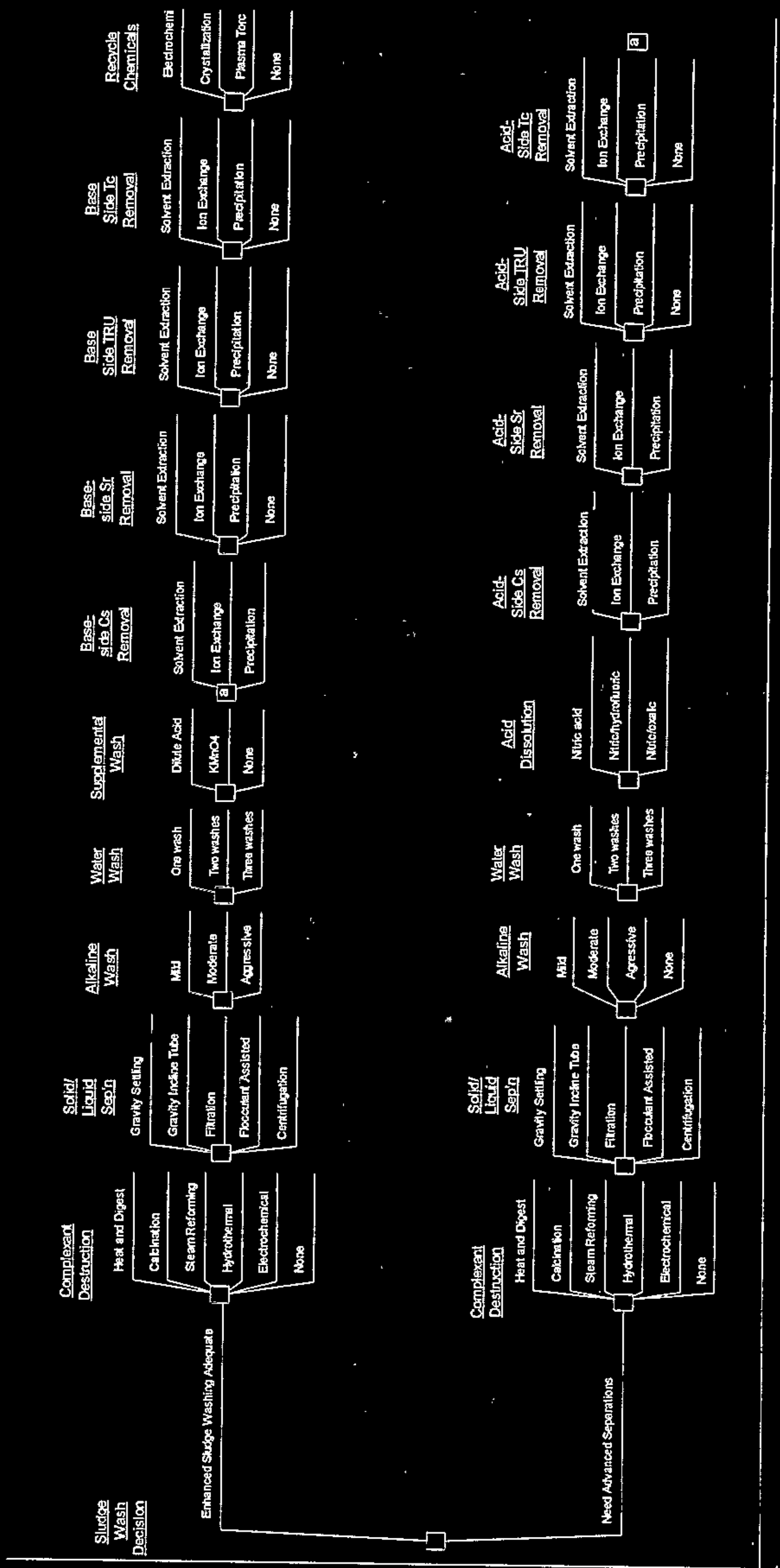


Figure 4-6. Decision Tree for Sludge Washing Decision

complexant destruction, solid/liquid separation, and chemical recycling will be implemented. If the initial decision is that advanced separations are required, then a second track is taken wherein additional decisions, such as the choice of acid dissolution technology and the choice of technologies for removing Cs, Sr, Tc, and TRU from acid streams, must be made.

As with the other components of the SWDM, the decision tree in Figure 4–6 is intended to be illustrative of the envisioned approach and should not be considered complete. It is anticipated that additional technologies will be identified that should be incorporated in the decision tree. It is also anticipated that significant work will need to be performed to structure the tree to represent interdependencies between decisions (e.g., you can't choose technology X for need 1 if you choose technology Y for need 2) before it is completed. The decision tree will be updated through circulation for comment as well as through workshops before it is finalized.

Note that the decision tree in Figure 4–6 only accounts for the decisions related to the sludge washing decision and does not include uncertainties. As in the existing PDM, the SWDM will need to account for a number of uncertainties in the performance of pretreatment strategies. Initially, it is assumed that the major uncertainties identified in the existing PDM (i.e., regarding technical success, regulatory/political success, and accidents) will all need to be included in the SWDM decision tree. An abbreviated decision tree showing the decisions from Figure 4–6 as well as the major uncertainties from the existing PDM decision tree is depicted in Figure 4–7. It is anticipated that additional uncertainties will be added to the decision tree as detailed models of the impacts of individual technology choices are constructed. The process of constructing models for individual technologies is summarized in the section below and described in detail later in this report.

4.1.3 Reformulation of PDM Submodels

The existing PDM submodels are designed to convert detailed knowledge of how an entire pretreatment strategy will work into a set of performance measures used by the PDM value model. Thus, the existing PDM contains a submodel for each performance measure. The existing PDM submodels likely would not be adequate to evaluate individual technology decisions. Instead, additional modeling would be required to sensitize the model to the impacts of technology alternatives. It currently is envisioned that this additional modeling will be conducted one technology decision at a time, as is described in detail later in this report.

Generally, in order to extend the model to evaluate a specific technology decision, three primary steps must be taken:

1) A measure or set of measures must be developed for rating technologies based on their achievement of identified needs,

2) Models must be developed as necessary for relating choice of technology to degree of achievement of these needs, and

3) A means for translating scores on the "needs" measures into impacts on fundamental values, as identified in the objectives hierarchy in Figure 3–2, must be developed.

Figure 4–8 illustrates the entire evaluation process. For each set of alternative technologies, impacts are determined on the relevant "needs" measures reflecting how well each technology, if successfully implemented, would meet the identified needs. The technology development and implementation cost increments and the likelihood of technological success associated with each technology also would be recorded. The model would translate "needs" scores into impacts on the fundamental objectives and success likelihoods for pretreatment.

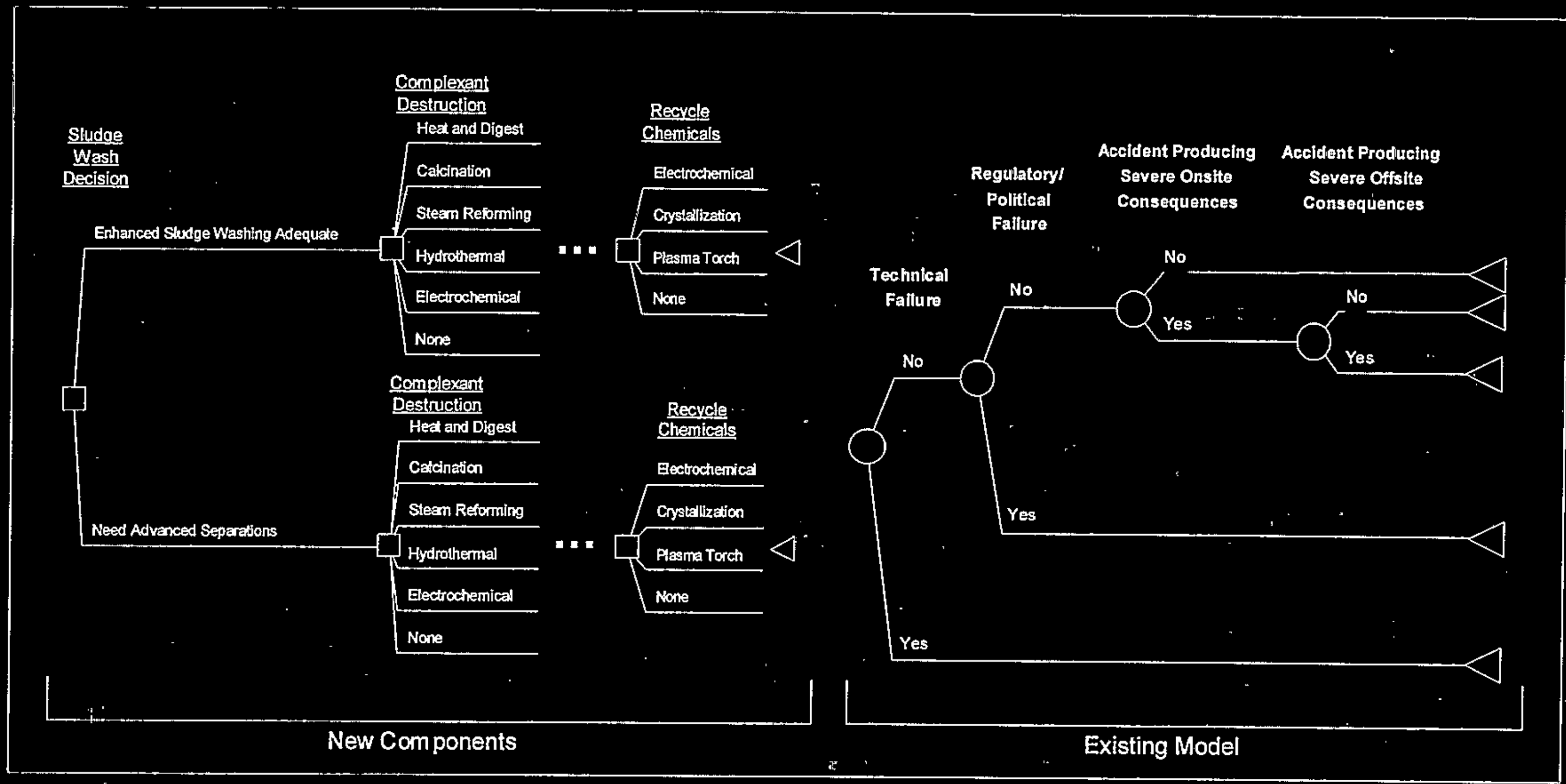


Figure 4-7. Revised Decision Tree for Evaluating Technology Development Efforts

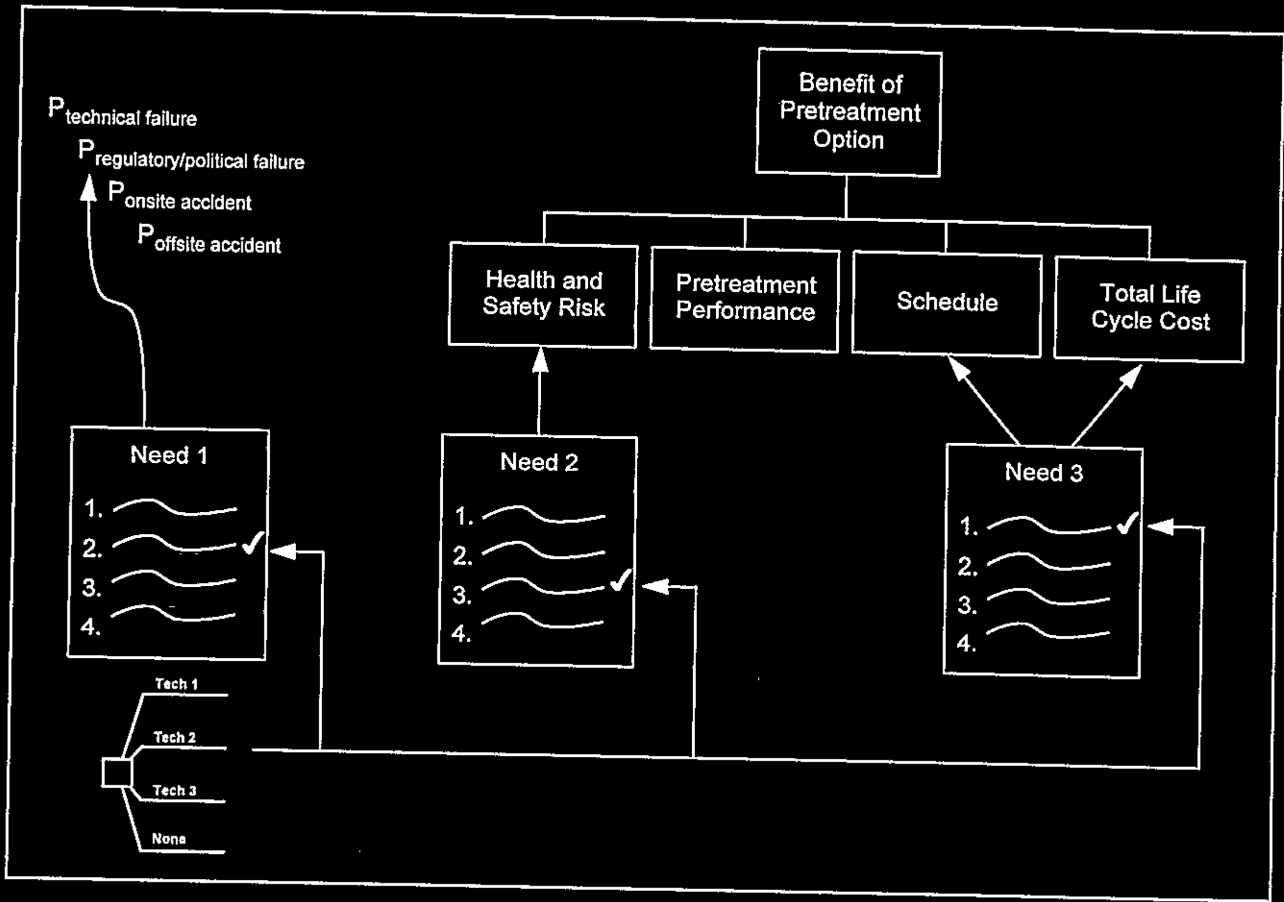


Figure 4–8. Technology Evaluation Process

4.1.4 Revision of the Value Model

It is anticipated that the current PDM value model (described earlier in this report) may need to be extended to facilitate evaluation of individual technologies. At the very least, additional low–level measures will need to be identified to measure achievement of individual technology needs as described above and as illustrated in Figure 4–8. These low–level measures correspond to "means" objectives that are important to the extent that they provide a means for achieving the fundamental objectives included in the current PDM. The value model will need to be revised as needed to account for all relevant means objectives and their relationships to fundamental objectives.

It is essential that the key value judgments (weights and single attribute utility functions) be assessed from appropriate managers before conclusions can be meaningfully drawn from the model. As mentioned earlier in this report, the current PDM value judgments are in "strawman" form. Thus, a formal assessment of values is a key part of the development of the SWDM to address the sludge washing decision.

4.1.5 SWDM Analysis Capabilities

The planned analysis capabilities of the SWDM model are designed to answer the crucial questions identified in Section 4.1.1.1 related to the sludge washing decision. This section depicts example outputs that the model would produce once fully operational. The outputs depicted in this section are intended only to illustrate the planned analysis capabilities of the model and **do not contain real data** at this point. The outputs are described below, organized by the specific question they are designed to help answer. Additional outputs could be developed as the needs of the various parties involved in the sludge washing decision are clarified.

Does enhanced sludge washing perform satisfactorily, or should advanced separations processes be used? What are the relative advantages and disadvantages of the two alternatives?

These are the fundamental questions to be addressed by the SWDM, and accordingly, the model would provide numerous outputs designed to help answer them. Example outputs illustrated below include cumulative probability distributions showing the expected value and level of uncertainty for overall performance of enhanced sludge washing and advanced separations decision alternatives (Figure 4–9), and comparisons of the two decision alternatives based on individual criteria, such as total cost (Figure 4–10).

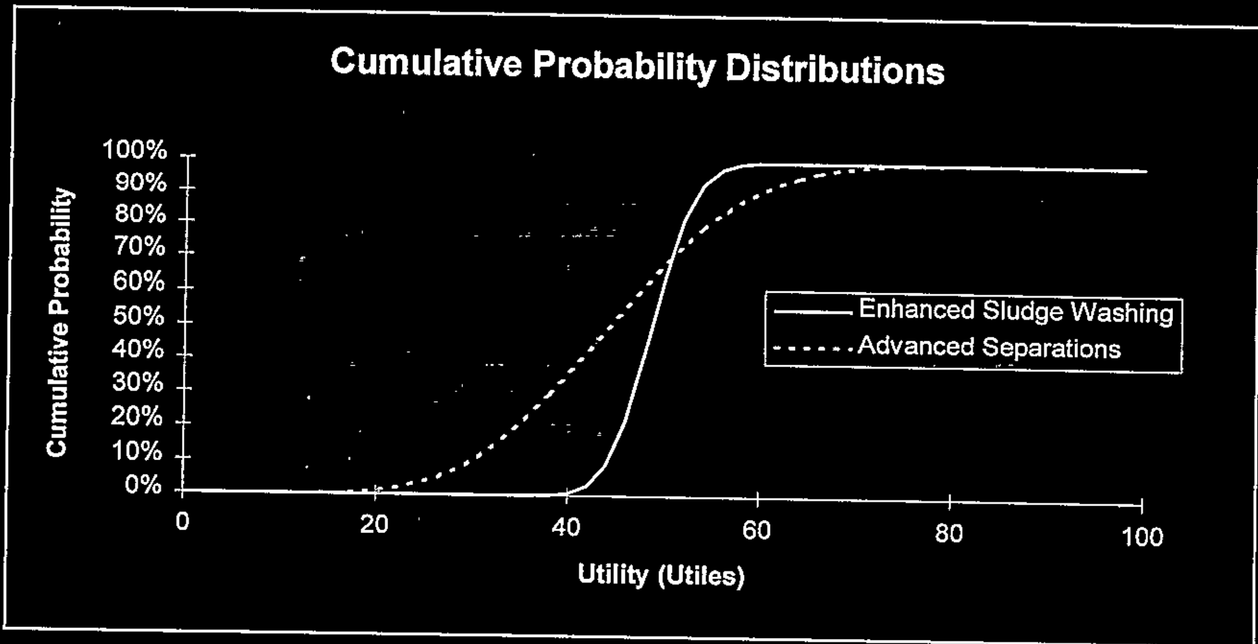


Figure 4–9. Cumulative Probability Distributions for Sludge Washing Decision

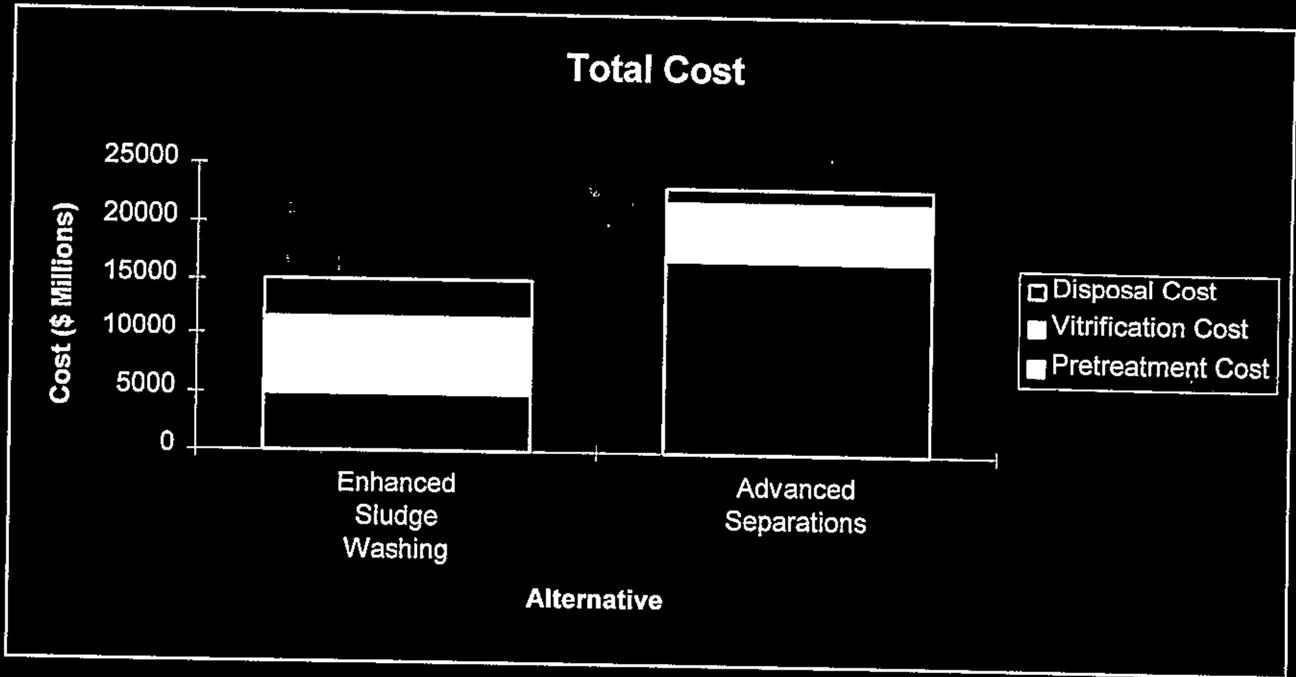


Figure 4–10. Evaluation of Sludge Washing Decision Based on Estimated Costs

Are the remaining uncertainties in the performance of enhanced sludge washing and advanced separations processes sufficiently small that a final choice between the two approaches is justified?

As studies are conducted to determine the performance of individual technologies, uncertainties regarding the performance of enhanced sludge washing and advanced separations processes will be reduced. Figure 4–11 below depicts the effect of studies of advanced separations technologies on the cumulative probability distribution for the overall benefit (utility) associated with choosing advanced separations. As depicted, improved information results in a narrowing of the spread of the probability distribution.

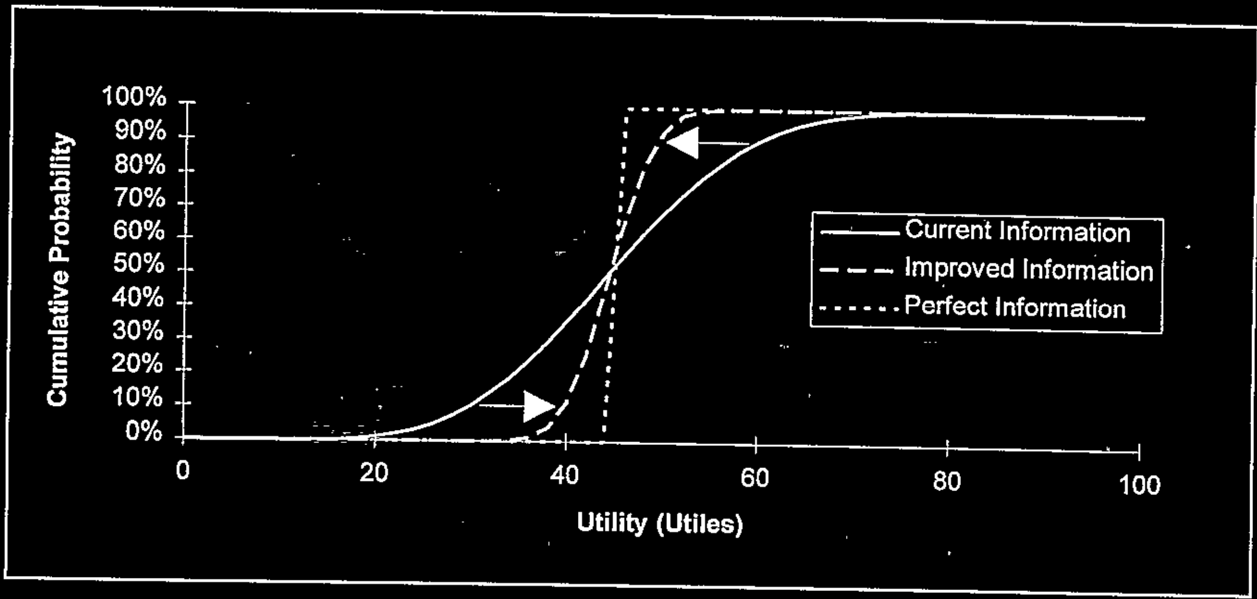


Figure 4–11. Effect of Uncertainty Resolution on Cumulative Distribution for Advanced Separations

The consequence of reducing uncertainties (and the reason for funding work that reduces uncertainties) is that decisions become easier. With perfect information about the performance of enhanced sludge washing and advanced separations processes, choosing a process would simply involve picking the process known to perform best. When uncertainty is involved, the decision becomes more difficult. Unfortunately, uncertainties can never be eliminated completely, and decisions must be made nonetheless. With regard to the sludge washing decision, it must be decided at some point that the expenditure of additional funds for resolving uncertainties is no longer worthwhile and that a single course of action should be taken.

Value of information theory provides a rigorous basis for determining when resolving uncertainties is no longer of sufficient value to justify deferring action. According to value of information theory, there is value to resolving uncertainties to the extent that better decisions could be made if the states of these uncertainties were known. Value of information analysis is easily represented and performed using decision trees. As an example, Figure 4–12 illustrates how a decision whether to resolve uncertainties regarding base–side cesium removal is modeled using a decision tree.

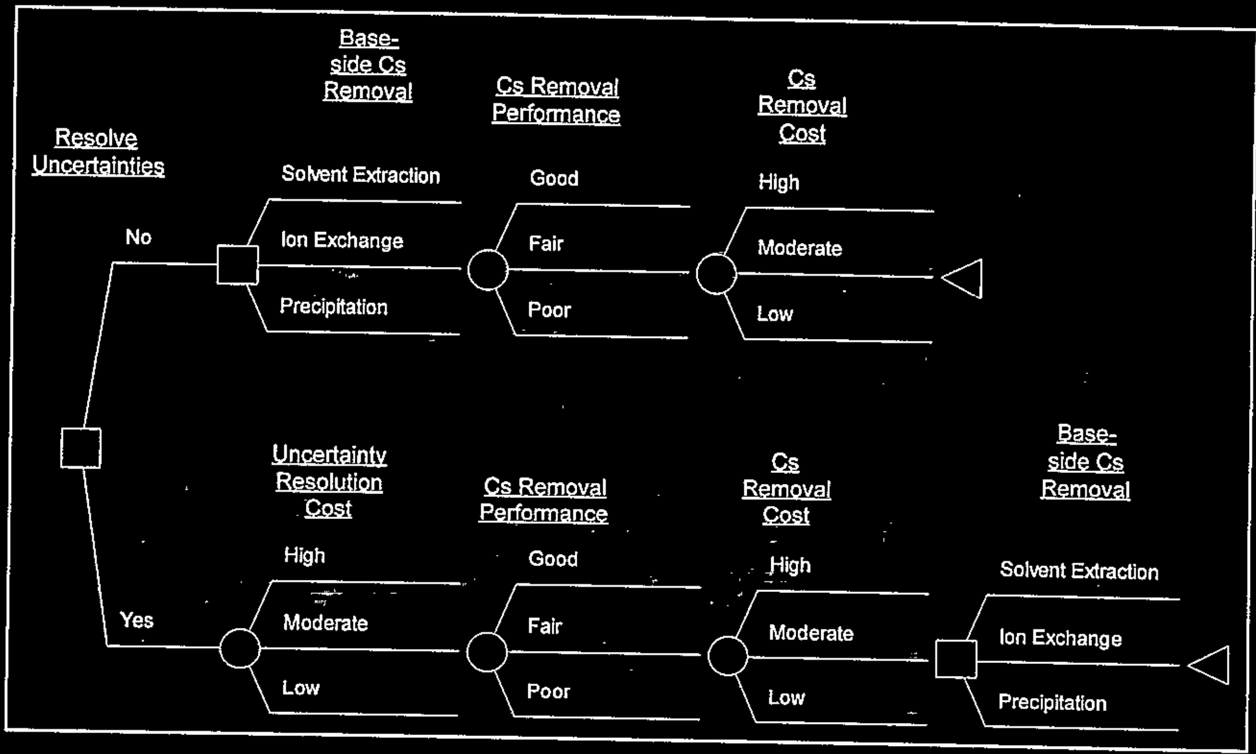


Figure 4–12. Decision Tree Illustrating Value of Information Analysis

As depicted in the figure, a decision must first be made regarding whether or not work is conducted to resolve uncertainties. If this work is not conducted, a decision about which base–side cesium removal process is implemented must be made prior to the resolution of uncertainties regarding cesium removal performance and cost. This requirement that the decision be made before uncertainties are resolved is represented in the decision tree by the fact that the decision precedes the uncertainties (in order from left to right) on this branch of the tree. If, on the other hand, a decision is made to resolve uncertainties, then the uncertainties are resolved before the decision is made, as shown in the lower branch of the decision tree. In this case, there is presumably some additional cost of collecting information that must be borne. The lower branch in the tree is preferable only if the value of information from resolving uncertainties outweighs the cost of collecting this information.

The value of information in the example in Figure 4–12 is defined as the difference between the value associated with the bottom branch of the tree, excluding uncertainty resolution cost, and the top branch of the tree. Value of information can be calculated similarly for any combination of uncertainties as well as for much more complicated decision trees.

To aid the sludge washing decision, value of information analyses can be performed identifying the potential value gained from resolving uncertainties regarding individual technologies relevant to this decision. Figure 4–13 below depicts the value of information associated with various technology uncertainties (organized by technology) under various assumptions about the state of the sludge washing decision. The series labeled "Unconstrained" indicates the value of information on these technologies assuming no decision has yet been made regarding the adequacy of enhanced sludge washing. The other series illustrate the value of resolving residual resolving residual uncertainties once the primary sludge washing decision has been made, first assuming enhanced sludge washing is chosen, then assuming advanced separations is chosen.

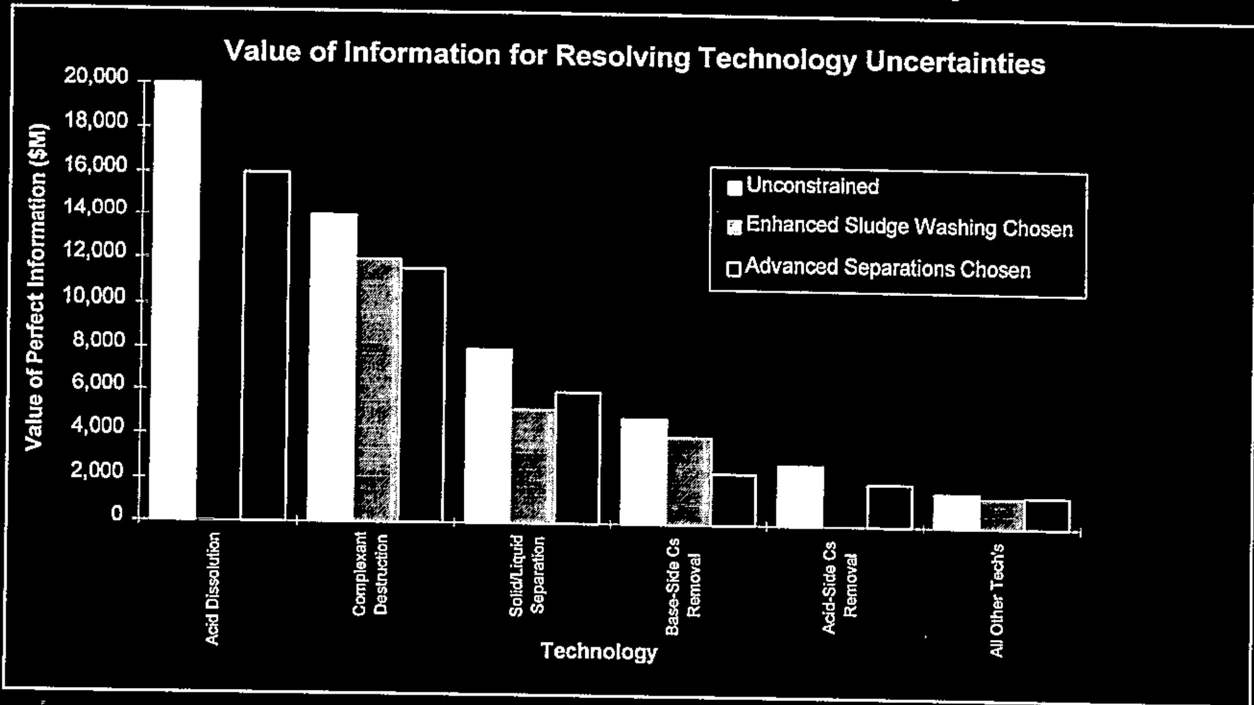


Figure 4–13. Example Value of Information Output for Various Sets of Uncertainties

The height of the bars on the graph can be interpreted as giving an upper bound on how much should be spent to study remaining uncertainties about the technologies listed along the x–axis. As the quality of information improves and the inputs to the SWDM are updated accordingly, the height of these bars would decrease. At some point, the cost of resolving residual uncertainties for certain technologies will no longer be justified by the potential value of information.

What are the costs and benefits of resolving specific residual uncertainties before choosing between enhanced sludge washing and advanced separations processes?

The value of information analyses described above are useful to inform high–level strategic decisions about when to study and when to take action. More detailed value of information analyses also can be conducted to identify where funds for uncertainty resolution should be targeted in order to aid low–level technology decisions. Figure 4–14 shows an example of the results of such an analysis depicting the value of resolving six uncertainties surrounding the choice of a process for cesium removal: cost and performance for each of three candidate processes.

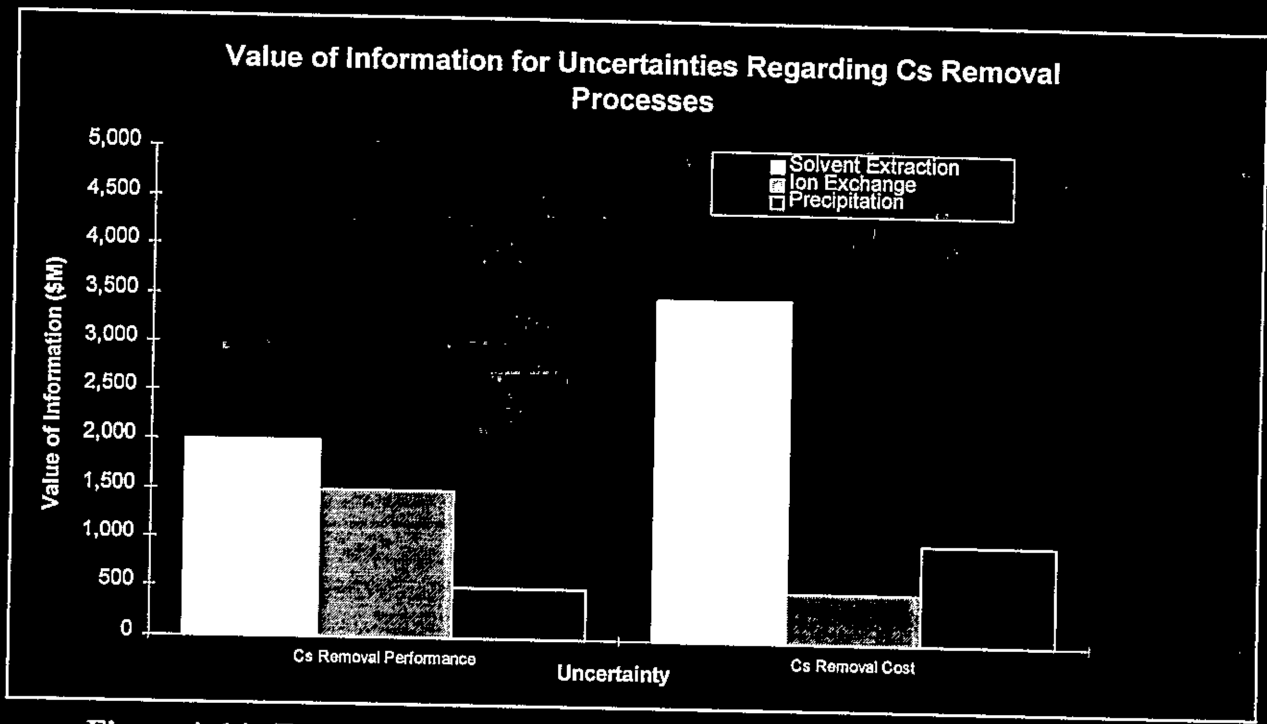


Figure 4–14. Example Output Showing Value of Resolving Specific Technology Uncertainties

Additional information can be assessed on the expected cost of continuing work to resolve uncertainties prior to making a decision. This information can be presented alongside information regarding the expected value of perfect information to determine to what extent such additional work is warranted, as illustrated in Figure 4–15 below.

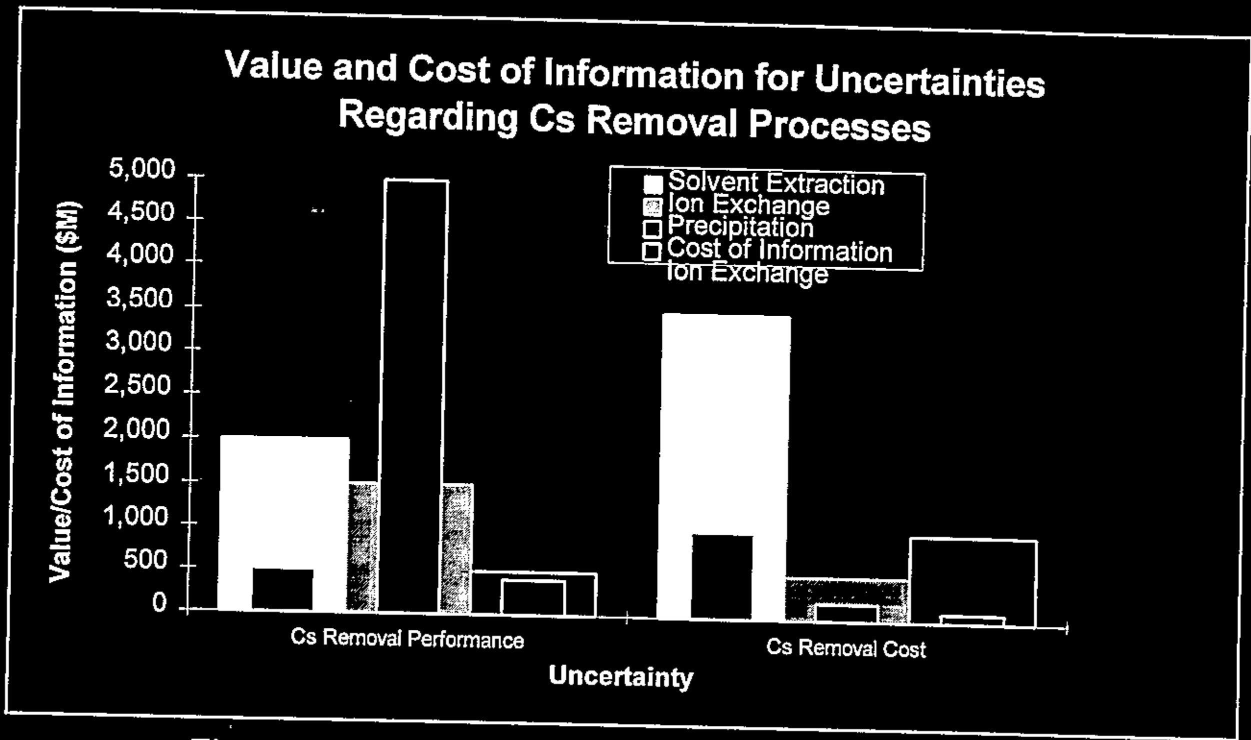


Figure 4–15. Comparison of Value and Cost of Information

What specific technologies should be used if enhanced sludge washing or some minor variation is implemented? What are the relative advantages and disadvantages of alternative technology choices?

As discussed earlier, once the primary decision is made regarding whether or not enhanced sludge washing is adequate, many technology decisions remain to be made. The SWDM would be designed to produce numerous outputs analyzing these low–level technology decisions. Several example outputs are shown below.

Figure 4–16 illustrates one key output from the SWDM: a recommended decision policy highlighting the best setting for each analyzed technology decision. The alternatives highlighted in this example output are for illustrative purposes only and are not intended to convey any information regarding preferred technologies.

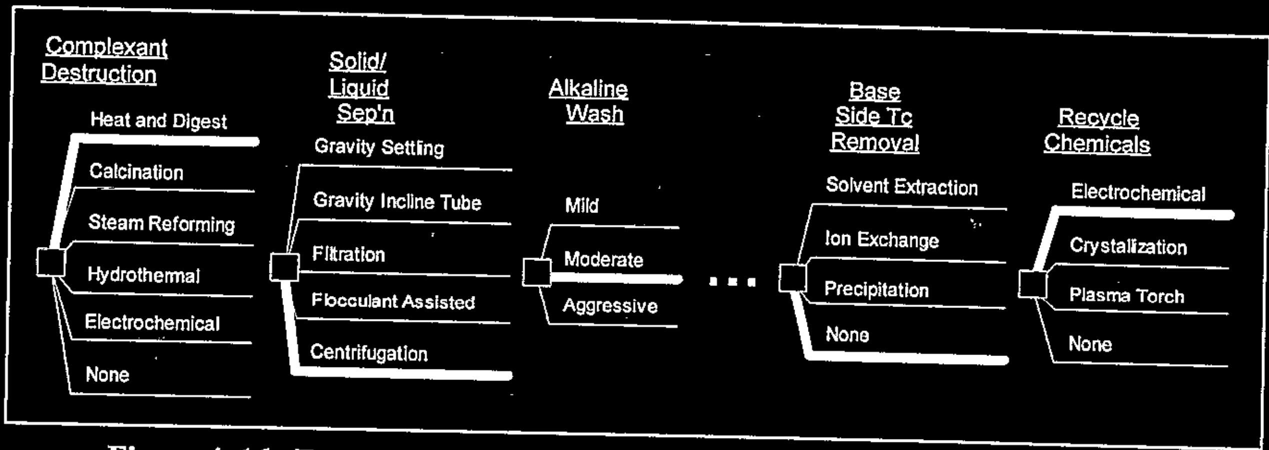


Figure 4–16. Example Excerpt from Model's Recommended Decision Policy

Beyond merely determining the best decision policy on an expected value basis, the SWDM could be used to analyze the reasons for the preference and the implications of alternative decisions. Again, there are numerous relevant outputs that the SWDM will be designed to produce. One example output shown in Figure 4–17 is a graph showing the sensitivity of the overall value of pretreatment to alternative choices at various places in the decision tree. The high end of the y–axis (utility scale) corresponds to the value associated with making optimal choices for each decision. The bars for each decision extend down to show the reduction in value that would result from choosing the worst possible option for the decision. Thus, large bars correspond to decisions for which it is particularly important to choose the optimal option, whereas small bars correspond to decisions which are more resilient: alternatives perform about equally well.

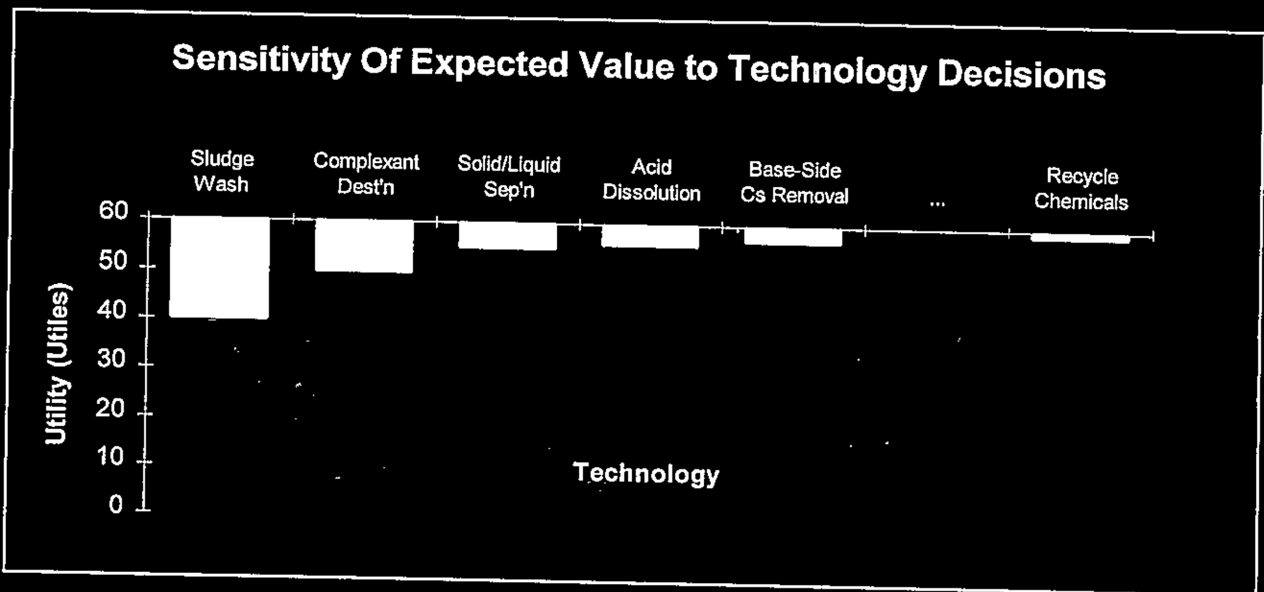


Figure 4–17. Example Output Illustrating Sensitivity of Pretreatment Benefit to Decisions

The same types of outputs could be generated to identify the technologies that should be used if advanced separations processes must be implemented as well as to illustrate the relative advantages and disadvantages of technology choices related to advanced separations.

How sensitive are the answers to all of the above questions to alternative views about the technical performance of individual technologies or of entire pretreatment strategies?

As with the current PDM, the SWDM could be implemented in a way that allows extensive sensitivity analysis to be performed. It is likely that it will be difficult to achieve complete technical consensus on the appropriate model inputs for individual technologies. Sensitivity analyses will be performed for key technology evaluation inputs to determine whether plausible variation in these inputs results in changes in decision policy. Figure 4–18 below illustrates an example sensitivity analysis output from the model showing the sensitivity of overall pretreatment benefit to alternative views about the effectiveness of precipitation processes for removing cesium from alkaline waste. The figure illustrates that over most of the range of values investigated, ion exchange remains the preferred alternative, but that a change in decision policy occurs if the estimated effectiveness of precipitation processes is above about 90 percent.

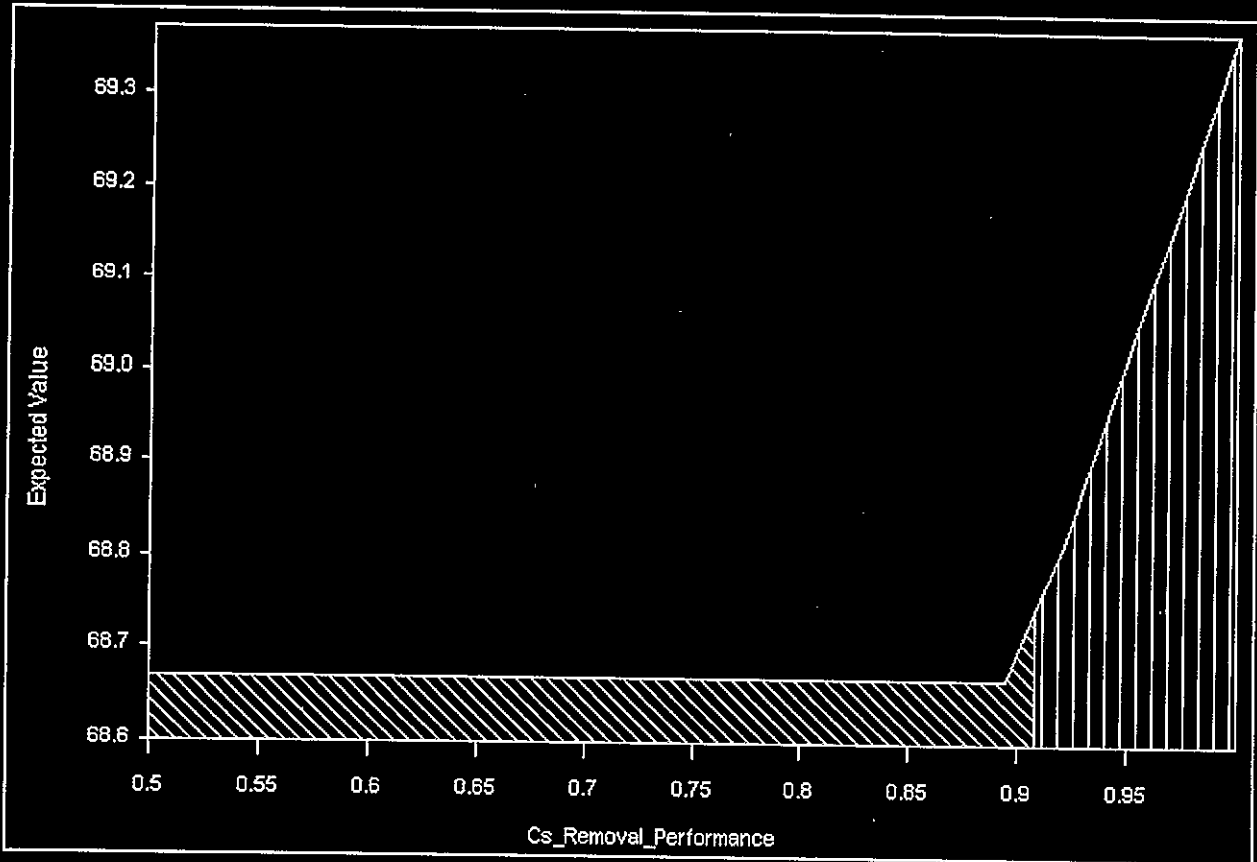


Figure 4–18. Sensitivity of Pretreatment Benefit to Performance of Precipitation Processes

How sensitive are the answers to all of the above questions to alternative views about the relative importance of achieving conflicting pretreatment objectives?

As with the current PDM, the SWDM could allow sensitivity to key value judgment inputs to be investigated. This type of analysis is useful to determine the implications of alternative values held by different stakeholders in TWRS decisions. Figure 4–19 depicts an example value sensitivity analysis showing the sensitivity of the benefits of enhanced sludge washing and advanced separations options to the weight applied to the HLW volume criterion.

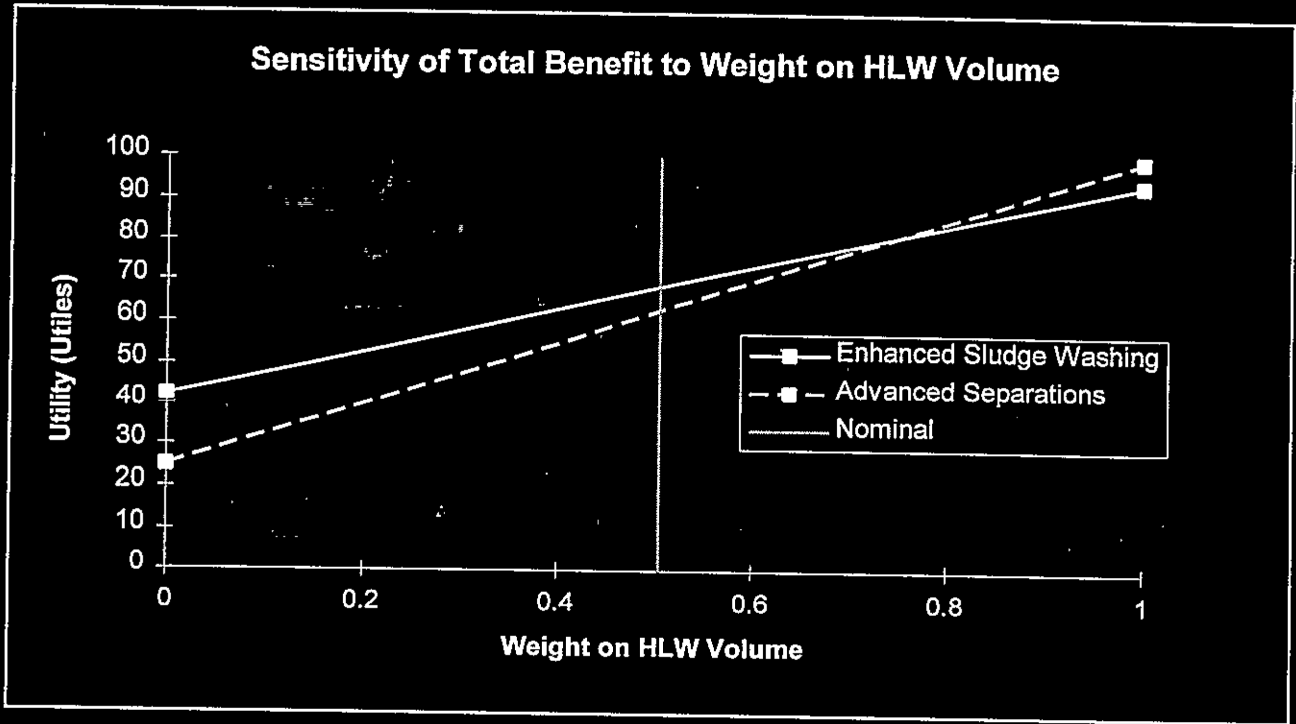


Figure 4–19. Example Illustrating Sensitivity Analysis for Weight on HLW Volume

4.2 DETAILED MODELING OF SPECIFIC ISSUES AND TECHNOLOGIES

This section describes the process for the identification and evaluation of specific issues relevant to the sludge washing decision.

4.2.1 General Approach

The SWDM would provide an overall evaluation of the strategies of no pretreatment, treatment of waste to an intermediate form, enhanced sludge washing, and extensive pretreatment separations, as well as any other operating scenarios that need to be considered. Additionally, it would make possible an in-depth analysis of specific issues that are relevant to the 1998 sludge washing decision. These issues address technologies to be employed, key uncertainties, and whether specific unit operations are a necessary part of the sludge washing operating scenario. These issues can be analyzed from a programmatic risk perspective that considers technical uncertainties, cost, schedule, and other stakeholder values. This section describes the process for in-depth analysis of specific issues and provides an illustrative example.

The application of PDM to the analysis of specific issues relevant to the sludge washing decision consists of the following seven steps:

1. ***Identify the issues.*** A list of issues relevant to the 1998 sludge washing decision will be identified and an initial prioritization of the issues will be created.

2. ***Develop qualitative influence diagrams.*** A clear understanding of the issues will be facilitated by the development of influence diagrams that graphically represent the issues. The influence diagram will depict the relationships among relevant decisions, uncertainties, and outcome values.

3. ***Develop quantitative influence diagrams.*** Quantifying the influence diagrams forces a clearer understanding of the essential relationships for an issue. It also makes it possible to carry out various quantitative analyses.

4. ***Use the quantitative models to obtain point estimates of key parameters.*** The values of these parameters will be benchmarked against more complex modeling outputs such as those from the Aspen[3] model when available.

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[3] Aspen is a software program that performs detailed flow mass balances. It is a trademark of Aspen Technologies.

5. ***Use quantitative model to determine key uncertainties.*** Sensitivity analysis will be carried out to determine for which input values variation within the range of their uncertainties can have a significant impact on output values of interest. Those input values having a significant impact will be treated as uncertain variables in subsequent analyses.

6. ***Perform risk analysis*** The quantitative model will be revised to incorporate uncertainties. This revised model then will be exercised to obtain expected values of key parameters as well as their probability distributions. The programmatic risk associated with each issue will be assessed. If the expected values of key output parameters are within acceptable ranges and the distributions of these potential outcomes present a level of risk that is tolerable, then the issue can be put to rest. If not, alternatives for risk management must be identified and analyzed.

7. ***Carry out decision analysis.*** Alternatives will be incorporated into the revised quantitative model and their performance will be analyzed. The analysis will include the expected performance of the alternatives on the key performance measures and the probability distributions over these measures. Additional analysis can be carried out to determine the expected value of additional information, as well as the value of technology development for the purpose of gaining more control over the outcomes.

4.2.2 Sludge Washing Example

This section illustrates the above process using the issue of whether Sr should be removed from the LLW. There are several reasons for being concerned about the amount of Sr in LLW. One concern is whether the operation of the LLW Vitrification plant would be possible with contact maintenance. The other concern involves the disposal requirements for the vitrified LLW. The current plan calls for remote maintenance for the LLW Vitrification plant which only requires that class C standards be met. It has not been decided what the requirements will be for disposal of vitrified LLW. The waste class limits for Sr are:

Class A, 0.04 Ci/m3
Class B, 150 Ci/m3
Class C, 7,000 Ci/m3

Additionally there are standards for the total amount of radionuclides for each of these classes. Thus, whether the amount of Sr is within acceptable limits will also depend on the amount of other source terms that are present in the waste. For purposes of the example, the other source terms will not be considered.

The amount of Sr in LLW depends on its solubility in the sludge wash solutions and therefore the aggressiveness of those washes. Sr is not very soluble in water or alkaline washes. If advanced separations should prove necessary then acid processes would be used and the solubilities for Sr would increase. This analysis will focus on the solubilities relevant to enhanced sludge washing. While Sr is relatively insoluble in most waste types, in those waste types that contain organic complexants, in particular in CC waste, the Sr becomes "complexed"

with the organics which are soluble; therefore, a large proportion of the Sr ends up in the LLW stream.
One alternative designed to prevent this is to destroy the organics, thus releasing the Sr which by itself has relatively low solubility. Another alternative is to remove the Sr from the LLW stream following the sludge washing as will be done for Cs (which is soluble in water and alkaline washes and therefore must be removed). Some Sr, in fact, may be removed from the LLW as part of the Cs removal process; the amount of Sr removed would depend on the Cs removal method employed. Thus, the key decisions for this analysis is whether to destroy organic complexants and/or remove Sr from the LLW stream. An initial influence diagram that captures these issues is shown in Figure 4-20.

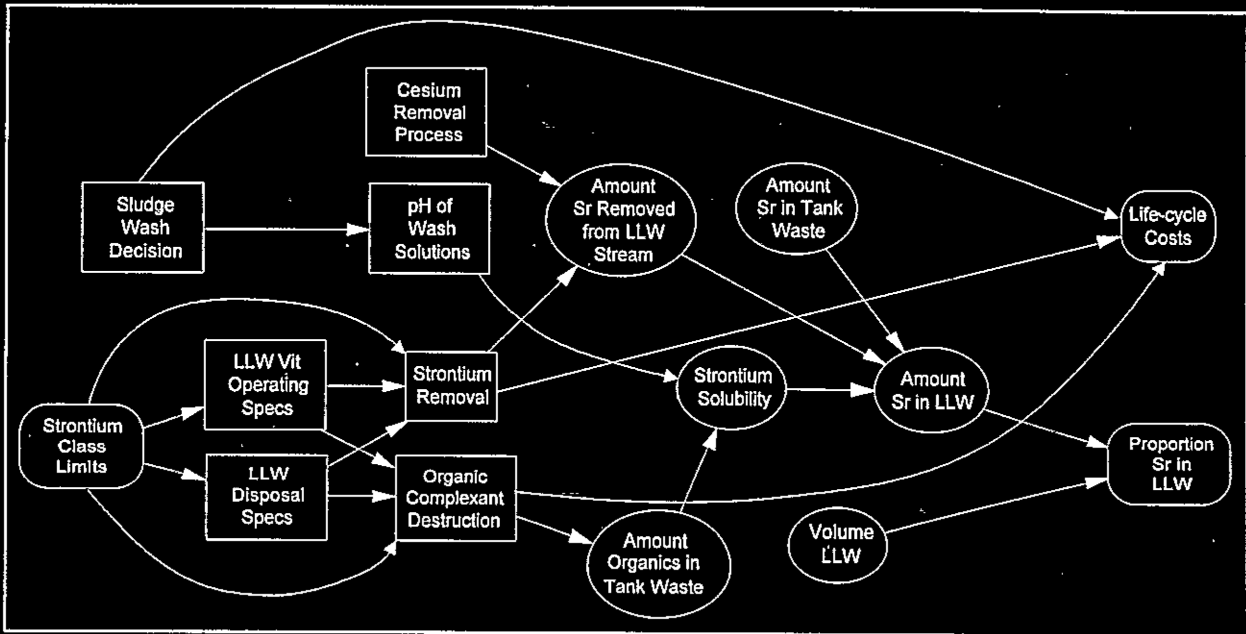
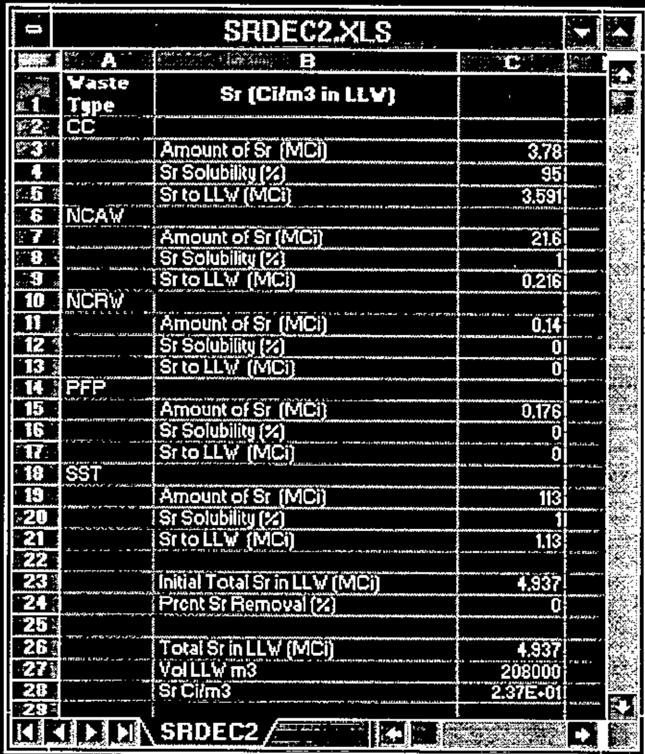


Figure 4–20. Individual Influence Diagram for Issue of Strontium in LLW

4.2.2.2 Analysis of Strontium Removal

Spreadsheet model.

A spreadsheet model that calculates the amount of Sr in LLW was developed to enable a more detailed quantitative analysis. This is shown in Figure 4-21. The amount of Sr that ends up in the LLW stream depends on the amount of Sr that initially is present in the waste prior to washing, and the amount that goes into solution during the wash. The amount that goes into solution depends on its solubility. It turns out that these values are very different depending on the waste type. As can be seen in Table 5, five waste types were identified. The spreadsheet calculates the Sr that will go to LLW for each of the waste types based on best estimates for the total amount of Sr for each waste type and the solubility of Sr for that waste type. These are then summed to determine the total Sr (in millions of curies) that goes to the LLW stream. The spreadsheet also has an input representing the percent of Sr removed to the HLW stream. The final calculation of Ci/m3 in LLW (the units for the class limits) depends on the volume of LLW as well as the amount of curies present. The result of these calculations is an estimated 24 Ci/m3 of Sr in LLW.



	A	B	C
1	Waste Type	Sr (Ci/m3 in LLW)	
2	CC		
3		Amount of Sr (MCi)	3.78
4		Sr Solubility (%)	95
5		Sr to LLW (MCi)	3.591
6	NCAW		
7		Amount of Sr (MCi)	21.6
8		Sr Solubility (%)	1
9		Sr to LLW (MCi)	0.216
10	NCRW		
11		Amount of Sr (MCi)	0.14
12		Sr Solubility (%)	0
13		Sr to LLW (MCi)	0
14	PFP		
15		Amount of Sr (MCi)	0.176
16		Sr Solubility (%)	0
17		Sr to LLW (MCi)	0
18	SST		
19		Amount of Sr (MCi)	113
20		Sr Solubility (%)	1
21		Sr to LLW (MCi)	1.13
22			
23		Initial Total Sr in LLW (MCi)	4.937
24		Prcnt Sr Removal (%)	0
25			
26		Total Sr in LLW (MCi)	4.937
27		Vol LLW m3	208000
28		Sr Ci/m3	2.37E+01
29			

Figure 4–21. Spreadsheet Model for Calculating Amount of Strontium in LLW

Sensitivity analysis.

To facilitate a sensitivity analysis, the variables from this spreadsheet were linked to DPL. These variables are represented as nodes in a DPL influence diagram. The resulting influence diagram for this DPL model is shown in Figure 4-22. This DPL model makes it possible to perform a value sensitivity comparison.

To carry out the value sensitivity comparison, each of the input variables was varied through its plausible range of values and the amount of Sr in Ci/m3 in LLW was calculated with the other variables held at their nominal values. The results from this analysis are displayed in the tornado diagram in Figure 4-23. The horizontal bars show the extent of variation in the amount of Sr as a result of plausible variation in each input. Thus, for example, Sr solubility in SST waste, whose nominal value is 1%, was varied from 0.1% to 5% and the Sr in Ci/m3 was seen to vary from 19 to 45 as compared to its nominal value of 24. As can be seen in Figure 37, six variables impact the amount of Sr in LLW.

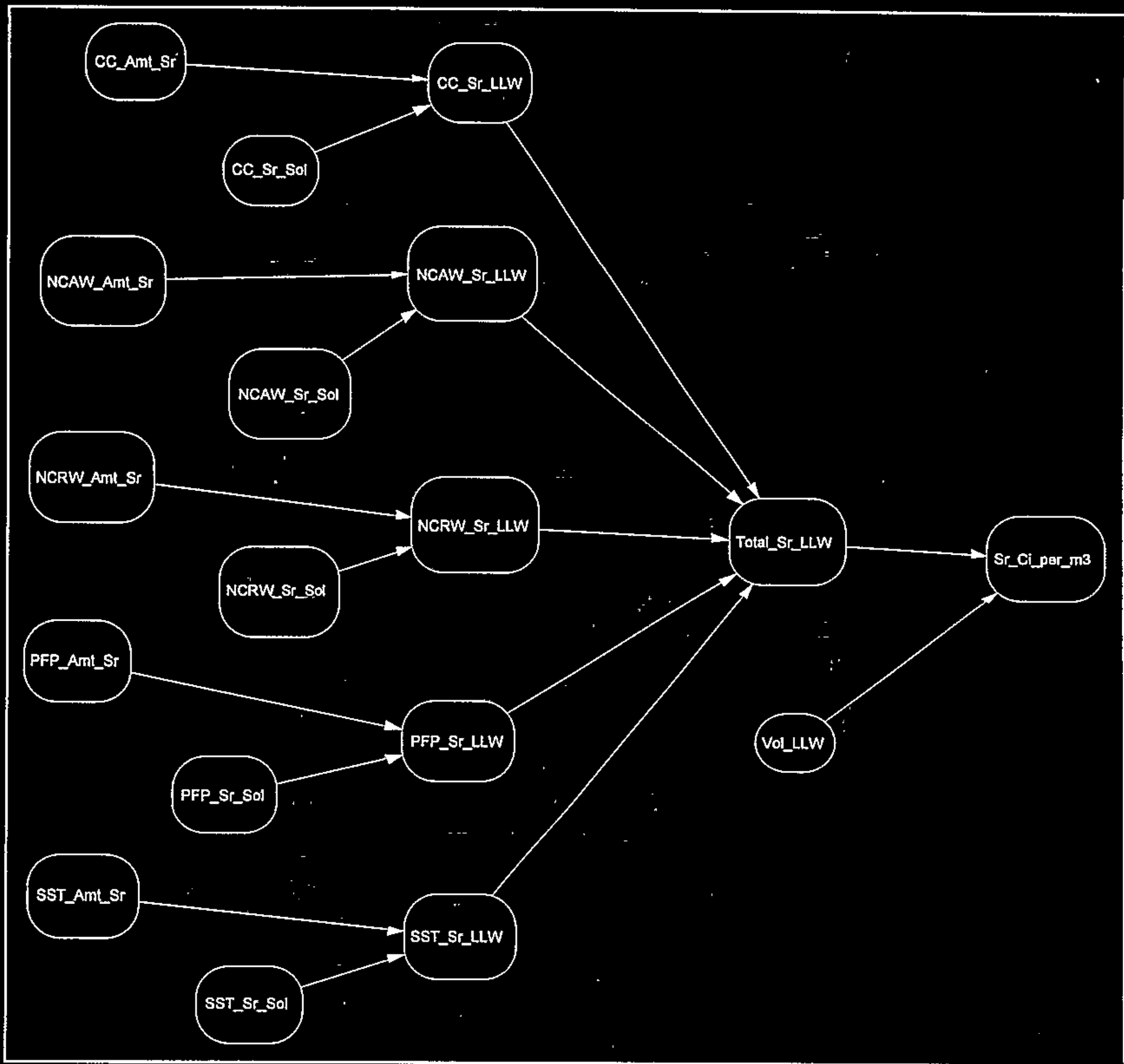


Figure 4–22. Influence Diagram in DPL Model for Calculating Amount of Strontium in LLW

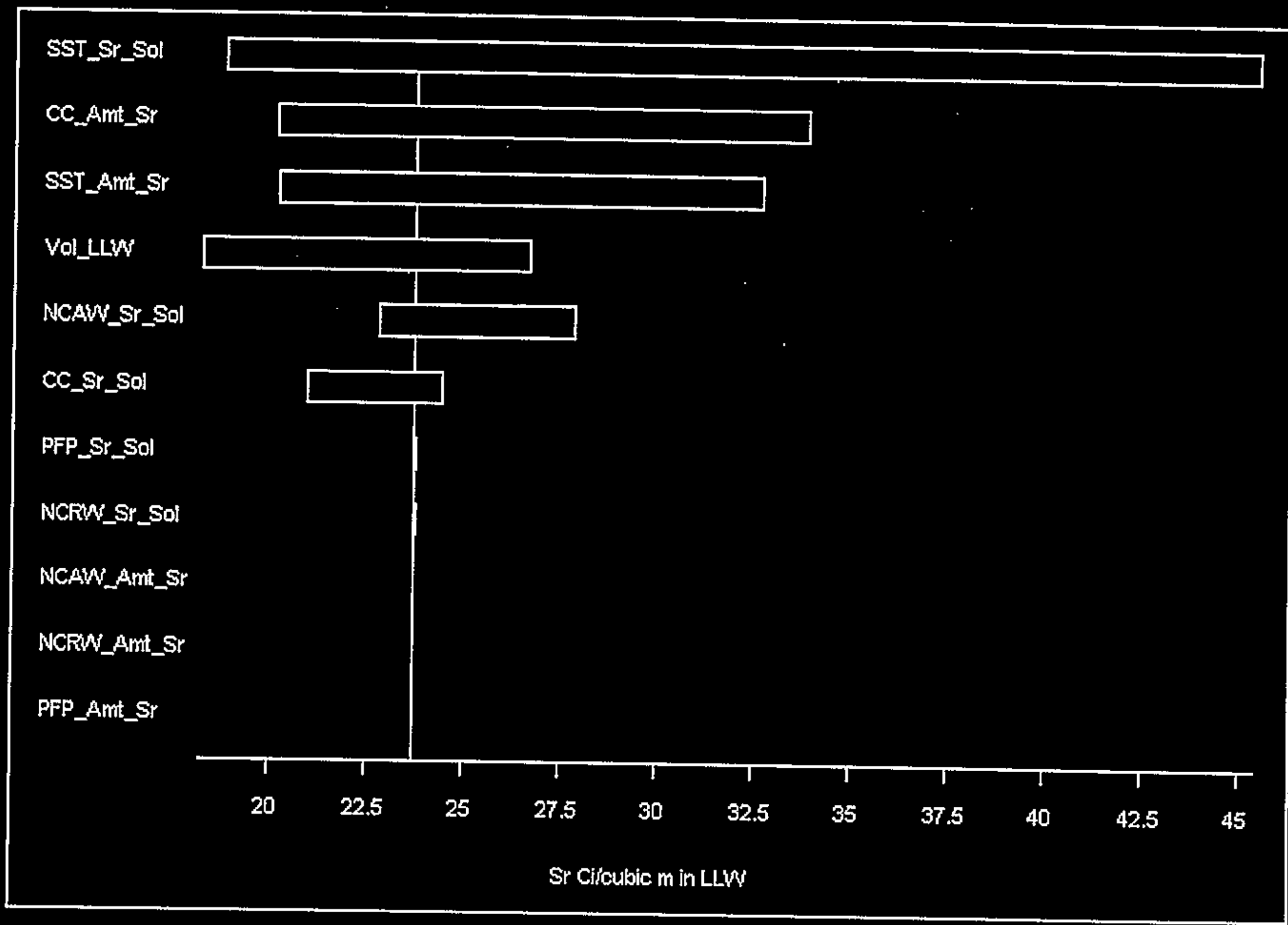


Figure 4–23. Tornado Diagram Showing Results from Sensitivity Analysis

Risk Analysis.

The DPL model was revised so that the six variables that impacted the amount of Sr in LLW were treated as uncertain variables. The influence diagram for the revised model is shown in Figure 4-24. The uncertain variables are represented as ovals in the figure. For each of these variables a probability distribution is obtained over the range of possible outcomes. For purposes of the example, the distributions are three-outcome discrete-event distributions. DPL calculates all possible 729 outcomes and their probabilities. The resulting (cumulative) distribution of outcomes is shown in Figure 4-25. The vertical line shows the expected value (EV) of 31 Ci/m3. What should be noticed is, first, the EV is different from the point estimate of 24 Ci/m3, and second, the range of possible outcomes is from approximately 10 Ci/m3 to over 100 Ci/m3. 100 Ci/m3 is still less than the class B limits of 150 Ci/m3 and much less than the class C limits of 7000 Ci/m3. In this case, the small probability of the higher outcome values would probably be judged to be well within the acceptable limits of risk, and it might be decided to put the issue to rest. To further illustrate the analytic process, assume that the risk of Sr content in LLW (in Ci/m3) being greater than the 24 Ci/m3 given by the point estimate was judged unacceptable. Then, the next step is an analysis of the risk management options.

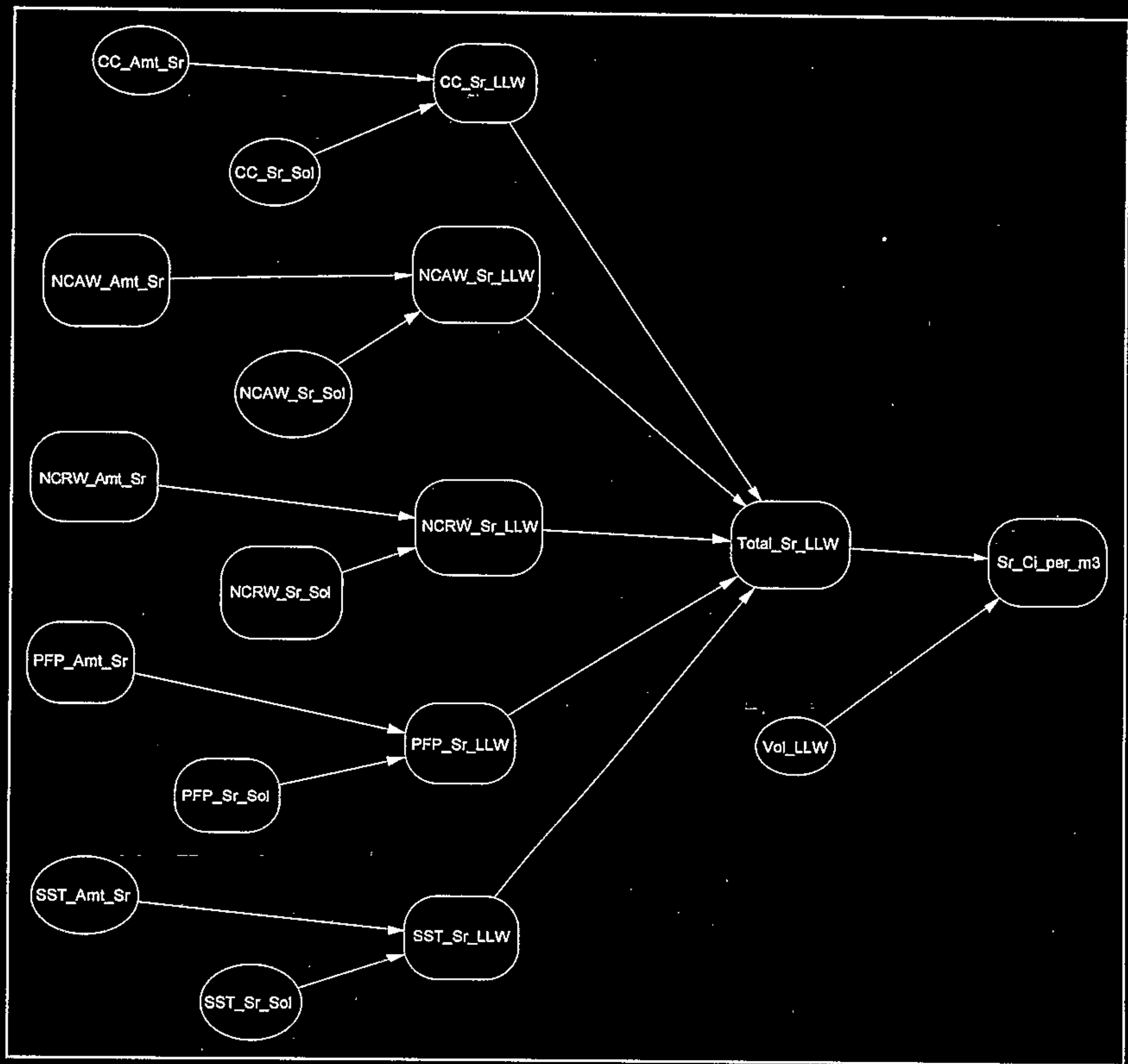


Figure 4–24. Influence Diagram in DPL Model for Risk Analysis

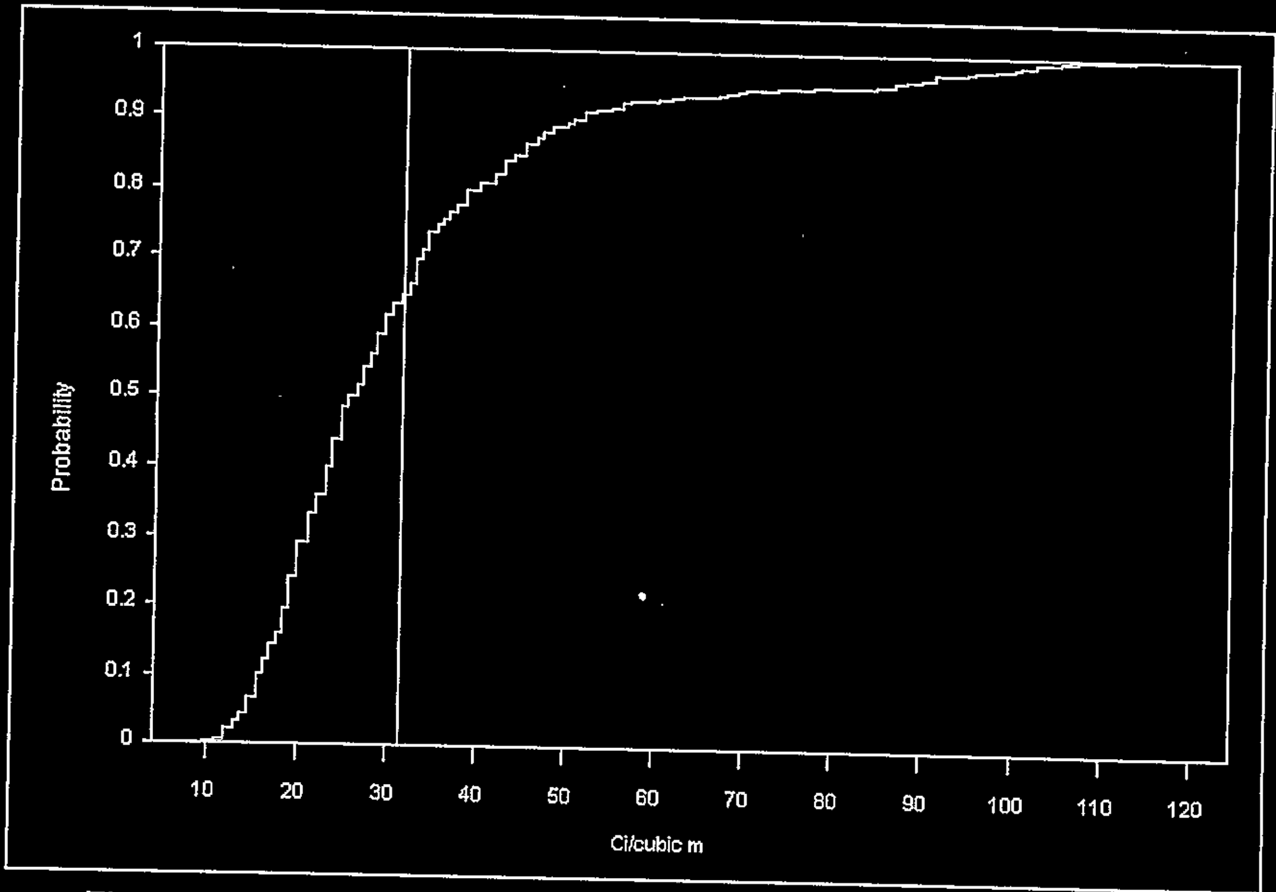


Figure 4–25. Cumulative Probability Distribution for Sr in LLW for Base Case

Decision Analysis.

The decision alternatives of organic complexant destruction and Sr removal were added to the model. The influence diagram for this model is shown in Figure 4-26. The decisions are indicated by rectangular nodes. The organic destruction decision is shown impacting the Sr solubility for CC waste, and the Sr removal decision is seen to impact the percent of Sr removed from LLW. Figure 4-27 shows that the impact of organic destruction on Sr solubility in CC waste is modeled in the decision analysis. If organics are not destroyed, the probability distribution for Sr solubility in CC waste is the same as in the risk analysis. If organics are destroyed, then it is assumed the solubility distribution would be similar to NCAW and SST waste.

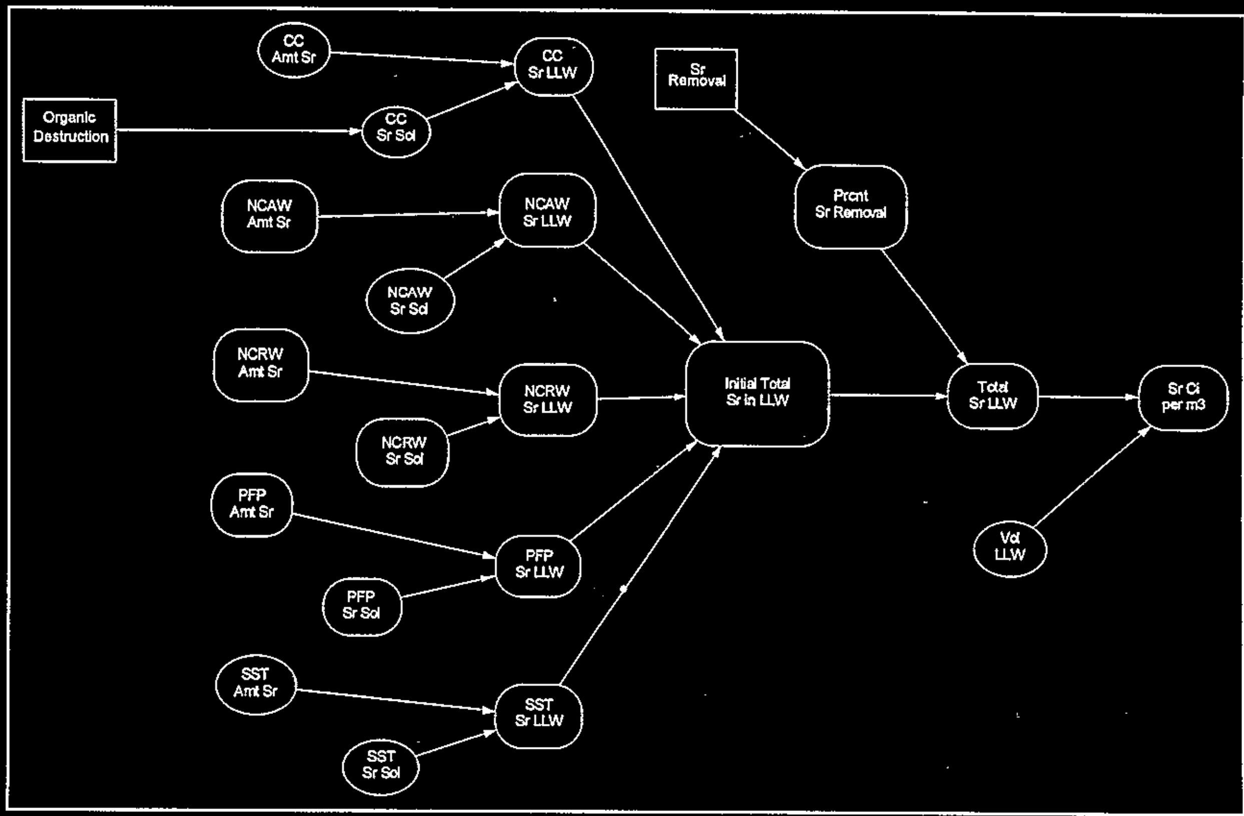


Figure 4–26. Influence Diagram for DPL Model Decision Analysis

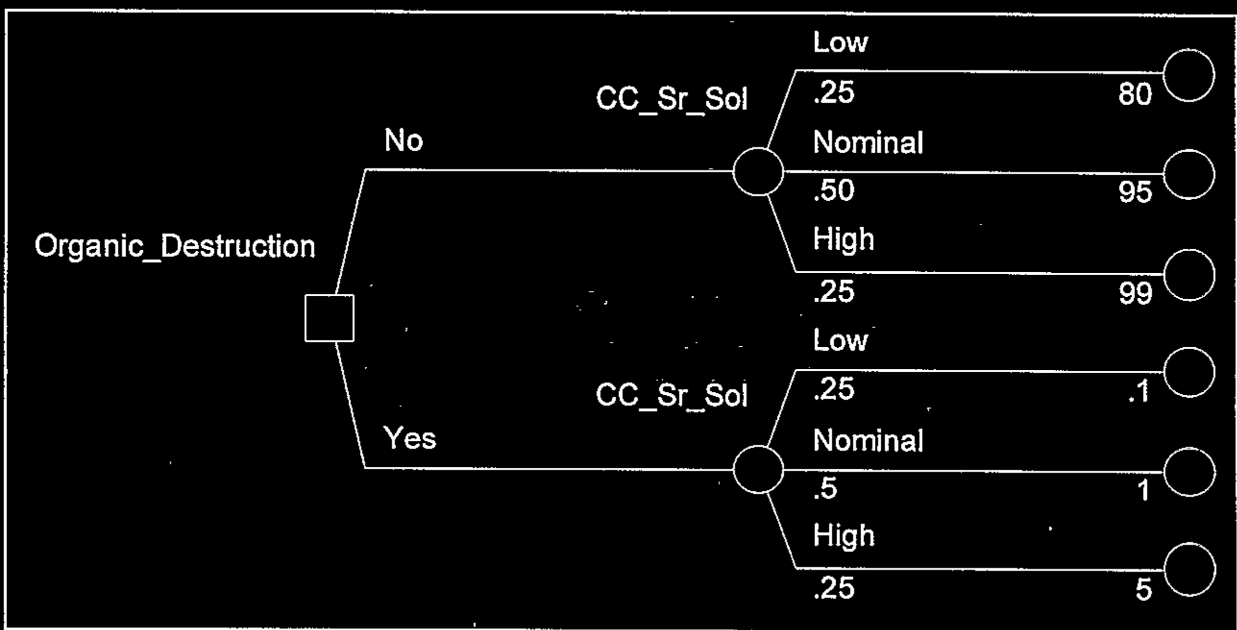


Figure 4–27. Decision Tree Showing Impact of Organic Destruction Decision on Sr Solubility Distribution in CC Waste

The analysis by DPL now calculates the 729 possible outcomes for each of the four combinations of decision alternatives and recommends the path that minimizes the expected Ci/m3. The minimal strategy is to destroy organics and remove strontium. The EV for this strategy is only 0.14 Ci/m3. The cumulative probability distribution for this strategy is shown in Figure 4-28. As can be seen in the figure, the amount of strontium is sure to be less than 0.9 Ci/m3, which is two orders of magnitude less than the maximum concentration if complexant destruction and Sr removal were not performed. The EVs for all four combinations of decision alternatives are shown in Figure 4-29. Note that the combination of not destroying organics and Sr removal has an expected value of 0.31 Ci/m3. The risk profile, shown in Figure 4-30, shows an upper limit not much different than for organic destruction and Sr removal. It may be that, if it is thought necessary to remove the Sr from LLW, then organic destruction may be redundant. An analysis that considered the trade-offs to include costs most likely would show this as optimal. Again, it should be emphasized that this analysis is for illustrative purposes only.

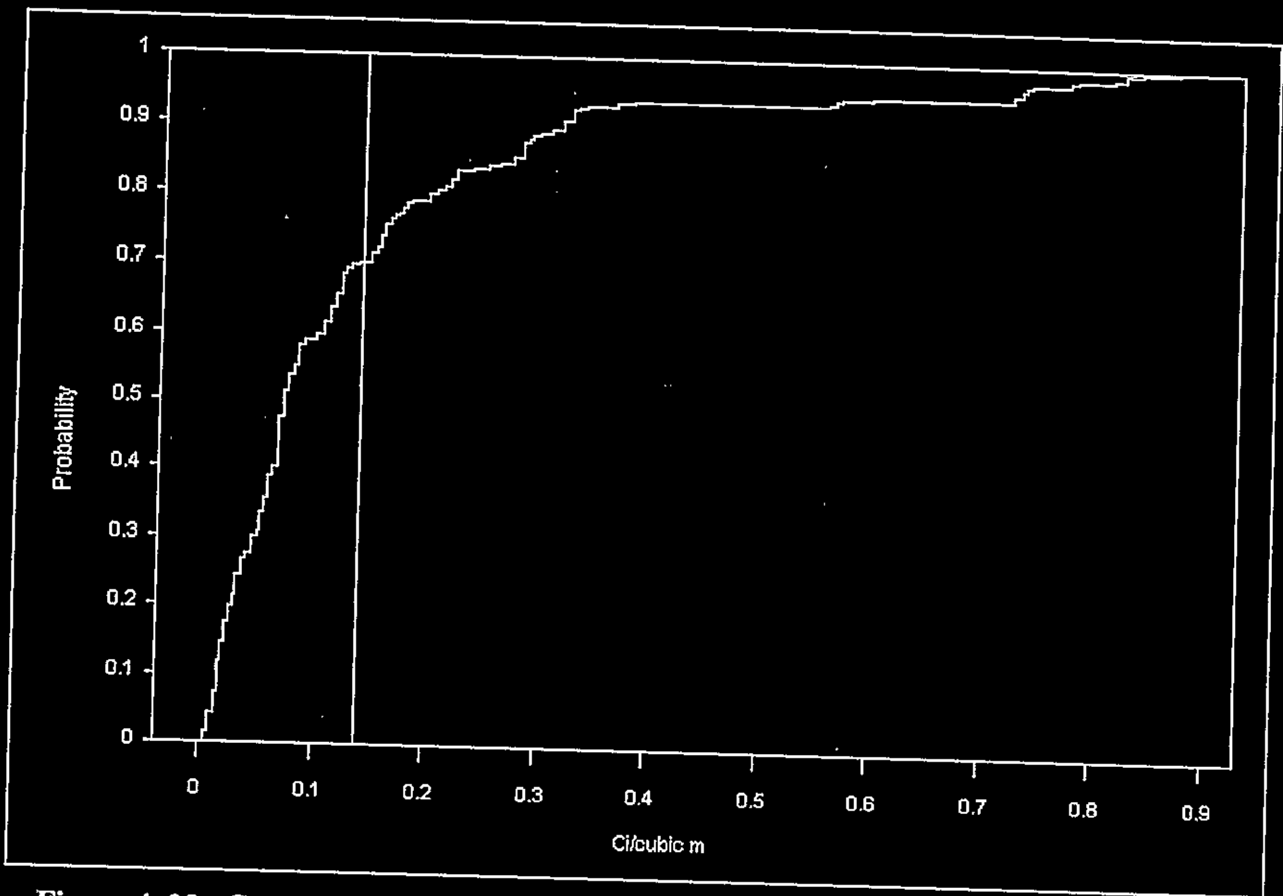


Figure 4–28. Cumulative Distribution for Sr in LLW if Organics are Destroyed and Sr Removed from LLW

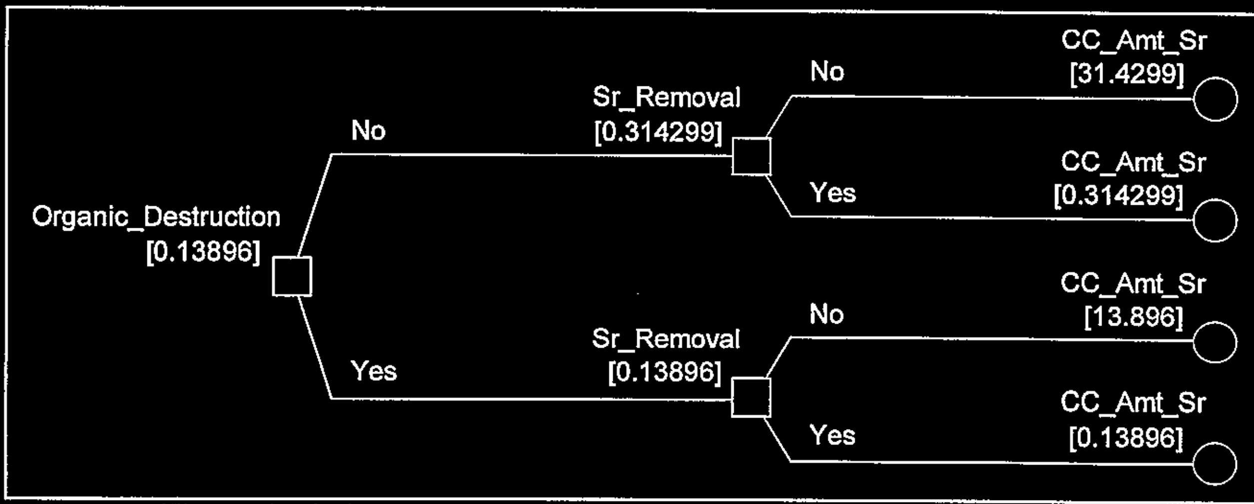


Figure 4–29. Expected Values for Sr Risk Management Alternatives

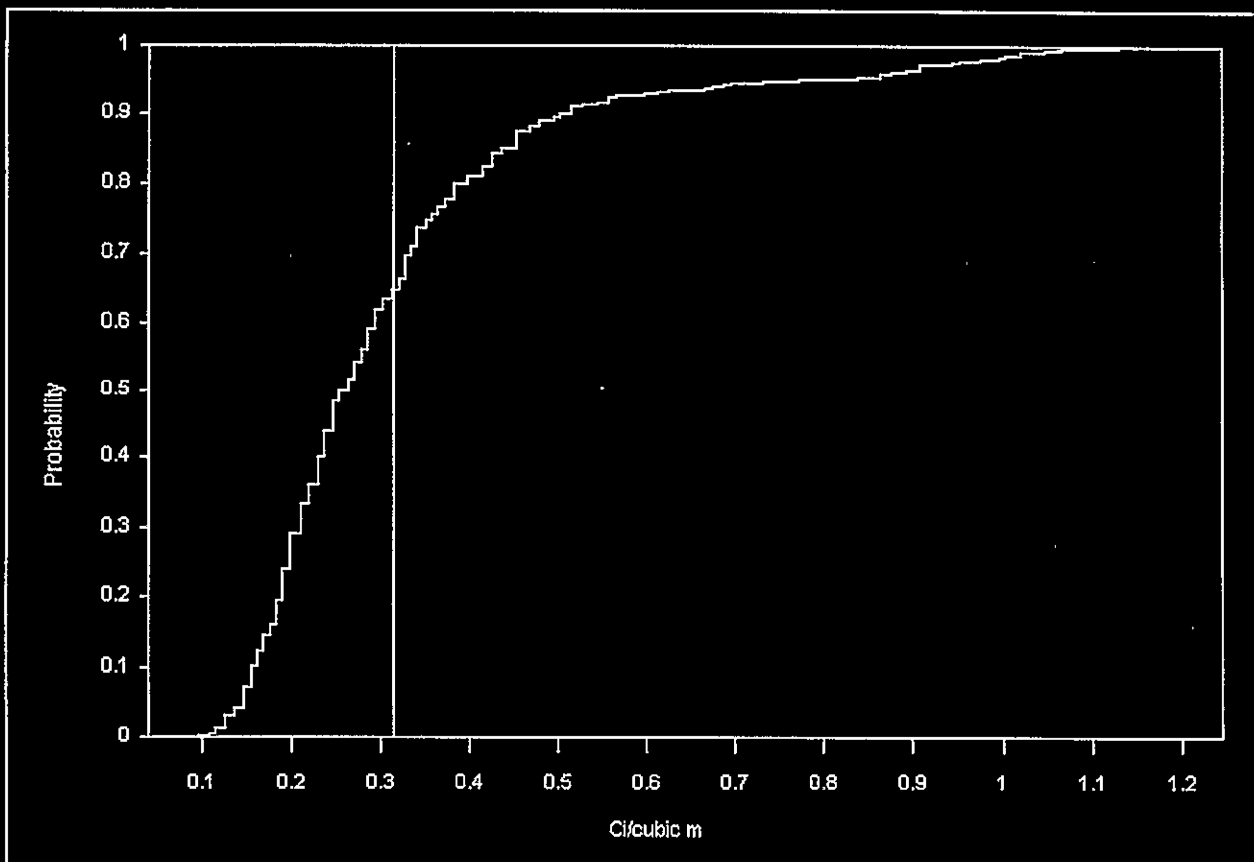


Figure 4–30. Cumulative Distribution for Sr in LLW if Organ ics are not Destroyed and Sr is Removed from LLW

5.0 RELATIONSHIP OF THE SWDM TO SLUDGE WASHING EVALUATION MILESTONES

As outlined in the *Enhanced Sludge Washing Evaluation Plan*, an iterative application of decision analysis will guide progress toward the enhanced sludge washing decision (Jensen, 1994). To ensure that the envisioned iterative use of the SWDM would be beneficial, it was crucial that each application of the model be designed to make use of the best currently available information and that model outputs be generated in a timely fashion in order to feed key decisions in the evaluation process. Clearly, the development and use of the SWDM must be carefully integrated with all other elements of the sludge washing evaluation effort. To this end, this section provides a preliminary identification of key milestones with which the development and application of the SWDM could interact. It is envisioned that many additional useful linkages could be identified as work on the SWDM progresses. The milestones identified in this section have been divided into two types: milestones which signify potential inputs to the development and application of the SWDM, and milestones for which the SWDM can provide useful analytical/decision support.

5.1 MILESTONES POTENTIALLY PROVIDING INPUTS TO THE SWDM

There are numerous research efforts under way to resolve key uncertainties related to the sludge washing decision. As these efforts progress, they will provide new and better information on the likely performance of enhanced sludge washing, of advanced separations, and of variations on these pretreatment concepts. The decision analysis effort centered around the SWDM is designed to make use of each additional relevant piece of information as it becomes available from these research efforts. Thus, a key step in planning SWDM use is the identification of research efforts providing such relevant information and of the times at which information will be available. Table 5–1 lists milestones associated with various research efforts which have been identified to date as potential input contributors for the SWDM. The nature of information assumed to be available from these efforts is briefly described.

5.2 MILESTONES POTENTIALLY SUPPORTED BY THE SWDM

The 1998 enhanced sludge washing decision, though often described as a single decision, is really more appropriately thought of as an ongoing decision process. To reach the 1998 decision point with adequate resolve requires numerous decisions to be made in the interim regarding such issues as where research funds should be targeted and what specific technologies should be used to implement candidate pretreatment processes. It is intended that the SWDM would be able to assist not only in the final 1998 decision, but in many of the crucial but lower level decisions to be made in the years leading up to 1998. To that end, an additional key goal of the SWDM effort is to identify in detail all decision–making and analytical needs for which the SWDM could be usefully employed. Table 5–2 lists milestones identified to date that could be supported by the SWDM and briefly describes the envisioned role of the SWDM in supporting these milestones.

Table 5–1. Milestones Potentially Providing Inputs for the SWDM

WHC TWRS Milestone Title	Milestone Control Number				Potential Inputs to SWDM
	1995	1996	1997	1998	
Issue feed process ability assessment report	T3C-95-104	T3C-96-107	T3C-97-109		• estimates of total glass production ranges based on different blending, pretreatment and glass composition • estimates of potential range of feed compositions to the HLW vitrification plants • uncertainties in tank waste inventory, pretreatment performance, and blending alternatives
Determine waste processing strategy and waste separations process	T3A-95-136	T3A-96-140	T3A-97-111		• pertinent information from trade study report • cost and schedule impacts for implementing advanced separations processes
Submit report summarizing the testing of enhanced sludge washing and related tank waste sludge pretreatment methods for samples of tank waste sludge	T3A-95-102	T3A-96-100	T3A-97-101		• results from testing of enhanced sludge washing and related tank waste sludge pretreatment methods • information on candidate tank waste pretreatment sequence and tank blending strategies • HLW glass volume production estimates for candidate tank waste pretreatment methods
Sludge washing / alkaline leach tests conducted at PNL/ LANL	T3A-95-132 T3A-95-133				• HLW glass volume estimates based on component material balances from sludge washing and alkaline leach tests
Tank characterization reports	T2D-95-102	T2D-96-102	T2D-97-102		• relevant data from the tank characterization reports
Issue TWRS process flowsheet		T3A-96-131			• new requirements, technical development results, and vendor information from the TWRS process flowsheet

Complete in-tank sludge washing process test			T3A-97-107		• estimated efficiency of a single sludge wash of Neutralized Current Acid Waste (NCAW)
Update estimates of tank waste types, compositions & quantities		T3C-96-114			• estimates of the potential range of feed compositions to the HLW vitrification plant • uncertainties in tank waste inventory, pretreatment performance, and blending alternatives

Table 5–2. Milestones Potentially Supported by the SWDM

WHC TWRS Milestone Title	Milestone Control Number				Potential Support Role for SWDM
	1995	1996	1997	1998	
Determine waste processing strategy and waste separations process	T3A-95-136	T3A-96-140	T3A-97-111		• assist in evaluating categories of separations alternatives including no pretreatment, treatment of waste to an intermediate form, enhanced sludge washing, and extensive pretreatment separations
Issue prototype decision model for waste pretreatment alternatives	T3A-95-140				• evaluate at least two alternatives, one of which will be consistent with the emerging TWRS baseline
Update estimates of tank waste types, compositions & quantities	T3A-95-112	T3A-96-110	T3A-97-105	T3A-98-100	• assist in the evaluation of enhanced sludge washing to determine whether advanced processes are required • provide insight into prioritizing programmatic risks

6.0 FY 1995 PLAN AND ACTIVITIES

This section describes the activities that were planned for FY 1995 to further develop the existing strawman pretreatment decision model to support the 1998 sludge washing evaluation plan, prior to the cancellation of this work. The primary pretreatment need addressed by these activities is the March 1998 TPA milestone number M-50-03, Complete evaluation of enhanced sludge washing to determine whether advanced sludge separation processes are required. The plan for meeting this milestone is discussed in WHC-EP-0805, *Enhanced Sludge Washing Evaluation Plan*. The activities planned for FY 1995 fall into four categories: Pretreatment Model Development, Sensitize Model to Individual Technologies, Evaluate Prototype Model, and WHC Modeling Support. Each of these is discussed below.

6.1 PRETREATMENT MODEL DEVELOPMENT

The existing pretreatment decision model will be updated to reflect the latest data available, the submodels will be given additional validation and review, the value model revised, and the model exercised to support decision making activities. This subtask consists of the following activities.

- **Continue data collection and validation for Case Beta, treatment of waste to an intermediate form, and the bounding alternatives of no separations and extensive separations.** The current TWRS process flow sheets and the extensive separations processing strategy document (WHC-EP-0791), and other documents to be identified will be reviewed and the data revised as necessary.

- **Validate SWDM submodels.** The various submodels used in SWDM to calculate performance parameters, such as HLW Volume and Total Life Cycle Cost, will be reviewed and modified as necessary. This will be done initially in an internal review by the modeling team in light of the additional data collection, and subsequently in a workshop consisting of cognizant scientists and engineers.

- **Analyze Case Beta and bounding alternatives.** SWDM will be exercised to evaluate Case Beta, treatment to an intermediate waste form and the bounding alternatives. The analysis will include expected performance of the alternatives, the risk associated with the alternatives, and sensitivity analysis.

- **Revise model as needed.** As a result of the initial analysis the model will be revised to incorporate additional uncertainties identified. The model will also be revised to correct inconsistencies with the more detailed flow sheets.

- **Develop value model for SWDM.** SWDM's value model will make possible the comparison of alternatives across all performance measures with a single number. This will consist of identifying the appropriate functional form for the value model, assessing and quantifying the relative importance of different levels of performance on the individual criteria, and assessing the relative importance of the criteria. This information will be obtained as a result of facilitated interviews with managers within the U.S. Department of Energy (DOE), Richland Operations Office (RL), WHC, and PNL, and possibly by other Hanford stakeholders.

6.2 SENSITIZE MODEL TO INDIVIDUAL TECHNOLOGIES

This task will identify issues that are relevant to the 1998 sludge washing decision. The issues will be initial represented as qualitative influence diagrams that will later be quantified and incorporated into SWDM to the extent feasible and/or desirable. This will consist of the following activities:

- **Identify technologies relevant to the 1998 sludge washing decision.** Technologies will be identified initially by reviewing recent and relevant TWRS documents. These will include *Technology Development in Support of the TWRS Process Flowsheet* (Orme 1994b), the *Integrated Technology Plan* (DOE 1994), and the *Enhanced Sludge Washing Evaluation Plan* (Jensen 1994). A workshop will be held subsequent to this to validate and supplement the initial list.
- **Identify areas of concern to the pretreatment process.** Identified will be key uncertainties and performance measures that are potential threats to the success of pretreatment process. These will be identified through literature review, sensitivity analysis with PDM, and a workshop. The output of the above two activities will be a technology by area of concern matrix showing which technologies impact which areas of concern. This will form the basis of further modeling effort.
- **Develop qualitative submodels.** Qualitative models will be developed relating the technologies and areas of concern identified in the above two activities. These submodels will qualitatively identify the relationships between the technology decisions, uncertainties, and impacts on performance measures. The submodels will be represented using influence diagrams. This will be a combination of internal effort on the part of the decision team and a workshop.
- **Quantify submodels.** The qualitative submodels will be quantified to the extent that it is feasible and/or desirable. This will be a combination of internal effort on the part of the decision team and a workshop.
- **Integrate submodels into SWDM.** SWDM will be revised to incorporate the submodels to the extent that it is desirable and/or feasible.

6.3 EVALUATE PROTOTYPE MODEL

This task will identify alternatives for evaluation by SWDM, collect data on the identified alternatives, evaluation and analysis of the alternatives, and revision of SWDM as necessary. The following activities will be carried out:

- **Identify alternatives for evaluation.** At least two significant variations or alternatives to Case Beta will be identified for evaluation by SWDM. These will be identified by a review of recent TWRS documents, discussions with individual scientists and engineers, a workshop, and by considering combinations of technologies suitable for pretreatment unit operations. Most likely candidates for evaluation will be Case Beta, treatment of waste to an intermediate form, no separations, advanced separations, and any irregular alternatives that the Environmental Impact Statement (EIS) may identify as desirable candidates for evaluation.
- **Collect data on alternatives.** Data for the alternatives identified in the previous activity will be obtained through review of recent documents, interviews with cognizant scientists and engineers, and a workshop.
- **Perform analysis of alternatives.** SWDM will be exercised to evaluate the identified alternatives. The analyses will include expected performance of the alternatives, the risk associated with the alternatives, and sensitivity analyses.
- **Revise prototype as needed.** As a result of the analysis the model will be revised to incorporate additional uncertainties identified.
- **Final analysis of alternatives.** Subsequent to model revision, alternatives will be reevaluated. This analysis will include expected performance, including risk, sensitivity analysis, value of information, and value of control.

6.4 WHC MODELING SUPPORT

WHC modeling will consist of the following activities:

- **Exercise model.** The developed model will be exercised to support M50-03-T2A and other milestones.
- **Additional model revisions as needed.** In conjunction with the previous activity, any revisions that are necessary will be made.

Additionally, a prototype model milestone report will be written documenting the SWDM and describing the results of the analysis.

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