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ENCLOSURE 1

# Decision Analysis To Support West Valley Tank Farm Transition End Point Development for HLW Tank Cleanup


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## DISCLAIMER

This Decision Analysis report is only one part of the evaluation. Additional studies are underway to evaluate the remaining criteria cited in correspondence from R. M. Bernero, Office of Nuclear Material Safety and Safeguards to J. Lytle, Office of Waste Management Environmental Restoration and Waste Management, dated March 9, 1993, however, the WVDP wants to maintain timely communications with the Nuclear Regulatory Commission (NRC) regarding each of the work products as they are developed. In this manner NRC's early input can be factored into the remaining studies being conducted. Specifically, we are seeking NRC's comments on the model's use of site specific data and the appropriateness of the methodology as it is applied to the site. Although results in the report are based on site specific data, they may be revised as updated information becomes available, NRC's input is obtained and other studies are completed.

## Overview of the Technical and Economic Feasibility Decision Model and Analysis for High Level Waste (HLW) Tank Heel Removal

The West Valley Demonstration Project (WVDP) Waste Tank Farm (WTF) consists of two pairs of underground tanks that have supported nuclear fuel processing in the past and are currently being used in the process of permanently isolating blended high-level radioactive wastes via vitrification. Removal of the HLW from the tanks must continue until any residual waste in the tanks is no longer classified as HLW. To achieve this, the cleanup must remove radionuclides to the maximum extent that is technically and economically practical and meet, as a minimum, performance based limits. The performance based limits have been tentatively defined based on the performance assessment associated with the Draft Environmental Impact Statement for Completion of the WVDP. This report quantifies the tank cleanup limits based on technical and economic considerations. It is proposed that this analysis model be included as a basis for the Nuclear Regulatory Commission's (NRC's) assessment regarding incidental waste determination of the HLW tanks' residue.

This study uses tools from decision analysis and social cost - benefit analysis to develop estimates of expected benefits and costs to society for levels of curie removal ranging up to 99.9% for four possible cleanup technology scenarios that are viewed as spanning the range of available or potentially available cleanup processes. At one extreme, all advanced technologies currently under development are assumed to be available. The opposite scenario has only current technologies available, while two other scenarios represent intermediate positions. "Benefits" to society for each technology scenario are calculated for various levels of curie removal by projecting the monetized value of avoided person-rems plus a credit for avoided closure costs. "Costs" to society are represented by operating expenses for the vitrification process plus capital costs for technology development. The study follows or adapts key elements of the NRC guidelines for regulatory analyses. The analytical model quantifies the process of HLW tank heel removal based on the existing and forecasted data supplemented by the WVDP operational experience. The key parameters associated with the model are:

- $2000 per person-rem avoided - same as the current value adopted by the NRC for their regulatory analyses
- 3% real discount rate - a conservative value recommended by the NRC for long duration projects
- WVDP operating costs of $2 Million/month for vitrification
- WVDP site specific capital costs for various technologies
- WVDP site specific projections for time to remove specific amounts of HLW
- Reference or starting point - 69% of the initial curies removed as of January 1998

The significant results from the analysis include:

- The Expected Net Social Benefit remains high up to approximately 94% curie removal for all the technologies. For further cleanup beyond this point, the Net Social Benefit shows a marked decline which is attributed to the increased difficulty and, therefore, higher costs of continued cleaning.

- Expected Net Social Benefit for all Technology Scenarios goes negative in the range of 98% to 99% curie removal.

The desired cleanup levels based on economic feasibility are sensitive to the costs of cleanup which consist of the operating costs and the capital costs. The operating costs are a function of the time to reach the necessary level of curie removal and dominate the total costs. The capital costs are a relatively small fraction of the total cleanup costs. As the current cleanup and the end of HLW vitrification approaches, a more precise value for these variables will become available. A revision of the input to the analytical model at the end of Phase I vitrification and prior to implementation of the subsequent steps of the stepped approach will enable WVNS to update the results of this analysis.

The technical and economic feasibility analysis model for the HLW tank heel removal, as described in this report, is useful for developing a project consensus and to initiate discussions with the NRC to seek their concurrence regarding the classification of tank residue as incidental waste.

**Decision Analysis to Support West Valley Tank Farm Transition End Point Development for HLW Tank Cleanup: Final Report**

Robert K. Perdue
Westinghouse Science & Technology Center
April 24, 1998

**Abstract**

The West Valley Demonstration Project Waste Tank Farm consists of four tanks that have supported nuclear fuel reprocessing in the past and are currently being used to support the vitrification of blended high level radioactive wastes (HLW). At its completion, this process must leave behind a sufficiently small amount of radionuclides in the tanks to allow any residual waste to be classified as "not HLW." This study uses the tools of decision analysis and applicable regulatory analysis guidelines to estimate societal costs and benefits of cleaning the waste tanks to a level that would meet safety-related regulatory guidelines while incorporating economic and technical considerations. A computer model is developed to implement the process. The results can be used in conjunction with other studies pertaining to the safety criterion and engineering aspects of the cleanup technologies to support an informed decision as to the appropriate endpoint for cleanup once the minimum acceptable safety criterion has been determined and achieved.

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## Executive Summary

The West Valley Demonstration Project Waste Tank Farm consists of two pairs of underground tanks that have supported nuclear fuel processing in the past and are currently being used in the process of permanently isolating blended high-level radioactive wastes (HLW) via vitrification. Cleaning and rinsing the HLW tanks must continue until any residual waste in the tanks is no longer classified as HLW. The problem is to decide when the tank cleanup (and, hence, the vitrification process) can be stopped. The definition of these tank cleanup "endpoints" must include applicable safety -related regulations, as well as technical and socially - economical feasibilty.

This study uses tools from decision analysis and social cost - benefit analysis to develop estimates of expected incremental monetary benefits and costs to society for levels of curie removal ranging up to 99.9% for four possible cleanup technology scenarios that are viewed as spanning the range of available or potentially available cleanup processes. At one extreme, all advanced technologies currently under development are assumed to be available. The opposite scenario has only current technologies available, while two other scenarios represent intermediate positions. "Benefits" to society for each technology scenario are calculated for various levels of curie removal by projecting the monetized value of avoided person-rems plus a credit for avoided closure costs. "Costs" to society are represented by operating expenses for the vitrification process plus capital costs for technology development. The study follows or adapts key elements of Nuclear Regulatory Commission guidelines for regulatory analysis. Salient conclusions include:

- Expected Net Social Benefit for all Technology Scenarios peaks in the range 89% to 92% curie removal and goes negative in the range of 98% to 99% curie removal.

- There is a high degree of statistical confidence that pushing cleanup to 99.9% for any Technology Scenario will yield a negative net social benefit.

The results can be used in conjunction with other studies pertaining to the safety criterion and engineering aspects of the cleanup technologies to support an informed decision as to the appropriate endpoint for cleanup once the minimum acceptable safety criterion has been determined and achieved.

**Decision Analysis to Support West Valley Tank Farm Transition End Point Development for HLW Tank Cleanup: Final Report**

## 1.0 Introduction

The West Valley Demonstration Project (WVDP) Waste Tank Farm (WTF) consists of two pairs of underground tanks that have supported nuclear fuel reprocessing in the past and are currently being used to support the vitrification of blended high-level (radioactive) wastes (HLW). HLW requires permanent isolation and is currently being solidified by the aforementioned vitrification process. The larger pair of tanks, known as 8D-1 and 8D-2, are carbon steel tanks holding the majority of the HLW and the smaller pair (8D-3 and 8D-4) are stainless steel tanks currently used to hold recycled materials from the vitrification process. At its completion, this process must leave behind a sufficiently small amount of radionuclides in the tanks to allow any residual waste to be classified as "not HLW."

The problem is to decide when the tanks are clean enough for such a reclassification; that is, when can the cleanup of the tanks (particularly, 8D-1 and 8D-2) and, hence, the vitrification process be discontinued? Definition of the "endpoints" for this cleanup process must consider applicable Nuclear Regulatory Commission (NRC) safety-based regulations, as well as technical and economic feasibility. A task team of WVDP professionals and managers (hereafter, the Team [22]) formed to address this issue has produced a document [10] addressing the safety - based regulations. This report is intended to complement the latter by using the tools of decision analysis and a social cost - benefit methodology to develop estimates of expected incremental monetary benefits and costs to society for levels of curie removal ranging up to 99.9% under four possible cleanup technology scenarios. At one extreme, all advanced technologies currently under development are assumed to be available. The opposite scenario has only current technologies available, while two other scenarios represent intermediate positions.

"Benefits" to society for each technology scenario are calculated for various levels of curie removal by projecting the monetized value of avoided person-rems plus a credit for avoided closure costs. "Costs" to society are represented by operating expenses for the vitrification process plus capital costs for technology development. The study follows or adapts key elements of Nuclear Regulatory Commission guidelines for regulatory analysis. The study is intended to serve as a source document to support the selection of a cost-effective and socially - beneficial cleanup option for tanks 8D-1 and 8D-2 once minimum safety criteria have been selected and met.

The plan of the report is as follows. Section 2 below provides a brief introduction to decision analysis. Section 3, defines the alternatives and decision criteria. Section 4 provides a derivation of the model's major equations and an overview of the computerized model used to quantify the decision criteria. Section 5 describes the derivation of model inputs. Section 6 presents the analytical results. Section 7 presents an uncertainty and sensitivity analysis, and Section 8 summarizes and provides conclusions.

## 2.0 Overview of Decision Analysis

Rooted in the axioms of rational decision theory, decision analysis is a powerful and practical tool for quantitatively dealing with the uncertainty, risk and complexity often associated with important decisions, including those involving public safety. Decision analysis is a structured process which can be characterized by the "decision analysis cycle" (Figure 1). The first phase of this process addresses *Problem Structuring* with a set of facilitating tools to define actionable alternatives, uncover the decision criteria that will be used to judge alternatives and identify the major information that will be required to quantify those criteria. In this study, for example, several alternative strategies were initially constructed, one dominant strategy was identified and tactical variations on this strategy were then evaluated. Further, a version of "net social benefit" consistent with the Nuclear Regulatory Commission's guidelines for regulatory analysis was identified as a logically appropriate decision criterion. Typically, an "influence diagram" tool is used to identify the key variables, their interrelationships and the elemental inputs required. In this study, early or preliminary influence diagrams helped guide the model building and were eventually refined to the diagrams shown in subsequent sections. The objectives for the Problem Structuring Phase are: a set of clearly-specified alternatives, a set of quantifiable decision

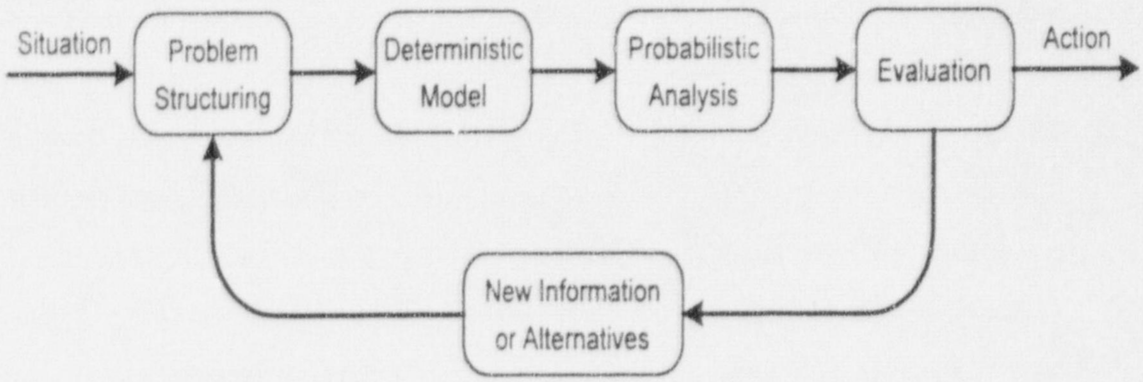



**Figure 1: The Decision Analysis Cycle**

criteria, a blueprint (i.e., the influence diagram) for at least a rapid prototype model that could quantify the value of the decision criteria for each alternative, and identification of the primary sources of information that will be required to implement the model.

The second or "*Deterministic Modeling*" Phase uses the influence diagrams to design and implement a computer model to compute values for the decision criteria. Initially, the model should be a rapid prototype - that is, have the look and feel of the final model but without the refinements necessary for a credible defense of the ultimate decision. This rapid prototype is supplied with very preliminary inputs for the sole purpose of performing sensitivity analysis to determine where subsequent model refinements and information-gathering should be focused. The objective for this stage is a computer model.

The *Probabilistic Analysis* Phase overlaps synergistically with the model-building effort in the Deterministic Modeling stage. The data for most important decisions is primarily judgmental or leavened with a heavy dose of (e.g., "engineering" ) judgment. Decision analysis has a set of techniques for extracting judgmental uncertainty as probabilistic information and/or combining subjective probabilities with "objective" statistics. These probabilistic assessments may initially be crude range estimates used for sensitivity analysis. The latter identifies the model variables that are critical in the sense of affecting choices and hence helps focus future modeling and data collection. Probability distributions for these critical inputs are then elicited in more detail as the model and the basis for a decision evolve. In this study, the rapid prototype was used to perform a sensitivity analysis that led to subsequent refinements in the method for forecasting the time to achieve specified levels of cleanup. This phase has three objectives: (1) Characterization of the uncertainty surrounding major inputs by probability distributions reflecting the best available state of knowledge. (2) Identification of critical variables. (3) Solutions of the model for values of the decision criterion or criteria which reflect the probabilistic uncertainty (and in certain cases, risk preferences and / or tradeoffs among different objectives).

Finally, the extent to which the process iterates back through the first three phases depends upon the results of the *Evaluation Phase,* which provides tools and principles for deciding whether and to what extent there is value in further information-gathering and analysis before making a decision. This phase helps insure that the study stays focused on its purpose - to provide a recommended course of action. If the decision is to "act" rather than "study some more" the process can be extended to support evaluation of implementation tactics. If the decision is to gather more information, the process can be employed to help structure a sequential information gathering and updating plan to improve the ultimate basis for a decision. The present study completed the first iteration through this cycle in December of 1997 with recommendations for further information - gathering and model refinements. The model and results described in this final report incorporate and build upon those recommendations.

## 3.0 Problem Structure Phase: Definition of Alternatives and Decision Criteria

### *3.1 Identification and Definition of Alternatives*

Of the four underground tanks used for spent nuclear fuel reprocessing at WVDP, 8D-3 has no inventory of radionuclides assigned to it and 8D-4, which has been used to hold slurry from the Vit Cell waste header, has only a minuscule fraction of the total Tank Farm radionuclide inventory [10, p.30]. Thus, attention is here focused on the two tanks 8D-1 and 8D-2. The former "...holds in-tank components of the Supernatant Treatment System (STS) and excess liquid decanted from 8D-2 to maintain process concentration for vit feed"[10, p.10]. Tank 8D-2 serves as the primary feed tank for the vit process.

A project kickoff meeting held on 27 June 1997 was devoted to the construction of a set of "strategy tables" which: (1) identify the major decision areas, (2) list the feasible options under each decision area, (3) support the identification of a set of actionable alternative strategies. Table 1 contains one such strategy table. The column headings represent the nine major decision areas where the Task Team thought that WVDP ostensibly has choices to make that will impact the decision at hand. Under each column, the Task Force identified the menu of options available (e.g., under the column labeled "Mobilize Solids, "More Pumps to Eliminate Dead Spots" is one option; another is (use) "Existing Mob Pumps (w/tweaking)." By selecting one or more options under each decision area , a "strategy" can be identified. Thus, for example, the italicized - underlined cells in Table 1 map out the *Momentum* strategy; that is, the strategy that currently holds the most currency with decision makers. While any number of strategies could be constructed in this manner, not all would be logically correct or of interest. In fact, all that is needed is *a limited number of clearly different and actionable* strategies which span the spectrum of conceivable alternatives. The Task Force identified five such strategies:

- Momentum Strategy (shown in Table 1)
- Containment Strategy (**Appendix**)
- Unrestricted Use Strategy (**Appendix**)
- Vacuum Technology Strategy (**Appendix**)
- Oxalic Acid Strategy (**Appendix**)

**Table 1: "Momentum" Strategy Table**

| Mobilize Solids | Clean Tank Internals | Transfer Solids | Vitrification Proc. Oper. | Vitrified Cannisters | Verification of Results | Charac. of Waste | Definition of Limits | Phy./Chem. Properties |
|---|---|---|---|---|---|---|---|---|
| *Existing Mob Pumps (w/tweakin* | Ultrasonic Cleaning | Existing Pumps (no tweaking) | Run the way it is | Stick to "300" limit | *Process-based Knowledge* | *Use Grout to meet requirem't of LLW* | Rad limits: Unrestricted/Sitewide Greenfield | *Treat Rad alone (assume good enough for Haz)* |
| *More Pumps to elim dead spots* | Mechnical Cleaning | *Modify Pumps to enhance transfer* | Install Solids Separation Equipment | At pt of dim. returns, continue | Direct Measurement (in situ, no | Use Nongrout material for | Rad Limits: Restricted Use/ site | Include Hazardous consideration |
| Better Suspension | *Power Washing (& acid if necessary)* | *Add Grinders to help transfer* | Use Oxlate Feed Stream ("Global | At the pt of dim. returns, change to | *Visual Exam* | Use nuclie[illegible]-sensitive retainers | Rad Limits: restrict or unrestriced | |
| Mod/repl nozzle @ bottom | Chemical Cleaning | Add Movable Sump Pump | *Adjust the Glass Recipe (min #* | Make "Light" cannisters | "Grab Sample" | Do Nothing so clean its greenfield | Rad Limits: restricted [illegible]ite v | |
| *Sluicers @ ≤16"* | "None of the above" | Replace Pumps w/ Fixed Suction | Don't Replace Failed Equip after | | Sample Side Stream from one | - Character. everything | *Adapt Available Technologies (only)* | |
| Eductor Tubes | | Replace Pumps w/ Movable Suction | Additional Waste Str'ms from proc | | Process-based Knowledge + | | Research & Develop New Technolog | |
| Impeller Mixers | | Replace Pumps w/ vacuum tech | | | Verify by Survey what is left behind | | *Emphasize Cleanup* | |
| Air Lance | | | | | Monitor Results | | Emphasize Containment (clean to a pt | |
| Chem. to increase Viscosity | | | | | | | Actively Manage Leak Likelihood | |
| Revise way of using caustic | | | | | | | | |
| Use Oxalic Acid | | | | | | | | |

Subsequent discussion and review [22] of these tables yielded the following insights.

First, the Containment Strategy is really a strategy for closure, not "transition" (the phase of interest here) and is hence outside the purview of the Team. Second, there are three major decision areas dealing directly with Tank Farm cleanup: Mobilize Solids, Clean Tank Internals, and Transfer Solids, and the choices made under these three headings are unaffected by whether the site is to be classified as "restricted" or "unrestricted" (compare "Unrestricted Use" Strategy with Momentum Strategy in the **Appendix**). Third, "Oxalic Acid" and "Vacuum Technology" are "clearly different" strategies only if they are carried to extremes; taken in moderation they are tactical options under the Momentum Strategy. Fourth, while the Team started with nine decision areas to consider, only three are of relevance to the cleanup decisions which can be impacted by Team recommendations. Finally, due to the long lead time required to implement technical options, a sufficient number of resource allocation decisions have already been made to severely restrict the set of strategies and even tactical options. These historical decisions have been guided by a tactical version of the Momentum Strategy called the *Stepped Approach*.

The Stepped Approach is described in [6]. Essentially, this approach involves sequentially deploying ever more sophisticated technologies to remove the zeolite in 8D-1 and the HLW sludge in 8D-2 as the need arises. Many of the long-lead time items are either under development or, in some cases, even under order. The basic premise of the Stepped Approach is that the technologies should be available if and when they are needed. A meeting with WVDP experts ([19], with dates for implementation added later as per a meeting with [17] and by reference to Attachments to [6] produced the clustering of the Stepped Approach's constituent technologies into the "Technology Options" in Table 2 , with the Baseline option being a collection of the current or currently-planned technologies and Technology Options B, C, D, and E representing more advanced technologies.

| Table 2: Technology Options List |
|---|
| **A. Baseline for 8D-1**: Mob pump seal leakage is being addressed. Replace bottom part of Mob in M-3 riser. Increase rotational speed of all mo[illegible]mps. Purchase complete mob pump to put in M-5 riser. Pieces for modification of marginal transfer pump are on order ( may not modify). Designed and ordered long-lead mast-mounted part of delivery system (crucial element for end effectors like sluice/spray/vac system and is the delivery system for grinders, cameras, Weidemann mechanical arm. **Baseline for 8D-2:** Busted mob pump will be fixed. New pump in the empty riser. Rotational speed and leaking seal will be fixed. Decant pump will be replaced in 1997. |
| **B. Grinders (or other solids reducing option) for 8D-1:** Alternative [illegible] modifying marginal transfer pump. Have conceptual designs and grinders for testing (not encouraging results). Mast-mounted but no arms needed. Nominal plan is to install July 1998. **For 8D-2**: No grinder option. |
| **C. Weidemann Mechanical Arm for 8D-1**: Once installed, water level can be lowered and appropriate end effectors (sluice, spray, vacuum) can be attached to wash, spray, swab, etc. as needed. Operational time thought to be "lengthy." Nominal installation date is July 1998. **For 8D-2:** Ditto. Although not strictly necessary, if a mechanical arm is installed in 8D-1, another is assumed to be installed in 8D-2 (alternative is to use one [illegible] sequentially in both tanks). |
| **D. Tool Delivery System for 8D-1**: This will be a moble system to get the hard to reach places with high pressure spray and deployed using aforementioned mast. "Use to get the last few curies." Would not address size reduction problem. Very "researchy" at this stage with non-trivial risk of failure to perform intended function. Nominal installation date is April 1999. **For 8D-2**: Ditto. |
| **E. Oxalic Acid for 8D-1**: Use to break down solids and then rinse out. Could use at virtually anytime but the more solids there are, the more acid required (40 liters of acid per Kg of solids) and the greater the risk of eating a hole in the tank. Momentum strategy is to wait for mechanical methods to reduce solids to a level where only a safe level of acid need be used. Would need a contingency plan for possible acid-induced tank leak. For 8D-2: If use acid in 8D-1 then 8D-2 gets acid by transfer, although the reverse is not true. Assumption is acid would be applied to both. No nominal date (sometime after mechanical means have been deployed). |

Under the Stepped Approach, the Baseline is continued until there is a demonstrated need to augment the Baseline technology to offset declining efficiency in transferring zeolite/sludge. The implied progression is A to B to C to D (if available) and perhaps E if mechanical means fail. It is not the intent of this report to evaluate the optimal timing of the technology implementations. Rather, it is assumed that technology options such as the Weidemann Mechanical Arm will be implemented if they are technically viable at the appropriate time and there is a perceived technical need. Since, however, we do not presently know whether the advanced technical options will in fact be available at the appropriate time, alternative strategies or scenarios that bound the likely technical choices are constructed. One such bounding scenario is that the *Baseline* as defined in A of Table 2 turns out to be the only available option. At approximately the opposite extreme, a stylized version of the *Stepped Approach* is constructed by assuming that all options from A through D in Table 2 are implemented at their nominal projected dates of availability, and that (should it be necessary) Oxalic Acid is employed once 97 percent of the curies have been removed. Two intermediate strategies are also to be evaluated: (a) *Augmented Baseline*: Baseline Strategy is augmented by options B and C in the second-half of 1998. No other options are implemented. (b) *Stepped Approach without Acid*: Stepped Approach Strategy with the deletion of Oxalic Acid's use. In summary, the study evaluates four Technology Scenarios:

**Table 3**

| **Technology Scenarios** |
|---|
| Baseline = Option A defined in Table 2. |
| Augmented Baseline = Baseline augmented by options B and C in Table 2. |
| Stepped Approach = All options & dates in Table 2, with Oxalic Acid used at 3% heel. |
| Stepped Approach w/o Acid = Stepped Approach without use of Oxalic Acid. |

For each Technology Scenario, the "alternatives" to be evaluated are alternative degrees of cleanliness, as measured by the fraction of the original inventories of curies removed.

### *3.2 The Decision Criteria*

The "Waste Tank Farm Transition End Points" document [10] identifies the Nuclear Regulatory Commission as the relevant regulatory agency in terms of gaining concurrence that the remaining waste can be classified as "not HLW". This event, in turn, will allow "...the shutdown of the melter at WVDP or declare the end of vitrification for the purpose of solidifying the HLW" [ibid. p. 5]. Tables 4.3.1 and 4.3.2 of the referenced document imply that, at the minimum, this cannot occur until "...An evaluation of the residue in Tank 8D-1 (8D-2, etc.) has been made relative to the *sum-of-fractions radionuclide limits* (emphasis added). The Sum - of - Fractions Rule essentially states that the sum of all ratios of remaining curies to their respective limiting counterparts (defined later in this document) sum to a value not exceeding unity. The ALARA (As Low As Reasonably Achievable) Rule is also likely to apply. If the Sum - of - Fractions Rule can be met for some fraction of the starting curies inventory that is less than 100 percent, then a justification will be needed to show that not only has the aforementioned rule being satisfied but also that the curies have been removed to the maximum technical and economically - feasible extent using best available technologies.

The "best available technology" will presumably be part of one of the scenarios in Table 3. The "economically - feasible" extent to which this technology is employed can, in principle, be determined by comparing the incremental benefits and costs to society of each degree of curie removal beyond that mandated by the Sum - of - Fractions Rule. Social cost - benefit analysis, as this type of analysis is called, is a branch of economics that is routinely applied to support certain categories of Federal and State decisions using guidelines [16] promulgated by the Federal Office of Management and Budget (OMB). The Nuclear Regulatory Commission (NRC) has adopted a version of social cost - benefit analysis to evaluate proposed regulatory actions pertaining to either power reactor or non - power reactor sectors. The NRC's provides its perspective on the use of "regulatory analysis" in NUREG/BR-0058 Rev. 2 [12] and also provides a Handbook, NUREG/BR-0184, [13] for performing such analyses. The latter Handbook prefers to call its version of social cost - benefit analysis "Value - Impact Analysis," and summarizes the essential elements of the analysis as follows (quotes are from pages 4.5 and 5.2 of [13]):

- "Values (Benefits): The beneficial aspects anticipated from a proposed regulatory action...."

- "Impacts (Costs): The costs anticipated from a proposed regulatory action...."
- "Section 4.1...requires that the value-impact of an alternative be quantified as the 'net value' (or 'net benefit').
- "The net value method calculates a numerical value that is intended to summarize the balance between the favorable and unfavorable consequences of the proposed action. The basic perspective of the net value measure is national economic efficiency. All values and impacts are added together and the total is intended to reflect the aggregate effect of the proposed action on the national economy."
- "To calculate a net value, all attributes must be expressed in common units, typically dollars. Person-rems of averted exposure, a measure of safety value, is converted to dollars via a dollar/person-rem equivalence factor...."

Expressed in the more conventional terminology of social cost - benefit accounting, the value - impact criterion is captured in the following equation:

(1) Net Social Benefit = Social Benefit - Social Cost.

The idea is to account for all the costs to society and then take credit for the monetized benefits of the proposed action. To account for the fact that: (a) "sunk" costs and benefits are irrelevant to the choice at hand, and (b) the variable Net Social Benefit is an uncertain quantity, (2) is modified as follows:

(2) Expected Incremental Net Social Benefit = Expected Incremental Social Benefit - Expected Incremental Social Cost.

The term "expected value" refers to the mean of a probability distribution and reflects awareness of the fact that the estimated Net Social Benefit will be an uncertain quantity described by a probability distribution of possible values. The term "incremental" reflects the fact that only those benefits and costs that have not yet been realized are relevant to the decision. In the following sections, the terms Expected Incremental Net Social Benefit or simply Net Social Benefit or Net Benefit are used interchangeably to refer to the variable defined in Equation 2.

To summarize, this section has identified a set of technology scenarios, alternatives defined as degrees of cleanliness for each technology scenario and decision criteria, Sum - of - Fractions (the focus of [10]) and Net Social Benefit (the focus of this study), for choosing the alternative that is best in the sense of meeting safety goals in a technically and economically efficient manner. The next step is specify a model capable of quantifying the decision criterion Net Social Benefit for each alternative.

## 4.0 Deterministic Phase: A Computer Model of the Decision Criteria

### *4.1 Net Social Benefit's relation to curies removed and "Time to RF"*

A model is required to predict the future course of Net Social benefit at each attained level of curie removal. It is assumed that virtually any level of curies could be removed by any of the technology strategies in Table 1 *if given enough time*. To be more precise, define a "curies reduction factor", RF, as,

(3) RF = cumulative curies removed / initial inventory of curies,

where it will be assumed that nuclides are homogeneously distributed throughout the zeolite or sludge in the two tanks and therefore the same reduction factor applies to all nuclides. The key variable is now "Time to (any specified) RF." This is a measurable and, more importantly, "assessable" variable - experts could reasonably be expected to form an opinion about the variable and produce a range estimate for its value. It is also a variable on which substantial evidence has already accrued via records on the amounts of the reference nuclides removed by each transfer.

The regulatory analysis guidelines [13, p. 4.5] define Social Cost to potentially include *incremental* (constant '97$) costs to any affected stakeholder, including the regulatory agencies. However, the major societal cost here is that generated by the Vitrification operation itself. Thus, Gross Social Cost for a Technology Option at the jth RF is defined as

(4) $\text{Gross Social Cost}_j = \text{Vit Variable Cost}_j + \text{Vit Capital Cost}_j$

where it is understood that all costs are incremental or 'going forward' costs measured in constant dollars (i.e., net of inflation) from some common time base. The Vit Capital Cost are the incremental capitalized expenditures required to deploy a technology (again, ignoring money already spent). The variable cost of achieving a specified RF is obtained from the product of incremental operating costs per unit time (operating cost/time) of the Vit operation and the time to the specified jth RF,

(5) $\text{Variable Cost}_j = \text{operating cost/time} \times \text{Time to Rf}_j$ .

The variable "operating cost/time" will be treated as a constant so that variable cost of a technology will be a linear function of the assessed or projected time to a specified curies reduction factor. Of course, Time to RF may be a non-linear function of RF so that variable cost itself may be a non-linear (e.g., exponential) function of RF. Equation 5 is incomplete in that the social cost accounting framework requires that a future stream of monetary values be discounted to a present value. Using the continuous compounding version of the formula for the present value of an annuity, Equation 5 is modified as follows:

(6) $\text{Variable Cost}_j = (\text{operating cost/time}) \times [(1/r) \times (1 - \exp(-r \times \text{Time to RF}_j))]$,

where r = the discount rate per unit time. The term in brackets is the "annuity factor" that converts the stream of future operating costs per unit time (the annuity) to a present value based on the projected number of months required to get to the stipulated reduction factor.

The Social Benefit side of (2) consists essentially of "pricing out" (in dollars) the safety - related risks that society will avoid by choosing the indicated alternative, and is modeled here as follows:

$$(7)\ \text{Gross Social Benefit}_i = \text{Value of Avoided Curies}_i + \text{Value of Avoided Closure Cost}_i\ .$$

Both of the right-hand variables in (7) are a function of curies removed which is equal to RF × initial inventory. Making this substitution into (7) and letting $Mci_i$ = the social value of radiation exposure avoided associated with an additional curie of the ith nuclide removed (which is very different across nuclides) and Mcc = the tradeoff weight that translates an additional curie of the ith nuclide removed into a dollar - equivalent savings in closure costs (also different across nuclides), yields the gross benefit of removing the stipulated fraction of the initial inventory of the ith nuclide,

$$(8)\ \text{Gross Social Benefit}_{ij} = ((Mci_i + Mcc_i) \times [(RF_j \times \text{initial inventory}_i) - \text{curies already removed}_i)]$$

The Mcc parameter (suggested by Kumar [22]) reflects the fact that the public is to be protected not only by cleanup of the tanks but also by engineered containment of the residues in the tanks. While this study is focused on the cleanup of the tanks, it does nevertheless recognize through the Mcc tradeoff parameter that the more resources invested in cleanup, the less need be invested in containment. Gross Social Benefit must also be converted to a present value basis and this is done through the calculation of the Mci described in a subsequent section.

Summing (8) across all eight relevant nuclides for a specified RF level yields the Gross Social Benefit for the jth RF,

$$(9)\quad GrossSocialBenefit_j = \sum_i GrossSocialBenefit_{ij}$$

Net Social Benefit for the jth RF is obtained by substituting (4) and (9) into (2). Equations (2) through (9) constitute the skeletal frame of a model of the Social Net Cost criterion.

*4.2 Overview of the Computer Model*

The computer model is implemented in Analytica®[23], a graphical, hierarchical modeling software package that uses Monte Carlo simulation methods to solve models with probabilistic inputs. An overview of the fleshed - out version of the model is diagrammed in Figure 2 (this is a screen shot of what the user actually sees when opening the model). The box at the extreme left of Figure 2 labeled *Technology Scenarios* contains the list of technical scenarios (described in Table 3). The box or decision node labeled *Curies Reduction FactorChoices* contains the alternative Reduction Factors (RF), ranging from 84% to 99.9%, to be evaluated for each Technology Scenario. Each of the remaining nodes in Figure 1 are modules containing sets of other equations and sub - modules that are presently hidden. One hidden input variable is Time-to-RF, which is in the *Time Module* (Figure 3). For each RF, the model generates a projection of Total Time to RF for each Technology Option which incorporates: (a) A regression model projection derived from a statistical analysis of historical transfers through January 19, 1998. This represents the projected future Baseline scenario. (b) Expert (probabilistic) assessments of the extent to which each non - Baseline candidate technology will change the Time to RF. (c ) The likelihood of delays associated with Melter failure (an increasing function of time in operation, as modeled by comparing each new time to the simulation drawing from a probability distribution on how long the Melter will last).

Figure 2: Model Over\ iew

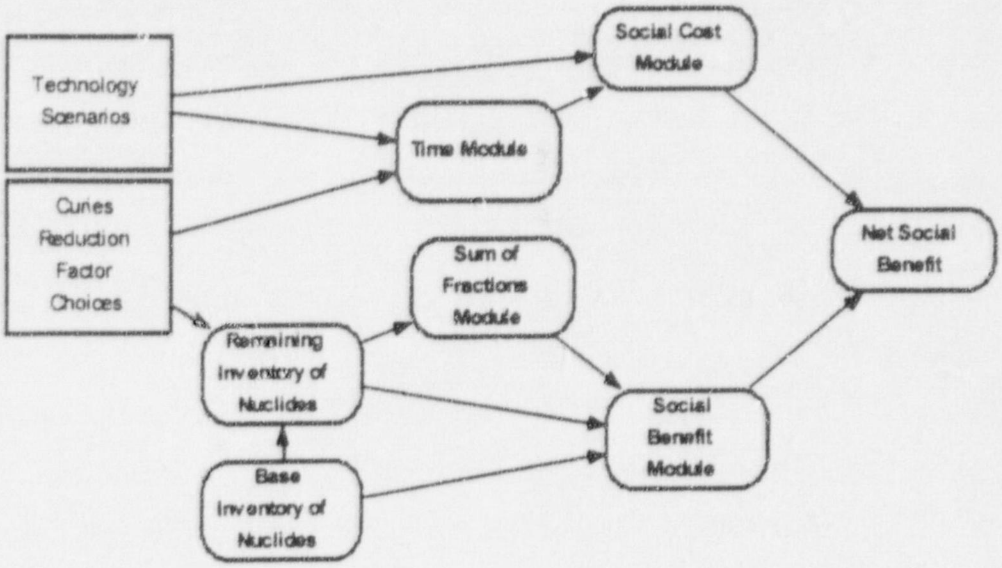
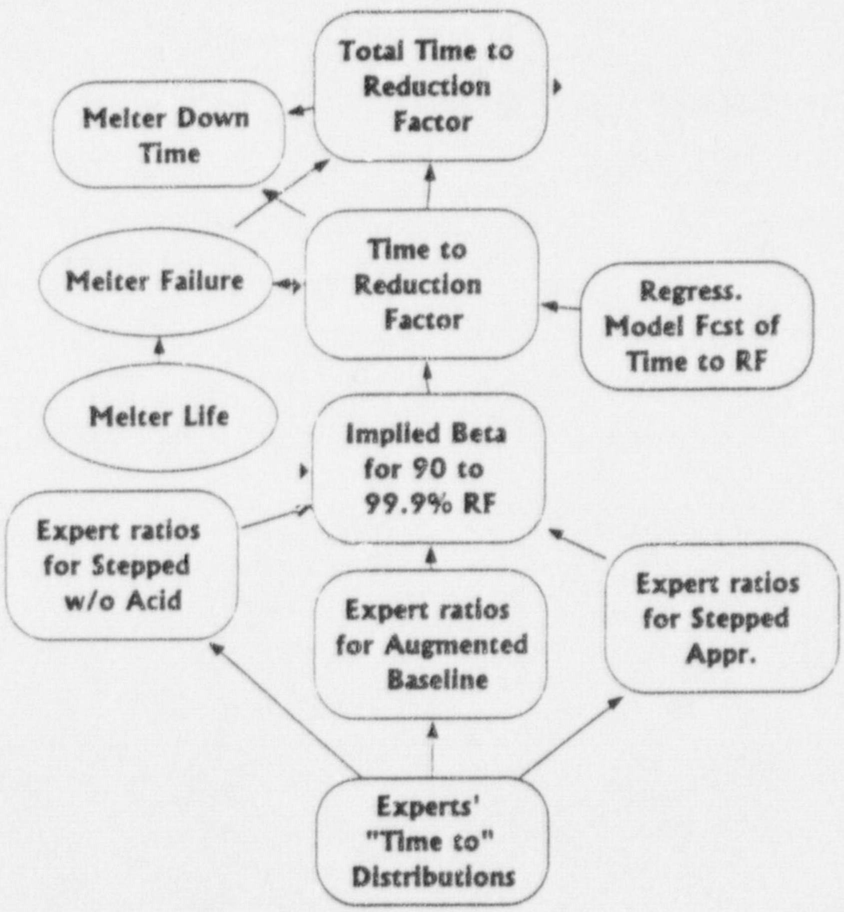



Figure 3: Time Module



As illustrated in Figure 4, the *Social Cost Module* converts the time projections into incremental cost projections for each technology option as per Equations 4 and 5, with Operating Cost/time and probabilistic projections of Capital Cost for each technology option being inputs. Moving back to the left of Figure 2, the choice of a curies reduction factor (combined with the initial inventory) yields a projection of curies removed and curies remaining, by nuclide, in the module entitled *Remaining Inventory of Nuclides* . The projected curies remaining are combined with the corresponding limiting curies (user input) in the *Sum of Fractions Module* to compute, for references purposes, the Sum-of-Fractions corresponding to the chosen RF and for each Technology on the list. As illustrated in Figure 5, the projected incremental curies removed (i.e., over and above those curies already removed as of January 19, 1998) are combined with estimates for the Mci (in Avoided Radiation Exposure per Curie Removed) and Mcc (Avoided Closure Cost per Curie Removed) to produce an estimate of the (incremental) Gross Social Benefit corresponding to the Sum-of-Fractions associated with the chosen RF and for each Technology. Finally, Equation 2 is invoked to calculate (incremental) *Net Social Benefit* for each Reduction Factor.

**Figure 4: Social Cost Module**

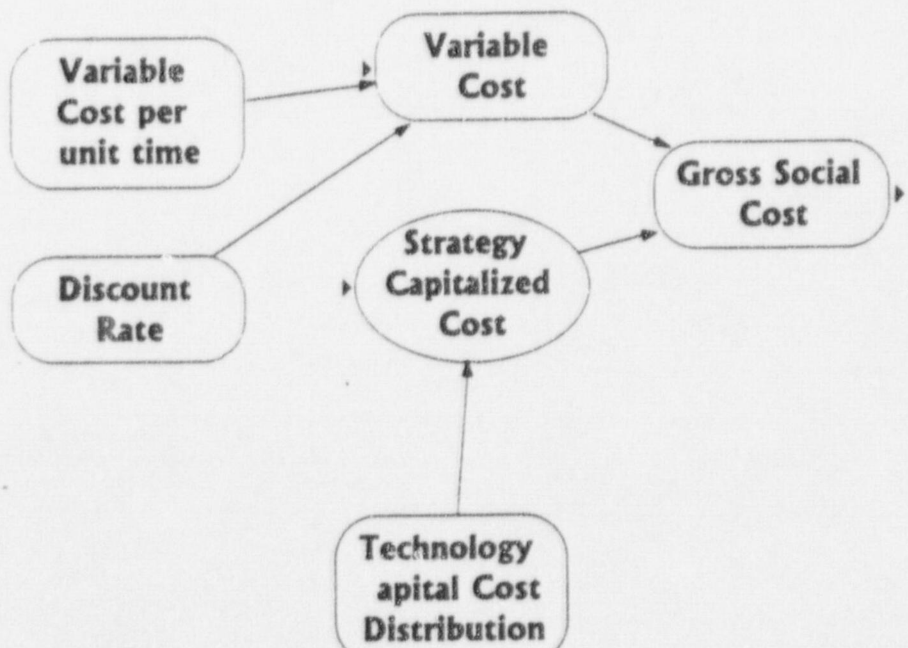
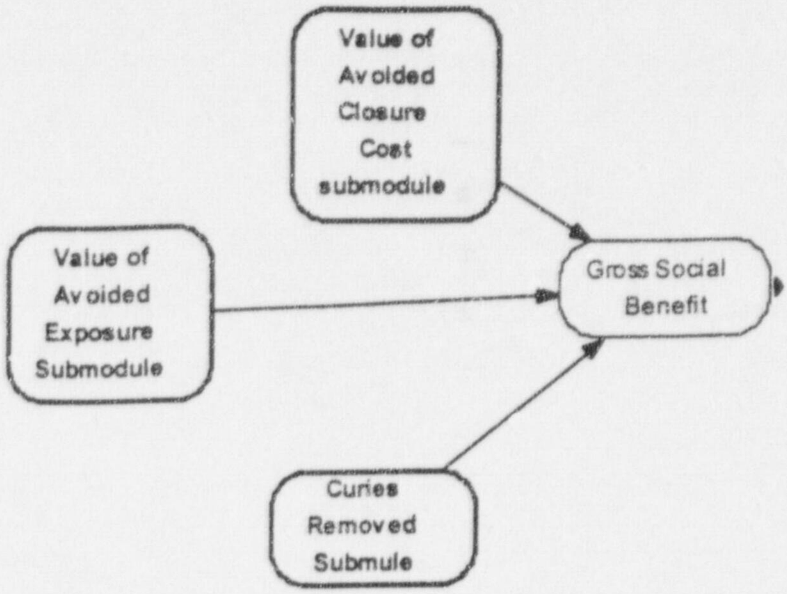


**Figure 5: Social Benefit Module**




## 5.0 Probabilistic Phase: Derivation of Model Inputs

### *5.1 Derivation of the Benefit Parameters (Mci, Mcc)*

**Table 4 Values for Isotope Inventory, Limiting Ci, Mci, Mcc**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Isotope Name | Initial (1996) Inventory[1] | Limiting Ci @ 100 mR/yr (= Gi)[2] | Mci = $ value of avoided exposure per Ci[3] | Mcc=$ value of avoided closure cost per Ci[4] |
| Am-241 | 5.35E+4 | 1.34E+30 | 0 | 0 |
| C-14 | 1.37E+2 | 5.50E+1 | 72,700 | 49,078 |
| Np-237 | 2.35E+1 | 0.88E+0 | 4,545,000 | 3,643,835 |
| Pu-238 | 8.04E+3 | 1.26E+22 | 0 | 0 |
| Pu-239 | 1.65E+3 | 1.48E+3 | 2703 | 1,852 |
| Tc-99 | 3.5E+1 | 7.00E+1 | 52,140 | 40,672 |
| Sr-90 | 5.81E+6 | [illegible].40E+13 | 0 | 0 |
| Cs-137 | 6.29E+6 | 3.80E+28 | 0 | 0 |

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[1] [ WVDP-267 rev 0(draft) 8/1/97m Table 5.1.1, p.29]. Tc-99 initial inventory revised as per [ Champion ]
[2] ibid.
[3] See text.
[4] See text.

Table 4 contains the data used to estimate Mci and Mcc. The limiting curies have been estimated in "Performance Assessment" work described in [3] and [6] and relate to the maximum curies of the indicated nuclide which could be left in the tanks without exceeding an onsite (offsite) risk equivalent of 500 mR/yr (25 mR/yr). The latest limits are listed in Table 5.1.1 of [10] for eight relevant radionuclides. The same document scaled the curie limits to match the more recently - promulgated 100 mR/yr on-site requirement. It is these 100 mR/yr - based onsite limits that are used in this study. For reference purposes, the Sum of Fractions rule defined in [10, p. 27 ] is repeated here:

> Let Si represent the curies of the ith radionuclide remaining in the WTF and Gi be the "proposed" limiting or allowable curies for the ith radionuclide (estimated under the assumption that the ith radionuclide is the only one present). Then the sum-of-fractions rule states that the sum across all radionuclides of the ratios Si to Gi must be no greater than unity,
>
> (10) $\Sigma(Si \div Gi) \leq 1$ .

The calculation of Mci ( the value of avoided radiation associated with removal of a curie of the indicated nuclide) in Table 4 is as follows. The limiting curies shown in Column 2 of Table 4 are equivalent to 100 mR/yr = 0.1 Rem/yr to the "maximum exposed" onsite individual. An estimate of the radiological dose to the entire (roughly 12 miles/ 20 kilometers radius) exposed population (i.e., person-rems) is not available and its authoritative calculation is beyond the scope of this analysis. However, a rough estimate is obtained by setting person-rems = 600 maximum exposed population × .1Rems/yr = 60 person-rems/yr, where the figure of 600 is from the Draft Environmental Impact study [9, Table 4-14, p. 4-59 for West Valley]. The societal health and property cost per person-rem is set at $2000 as per [12, p. 22]. Using the real discount rate for Value-Impact calculations of 3% [12, p. 23] suggested for long-range benefit flows, the present value of $2000 × 60 person-rems/yr into perpetuity is $120,000 per year ÷ .03 = $4,000,000. Hence $Mci_i$ = $4M/Gi = an estimate of the value (in terms of avoided onsite exposure) of removing (i.e., transferring to the CFMT) one curie of the indicated nuclide (column 4 of Table 4). The societal benefit of reducing onsite exposure is not calculated because it is dominated by the onsite avoided risk.

The value for Mcc (value of avoided closure cost per curie removed) is estimated by relating changes in estimated closure costs of $13.3 million between two different grout / closure designs in [9, Table 4.1.3 p.107] to the resulting changes in limiting curies as ascertained by comparing [11, Table 4.1.1]with its counterpart in [10, Table 5.1.1]. The changes in Gi between the two dates were induced by the closure design changes. Dividing the $13.3M by the change in Gi between the two aforementioned tables yields Mcc in Table 4 above.

### *5.2 Regression Model for Baseline Forecast of Time to RF*

As of January 18, 1998, some 50 transfers had been made with about 69 percent of the estimated initial inventory of reference curies having been removed. This history (**Appendix**) provides a basis for a statistical analysis of the relationship between Time - to - RF (measured in the regression analysis as number of days from completion of the first transfer in June 25, 1996). Initially, a semi-log function of the following type was fit to the entire data range:

$$(11)\quad \text{Time to RF} = \alpha + \beta \text{Log}\,(1 - \text{RF}).$$

Where $\alpha$ and $\beta$ are regression constants to be estimated and the "log" is to base 10. This function has a slope that decreases in (1 - RF) and, hence, increases in RF; that is, it takes progressively more time to increase RF by one unit as RF increases. When estimated over all 50 transfers, this model overestimates the Time to RF for the first 15 transfers and, by a progressively larger amount, the last nine transfers. These periods roughly correspond to periods when the yield of curies per gallon was steadily increasing and steadily decreasing, respectively; with a long plateau interval in between. The following modification of (11) was estimated to test the statistical significance of the variation in regression parameters across the three aforementioned historical intervals:

(12) Time to RF = $\alpha_0 + \beta_0 \log(1-RF) + \alpha_1 Dum1 + \alpha_2 Dum2 + \beta_1 Dum1 \log(1-RF) + \beta_2 Dum2 \log(1-RF)$.

The Dum1 variable equals 1 if the observation refers to any of the first 42 transfers and zero thereafter. The Dum 2 variable equals 1 for the first 15 transfers and zero thereafter. The terms $\alpha_1$Dum1 and $\alpha_2$Dum2 thus let the constant term shift across the three historical periods while the terms $\beta_1$Dum1log(1-RF) and $\beta_2$Dum2 log(1-RF) perform the same function for the $\beta$ coefficient. The regression results for (12) are in Table 5.

**Table 5: Regression Analysis of Historical Transfers (Equation 12 in Text)**

| | $\alpha_0$ | $\beta_0$ | $\alpha_1$ | $\alpha_2$ | $\beta_1$ | $\beta_2$ | R-Bar Sqr (%) | Stand. Error |
|---|---|---|---|---|---|---|---|---|
| Estimated Value | 184.6 | 828.3 | -103.4 | -76.5 | -426.5 | -971.7 | 98.9 | 19.6 |
| t-Statistic | 2.80 | 5.44 | -1.56 | -5.65 | -2.69 | -2.98 | | |

The t - statistics indicate that the shifts in the $\beta$ coefficient over the historical period are statistically significant. Essentially, due to this structural change, only the last nine transfers are "relevant" for purposes of prediction. Setting all Dum variables equal to zero produces the model that fits the last nine transfers:

(13) Time to RF = $184.6 - 828.3 \log(1-RF)$.

The regression summary for fitting this model to the last nine transfers is in the **Appendix**. This model has an R-Bar Squared of 98.5% (that is, as described in any introductory statistics text, the variation in (1-RF) "explains" 98.5% of the variation in the last nine observations) and a "standard error of $\beta$" = 35.8. Examination of the residu[illegible] ·dicates no tendency to over- or under - predict. Forecasts are obtained by inserting the appropriate RF into (12) and then: (a) subtracting 598 days from the projection to bring it to the January 19, 1998 starting date, and (b) dividing the result by 30 to convert to months. The result is a forecast of the Mean Time to RF for the Baseline Technology. The commonly - used standard deviation of this forecast value is:

(14) Std. Dev. = $((1/N) + ((\log(1\text{-}RF_j) - \text{historical mean of } (\log(1\text{-}RF_j))^2 (\text{ Std. Error of } \beta)^2)^{0.5}$

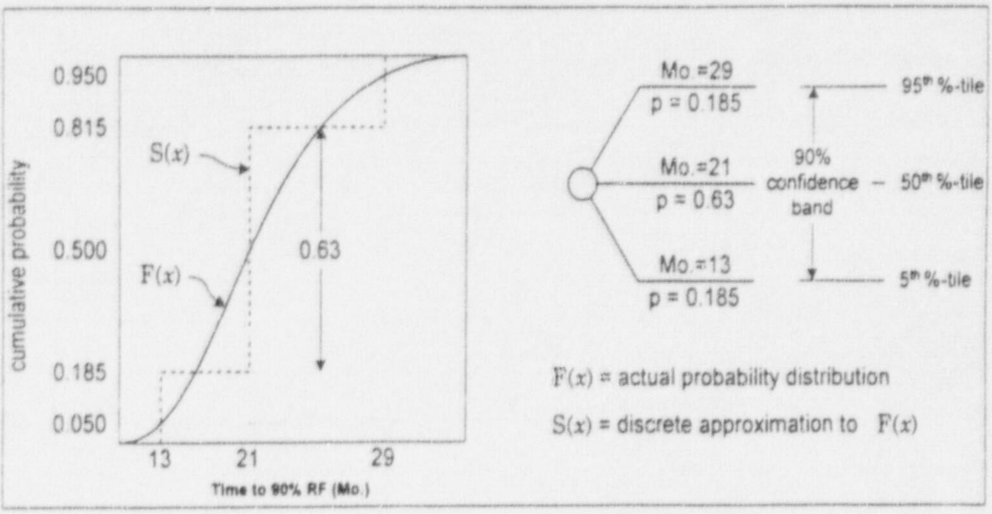
$$=((1/9) + (\log(1\text{-}RF_j) - (-)0.431)^2 (35.8)^2)^{0.5}$$

Where N = number of observations used in the regression analysis. For simulation purposes, it is assumed that future values of Time to RF for the Baseline can be approximated by a normal distribution with a mean value generated by (13) and a standard deviation as given in (14). The simulation model samples from this normal distribution to get a projected Time to RF for the Baseline Scenario expressed in days from January 19, 1998 and then divides the result by 30 to convert to months.

*5.3 Derivation of Probabilistic Projections of Time to RF for the Other Technologies*

No relevant historical data exists on Time to RF for the alternatives to the Baseline Technology option. For that matter, we do not have statistically useful "objective" information on capital costs for each technology scenario or for melter life and melter down time in the event of a major failure. Consequently, the uncertainties associated with future values for these variables have been encoded as probability distributions that reflect the engineering judgment of West Valley site experts. These subjective probability distributions have been elicited by decision analysis procedures [15, Chapter 8 ] as three - point approximations to assumed continuous probability distributions as illustrated in Figure 6.

**Figure 6: Three-Point Approximation to a Continuous Cumulative Probability Distribution**




Essentially, the expert provides a median estimate for the uncertain variable - for example, median Time to 90% Reduction Factor = 21 months for Baseline Technology - and two symmetric extreme percentiles - for example, the 5th and 95th percentiles (or "fractiles" as they are sometimes called) are estimated by the expert to be 13 and 29 months, respectively. A standard probability distribution approximation formula (the "Extended Pearson - Tukey 3 point Approximation" illustrated in Figure 6) is then applied to obtain the discrete 3-point probability distribution used in the simulation model. Table 6 contains expert assessments for Time to RF for RF = 90%, 97%, 99% and 99.9% for the Baseline technology and expert assessments for all other Technology Scenarios for the 99.9% RF. These assessments, predicated on a July, 1997 base date, are averages of those initially provided by WVDP experts [17], and [18] and subsequently reviewed and augmented to include ranges for RF = 99.9% by [8, **Appendix**]. For comparative purposes, the regression model forecasts for Baseline, adjusted to the July, 1997 base (for this table only), are also shown.

**Table 6: Comparison of Experts' Assessed Times ( months from 7/97) to Selected Reduction Factors with Regression Model Forecasts (in parentheses)**

| Technology (RF) | Low (5th %tile) | Median | High (95th %tile) |
|---|---|---|---|
| Baseline (90%) | 13 (17) | 21 (20) | 29 (23) |
| Baseline (97%) | 18 (31) | 25 (34) | 39 (38) |
| Baseline (99%) | 24 (43) | 31 (47) | 65 (52) |
| Baseline (99.9%) | 30 (68) | 43 (75) | 80 (82) |
| Aug. Baseline (99.9%) | 27 | 38 | 62 |
| Stepped w/o (99.9%) | 28 | 39 | 49 |
| Stepped Appr. (99.9%) | 28 | 34 | 47 |

Note that the regression model forecast (which, because of the normal distribution assumption, is both a mean and a median value) differs from the experts' median projection by only one month at RF=90 percent.. Thereafter, however, the regression model's forecast is progressively above the experts'. Note, however, that the regression forecast falls within the Experts' 90 percent confidence band for all RF values or, equivalently, the Experts' were sufficiently uncertain that, in statistical parlance, they could not reject the possibility that the actual Time would be as high as that projected by the regression model at a 10 percent "level of significance." If in fact the future path of the time to each RF is describable by the non-linear regression model, then it would not be surprising if the experts were to underestimate the model's path: it is difficult, in the absence of electronic aids, to correctly incorporate compounding into, say, an estimate of accrued interest on a bond. It is an easier cognitive task to evaluate the extent to which choosing an alternative will lead to a relative deviation from some base, and this is how the information in Table 6 is used. Specifically, the model:

- Assumes that forecasts for all technology scenarios equal the Baseline Regression model forecast for any RF $\leq$ 90 percent.

- Computes a forecast for each non-Baseline scenario and a new slope coefficient ($\beta$) for each non-Baseline scenario for the interval RF > 90 percent as follows:

  Let $ER_k$ = Ratio of Expert Assessment of Time to 99.9% for kth Technology Scenario to Expert Assessment of Time to 99.9% for Baseline, then projected Time to 99.9% for the kth Technology Scenario = $ER_k \times$ Regression Forecast to 99.9% for Baseline. The imputed slope coefficient for the kth Technology that will fit Equation 13 to the Times to RF =90% and RF = 99.9% is derived as follows:

  Projected Time to 99.9% for kth Technology = Time to 90% + incremental time from 90% to 99.9% as projected by Equation 13. Substituting Equation 13 evaluated at RF = .90 and noting that incremental time from 90 to 99.9% can be written as $\beta(\log(.001) - \log(.10)) = 2\beta$, the imputed value of $\beta$ for the kth technology is:

$$(15)\quad \beta_k = (((ER_k(185\text{-}598\text{-}828 \log(.001)) - (185\text{-}598\text{-}828 \log(.10)))/(\log(.001) - \log(.10)) = (2071ER_k - 415)/2$$

The simulation model samples from the discrete probability distributions on the expert assessments whose percentiles are given in Table 6 and forms new distributions on $ER_k$ and $\beta_k$ in Equation 15. The mean values for the imputed slope coefficients for Equation 13 for the interval 90% < RF ≤ 99.9% are in Table 7. For each non-Baseline Technology Scenario, the simulation model samples from the probability distribution on $\beta$, substitutes the result into Equation 13 and then generates a projection of Time to RF. This approach combines both the "objective" evidence from the historical experience, and the experts' knowledge and informed judgment about that for which no historical data exists.

**Table 7: Mean Imputed Values of $\beta_k$ for Equation 13 ($90\% < RF \leq 99.9\%$)**

| Technology Scenario | Mean Value of $\beta$ |
|---|---|
| Baseline (i.e., regression model) | 828 |
| Augmented Baseline | 760 |
| Stepped Approach | 639 |
| Stepped Approach w/o Acid (for RF > 97%) | 719 |

*5.4 Derivation of Capital Costs and Other Inputs*

Table 8 contains probabilistic estimates for incremental capital costs for the indicated strategy alternative.. These are probabilistic combinations of three-point probabilistic ranges for individual capital components elicited from a WVDP expert [20]. Thus, for example, Augmented Baseline Capital Costs includes the Baseline incremental capital costs (ignoring money already spent) plus the incremental cost of deploying the grinders and mechanical arm by the stipulated date in Table 2.

**Table 8: Estimates of Incremental Capital Costs ($ 000)**

| Strategy Alternative | Low (5th Percentile) | Median | High (95th Percentile) |
|---|---|---|---|
| Baseline | 300 | 500 | 700 |
| Current Mechanical | 1100 | 1450 | 2000 |
| Tool Delivery System | 3800 | 4540 | 5200 |
| Oxalic Acid | 4040 | 4900 | 5710 |

The variable cost per unit time is set equal to the approximate average monthly total cost of $2 million for the Vitrification Operations Cost over the past two years ( [1], in **Appendix** ). The high, median and low estimates of remaining Melter life are 18, 60, and 96 months, respectively (Source: [21]). A Melter failure is assumed to add between 6 and

18 months (based on assessments provided by [21] and [17]) to total duration and is modeled by a uniform distribution between those two extremes

Finally, NUREG/BR-0184 [13, p. B.2] specifies that "When the time horizon associated with a regulatory action exceeds 100 years, ... the *net value* (emphasis added) should be calculated using the 3% real discount rate." This study initially follows the implication that both Gross Benefits, which occur over hundreds of years, and Variable Costs, which occur over only a half - dozen or so years, should be discounted by the 3% rate. Sensitivity analysis is then used to show the impact of continuing to discount benefits at 3% but discounting Variable Costs at 7% per annum. Capital costs are relatively near-term expenditures and, thus, not discounted.

**6.0 Probabilistic Phase: The Simulation Model's Expected Value Projections**

**Note:** Data for all graphs in this section can be found in the **Appendix**

The simulation model samples (using a variant of Monte Carlo called "Median Latin Hypercube") from all probability distributions describing the uncertain inputs during each of a large number of trials (500) and, for each trial, calculates a value for each variable of interest. Relative frequency distributions of results from all trials are calculated and the resulting relative frequencies are interpreted as probabilities. The mean (i.e., "expected") value of each variable is calculated (as the sum of the probability - weighted outcomes), as are various other summary statistics and confidence bands. This section presents the expected values for all variables of interest. A subsequent section presents the associated confidence intervals that bound these "best estimates."

*6.1 Sum-of-Fractions and Gross Benefits*

As indicated in Figure 7, there is an equivalent RF for every Sum-of-Fraction level. The Gross Benefit of achieving any stipulated Sum-of-Fractions or, equivalently, the corresponding RF, is the imputed value to society of both the risks avoided and the reduction in associated closure costs. As indicated in Figure 8, the (present value) of Expected Incremental Gross Social Benefits of moving cleanup of curies from the base period RF value of 69% to an RF of 84% is worth about $33 million to society in constant 1997 prices. Each additional percentage point in RF has a gross benefit of approximately $2 million. The expected incremental gross benefit of moving from an RF = 97 percent, where the Sum-of-Fractions is just under unity for the current closure design, to an RF of 99.9% is about $6 million.

Figure 7: Sum of Fractions Corresponding to Selected Reduction Factors (Dose Limit=100mR/yr)

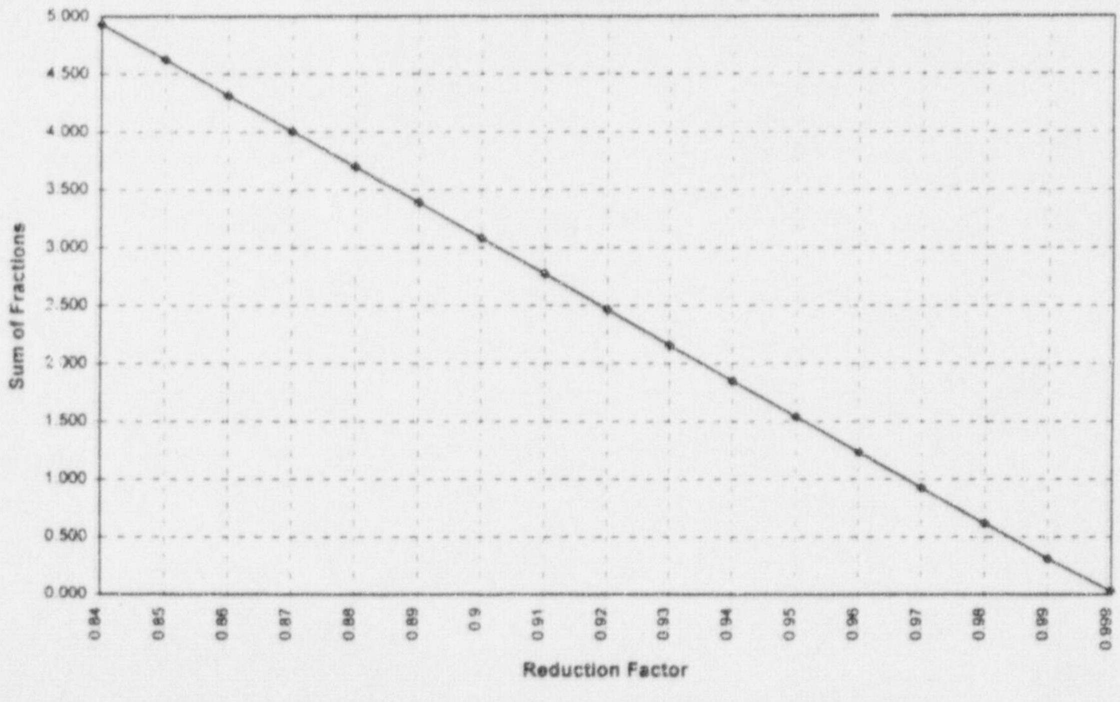
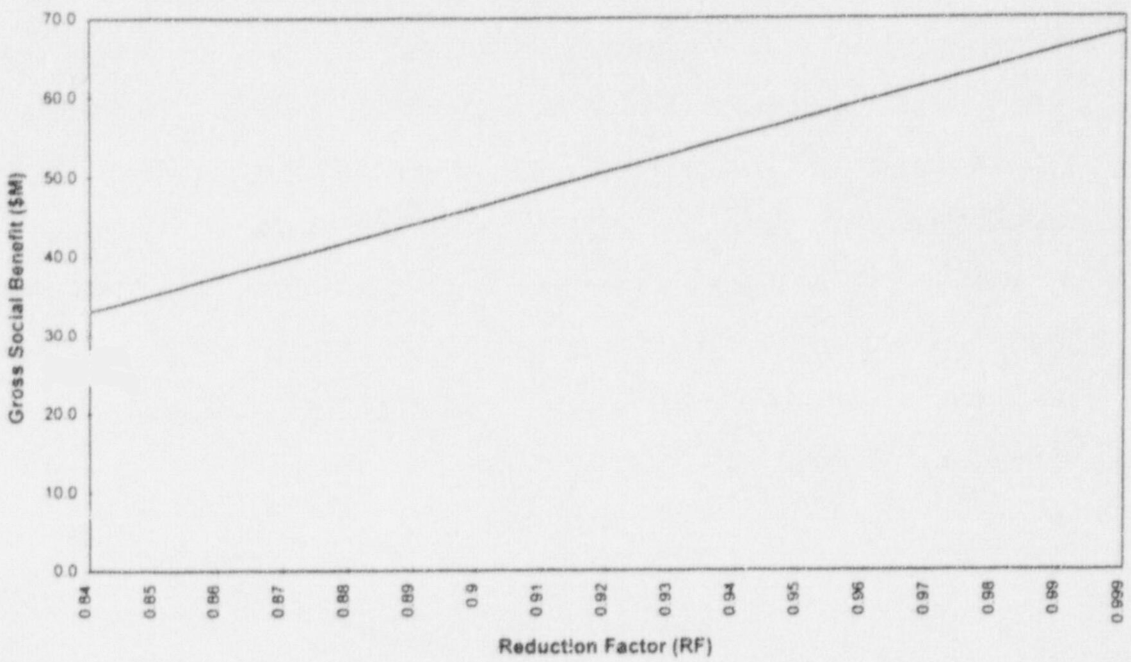


**Figure 8: Incremental Gross Social Benefit of Moving from RF = 69% to Indicated Reduction Factor**



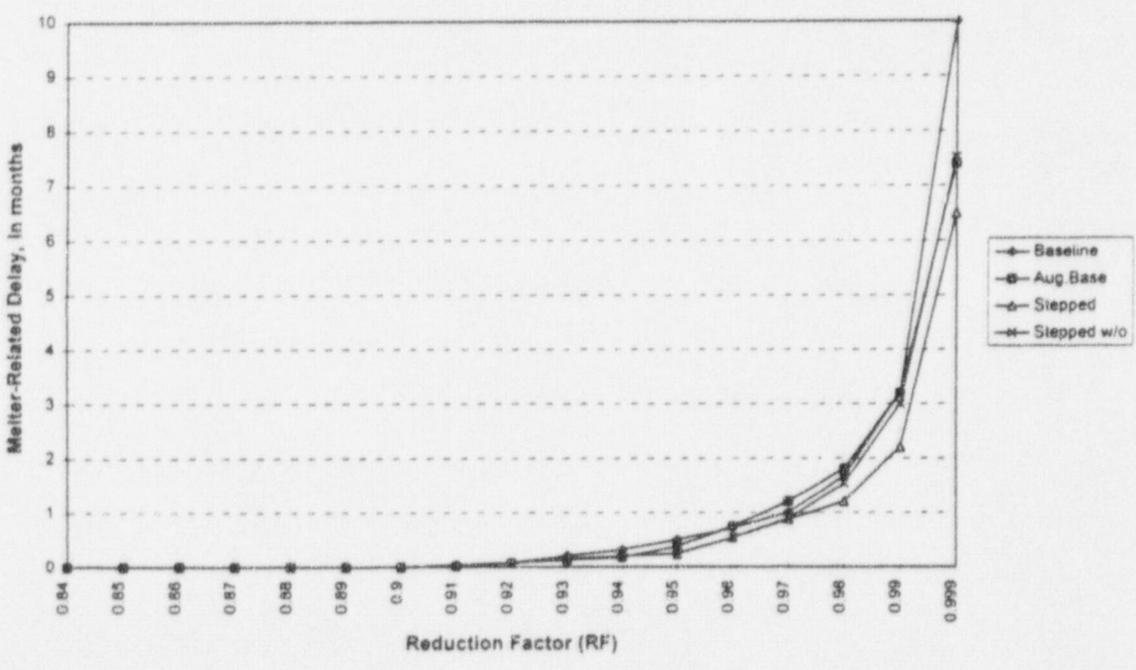

### *6.2 Time to RF*

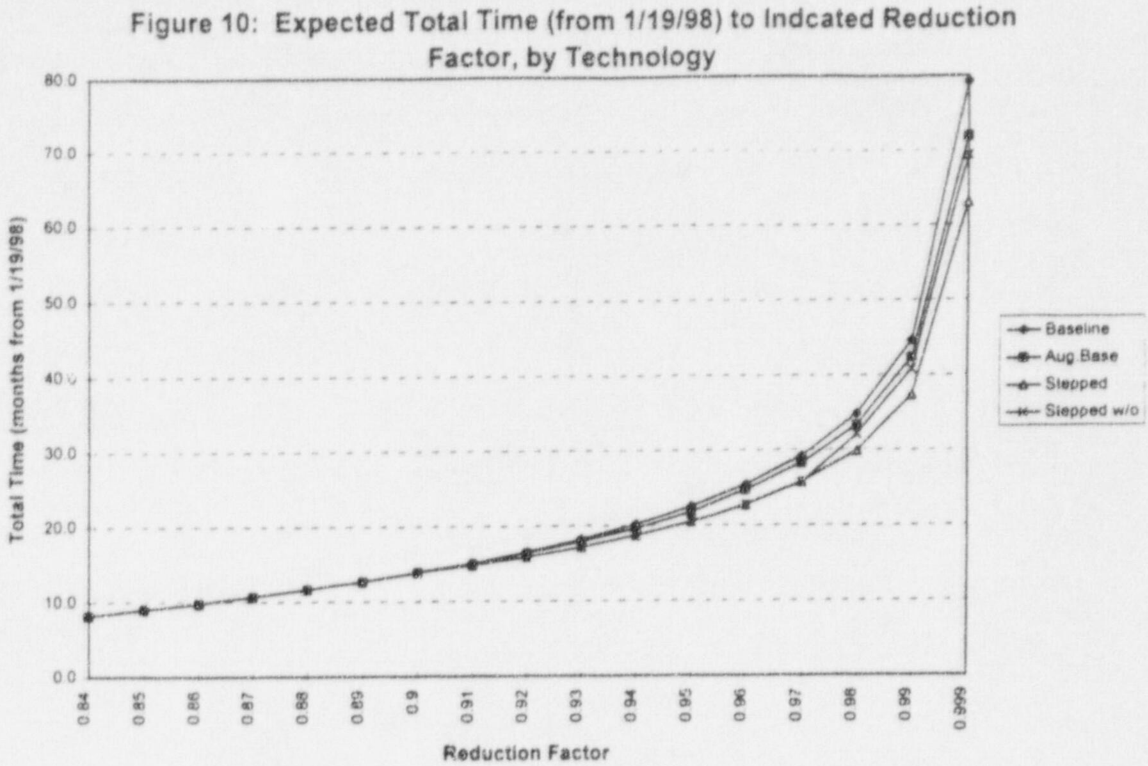
The projected expected total time to each RF must incorporate the increasing likelihood of melter failure (and consequent downtime) as the target RF is increased. The simulation results for the expected incremented time associated with melter failure are plotted in Figure 9. Contribution to Total Time from melter failure increases sharply for all technologies after an RF of 97 percent, reaching a high of 10 months for the Baseline at the 99.9% RF.

As illustrated in Figure 10, The <u>Expected Total Time to RF</u> (= expected Time to RF + incremental time due to melter failure) also increases sharply for the higher RF values. Under all Technology Scenarios, the Expected Incremental Time to RF = 90% is 14 months. From 90% to 97%, the Stepped Approach takes the shortest time at 25.8 months (3.4 months shorter than if the Baseline materializes). To go from 97% to 99.9%, the

Stepped Approach is expected to require an additional 37 months; or about the same time as it is expected to take to get from 69% to 99 percent. Depending on which technology is actually deployed, the expected total times to 97% range from 26 months (Stepped Approach) to 29 months (Baseline) for a range of 3 months. The range over the same technologies for getting to 99.9% is from 63 months (Stepped Approach) to 79 months (Baseline), or a range of 16 months. Thus, the question of which Technology Scenario will actually materialize becomes exponentially more important as higher RF values are contemplated. In comparing technology scenarios, it should be remembered that, while the expected value incorporates the possibility that the technology might take an inordinately long time to reach a specified RF (as indicated in the uncertainty analysis in a subsequent section), the possibility that a technology might *never* reach a specified RF is not considered.

**Figure 9: Expected Contribution of Melter Failure to "Total Time to RF," by Technology**

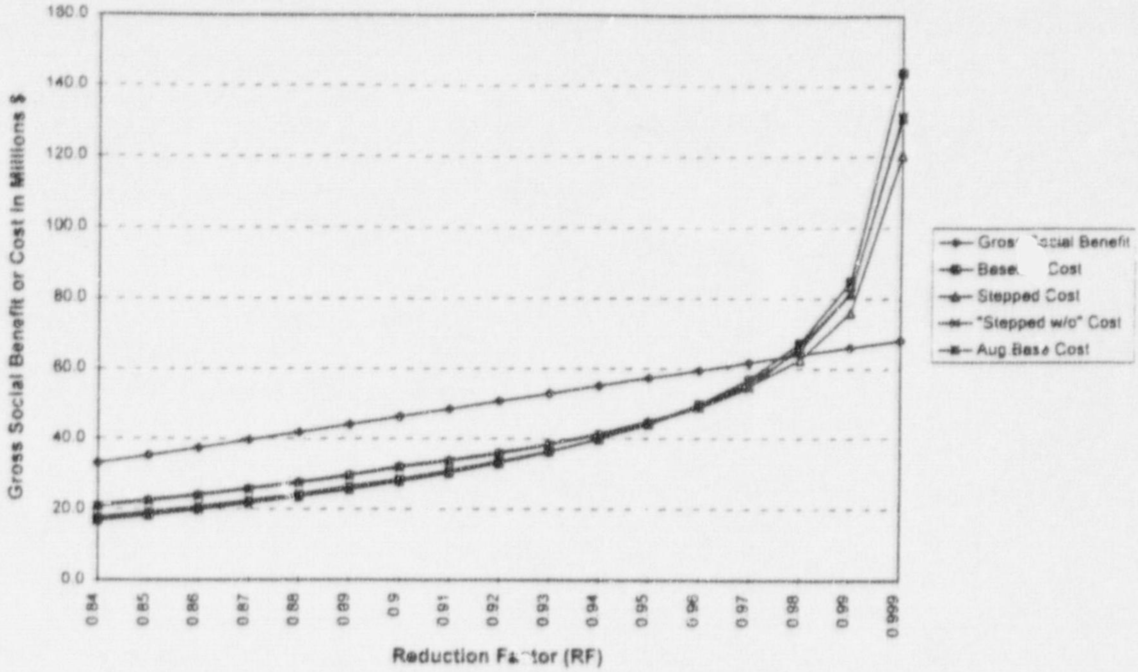





*6.3 Gross Social Cost*

Figure 11 compares the Gross Benefit projection with the Expected (present value of ) Incremental Gross Social Cost (constant 1997 prices) of achieving those benefit levels for each of the four Technology Scenarios. For example, the expected incremental social cost of moving cleanup from the base period RF of 69% to 84% with the Stepped Approach is about $21 million, or some $12 million less than the corresponding Gross Benefit of $33 million. However, while benefits increase linearly for higher RF, costs climb exponentially, so that, for example, the Stepped Approach expected cost grows by ($55M - $32M =) $23 million (for a percentage increase of 72%) between RF = 90% and 97%, while benefits over the same interval grow by ($62M - $46M =) $16 million (percentage increase of 35%). Between RFs 97% and 99.9%, benefits increase by only 10% while Stepped Approach costs grow by 110 percent, so that it costs ($120M - $55M =) $65 million to obtain an additional benefit of $6 million.

Figure 11: Expected Incremental Gross Social Benefit & Cost of Moving from RF=69% to Indicated Reduction Factor, by Technology

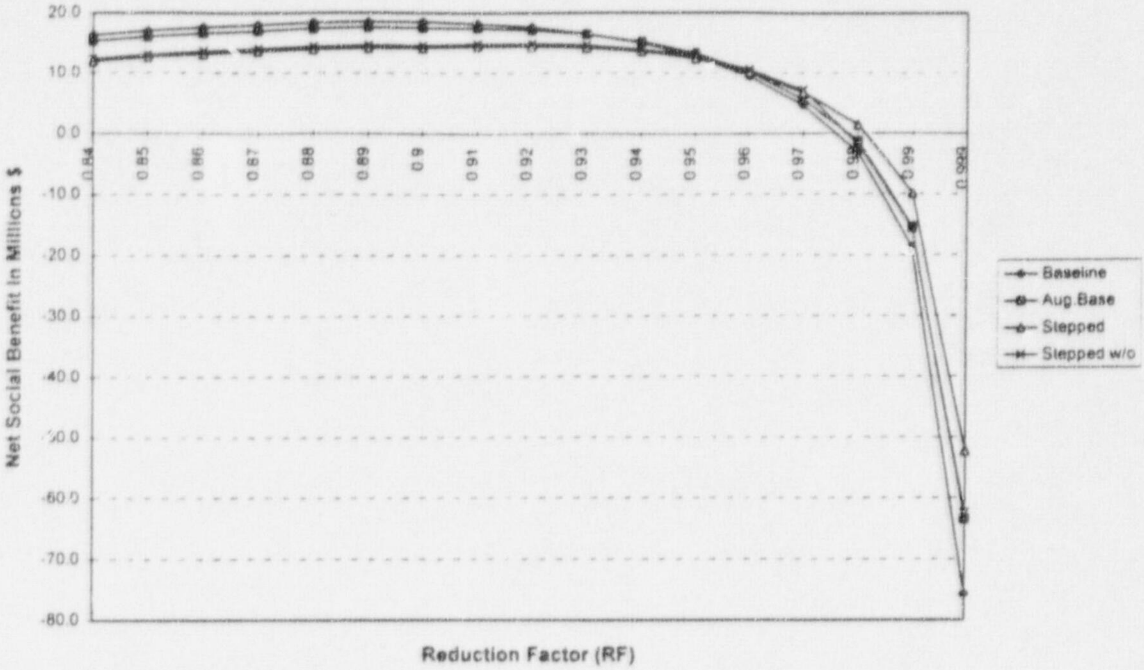



*6.4 Net Social Benefits*

Figure 12 graphs Expected (present value of ) Incremental Net Social Benefit of moving from RF = 69% to the indicated Reduction Factor for each Technology Scenario. Salient points are as follows:

- The highest Net Social Benefit is \$18.5 million, achieved by the Baseline scenario at RF = 90 percent.
- All Technology Scenarios peak in the range of Rf =89% to 92% and go negative in the range of RF = 98% to 99%.
- For RF values equal to or greater than 97% , the highest Net Social Benefit occurs under the Stepped Approach w/o Acid scenario (+\$7.2 million) at an RF equal to 97 percent.
- For RF values exceeding 97%, the Stepped Approach is highest at (+\$1.4 million) at RF = 98 percent.
- The range of Net Social Benefits across all Technology Scenarios at RF = 99.9% is from –\$76 million (Baseline) to –\$52 million (Stepped Approach).

Figure 12: Expected Incremental Net Social Benefit of Moving from RF=69% to Indicated Reduction Factor, by Technology



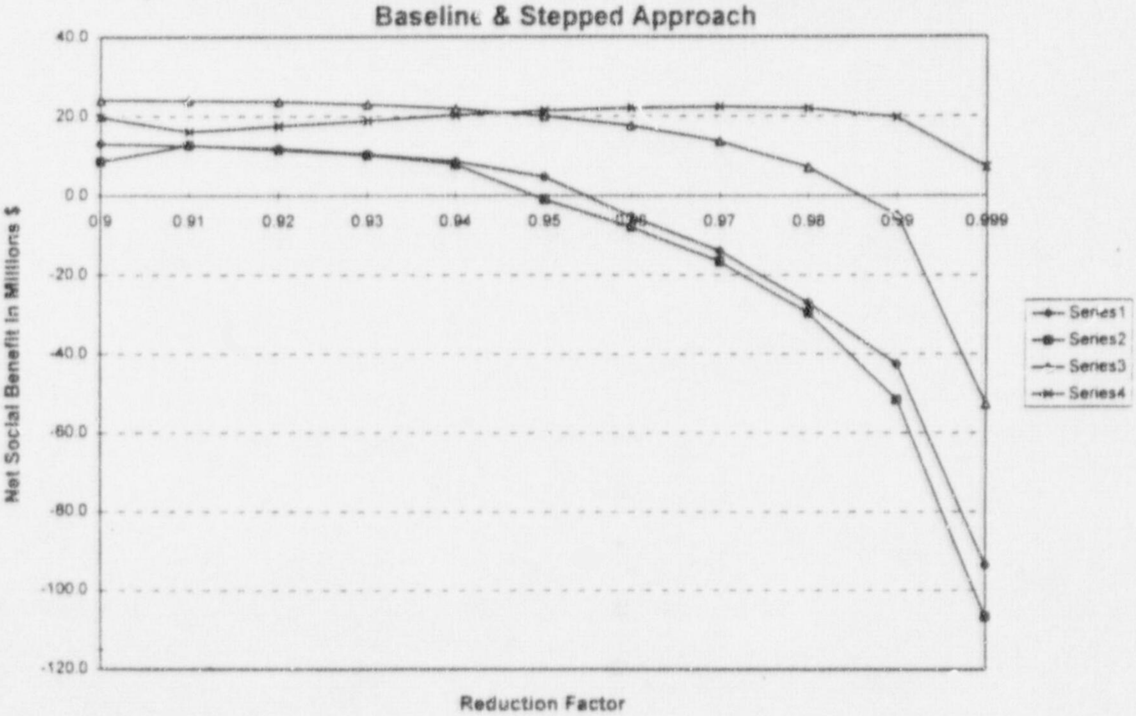

## 7.0 Evaluation Phase: Uncertainty and Sensitivity Analysis

**Note:** All data used in this section's graphs can be found in the **Appendix.**

### *7.1 Uncertainty Analysis*

The regulatory analysis guidelines [13] recommend that an uncertainty analysis be performed. As indicated in the preamble to the previous section, the simulation model constructs probability distributions on all variables of interest and calculates summary statistics, including "confidence bands;" that is, upper and lower values where the variable has a specified probability of falling. This is accomplished by first constructing cumulative probability distributions for the variable, and then picking off relevant percentile values. For example, using the $5^{th}$ and $95^{th}$ percentiles would produce a 90 percent confidence band ( a "percentile" indicates the probability of getting a value less than or equal to the indicated value - for example, there is a 95% chance of getting a net social benefit less than or equal to $20.9 million at RF = 84% for the Baseline scenario). The **Appendix** ("Data Used in Graphs (Sheet 2)") contains the $5^{th}$ and $95^{th}$ percentiles for all Net Social Benefit projections. Figure 13 contains 90 percent confidence bands for the Baseline and Stepped Approach scenarios. These bands provide an interval for each RF such that there is a 5% chance of Net Social Benefit falling below the low value and a 5% chance of falling above the high number. The bands get wider as RF increases. This uncertainty emanates entirely from the cost side, and the bulk of the latter is from the probability distributions describing Total Time to RF. The lower band is positive up to an RF of 95 percent for both Technology Scenarios. At an RF of 97 percent, the band includes the possibility of a negative net benefit (12% and 30% probabilities (read from the cumulative probability distributions that produce the confidence bands) for Baseline and Stepped Approach, respectively). By the 99.9% RF, the possibility of getting a positive net benefit can be decisively rejected (i.e., the probability of a negative outcome is almost unity) for the Baseline scenario. The Stepped Approach scenario's outcome at RF = 99.9%, however, is sufficiently uncertain that the possibility of getting the job done quickly enough to generate a positive net social benefit cannot be rejected (there is about a 15% probability of a positive outcome).

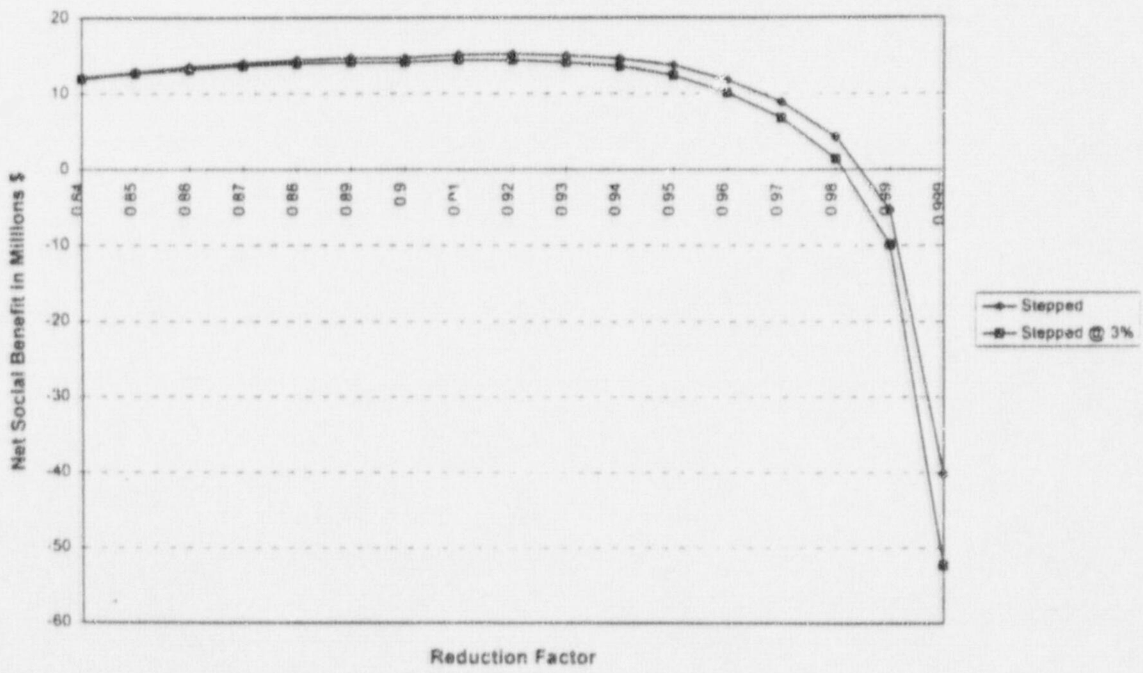
**Figure 13: Incremental Net Social Benefit - 90% Confidence Bands for Baseline & Stepped Approach**



*7.2 Sensitivity to Alternative Discount Rate on Variable Cost*

The use of a 3 percent per annum discount rate on both costs and benefits is, as indicated in Section 5.4, consistent with regulatory analysis guidelines calling for the discounting of net values at 3 percent when dealing with time horizons in excess of 100 years. However, it might also be argued that this understates true net benefits. Specifically, while the benefits accrue over many years, the costs are incurred in a relatively small number of years. Hence, an argument can be made for discounting Gross Benefits at 3 percent, as before, but using a 7% discount (recommended for short time horizons) on the cost side. This is done in Figure 14 for the Stepped Approach scenario (results for all scenarios are in the Appendix ("Sheet 3"). The results are noticeably different only for the highest RF, where Expected Incremental Net Social Value is increased by about $12 million. However, the result is still a very negative $40 million, and no substantive changes in perspective occur as a result of the change in discounting procedure.

**Figure 14: Comparison of Expected Net Benefit for Stepped Approach w/Cost discounted at 3% versus 7%**



## 8.0 Summary and Conclusions

This study provides estimates of expected incremental benefits and costs to society for levels of curie removal ranging up to 99.9% for four possible Technology Scenarios that bound the range of available or potentially available cleanup processes. At one extreme, ("Stepped Approach") all advanced technologies currently under development are assumed to be deployable at their nominal projected dates of availability. The opposite scenario ("Baseline") has only current technologies available, while two other scenarios represent intermediate positions. "Benefits" are measured by the imputed value of person-rems avoided plus a credit for closure costs avoided. "Costs" are direct expenses of continuing to run the Vitrification Operation and capital costs of developing and deploying the technologies. A computer model implemented in a commercial probabilistic simulation package produces probabilistic forecasts and performs uncertainty analysis. The study's main results are:

- All Technology Scenarios peak in the range of Rf =89% to 92% and go negative in the range of RF = 98% to 99%.
- For RF values equal to or greater than 97% , (approximately the RF at which the Sum-of-Fractions Rule is currently satisfied) the highest Net Social Benefit occurs under the Stepped Approach w/o Acid scenario (+$7.2 million) at an RF equal to 97 percent.
- The range of Net Social Benefits across all Technology Scenarios at RF = 99.9% is from –$76 million (Baseline) to –$52 million (Stepped Approach).
- There is a high degree of statistical confidence that pushing cleanup to 99.9% for any Technology Scenario will yield a negative net social benefit.

These results can be used in conjunction with other studies pertaining to the safety criterion and engineering aspects of the cleanup technologies to support an informed decision as to the appropriate endpoint for cleanup once the minimum acceptable safety criterion has been determined and achieved.

## References

### WVDP and DOE Documents:


1. "Analysis of Vitrification Operations Cost: July '96 through January 8 '98" from office of H. W. Morse/J.B. Green, 2/20/98. **(Appendix)**
2. Champion, Bill, "Update of the HLW Storage Area and Vitrification Facility Waste Characterization Report," (WVDP-EIS-017), September 30, 1997
3. Dames & Moore, "Derivation of Residual Radionuclide Inventory Guidelines for the WNYNSC High-Level Waste Tanks," August, 1996.
4. DOE/EIS-0226-D, "Draft Environmental Impact Statement for Completion of West Valley Demonstration Project and Closure or Long-Term Management of Facilities at the Western New York Nuclear Service Center," U. S. Department of Energy, January, 1996.
5. Drobot, A. "Curies Processed," memo # CD:97:0043, 7/14/97.
6. Hammelman, James E., "Final Report on Task 11B" (attached to a memo dated July 18, 1997 to Dan Sullivan describing "long term performance assessment models").
7. [illegible]t, James, "Attachment A: HLW Tank Farm Transition Stepped Approach for Zeolite Removal [illegible]D-1," memo # CA:97:0042, July, 1997.
8. [illegible], Shyam, "Table updated - added Assessed Times for 99.9% from Fred Damerow 2/17/98" (Fax [illegible]eived from 2/21/98). **(Appendix)**
9. WVDP-EIS-033 rev 01, "Revised Tank Farm and Vitrification Facility Closure Design Information," (D. Wescott), 7/23/97.
10. WVDP-267 rev 0 (2nd Draft), "Waste Tank Farm Transition End Points," memo CA:97:0055, August 8, 1997.
11. WVDP-267 rev 0 (1st Draft), "Waste Tank Farm Transition End Points," memo WD:96:0971, December 20, 1996.


### U. S. Nuclear Regulatory Commission Documents:


12. NUREG/BR-0058 rev 2, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," November, 1995.
13. NUREG/BR-0184 "Regulatory Analysis Technical Evaluation Handbook," January, 1997.
14. NUREG/CR-6349, "Cost - Benefit Considerations in Regulatory Analysis," October, 1995.

## Other Documents and Texts:

15. Clemen, Robert T., *Making Hard Decisions: An Introduction to Decision Analysis*, PWS-Kent Publishing Co., Boston MA, 1991.

16. U.S. Office of Management and Budget (OMB), "Regulatory - Impact Analysis Guidance," Appendix V in *Regulatory Program of the United States Government. April, 1991 - March 31, 1992.*.

## Interviews Referenced (name(s) of individual(s) interviewed and date):

17. Conners, Bernie, August 8, 1997.

18. Damerow, Fred and Fazio, John, August 8, 1997.

19. Hurst, James and Kumar, Shyam, August 6, 1997.

20. Hurst, James, July 16, 1997.

21. Palmer, Ron, July 16, 1997.

22. "Team" (Core members of this team are: Fred Damerow, James Hurst, meetings on Shyam Kumar (Team Leader), Om Menderatta, and V. K. Sharma, all with WVDP) July 15-16, 1997.

## Software:

23. Analytica 1.1.1 for Windows, Decisioneering, Inc., 1515 Arapahoe Street, Suite 1311, Denver, CO 80202.

# APPENDIX

## Table of Contents

## "UNRESTRICTED USE" STRATEGY TABLE

| Mobilize Solids | Clean Tank Internals | Transfer Solids | Vitrification Proc. Oper. | Vitrified Cannisters | Verification of Results | Charac. of Waste | Definition of Limits | Phy./Chem. Properties |
|---|---|---|---|---|---|---|---|---|
| Existing Mob Pumps (w/tweaking) | Ultrasonic Cleaning | Existing Pumps (no tweaking) | Run the way it is | Stick to "300" limit | Process-based Knowledge, including statistical inferences | Use Grout to meet requirem'ts of LLW classification | Rad limits: Unrestricted/ Sitewide Greenfield | Treat Rad alone (assume good enough for Haz) |
| More Pumps to elim. dead spots | Mechnical Cleaning | Modify Pumps to enhance transfer | Install Solids Separation Equipment | At pt of dim. returns, continue | Direct Measurement (in situ, no sampling of level, of nuclieds) | Use Nongrout material for leaching purposes | Rad Limits: Restricted Use/ site wide | Include Hazardous consideration |
| Better Suspension | Power Washing (& acid if necessary) | Add Grinders to help transfer | Use Oxlate Feed Stream ("Global Decision") | At the pt of dim. returns, change to oxalic acid (increases # cannisters) | Visual Exam | Use nuclied - sensitive retainers | Rad Limits: restrict or unrestriced on facility by facility basis | |
| Mod/repl nozzle @ bottom | Chemical Cleaning | Add Movable Sump Pump | Adjust the Glass Recipe (min # cannisters) | Make "Light" cannisters | "Grab Sample" | Do Nothing because so clean it's not even LLW | Rad Limits: restricted offsite v. onsite | |
| Sluicers @ <16" | "None of the above" | Replace Pumps w/ Fixed Suction | Don't Replace Failed Equip after a point | | Sample Side Stream from one spot | Greenfield- characterize everything | Adapt Available Technologies (only) | |
| Eductor Tubes | | Replace Pumps w/ Movable Suction | Additional Waste Str'ms from proc bldg to vit facility | | Process-based Knowledge + nonrepresentative sampling | | Research & Develop New Technologies | |
| Impeller Mixers | | Replace Pumps w/ vacuum tech | | | Verify by Survey what is left behind | | Emphasize Cleanup | |
| Air Lance | | | | | Monitoring of Results | | Emphasize Containment (clean to a pt then contain) | |
| Chem. to increase Viscosity | | | | | | | Actively Manage Leak Likelihood (e.g., dry out tank) | |
| Revise way of using caustic | | | | | | | | |
| Use Oxalic Acid | | | | | | | | |

# "CONTAINMENT" STRATEGY TABLE

| Mobilize Solids | Clean Tank Internals | Transfer Solids | Vitrification Proc. Oper. | Vitrified Cannisters | Verification of Results | Charac. of Waste | Definition of Limits | Phy./Chem Properties |
|---|---|---|---|---|---|---|---|---|
| **Existing Mob Pumps (w/tweaking)** | Ultrasonic Cleaning | **Existing Pumps (no tweaking)** | Run the way it is | **Stick to "300" limit** | Process-based Knowledge, including statistical inferences | **Use Grout to meet requirem'ts of LLW classification** | Rad limits: Unrestricted/ Sitewide Greenfield | **Treat Rad alone (assume good enough for Haz)** |
| **More Pumps to elim. dead spots** | Mechnical Cleaning | Mod[illegible] Pump[illegible] to enhance transfer | [illegible]nstall Solids Separation Equipment | At pt of dim. returns, continue | **Direct Measurement (in situ, no sampling of level, of nuclieds)** | **Use Nongrout material for leaching purposes** | Rad Limits: Restricted Use/ site wide | Include Hazardous consideration |
| Better Suspension | Power Washing (& acid if necessary) | Add Grinders to help transfer | Use Oxlate Feed Stream ("Global Decision") | At the pt of dim. returns, change to oxalic acid (increases # cannisters) | Visual Exam | **Use nuclied - sensitive retainers** | **Rad Limits: restrict or unrestriced on facility by facility basis** | |
| Mod/repl nozzle @ bottom | Chemical Cleaning | Add Movable Sump Pump | **Adjust the Glass Recipe (min # cannisters)** | Make "Light" cannisters | "Grab Sample" | Do Nothing because so clean it's not even LLW | Rad Limits: restricted offsite v. onsite | |
| **Sluicers @ <16"** | **"None of the above"** | Replace Pumps w/ Fixed Suction | Don't Replace Failed Equip after a point | | Sample Side Stream from one spot | Greenfield- characterize everything | **Adapt Available Technologies (only)** | |
| Eductor Tubes | | Replace Pumps w/ Movable Suction | Additional Waste Str'ms from proc bldg to vit facility | | Process-based Knowledge + nonrepresentative sampling | | Research & Develop New Technologies | |
| Impeller Mixers | | Replace Pumps w/ vacuum tech | | | Verify by Survey what is left behind | | Emphasize Cleanup | |
| Air Lance | | | | | Monitoring of Results | | **Emphasize Containment (clean to a pt then contain)** | |
| Chem. to increase Viscosity | | | | | | | **Actively Manage Leak Likelihood (e.g., dry out tank)** | |
| Revise way of using caustic | | | | | | | | |
| Use Oxalic Acid | | | | | | | | |

# "VACUUM TECHNOLOGY" STRATEGY TABLE

| Mobilize Solids | Clean Tank Internals | Transfer Solids | Vitrification Proc. Oper. | Vitrified Cannisters | Verification of Results | Charac. of Waste | Definition of Limits | Phy./Chem. Properties |
|---|---|---|---|---|---|---|---|---|
| **Existing Mob Pumps (w/tweaking)** | Ultrasonic Cleaning | Existing Pumps (no tweaking) | Run the way it is | **Stick to "300" limit** | **Process-based Knowledge, including statistical inferences** | **Use Grout to meet requirem'ts of LLW classification** | Rad limits: Unrestricted/ Sitewide Greenfield | **Treat Rad alone (assume good enough for Haz)** |
| More Pumps to elim. dead spots | Mechnical Cleaning | Modify Pumps to enhance transfer | Install Solids Separation Equipment | At pt of dim. returns, continue | Direct Measurement (in situ, no sampling of level. of nuclieds) | Use Nongrout material for leaching purpo. | Rad Limits: Restricted Use/ site wide | Include Hazardous consideration |
| Better Suspension | **Power Washing (& acid if necessary)** | Add Grinders to help transfer | Use Oxlate Feed Stream ("Global Decision") | At the pt of dim. returns, change to oxalic acid (increases # cannisters) | **Visual Exam** | Use nuclieu sensitive retainers | **Rad Limits: restrict or unrestriced on facility by facility basis** | |
| Mod/repl nozzle @ bottom | Chemical Cleaning | Add Movable Sump Pump | **Adjust the Glass Recipe (min # cannisters)** | Make "Light" cannisters | "Grab Sample" | Do Nothing because so clean it's not even LLW | Rad Limits: restricted offsite v. onsite | |
| **Sluicers @ <16"** | "None of the above" | Replace Pumps w/ Fixed Suction | Don't Replace Failed Equip after a point | | Sample Side Stream from one spot | Greenfield- characterize everything | **Adapt Available Technologies (only)** | |
| Eductor Tubes | | Replace Pumps w/ Movable Suction | Additional Waste Str'ms from proc bldg to vit facility | | Process-based Knowledge + nonrepresentative sampling | | Research & Develop New Technologies | |
| Impeller Mixers | | **Replace Pumps w/ vacuum tech** | | | Verify by Survey what is left behind | | **Emphasize Cleanup** | |
| Air Lance | | | | | Monitoring of Results | | Emphasize Containment (clean to a pt then contain) | |
| Chem. to increase Viscosity | | | | | | | Actively Manage Leak Likelihood (e.g., dry out tank) | |
| Revise way of using caustic | | | | | | | | |
| Use Oxalic Acid | | | | | | | | |

# "OXALIC ACID" STRATEGY TABLE

| Mobilize Solids | Clean Tank Internals | Transfer Solids | Vitrification Proc. Oper. | Vitrified Cannisters | Verification of Results | Charac. of Waste | Definition of Limits | Phy./Chem Properties |
|---|---|---|---|---|---|---|---|---|
| **Existing Mob Pumps (w/tweaking)** | Ultrasonic Cleaning | **Existing Pumps (no tweaking)** | Run the way it is | **Stick to "300" limit** | **Process-based Knowledge, including statistical inferences** | **Use Grout to meet requirem'ts of LLW classification** | Rad limits: Unrestricted/ Sitewide Greenfield | **Treat Rad alone (assume good enough for Haz)** |
| More Pumps to elim. dead spots | Mechnical Cleaning | Modify Pumps to enhance transfer | Install Solids Separation Equipment | At pt of dim. returns, continue | Direct Measurement (in situ, no sampling of level, of nuclieds) | Use Nongrout material for leaching purposes | Rad Limits: Restricted Use/ site wide | Include Hazardous consideration |
| Better Suspension | Power Washing (& acid if necessary) | Add Grinders to help transfer | **Use Oxlate Feed Stream ("Global Decision")** | At the pt of dim. returns, change to oxalic acid (increases # cannisters) | **Visual Exam** | Use nuclied - sensitive retainers | **Rad Limits: restrict or unrestriced on facility by facility basis** | |
| Mod/repl nozzle @ bottom | **Chemical Cleaning** | Add Movable Sump Pump | **Adjust the Glass Recipe (min # cannisters)** | Make "Light" cannisters | "Grab Sample" | Do Nothing because so clean it's not even LLW | Rad Limits: restricted offsite v. onsite | |
| Sluicers @ <16" | "None of the above" | Replace Pumps w/ Fixed Suction | Don't Replace Failed Equip after a point | | Sample Side Stream from one spot | Greenfield- characterize everything | **Adapt Available Technologies (only)** | |
| Eductor Tubes | | Replace Pumps w/ Movable Suction | Additional Waste Str'ms from proc bldg to vit facility | | Process-based Knowledge + nonrepresentative sampling | | Research & Develop New Technologies | |
| Impeller Mixers | | Replace Pumps w/ vacuum tech | | | Verify by Survey what is left behind | | **Emphasize Cleanup** | |
| Air Lance | | | | | Monitoring of Results | | Emphasize Containment (clean to a pt then contain) | |
| Chem. to increase Viscosity | | | | | | | Actively Manage Leak Likelihood (e.g., dry out tank) | |
| Revise way of using caustic | | | | | | | | |
| **Use Oxalic Acid** | | | | | | | | |

| Transfer # | Date | Calc. Xfer gals (v3-v1-v2) | Curies | Cum Ci | Days | um.day | RF | dum1 | dum2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 06/25/00 | 1899 | 48610 | 48610 | 0.00 | 0.00 | 0.00398 | 1 | 1 |
| 2 | 07/06/00 | 3119 | 67479 | 116089 | 11.00 | 11.00 | 0.00952 | 1 | 1 |
| 3 | 07/15/00 | 2714.2 | 92280 | 208369 | 9.00 | 20.00 | 0.01708 | 1 | 1 |
| 4 | 07/30/00 | 2434.6 | 121219 | 329588 | 15.00 | 35.00 | 0.02702 | 1 | 1 |
| 5 | 08/10/00 | 2020 | 124880 | 454468 | 10.00 | 45.00 | 0.03725 | 1 | 1 |
| 6 | 08/21/00 | 1995.7 | 146357 | 600825 | 11.00 | 56.00 | 0.04925 | 1 | 1 |
| 7 | 08/30/00 | 1266.6 | 83402 | 684227 | 9.00 | 65.00 | 0.05608 | 1 | 1 |
| 8 | 09/07/00 | 1762.7 | 118219 | 802446 | 8.00 | 73.00 | 0.06577 | 1 | 1 |
| 9 | 09/17/00 | 2865.4 | 113003 | 915449 | 10.00 | 83.00 | 0.07594 | 1 | 1 |
| 10 | 09/26/00 | 2083 | 136385 | 1051834 | 9.00 | 92.00 | 0.08622 | 1 | 1 |
| 11 | 10/08/00 | 1854.3 | 113549 | 1165383 | 12.00 | 104.00 | 0.09552 | 1 | 1 |
| 12 | 10/17/00 | 1922.2 | 133423 | 1298806 | 9.00 | 113.00 | 0.10646 | 1 | 1 |
| 13 | 10/24/00 | 2459 | 168198 | 1467004 | 7.00 | 120.00 | 0.12025 | 1 | 1 |
| 14 | 11/05/00 | 2843 | 135734 | 1602738 | 11.00 | 131.00 | 0.13137 | 1 | 0 |
| 15 | 11/13/00 | 2207 | 113583 | 1716321 | 8.00 | 139.00 | 0.14068 | 1 | 0 |
| 16 | 11/28/00 | 3125 | 164316 | 1880637 | 15.00 | 154.00 | 0.15415 | 1 | 0 |
| 17 | 12/08/00 | 3485 | 208519 | 2089156 | 10.00 | 164.00 | 0.17124 | 1 | 0 |
| 18 | 12/18/00 | 3442 | 204985 | 2294141 | 10.00 | 174.00 | 0.18804 | 1 | 0 |
| 19 | 12/31/00 | 3010 | 176713 | 2470854 | 13.00 | 187.00 | 0.20253 | 1 | 0 |
| 20 | 01/09/00 | 3467 | 224923 | 2695777 | 10.00 | 197.00 | 0.22097 | 1 | 0 |
| 21 | 01/24/01 | 3393 | 192021 | 2887798 | 15.00 | 212.00 | 0.23670 | 1 | 0 |
| 22 | 02/28/01 | 2590 | 197267 | 3085065 | 34.00 | 246.00 | 0.25287 | 1 | 0 |
| 23 | 03/11/01 | 3520 | 240355 | 3325420 | 13.00 | 259.00 | 0.27258 | 1 | 0 |
| 24 | 04/14/01 | 3520 | 181645 | 3507065 | 33.00 | 292.00 | 0.28746 | 1 | 0 |
| 25 | 04/23/01 | 3251 | 238377 | 3745442 | 39.00 | 331.00 | 0.30700 | 1 | 0 |
| 26 | 05/03/01 | 3681 | 200006 | 3945448 | 10.00 | 341.00 | 0.32340 | 1 | 0 |
| 27 | 05/11/01 | 3383 | 224250 | 4169698 | 8.00 | 349.00 | 0.34178 | 1 | 0 |
| 28 | 05/20/01 | 3510 | 218643 | 4388341 | 9.00 | 358.00 | 0.35970 | 1 | 0 |
| 29 | 05/28/01 | 3822 | 229325 | 4617666 | 8.00 | 366.00 | 0.37850 | 1 | 0 |
| 30 | 06/07/01 | 3665 | 236434 | 4854100 | 9.00 | 375.00 | 0.39788 | 1 | 0 |

| Transfer | Date | Calc. Xfer gal's | Curies | Cum Ci | Days | um.day | RF | dum1 | dum2 |
|---|---|---|---|---|---|---|---|---|---|
| 31 | 06/19/01 | 3856 | 203925 | 5058025 | 12.00 | 387.00 | 0.41459 | 1 | 0 |
| 32 | 06/29/01 | 4275 | 212324 | 5270349 | 10.00 | 397.00 | 0.43200 | 1 | 0 |
| 33 | 07/10/01 | 4041 | 205013 | 5475362 | 11.00 | 408.00 | 0.44880 | 1 | 0 |
| 34 | 07/20/01 | 3759 | 203042 | 5678404 | 10.00 | 418.00 | 0.46544 | 1 | 0 |
| 35 | 07/30/01 | 4231 | 188739 | 5867143 | 10.00 | 428.00 | 0.48091 | 1 | 0 |
| 36 | 08/22/01 | 4094 | 232010 | 6099153 | 23.00 | 451.00 | 0.49993 | 1 | 0 |
| 37 | 09/02/01 | 4392 | 220831 | 6319984 | 10.00 | 461.00 | 0.51803 | 1 | 0 |
| 38 | 09/12/01 | 4843 | 230781 | 6550765 | 10.00 | 471.00 | 0.53695 | 1 | 0 |
| 39 | 09/23/01 | 4827 | 203548 | 6754313 | 11.00 | 482.00 | 0.55363 | 1 | 0 |
| 40 | 10/04/01 | 4928 | 204806 | 6959119 | 11.00 | 493.00 | 0.57042 | 0 | 0 |
| 41 | 10/15/01 | 5244 | 196530 | 7155649 | 11.00 | 504.00 | 0.58653 | 0 | 0 |
| 42 | 10/24/01 | 5132 | 175587 | 7331236 | 9.00 | 513.00 | 0.60092 | 0 | 0 |
| 43 | 11/02/01 | 5154 | 150195 | 7481431 | 8.00 | 521.00 | 0.61323 | 0 | 0 |
| 44 | 11/11/01 | 5132 | 138992 | 7620423 | 9.00 | 530.00 | 0.62462 | 0 | 0 |
| 45 | 12/07/01 | 7904 | 173553 | 7793976 | 26.00 | 556.00 | 0.63885 | 0 | 0 |
| 46 | 12/20/01 | 8643 | 207262 | 8001238 | 13.00 | 569.00 | 0.65584 | 0 | 0 |
| 47 | 01/10/02 | 8892 | 191957 | 8193195 | 20.00 | 589.00 | 0.67157 | 0 | 0 |
| 48 | 01/19/02 | 8823 | 158939 | 8352134 | 9.00 | 598.00 | 0.68460 | 0 | 0 |

SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.99353421 |
| R Square | 0.98711022 |
| Adjusted R S | 0.98526883 |
| Standard Erro | 4.60938638 |
| Observations | 9 |

ANOVA

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 1 | 11389.4971 | 11389.4971 | 536.066071 | 7.1118E-08 |
| Residual | 7 | 148.7251 | 21.2464428 | | |
| Total | 8 | 11538.2222 | | | |

| | Coefficients | tandard Erro | t Stat | P-value | Lower 95% |
|---|---|---|---|---|---|
| Intercept | 184.553268 | 15.4907867 | 11.9137441 | 6.6736E-06 | 147.923404 |
| X Variable 1 | -828.312535 | 35.7754474 | -23.1531007 | 7.1118E-08 | -912.907965 |

RESIDUAL OUTPUT

| Observation | Predicted Y | Residuals |
|---|---|---|
| 1 | 488.507135 | 4.49286505 |
| 2 | 502.256295 | 1.74370503 |
| 3 | 515.001188 | -2.00118755 |
| 4 | 526.273207 | -5.27320718 |
| 5 | 537.0288 | -7.02879957 |
| 6 | 550.926647 | 5.07335269 |
| 7 | 568.259584 | 0.74041556 |
| 8 | 585.093422 | 3.90657765 |
| 9 | 599.653722 | -1.65372168 |

ANALYSIS OF VITRIFICATION OPERATIONS COST
JULY '96 through JANUARY '98
(Cost Data in Thousands)

ADMINISTRATIVELY CONFIDENTIAL COSTING INFORMATION
REMOVED FROM REPORT

Received from H. W. Morse/J. B. Green on 2/20/98

Data Used in Graphs (Sheet 1)

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.84 | 4.930 | 33.0 | 8.2 | 8.2 | 8.2 | 8.2 | 16.7 | 21.2 | 20.7 | 16.3 | 26.1 | 17.7 |
| 3 | 0.85 | 4.622 | 35.2 | 9.0 | 9.0 | 9.0 | 9.0 | 18.2 | 22.7 | 22.2 | 17.6 | 27.5 | 19.2 |
| 4 | 0.86 | 4.313 | 37.4 | 9.8 | 9.8 | 9.8 | 9.8 | 19.9 | 24.3 | 23.8 | 19.3 | 29.2 | 20.8 |
| 5 | 0.87 | 4.005 | 39.6 | 10.7 | 10.7 | 10.7 | 10.7 | 21.6 | 26.0 | 25.6 | 21.0 | 31.1 | 22.6 |
| 6 | 0.88 | 3.697 | 41.8 | 11.7 | 11.7 | 11.7 | 11.7 | 23.5 | 27.9 | 27.4 | 22.9 | 32.9 | 24.4 |
| 7 | 0.89 | 3.389 | 44.0 | 12.7 | 12.7 | 12.7 | 12.7 | 25.5 | 29.9 | 29.5 | 24.7 | 35.1 | 26.5 |
| 8 | 0.9 | 3.081 | 46.2 | 13.9 | 13.9 | 13.9 | 13.9 | 27.8 | 32.2 | 31.8 | 26.8 | 37.6 | 28.7 |
| 9 | 0.91 | 2.773 | 48.4 | 15.1 | 15.0 | 14.8 | 14.8 | 30.2 | 34.0 | 33.6 | 32.5 | 35.7 | 31 |
| 10 | 0.92 | 2.465 | 50.6 | 16.6 | 16.4 | 15.9 | 15.9 | 32.9 | 36.1 | 35.7 | 33.2 | 3[illegible].9 | 33.6 |
| 11 | 0.93 | 2.157 | 52.8 | 18.2 | 17.9 | 17.2 | 17.2 | 36.2 | 38.6 | 38.2 | 34.1 | 42.[illegible] | 36.5 |
| 12 | 0.94 | 1.849 | 55.0 | 20.2 | 19.6 | 18.7 | 18.7 | 39.8 | 41.4 | 41.0 | 35.0 | 47.2 | 39.8 |
| 13 | 0.95 | 1.541 | 57.2 | 22.5 | 21.8 | 20.5 | 20.5 | 44.3 | 44.9 | 44.5 | 36.1 | 58.2 | 43.9 |
| 14 | 0.96 | 1.232 | 59.4 | 25.4 | 24.7 | 22.7 | 22.7 | 49.7 | 49.1 | 48.6 | 37.5 | 67.4 | 4[illegible].2 |
| 15 | 0.97 | 0.924 | 61.6 | 29.2 | 28.3 | 25.8 | 25.7 | 56.8 | 54.9 | 54.4 | 39.3 | 78.3 | 55.9 |
| 16 | 0.98 | 0.616 | 63.8 | 34.8 | 33.3 | 29.9 | 32.1 | 67.1 | 62.4 | 66.1 | 41.9 | 93.5 | 65.1 |
| 17 | 0.99 | 0.308 | 66.0 | 44.6 | 42.4 | 37.3 | 40.8 | 84.8 | 75.9 | 81.7 | 46.4 | 117.7 | 81.4 |
| 18 | 0.999 | 0.031 | 68.0 | 79.2 | 71.9 | 63.0 | 69.3 | 143.8 | 120.3 | 130.6 | 61.0 | 174.8 | 131.4 |
| 19 | | | | | | | | | | | | | |
| 20 | A = Reduction Factor | | | | | | | | | | | | |
| 27 | B = Sum of Fractions | | | | | | | | | | | | |
| 28 | C = Mean of Gross Social Benefit ($M) | | | | | | | | | | | | |
| 29 | D = Mean of Total Time to RF - Baseline (Month) | | | | | | | | | | | | |
| 30 | E=Mean of Total Time to RF - Augmented Baseline (Month) | | | | | | | | | | | | |
| 31 | F = Mean of Total Time to RF - Stepped Approach (Month) | | | | | | | | | | | | |
| 32 | G = Mean of Total Time to RF - Stepped w/o ACID (Month) | | | | | | | | | | | | |
| 33 | H = Mean of Gross Social Cost - Baseline ($M) | | | | | | | | | | | | |
| 35 | I = Mean of Gross Socal Cost - Stepped Approach ($M) | | | | | | | | | | | | |
| 36 | J = Mean of Gross Social Cost - Stepped w/o Acid ($M) | | | | | | | | | | | | |
| 37 | K = 5th Percentile of Gross Social Cost - Stepped Approach ($M) | | | | | | | | | | | | |
| 38 | L = 95th Percentile of Gross Social Cost - Stepped Aproach ($M) | | | | | | | | | | | | |
| 39 | M = Mean of Gross Social Cost - Augmented Baseline ($M) | | | | | | | | | | | | |

Data Used in Graphs (Sheet 2)

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.84 | 16.3 | 15.3 | 11.9 | 12.3 | 11.5 | 10.5 | 7.0 | 7.8 | 20.9 | 20.1 | 16.4 | 17.1 |
| 3 | 0.85 | 17.0 | 16.0 | 12.6 | 13.0 | 12.2 | 11.2 | 7.7 | 8.1 | 21.8 | 20.9 | 17.4 | 17.9 |
| 4 | 0.86 | 17.6 | 16.6 | 13.1 | 13.6 | 12.8 | 11.7 | 8.2 | 8.6 | 22.4 | 21.4 | 18.0 | 18.4 |
| 5 | 0.87 | 18.0 | 17.0 | 13.6 | 14.0 | 13.1 | 12.0 | 8.6 | 9.0 | 23.1 | 22.0 | 18.7 | 19.1 |
| 6 | 0.88 | 18.4 | 17.4 | 13.9 | 14.4 | 13.3 | 12.5 | 8.9 | 9.3 | 23.6 | 22.5 | 19.0 | 19.6 |
| 7 | 0.89 | 18.5 | 17.6 | 14.1 | 14.6 | 13.3 | 12.2 | 8.8 | 9.2 | 23.7 | 22.7 | 19.3 | 19.7 |
| 8 | 0.9 | 18.5 | 17.5 | 14.1 | 14.5 | 13.0 | 12.2 | 8.5 | 9.0 | 24.0 | 23.0 | 19.7 | 20.0 |
| 9 | 0.91 | 18.2 | 17.5 | 14.4 | 14.8 | 12.6 | 15.8 | 12.7 | 13.1 | 23.9 | 19.1 | 16.0 | 16.4 |
| 10 | 0.92 | 17.6 | 17.1 | 14.4 | 14.8 | 11.9 | 13.4 | 11.5 | 11.9 | 23.6 | 20.5 | 17.5 | 17.9 |
| 11 | 0.93 | 16.5 | 16.4 | 14.1 | 14.6 | 10.5 | 10.9 | 10.1 | 10.4 | 22.9 | 21.7 | 18.8 | 19.2 |
| 12 | 0.94 | 15.0 | 15.2 | 13.6 | 13.9 | 8.6 | 7.7 | 7.8 | 8.2 | 21.8 | 22.7 | 20.2 | 20.5 |
| 13 | 0.95 | 12.7 | 13.3 | 12.4 | 12.8 | 4.7 | -7.1 | -1.0 | -0.5 | 20.0 | 23.4 | 21.3 | 21.5 |
| 14 | 0.96 | 9.5 | 10.2 | 10.1 | 10.6 | -5.3 | -17.0 | -8.0 | -7.5 | 17.6 | 23.9 | 22.0 | 22.5 |
| 15 | 0.97 | 4.7 | 5.7 | 6.8 | 7.2 | -14.0 | -29.4 | -16.7 | -16.4 | 13.6 | 23.8 | 22.3 | 22.6 |
| 16 | 0.98 | -3.2 | -1.3 | 1.4 | -1.8 | -27.1 | -45.2 | -29.7 | -33.4 | 7.1 | 22.8 | 21.9 | 19.3 |
| 17 | 0.99 | -18.8 | -15.4 | -9.9 | -15.7 | -42.7 | -67.9 | -51.7 | -57.0 | -4.9 | 19.6 | 19.7 | 15.8 |
| 18 | 0.999 | -75.8 | -63.4 | -52.3 | -62.5 | -93.6 | -134.8 | -106.8 | -122.6 | -52.7 | 3.9 | 7.1 | -0.7 |
| 19 | | | | | | | | | | | | | |
| 20 | A = Reduction Factor | | | | | | | | | | | | |
| 29 | B = Mean of Net Social Benefit ($M) - Baseline | | | | | | | | | | | | |
| 30 | C = Mean of Net Social Benefit ($M) - Augmented Baseline | | | | | | | | | | | | |
| 31 | D = Mean of Net Social Benefit ($M) - Stepped Approach | | | | | | | | | | | | |
| 32 | E = Mean of Net Social Benefit ($M) - Stepped w/o Acid | | | | | | | | | | | | |
| 33 | F = 5th Percentile of Net Social Benefit ($M) - Baseline | | | | | | | | | | | | |
| 34 | G = 5th Percentile of Net Social Benefit ($M) - Augmented Baseline | | | | | | | | | | | | |
| 35 | H = 5th Percentile of Net Social Benefit ($M) - Stepped Approach | | | | | | | | | | | | |
| 36 | I = 5th Percentile of Net Social Benefit ($M) - Stepped w/o Acid | | | | | | | | | | | | |
| 37 | J = 95th Percentile of Net Social Benefit ($M) - Baseline | | | | | | | | | | | | |
| 38 | K = 95th Percentile of Net Social Benefit ($M) - Augmented Baseline | | | | | | | | | | | | |
| 39 | L = 95th Percentile of Net Social Benefit ($M) - Stepped Approach | | | | | | | | | | | | |
| 40 | M = 95th Percentile of Net Social Benefit ($M) - Stepped w/o Acid | | | | | | | | | | | | |

Data Used in Graphs (Sheet 3)

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.84 | 0 | 0 | 0 | 0 | 16.5 | 15.5 | 12.1 | 12.5 | 11.9 | |
| 3 | 0.85 | 0 | 0 | 0 | 0 | 17.2 | 16.3 | 12.8 | 13.3 | 12.6 | |
| 4 | 0.86 | 0 | 0 | 0 | 0 | 17.9 | 16.9 | 13.5 | 13.9 | 13.1 | |
| 5 | 0.87 | 0 | 0 | 0 | 0 | 18.4 | 17.4 | 14 | 14.4 | 13.6 | |
| 6 | 0.88 | 0 | 0 | 0 | 0 | 18.8 | 17.8 | 14.4 | 14.8 | 13.9 | |
| 7 | 0.89 | 0 | 0 | 0 | 0 | 19.1 | 18.1 | 14.7 | 15.1 | 14.1 | |
| 8 | 0.9 | 0 | 0 | 0 | 0 | 19.2 | 18.2 | 14.7 | 15.2 | 14.1 | |
| 9 | 0.91 | 0.04 | 0.02 | 0.02 | 0.02 | 19 | 18.2 | 15.1 | 15.5 | 14.4 | |
| 10 | 0.92 | 0.08 | 0.08 | 0.08 | 0.08 | 18.5 | 17.9 | 15.2 | 15.6 | 14.4 | |
| 11 | 0.93 | 0.21 | 0.13 | 0.15 | 0.15 | 17.6 | 17.4 | 15 | 15.5 | 14.1 | |
| 12 | 0.94 | 0.31 | 0.18 | 0.2 | 0.2 | 16.3 | 16.5 | 14.6 | 15 | 13.6 | |
| 13 | 0.95 | 0.5 | 0.37 | 0.24 | 0.25 | 14.4 | 14.9 | 13.7 | 14.2 | 12.4 | |
| 14 | 0.96 | 0.71 | 0.74 | 0.54 | 0.54 | 11.6 | 12.2 | 11.8 | 12.3 | 10.1 | |
| 15 | 0.97 | 1 | 1.2 | 0.87 | 0.89 | 7.4 | 8.4 | 8.9 | 9.4 | 6.8 | |
| 16 | 0.98 | 1.66 | 1.8 | 1.2 | 1.53 | 0.5 | 2.4 | 4.3 | 1.1 | 1.4 | |
| 17 | 0.99 | 3.2 | 3.2 | 2.2 | 2.99 | -12.9 | -9.5 | -5.4 | -10.3 | -9.9 | |
| 18 | 0.999 | 10 | 7.4 | 6.5 | 7.51 | -58.9 | -47.7 | -40.2 | -48.3 | -52.3 | |
| 19 | | | | | | | | | | | |
| 20 | A = Reduction Factor | | | | | | | | | | |
| 21 | B = Expected Melter Down Time - Baseline (months) | | | | | | | | | | |
| 22 | C = Expected Melter Down Time - Augmented Baseline (months) | | | | | | | | | | |
| 23 | D = Expected Melter Down Time - Stepped Approach (months) | | | | | | | | | | |
| 24 | E = Expected Melter Down Time - Stepped w/o Acid (months) | | | | | | | | | | |
| 25 | F = Expected Net Benefit @ 7% Disc.Rate on Cost - Baseline | | | | | | | | | | |
| 26 | G = Expected Net Benefit @ 7% Disc.Rate on Cost - Augmented Baseline | | | | | | | | | | |
| 27 | H = Expected Net Benefit @ 7% Disc. Rate on Cost - Stepped Approach | | | | | | | | | | |
| 28 | I = Expected Net Benefit @ 7% Disc. Rate on Cost - Stepped w/o Acid | | | | | | | | | | |
| 29 | J = Expected Net Benefit @ 3% Disc. Rate on Cost - Stepped Approach (copied from Sheet 2) | | | | | | | | | | |

- **Prototype Techno-Economic Evaluation Model for Tank 8D...**
  - **Base Inventory of Nuclides**
    - Base Am-241
    - Base Cs
    - Base C-14
    - Base NP-237
    - Base Pu-238
    - Base Pu-239
    - Base Sr
    - Base Tc-99
  - **Social Cost Module**
    - Strategy Capitalized Cost
    - **Technology Capital Cost Distributions**
      - P-T Appx for Base Capital
      - P-T Appx for Base+Mech
      - common index for base
      - Common Index for base + mech
      - Prob for Base Capital
      - Prob for Base + Mech
      - triangular for acid cap(alone)
      - Triangular for Tool Sys Capital(alone)
      - Values for Base Capital
      - Values for Base +Mech
      - Values for Tool Sys (alone)
    - Discount Rate
    - Gross Social Cost
    - Variable Cost
    - Variable Cost per unit time
  - Curies Reduction Factor Choices
  - **Social Benefit Module**
    - **Curies Removed Submule**
      - Am-241 Removed
      - Cs Removed
      - C-14 Removed
      - Fraction already removed
      - Np-237 Removed
      - Pu-238 Removed
      - Pu-239 Removed
      - Sr Removed
      - Tc-99 Removed

- Total Curies Removed Since 7/1/97
- Gross Social Benefit
- **Value of Avoided Closure Cost submodule**
  - Value of a Am-241 Curie (mcc)
  - Value of a C-14 Curie (mcc)
  - Value of a Cs Curie (mcc)-Read me!
  - Value of a Np-237 Curie (mcc)
  - Value of a Pu238 Curie (mcc)
  - Value of a Pu239 Curie (mcc)
  - Value of a Sr Curie (mcc)
  - Value of a Tc-99 Curie (mcc)
- **Value of Avoided Exposure Submodule**
  - Value of a Am-241 Curie (mci)
  - Value of a C-14 Curie (mci)
  - Value of a Cs Curie (mci)-Read me!
  - Value of a Np-237 Curie (mci)
  - Value of a Pu238 Curie (mci)
  - Value of a Pu239 Curie (mci)
  - Value of a Sr Curie (mci)
  - Value of a Tc-99 Curie (mci)

**Net Social Benefit**
- Net Social Benefit (dose limit=100mR/yr)

**Remaining Inventory of Nuclides**
- Remaining Am-241
- Remaining Cs
- Remaining C-14
- Remaining NP-237
- Remaining Pu-238
- Remaining Pu-239
- Remaining Sr
- Remaining Tc-99
- Sampling or Verification Error

**Sum of Fractions Module**
- **Limiting Curies Module**
  - Limiting Curies for Am-241
  - Limiting Curies for C-14
  - Limiting Curies for Cs-137
  - Limiting Curies for NP-237
  - Limiting Curies for Pu-238
  - Limiting Curies for Pu-239

- Limiting Curies for Sr90
- Limiting Curies for Tc-99
- **Sum of Fraction Rule**
  - Am-241 Fraction
  - C-14 Fraction
  - Cs Fraction
  - NP-237 Fraction
  - Pu-238 Fraction
  - Pu-239 Fraction
  - Sr Fraction
  - Sum of Fractions
  - Tc-99 Fraction
- Technology Choices
- **Time Module**
  - Expert ratios for Stepped Appr.
  - Expert ratios for Augmented Baseline
  - **Experts' "Time to" Distributions**
    - Acid Time to 99
    - Acid Time to 999
    - Base Time to 90
    - Base Time to 93
    - Base Time to 95
    - Base Time to 97
    - Base Time to 99
    - Base Time to 999
    - common index for Base Time (90 & 97)
    - Curr Time to 90
    - Curr Time to 93
    - Curr Time to 95
    - Curr time to 97
    - Curr Time to 99
    - Curr Time to 999
    - Probabilities (P-T Approx.)
    - TDS Time to 97
    - TDS Time to 99
    - TDS Time to 999
    - Values for Base 90
    - Values for Base 97
    - Values for Curr Mech 90
    - Values for Curr Mech 97

- Values for Tool Sys 97
- Values for Tool sys 99
- Values for Acid 99
- Values for acid 999
- Values for Base 999
- Values for Base 93
- Values for Base 95
- Values for Base 99
- Values for Curr Mech 93
- Values for Curr Mech 95
- Values for Curr Mech 99
- Values for cur 999
- Values for Tool Sys 999

- Implied Beta for 90 to 99.9% RF
- Melter Down Time
- Melter Failure
- Melter Life
- **Regress. Model Fcst of Time to RF**
  - Baseline Fcst of Time to RF
  - Mean of Baseline Fcst
  - Standard Deviation of Baseline Fcst
- Expert ratios for Stepped w/o Acid
- Time to Reduction Factor
- Total Time to Reduction Fac'

Note: Table updated - added Assessed Times for 99.9% from Fred Damerow 2/17/98

**Assessed Times ( months) to 90%, 97%, 90%, and 99.9% Reduction Factors**

| Strategy Alternative | Low (5th Percentile) | Median | High (95th Percentile) |
|---|---|---|---|
| Baseline (90%) | 13 | 21 | 29 |
| Baseline (97%) | 18 | 25 | 39 |
| Baseline (99%) | 24 | 31 | 65 |
| Baseline (99.9%) | 30 | 43 | 80 |
| Current Mech (90%) | 13 | 20 | 29 |
| Current Mech (97%) | 18 | 23 | 39 |
| Current Mech (99%) | 24 | 29 | 47 |
| Current Mech(99.9%) | 27 | 38 | 62 |
| Tool Dlvry Sys (90%) | NA | NA | NA |
| Tool Dlvry Sys (97%) | 21 | 24 | 30 |
| Tool Dlvry Sys (99%) | 25 | 32 | 37 |
| Tool Dlvry Sys (99.9%) | 28 | 39 | 49 |
| Oxalic Acid (90%) | NA | NA | NA |
| Oxalic Acid (97%) | NA | NA | NA |
| Oxalic Acid (99%) | 24 | 28 | 35 |
| Oxalic Acid (99.9%) | 28 | 34 | 47 |