9-SW0-SHYAM-R1

ENCLOSURE 3

Decision Analysis To Support End Point Development for HLW Tank Cleanup: 1999 Update

Robert K. Perdue
Westinghouse Science & Technology Center

15 February 1999

Work performed for West Valley Nuclear Services Company, Inc. under Inter-works Requisition P.O. 19-94013-I-LH

Westinghouse STC
1310 Beulah Road
Pittsburgh, PA 15235-5098

Decision Analysis to Support End Point Development for HLW Tank Cleanup: 1999 Update

Robert K. Perdue
Westinghouse Science & Technology Center
15 February 1999

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 contamination to be classified as "not HLW." An earlier version of this report described the methodology, a computer model, and the results of applying that methodology to data then available to estimate social net benefits for various levels of curie removal. This report is an update of that study. It uses new data to provide projections of monetized social benefits and costs for removal of various amounts (up to 99.9%) of the original curies inventory. 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 of the HLW tanks.

Acknowledgment

The author gratefully acknowledges the assistance of Shyam Kumar, Team Leader for the task team of WVDP professionals and managers assembled to address the subject matter of this report. Valuable contributions were also made by the core members of that team, including Fred Damerow, James Hurst, Om Menderatta, and V. K. Sharma. Gratitude is also extended to other individuals who made specific contributions as noted in the text.

Table of Contents

Section Number		Page Number
	Abstract & Acknowledgment	ii
	List of Tables	iv
	List of Figures	v
	Executive Summary	vi
1.0	**Introduction and Comparison with Earlier Work**	1
2.0	**Definition of Alternatives and Decision Criteria**	2
2.1	*Identification and Definition of Alternatives*	2
2.2	*The Decision Criteria*	4
3.0	**Model of the Decision Criteria**	6
3.1	*Social Net Benefit' Relation to Curies Removed & "Time to RF"*	6
3.2	*Overview of the Computer Model*	8
4.0	**Derivation of Model Inputs**	10
4.1	*Derivation of Benefit Parameters*	10
4.2	*Regression Model for Baseline Forecast of Time to RF*	11
4.3	*Derivation of Projections for other Technologies*	13
4.4	*Derivation of Capital Costs and Variable Cost per Month*	15
4.5	*Melter Life*	15
4.6	*Discount Rate*	16

Table of Contents (continued)

Section		Page
5.0	**Simulation Model's Expected Value Projections**	16
5.1	*Sum of Fractions and Gross Benefit*	16
5.2	*Time to Residue fraction*	18
5.3	*Gross Social Cost*	19
5.4	*Net Social Benefits*	21
6.0	**Uncertainty and Sensitivity Analysis**	22
6.1	*Uncertainty Analysis*	22
6.2	*Sensitivity to Omitted Uncertainties*	23
7.0	**Summary and Conclusions**	24
	References	25
	Appendix (Table of Contents)	27

List of Tables

		Page Number
Table 1	Technology Options List	3
Table 2	Technology Scenarios	4
Table 3	Values for Isotope Inventory, Limiting Ci, Mci, Mcc	10
Table 4	Regression Analysis of Historical Transfers	12
Table 5	Selected Fractiles...on Time to RF=99.9%....	14
Table 6	Present Value of Future Capital Expenditures	15
Table 7	Sum of Fractions, Remaining Curies & Gross Social Benefits	17
Table 8	Mean Melter Down Time & Total Time to Residue fraction	18
Table 9	Mean Incremental Gross Variable & Total Social Cost	20
Table 10	Mean Value of Expected Incremental Net Social Benefit	21
Table 11	Probability Bands on Net Social Benefit	23

List of Figures

		Page Number
Figure 1	Model Overview	9
Figure 2	Three - Pt Approximation to a Continuous Probability Distribution	13
Figure 3	Mean Incremental Total Time to Indicated Residue Fraction	19
Figure 4	Mean Incremental Gross Variable and Total Social Cost	20
Figure 5	Mean Incremental Net Social Benefit, by Residue Fraction & Technology Scenario	22

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 economic practicality.

This report is an update of an earlier study that used 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%. New data is used to provide projections of net social benefit for five 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 three 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 and installation. The study follows or adapts key elements of Nuclear Regulatory Commission guidelines for regulatory analysis. Salient conclusions are:

- The analysis does not support carrying the cleanup beyond the 3% residue fraction approximately required by the Sum-of-Fractions Rule.
- Unless it is determined for other reasons (e.g., a "concentrations" criterion) to go beyond the 2% residue fraction, the analysis does not support additional investment in any non-Baseline technology option.
- If it is determined to go substantially beyond the 2% residue fraction, then the Augmented+Acid scenario is expected to provide the least negative net societal 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 End Point Development for HLW Tank Cleanup: 1999 Update

1.0 Introduction and Comparison with Earlier Work

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 contamination to be classified as "not HLW."

The problem is to decide when the tanks are clean enough for such a decision; 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 practicality. An earlier report [18] described the methodology, a computer model, and the results of applying that methodology to data then available to estimate social net benefits for various levels of curie removal. This report is an update of that study. As before, this study follows or adapts key elements of Nuclear Regulatory Commission guidelines for regulatory analysis [13]. "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 and installation.

However, this revision makes use of additional production experience up through the end of 1998, by which time more than 90% of the initial inventory of curies had been removed, and also uses revised estimates of capital costs for the various technologies. Further, the technology scenarios themselves have been updated and expanded. This new data is used in the previously-developed computer model to provide projections of monetized social benefits and costs for hypothesized "residue fractions" ranging from the current 9% (= the estimated fraction of the original inventory remaining) up to 0.01% (equivalent to a reduction factor of 99.9%) for five alternative cleanup technology scenarios. Information for this report was gathered in a one-day interview session on December 14, 1998 with WVNS experts, with additional information on costs and production subsequently received via the mail. This source material has been placed in the **Appendix**. This revision is intended to serve as a self-contained source document. Consequently, all salient features of the methodology described in the earlier report are repeated in this revision.

2.0 Definition of Alternatives and Decision Criteria

2.1 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 minor 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 vitrification process.

Due to the long lead time required to implement tank cleaning options, a sufficient number of resource allocation decisions have already been made [illegible] severely restrict the set of strategies and even tactical options. These historical decisions have been guided by a "*Stepped Approach*" that envisions sequentially deploying ever more sophisticated and developmental technologies to remove the zeolite in 8D-1 and the HLW sludge in 8D-2 until a "no HLW' decision can be made. The long-lead time items envisioned are either under development or, in most cases, under order. The basic premise of the Stepped Approach is that the technologies should be available if and when they are needed. Technology options were reviewed on December 14, 1998 with Fred Damerow and John Fazio and later with Dan Meess (see "Record of Interviews..." in the **Appendix**). The most current technology deployment plan (see "Record of Interviews..." in **Appendix**) has been used to update the earlier study's "Technology Option List." The new list, which excludes the "grinders" option of the earlier report and provides new nominal dates for implementation, is in Table 1 below. Option A, the **Baseline,** represents the tools and techniques (mobilization and transfer pumps) that have been used to date and could continue to be deployed with no development or first-time engineering required. Technology Options B, C, and D representing more advanced technologies that would require significant first time development and engineering to deploy.

Table 1: Technology Options List
A. **Baseline for 8D-1**: Mob pumps in risers M-1, M-2, M-3 (working by 2QFY99), M-5 (working by 2QFY99). Transfer pump in M-8, G-004 decant pump. **Baseline for 8D-2:** Mob pumps in risers M-1, M-2, M-3, M-4, M-5, M-6. Decant pump in M-8. Transfer pump in M-9
B. **Weidemann Mechanical Arm for 8D-1**: Once installed, water level can be lowered and appropriate end effectors (sluice, spray, vacuum (in development)) can be attached to wash, spray, swab, etc. as needed. Operational time thought to be "lengthy." Nominal installation date is 3QFY99 in riser M-7. **For 8D-2:** Ditto, with nominal installation date of 4QFY99.
C. **Tool Delivery System("Tarzan")** : This will be a mobile 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 developmental at this stage with non-trivial risk of failure to perform intended function. Nominal installation date is 4QFY01 in 8D-2 only.
D. **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 perforating the tank. Current 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. Assumption is acid would be applied to both. No nominal date but sometime after mechanical means have been deployed to get down to less than a 2% residue fraction

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 and perhaps D 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 Mechanical Arm will be implemented if they are technically viable at the appropriate time and if 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 1 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 are implemented at their nominal projected dates of availability, and that Oxalic Acid is employed once 98 percent of the curies have been removed[1]. Three intermediate strategies are also to be evaluated: (a) *Augmented Baseline*: Baseline Strategy is augmented by option B on the nominal installation date. No other options are implemented. (b) *Augmented + Acid*: Augmented Baseline plus of Oxalic Acid's use once a 2 % residue fraction is achieved. This, of course, requires capital and material expenditures for the acid in anticipation of reaching the 2% residue fraction - even if the decision is not to go that far. (c)

---

[1] More recently, the thinking has been to wait until less than 1 percent. However, the results here assume 2 percent.

Augmented + TDS: Augmented Baseline plus the "Tool Delivery System" assuming it is available by the nominal date. In summary, the study evaluates four Technology Scenarios:

Table 2

Technology Scenarios
Baseline = Option A defined in Table 1.
Augmented Baseline = Options A+ B
Augmented + Acid = Options A+B+D
Augmented + TDS = Options A+B+C
Stepped = Options A+B+C+D

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.- called the "reduction factor" or, equivalently, the residue fraction (1 minus the reduction factor).

2.2 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 contamination 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) principle 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 Sum - of - Fractions Rule been satisfied but also that the curies have been removed to the maximum technical and economically - practical extent using best available technologies.

The "best available technology" will presumably be part of one of the scenarios in Table 2. The "economically - practical" 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. 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 4.4...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, (1) 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, 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 residue level that is best in the sense of setting and meeting tank cleanup goals in a technically and economically efficient manner. The next step is to specify a model capable of quantifying the decision criterion Net Social Benefit for each cleanup level.

3.0 Model of the Decision Criteria

3.1 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 technologies 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" or its complement *Residue Fraction* = 1 - 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) Gross Social Cost_j = Vit Variable Cost_j + 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) 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,

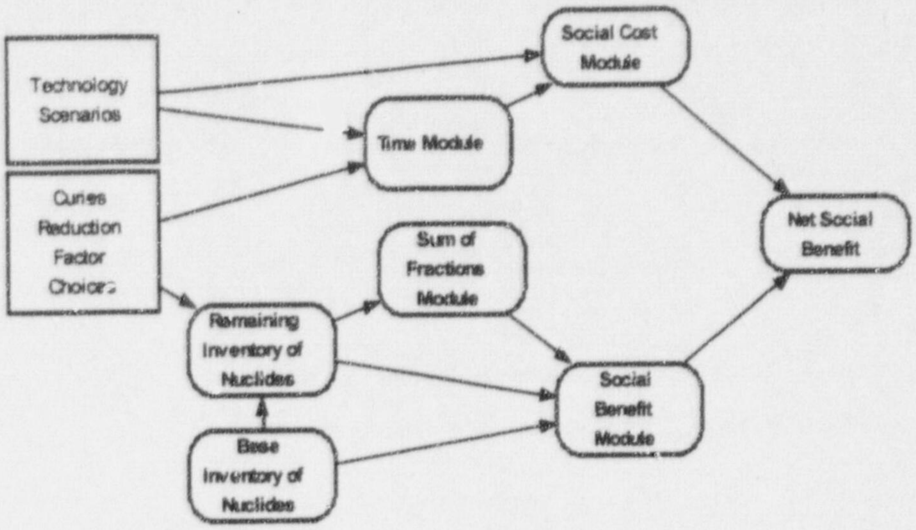
$$(9) \qquad GrossSocialBenefit_j = \sum_i GrossSocialBenefit_{ij}$$

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.

3.2 Overview of the Computer Model

The computer model is implemented in Analytica®[19], a graphical, hierarchical modeling software package that uses Monte Carlo simulation methods to solve models with probabilistic inputs. An overview of the model is diagrammed in Figure 1 (this is a screen shot of what the user actually sees when opening the model). The box at the extreme left of Figure 1 labeled *Technology Scenarios* contains the list of technical scenarios (described in Tables 1 and 2). The box or decision node labeled *Curies Reduction Factor Choices* contains the alternative Reduction Factors (RF), or Residue fractions (1- RF) 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. One hidden input variable is Time-to-RF, which is in the *Time Module*. 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 September 14, 1998 (the last historical "transfer" available at the time of this analysis). This represents the projected future Baseline scenario. (b) Expert (probabilistic) assessments of the extent to which each non - Baseline candidate technology will reach the stipulated reduction factor. (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 1: Model Overview



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 1, the choice of a curies reduction factor or residue fraction (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. The projected incremental curies removed (i.e., over and above those curies already removed as of 1 January, 1999) are combined with estimates for the Mci (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.

4.0 Derivation of Model Inputs

4.1 Derivation of the Benefit Parameters (Mci, Mcc)

Table 3: Values for Isotope Inventory, Limiting Ci, Mci, Mcc

1	2	3	4	5
Isotope Name	Initial (1996) Inventory	Limiting Ci @ 100 mR/yr (= Gi)	Mci = $ value of avoided exposure per Ci	Mcc=$ value of avoided closure cost per Ci
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	5.05E+6	4.40E+13	0	0
Cs-137	6.29E+6	[illegible].80E+28	0	0

Table 3 contains the data used to estimate Mci and Mcc. The only change from the original study is that the estimate of the initial inventory of Sr-90 in column 2 has been reduced from 5.81E+6 to 5.05E+6 curies ["Record of Interviews..., **Appendix**]. The impact of this change on the analysis is examined in Section 6.2 of this report. 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) $\sum(Si \div Gi) \leq 1$.

sum-of-fractions rule states that the sum across all radionuclides of the ratios Si to Gi must be no greater than unity,

$$(10) \quad \sum(Si \div Gi) \leq 1 \ .$$

The calculation of Mci (the value of avoided radiation associated with removal of a curie of the indicated nuclide) in Table 3 is as follows. The limiting curies shown in Column 3 of Table 3 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 Statement [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 offsite 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 offsite 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 3 above.

4.2 Regression Model for Baseline Forecast of Time to RF

As of September 14, 1998, some 58 transfers had been made with 90.8 percent of the estimated initial inventory of reference curies having been removed. All calculations refer to sampling measurements for removal of Cs-137 and Sr- 90 curies without allowance for decay. It is assumed that the same fraction applies to all isotopes, measured and unmeasured. 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 24, 1996). Various functional forms were applied (including linear, log-log, reciprocal, log-reciprocal) before choosing the following semi-log function:

$$(11) \quad \text{Time to RF} = a + b \text{ Log } (1 - RF).$$

Where a and b 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. Visual inspection of regression residuals suggested that the model should be fitted to the last 34 transfers (i.e., transfers 24 through 58). The regression results for (12) are in Table 4 (more details on the regression are in the **Appendix**).

Table 4: Regression Analysis of Historical Transfers (Equation 11 in Text)

Parameter:	a	b	R-Bar Sqr (%)	Std. Error
Estimated Value	209	-612	98.3	20.2
t - Statistic	26.9	-43.2		

This model has an R-Bar Squared of 98.3% (that is, as described in any introductory statistics text, the variation in (1-RF) "explains" 98.3% of the variation in the last 34 observations) and the t-Statistics indicate that it is highly unlikely that the true value of either parameter is zero. Unlike other candidate functional forms, this model generates forecasts that are similar ('in the same ball park") to those elicited from the experts (discussed below). Forecasts for the Baseline scenario (which represents a continuation of historical trends) are obtained by inserting the appropriate RF into the following equation:

$$\text{(12)}\quad \text{Time to RF} = 209 - 612 \log(1\text{-RF})$$

and then: (a) subtracting 920 days from the projection to bring it to a January 1, 1999 starting date, and (b) dividing the result by 30 to convert to months. The result is a forecast of the mean Time to the selected Residue fraction (1- RF) for the Baseline Technology. The commonly - used standard deviation of this forecast value is:

$$\text{(13)}\quad \text{Std. Dev.} = ((\text{RMS/N}) + ((\log(1\text{-RF}_j) - \text{historical mean of } (\log(1\text{-RF}_j))^2 (\text{ Std. Error of b})^2)^{0.5}$$

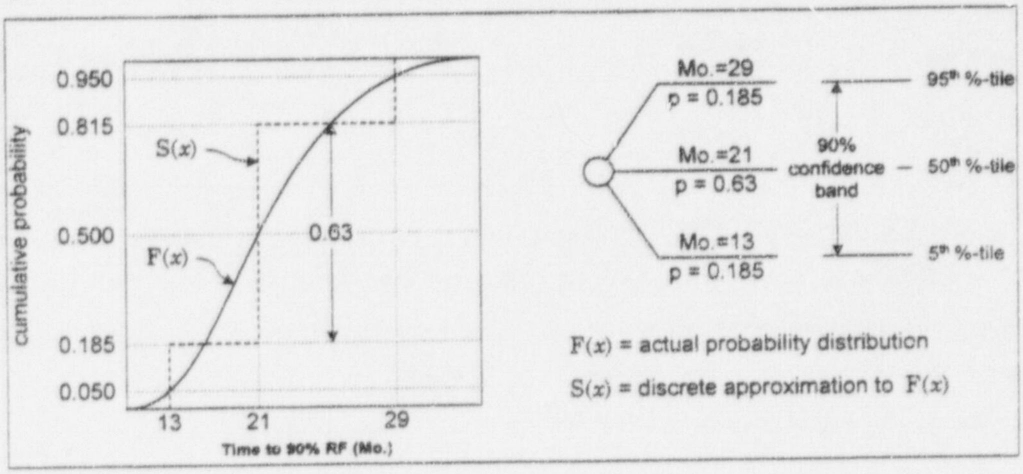
$$=((407/34) + (\log(1\text{-RF}_j) - (-)0.48)^2 (14)^2)^{0.5}$$

where RMS = Residual Mean Square and 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 (12), converted to months from 1/1/99, and a standard deviation, converted to months, as given in (13)

4.3 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 2.

Figure 2: 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" is illustrated in Figure 2) is then applied to obtain the discrete probability distribution used in the simulation model. In this case, independent assessments of calendar times to selected RF were obtained from three WVNS experts (see "Record of Interviews..." in the **Appendix**). These independent projections were then combined into an "averaged" forecast as follows:

- First, each set of assessed times was converted to a discrete probability distribution.
- Second, a Monte Carlo simulation sampled from each expert's distribution, the results from each trial were summed and then divided by three (i.e., averaged).

- The resulting frequency distribution on the averaged trial results is the distribution on time to the indicated reduction factor or residue fraction that will be used..

Table 5 contains selected fractiles (low, 25th, 50th, 75th, and high) from the distribution for the experts' averaged assessments for Time to RF = 99.9% (residue fraction = 0.1%) for each non-Baseline Technology Scenarios plus a statistical extrapolation of the Baseline. Two of the three experts interviewed on 12/14/98 agreed that the Baseline technology alone could not achieve a residue fraction smaller than 1 to 2%. Thus, the projections to smaller residue fractions should be viewed as statistical extrapolations only, useful as bench marks against which the experts' judgmental forecasts for the other technology scenarios can be compared. All times are calendar months from 1 January 1999.

Table 5
Selected Fractiles of Distributions on Time to RF=99.9% (Residue fraction=0.1%), by Technology Scenario (months from 1/1/99)

	Minimum	25th	50th (Median)	75th	Maximum
Baseline	32	37	38	39	44
Augmented Baseline	18	26	29	34	46
Augmented + Acid	10	16	20	27	34
Augmented + TDS	31	37	40	45	53
Stepped	28	33	38	44	50

The previous model's Time Module has been revised. Now the experts' assessments in Table 5 are used as forecasts (along with the statistical extrapolation for the Baseline) of the incremental number of months to the indicated 0.1% residue fraction. Given the fractiles in Table 5, an empirical probability distribution is formed by linear interpolation between fractiles. Values for intermediate residue fractions between 9% (as of January 1, 1999) and 0.1% are then computed by:

(1) assuming that the time path is generated by a semi-log function like Equation 11, so that the incremental time (from 1/1/99) between the last observed residue fraction (1- .91) and any specified residue fraction above the latter is:

(14) Time to (1-RF) = b×(log (1-RF) - log (1-.91)) = b×(log (1-RF) + 1.046),

(2) calculating the implied b (i.e., the b coefficient in (11) coefficient that would be consistent with the last historical value and the sampled assessed time (from distributions formed from Table 5) to the 0.1% residue fraction,

(15) Implied b = Assessed Time to (1-.999) ÷ (log (1-.999) - log (1-.91)

= Assessed Time ÷ (-1.954),

(3) and then substituting the result of (15) back into (14) to generate the forecast for the intermediate residue fraction. Repeated Monte Carlo sampling from the distributions formed from Table 5 on time to the 0.1% residue fraction will produce a distribution on Implied b and hence on the time to any specified residue fraction between 9% and 0.1%.

4.4 Derivation of Capital Costs & Variable Cost per Month

Table 6 contains estimates for future incremental capital costs converted to a present value as of 1/1/1999 using a 7% discount value (more about the discount rate below)for each scenario. These are derived from projections supplied by Morse and Brodini (see "Record of Interviews..." **Appendix**), and represent what should be fairly solid estimates of additional (i.e., ignoring what is already spent) capital costs (FY1999 and 2000). They are, in some cases, two to three times the earlier projections (which were actually made in 1997 when the advanced technologies were still in the conceptual design stage) and thus play a more important role in this analysis than in the previous projections.

Table 6: Present Value (@7%) of future Capital Expenditures, by Technology Scenario ($)	
Baseline	654,000
Augmented Baseline	6,254,000
Augmented + Acid	9,766,000
Augmented + TDS	8,808,000
Stepped	12,320,000

The variable cost per month ("operating cost/time") for Equation 6 is set equal to the projected average monthly total cost of $1,378,000 for the Vitrification Operations Cost over the next two years (in **Appendix**).

4.5 Melter Life and Down Time Inputs

As noted earlier, the probability of a major melter failure increases with time in operation. The simulation model compares each new time of operation to the simulated time the Melter will last and then either shuts down or continues accordingly. The previous estimates of remaining Melter life (median=60 months, from [21]) have been adjusted to a median of 43 months to reflect passage of time ("Record of Interviews..."**Appendix**). A Melter failure is still 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.

4.6 Discount Rate

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." The previous study initially followed 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 was then used to show the impact of continuing to discount benefits at 3% but discounting Variable Costs at 7% per annum. The latter approach of using a higher rate for the relatively short-term costs is more favorable to safety and possibly what the NUREG document intended to recommend. Thus, this study uses a discount rate of 7% for all costs and 3% for benefits.

5.0 The Simulation Model's Expected Value Projections

The simulation model samples from all probability distributions describing the uncertain inputs during each of a large number of trials 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."

5.1 Sum-of-Fractions and Gross Benefits

As indicated in Table 7, there is an equivalent reduction factor (RF) and residue fraction (1-RF) for every Sum-of-Fraction level (dose limit = 100mR/yr). The Gross Social Benefit of achieving any stipulated Sum-of-Fractions or, equivalently, the corresponding residue fraction, is the imputed value to society of both the public health risks avoided and the reduction in associated closure costs, and increases linearly with reductions in residue fraction. As indicated in Table 7, the (present value) of Expected (<u>Incremental</u>)

Gross Social Benefits of moving cleanup of curies from the base period residue fraction value of 9% to a residue fraction of 3%, where the Sum-of-Fractions Rule is approximately satisfied for the current closure design, (i.e., where Sum-of-Fractions ≥1) is worth about $13.2 million to society in constant 1999 prices. All of this incremental benefit emanates from removing portions of the inventories of just four isotopes - C-14, Np-237, Pu-239 and Tc-99. The 3% residue fraction is estimated (by the assumption that all nuclides are homogeneously distributed) to contain about 55 curies of these four isotopes, including only 1 curie of Tc-99. Going from the 3% residue fraction to a .001=0.1% residue fraction entails removing just 53.5 of these important curies for an additional Gross Social Benefit of $6.4 million. Of the latter benefit, 88% ($5.7M) is derived from the removal of less than one (1) curie of Np-237. This raises two questions, (1) What is the statistical margin of error in the measure of curies for these four isotopes (particularly, Np-237)? (2) what is the incremental societal cost of removing these curies? The analysis necessary to answer the first question is not currently available and is not addressed in this study. The second question is addressed in the following sections.

Table 7: Sum-of-Fractions, Remaining Curies for Select Isotopes, & Gross Social Benefits by Residue fraction

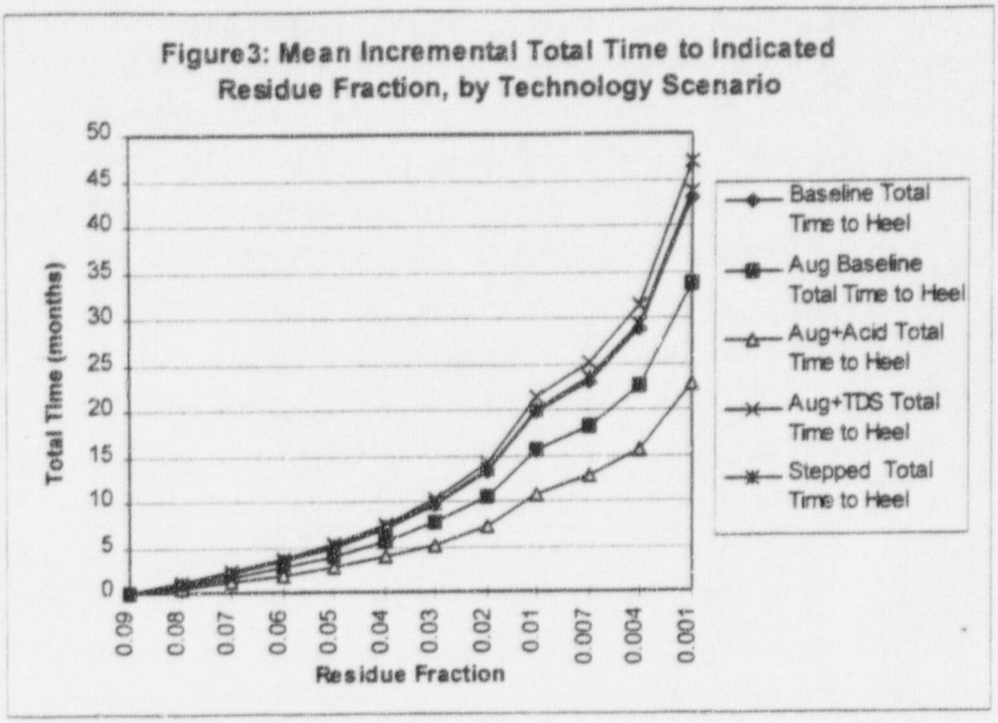
Residue fraction (1-RF)	Sum-of Fractions	C-14 Ci Remaining	Np-237 Ci Remaining	Pu-239 Ci Remaining	Tc-99 Ci Remaining	Gross Benefit ($M)
0.09	2.77	12.33	2.12	148.50	3.15	0
0.08	2.47	10.96	1.88	132.00	2.80	2.20
0.07	2.16	9.59	1.65	115.50	2.45	4.40
0.06	1.85	8.22	1.41	99.00	2.10	6.60
0.05	1.54	6.85	1.18	82.50	1.75	8.80
0.04	1.23	5.48	0.94	66.00	1.40	11.00
0.03	0.92	4.11	0.71	49.50	1.05	13.20
0.02	0.62	2.74	0.47	33.00	0.70	15.41
0.01	0.31	1.37	0.24	16.50	0.35	17.61
0.007	0.21	0.96	0.17	11.55	0.25	18.27
0.004	0.12	0.55	0.09	6.60	0.14	18.93
0.001	0.03	0.14	0.02	1.65	0.04	19.59

5.2 Time to Residue fraction

The projected expected total time to each residue fraction, along with capital costs, essentially determines the cost of achieving that residue fraction and must incorporate the increasing likelihood of melter failure (and consequent downtime) as the target residue fraction is increased. The simulation results for the expected incremented time associated with melter failure are given in Table 8. Contribution to Total Time from melter failure increases sharply for all technologies after a residue fraction of 3 percent, reaching a high of 5 months for the Baseline and 6 months for Augmented +TDS at a residue fraction of 0.1%. Depending on which technology is actually deployed, The Expected Total Time to 3% residue fraction (= expected Time to 3% + incremental time due to melter failure) ranges from about 5 months (Augmented +Acid) to 10 months (Augmented+TDS) measured from 1 January 1999. Values for less than 99.9% are interpolated as described earlier and the result for Augmented+TDS is (as pointed out by Damerow in an early review of this document) likely to be an underestimate because the TDS is unlikely to be installed before mid-2000. The range over the same technologies for getting from 3% down to 0.1% is from 17.6 months (Augmented+Acid) to 36.6 months (Augmented +TDS), or, in other words, time to reach successively higher levels of cleanliness increases exponentially for all technology scenarios. Measured in terms of time required to reach a 3% residue fraction, the Augmented+Acid is most efficient and the Augmented+TDS is least efficient. From 3% residue fraction to 0.1%, the most efficient is Augmented+Acid (applied on or after a 2% residue fraction is achieved).

Table 8: Mean Melter Down Time & Mean Total Time to Residue fraction (Months)

	Baseline		Augmented Baseline		Augmented + Acid		Augmented + TDS		Stepped Scenario	
Residue fraction	Melter Down Time	Total Time to Residue fraction	Melter Down Time	Total Time to Residue fraction	Melter Down Time	Total Time to Residue fraction	Melter Down Time	Total Time to Residue fraction	Melter Down Time	Total Time to Residue fraction
0.09	0	0	0	0	0	0	0	0	0	0
0.08	0	.99	0	.79	0	.55	0	1.1	0	1.0
0.07	0	2.1	0	1.7	0	1.2	0	2.3	0	2.1
0.06	.03	3.5	0	2.7	0	1.9	.03	3.7	.33	3.5
0.05	.07	5.0	.06	4.0	.03	2.8	.07	5.4	.60	5.1
0.04	.11	7.0	.07	5.5	.03	3.9	.11	7.5	.15	7.1
0.03	.30	9.6	.20	7.6	.05	5.2	[illegible]	10.3	.26	9.7
0.02	.53	13.2	.27	10.4	.18	7.3	.6	14.3	.57	13.4
0.01	1.2	19.8	.70	15.5	.41	10.8	1.5	21.5	1.3	20.1
0.007	1.5	23.1	1.0	18.2	.62	12.7	1.8	25.1	1.8	23.6
0.004	2.6	28.9	1.6	22.6	.77	15.5	3.0	31.3	2.7	29.3
0.001	5.0	43.0	3.6	33.8	1.6	22.9	5.9	46.9	5.3	43.8

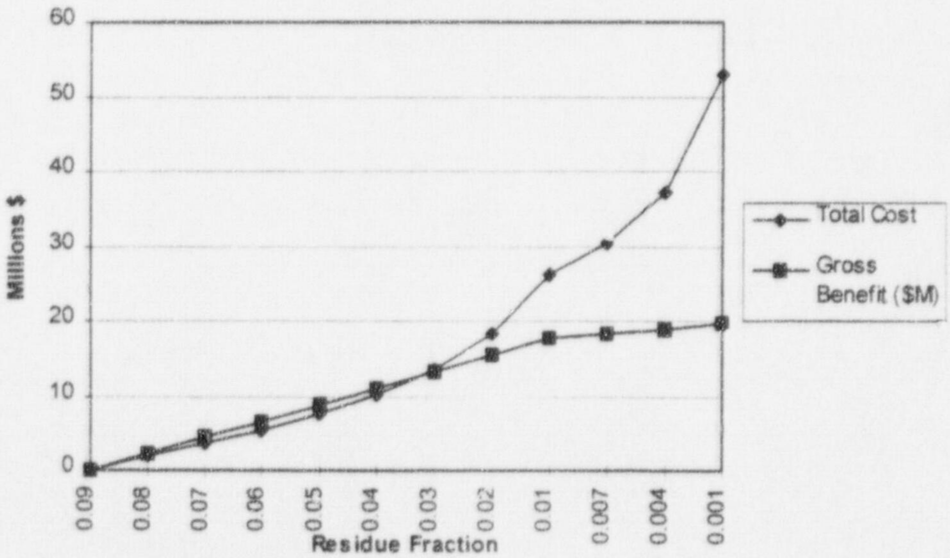


5.3 Gross Social Cost

Use of the most efficient technology does not always equate to using the most cost-effective technology. Table 9 compares the Expected (present value of) Incremental Gross Social Cost (constant 1999 prices) of achieving the various residue fraction levels for each of the Technology Scenarios. For example, the expected incremental social cost of moving cleanup from the base period residue fraction of 9% to 3% is \$16.9 million, which is \$3.4 million more expensive than the cheapest way to get there (i.e., with the Baseline scenario). In this case, the variable cost advantage that Augmented+Acid enjoys over Baseline is more than offset by the capital cost disadvantage. If, however, the objective is to go all the way to a 0.1% residue fraction, then the high capital cost of the Augmented+Acid option is off set by the lower time to get there and the associated variable cost saving so that Acid is cheaper by \$9 million over its nearest competitor (Augmented Baseline). Baseline is cheapest for any residue fraction of 1% or more. This is because there are not sufficient curies left to remove to allow the non-Baseline technology scenarios' superiority in variable cost to offset their relatively higher capital costs.

Table 9: Mean Incremental Gross Variable andTotal Social Cost (millions $)										
	Baseline		Augmented Baseline		Augmented + Acid		Augmented + TDS		Stepped Scenario	
Residue fraction	Variable Cost	Total Cost	Variable Cost	Total Cost	Variable Cost	Total cost	Variable Cost	Total Cost	Variable Cost	Total Cost
0.09	0	0	0	0	0	0	0	0	0	0
0.08	1.4	2.0	1.1	7.3	0.8	10.5	1.5	10.3	1.4	13.7
0.07	2.9	3.6	2.3	8.6	1.6	11.4	3.1	11.9	2.9	15.3
0.06	4.7	5.4	3.7	10.0	2.6	12.4	5.0	13.9	4.8	17.1
0.05	6.8	7.5	5.5	11.7	3.8	13.6	7.4	16.1	6.9	19.2
0.04	9.4	10.1	7.5	13.7	5.3	15.0	10.1	18.9	9.6	21.9
0.03	12.8	13.5	10.2	16.5	7.1	16.9	13.8	22.6	12.9	25.2
0.02	17.5	18.2	13.8	20.0	9.8	19.6	18.9	27.7	17.8	30.1
0.01	25.7	26.3	20.3	26.6	14.3	24.1	27.8	36.6	26.0	38.3
0.007	29.7	30.3	23.7	29.9	16.8	26.5	32.1	40.9	30.3	42.6
0.004	36.5	37.1	29.0	35.2	20.3	30.0	39.3	48.1	37.0	49.3
0.001	52.3	52.9	41.9	48.2	29.2	39.0	56.3	65.1	53.0	65.3

Figure 4: Mean Incremental Benefit & Cost by Residue Fraction (Baseline)



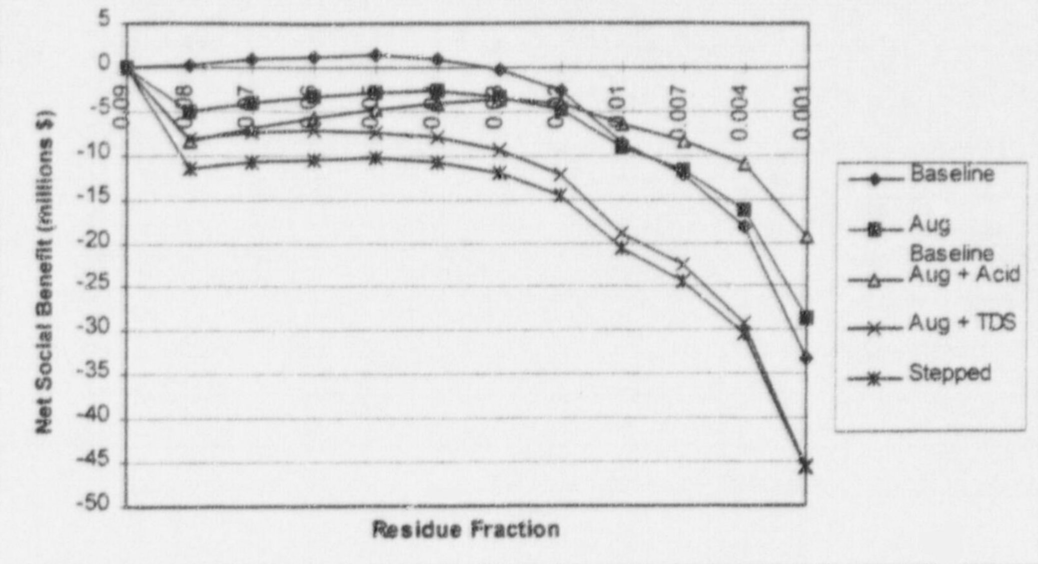
5.4 Net Social Benefits

Gross Social Benefits increase linearly as residue fraction is reduced while Gross Social Costs increase exponentially. This, of course, can produce a curve for the difference between the two, Expected Incremental Net Social Benefit (millions $, in constant 1999 prices), that at first rises, reaches a maximum and then falls rapidly. Such is the case for all five technology scenarios in Table 10. Specifically, the Baseline scenario shows increasing Net Social Benefits up to a residue fraction of 5% and then declining but still positive up to just under a 3% residue fraction (which, it will be recalled, is also the approximate residue fraction at which the Sum-of-Fractions Rule is just satisfied). Thereafter, net benefit is negative and declining exponentially. The Baseline is the only scenario with a positive net benefit for any residue fraction less than the current 9%. This is quite simply because it requires very little additional capital to continue using the Baseline approach. For residue fractions below 2%, the Augmented+Acid scenario has the least negative Net Social Benefit. If the Baseline is excluded, the Augmented Baseline has the least negative Net Social Benefit for residue fractions between 9% and 3 percent, with a peak at the 4% residue fraction.

Table 10: Mean Value of Incremental Net Social Benefit (Millions $)

Residue fraction	Baseline	Augmented Baseline	Augmented + Acid	Augmented + TDS	Stepped Scenario
0.09	0	0	0	0	0
0.08	0.2	-5.1	-8.3	-8.1	-11.5
0.07	0.9	-4.2	-7.0	-7.5	-10.9
0.06	1.2	-3.4	-5.8	-7.3	-10.5
0.05	1.3	-2.9	-4.8	-7.4	-10.4
0.04	1.0	-2.7	-4.0	-7.9	-10.9
0.03	-0.2	-3.3	-3.5	-9.4	-12.0
0.02	-2.7	-4.7	-4.2	-12.3	-14.6
0.01	-8.7	-9.0	-6.5	-19.0	-20.7
0.007	-12.1	-11.7	-8.3	-22.6	-24.4
0.004	-18.2	-16.3	-11.1	-29.2	-30.4
0.001	-33.3	-28.6	-19.4	-45.5	-45.7

Figure 5: Mean Incremental Net Social Benefit, by Residue Fraction & Technology Scenario



6.0 Uncertainty and Sensitivity Analysis

6.1 Uncertainty Analysis

The regulatory analysis guidelines [13] recommend that an uncertainty analysis be performed. As indicated in the preamble to the previous ·ction, the simulation model constructs probability distributions on all variables of interest and calcula summary statistics, including "probability bands;" that is, upper and lower values where the variable h.. ..pecified probability of falling. This is accomplished by first constructing cumulative probability distributions for the variable, and then picking off relevant fractile values. For example, using the 5th and 95th fractiles would produce a 90 percent probability band (a "fractile" indicates the probability of getting a value less than or equal to the indicated value and is the discrete counterpart to the term "percentile") Table 11 contains 90 percent probability 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 the target residue fraction declines. This (modeled) uncertainty emanates entirely from the cost side, and the bulk of the latter is from the probability distributions describing Total Time to RF. For residue fractions of 2 to 3 percent, the bands include the possibility of a positive net benefit for Baseline, Augmented Baseline and Augmented + Acid. The hypothesis of a true positive net benefit at a 0.1% residue fraction, however, is decisively rejected in all technology scenarios (that is, the probability band at the 0.1% residue fraction does not include a positive net benefit).

Table 11: Probability Bands on Net Social Benefit (Millions $)										
	Baseline		*Augmented Baseline*		*Augmented + Acid*		*Augmented + TDS*		*Stepped Scenario*	
Residue fraction	*5th Fractile*	*95th Fractile*	*5th Fractile*	*95th Fractle*	*5th Fractile*	*95th Fractile*	*5th Fractile*	*95th Fractile*	*5th Fractile*	*95th Fractile*
0.09	0	0	0	0	0	0	0	0	0	0
0.08	0.9	0.3	-5.6	-4.8	-8.7	-8.0	-8.4	-7.8	-11.9	-11.2
0.07	0.5	1.2	-5.2	-3.4	-7.8	-6.2	-8.3	-6.9	-11.6	-10.1
0.06	0.6	1.9	-5.0	-2.1	-7.2	-4.6	-8.5	-6.1	-11.7	-9.3
0.05	0.5	2.3	-5.2	-1.0	-6.8	-3.0	-9.0	-5.7	-12.2	-8.7
0.04	-0.1	2.2	-5.9	-0.7	-6.7	-1.5	-10.3	-5.7	-13.2	-8.4
0.03	-1.6	1.7	-7.5	0.4	-7.3	-0.3	-12.5	-6.2	-15.1	-8.7
0.02	-4.6	-0.9	-10.4	0.3	-9.0	0.5	-16.6	-7.8	-18.8	-9.9
0.01	-23.2	-4.3	-17.7	-1.5	-13.5	0.4	-33.8	-12.0	-35.9	-13.5
0.007	-26.3	-7.0	-25.2	-2.9	-16.6	-0.1	-37.3	-14.5	-40.5	-15.8
0.004	-33.5	-11.4	-32.5	-5.4	-22.8	-1.3	-44.0	-18.8	-47.7	-19.7
0.001	-46.6	-23.0	-50.0	-12.4	-39.4	-5.2	-62.1	-30.0	-64.1	-29.9

6.2 Sensitivity to Omitted Uncertainties

The primary omitted uncertainties are on the "benefits" side. A new dose limit or new estimates of the limiting curies for the four important isotopes could significantly alter the estimated value of the curies removed and, hence, affect the above avoided risk benefit calculations. Abstracting from these changes, the most important omitted uncertainty is margin of error in the estimated inventory and removal of curies for C-14, Np-237, Pu-239 and Tc-99. Small changes in Np-237, in particular, could produce substantial changes in the calculated benefits. Further, the estimate of the current remaining residue fraction of 9 percent is predicated on a best estimate of the beginning inventory of Sr-90 and Cs-137 (the two isotopes actually measured during transfers). Changes in these estimates effect both costs and benefits. For example, the best estimate of Sr-90 beginning inventory of 5.81million curies used in the earlier study [18] was reduced to 5.05 million curies for this update. Had the original value been used in this update, the implication would be that more curies remain to be removed and, consequently, higher benefits are possible. In fact, using the higher beginning inventory number produces the following results: The highest mean Net Social Benefit is now achieved by the Augmented + Acid scenario (+$7.1 million) at a residue fraction of 3 percent (and stays positive to 0.4%). The second highest is for Augmented Baseline (+$6.9 million) at 4 percent (positive to 1%), and the third highest achieved by Baseline (+$5.8 million) at 7 percent (positive to 3%).

7.0 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% (i.e., a residue fraction of 0.1%) for five 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 major conclusions are:

- The analysis does not support carrying the cleanup below the 3.3% residue fraction approximately required by the Sum-of-Fractions Rule.
- Unless it is determined for other reasons (e.g., a "concentrations" criterion) to go belong the 2% residue fraction, the analysis does not support additional investment in any non-Baseline technology option; there are too few curies left to justify the additional capital expenditures required.
- If it is determined to go substantially below the 2% residue fraction, then the Augmented+Acid scenario is expected to provide the least negative net societal benefit.

To put a finer point on the second bullet, suppose the Augmented+Acid scenario is used. From Table 9 it is calculated that moving from a residue fraction of 3% to 0.1% will cost an additional $22.1 million. As noted earlier, this reaps an incremental gross benefit of only $6.4 million; most of which would have to come from the removal of less than 1 curie of Np-237.

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 (Note: Additional references for this update are in the "Record of Interviews...," Appendix).

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.
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. Hurst, James, "Attachment A: HLW Tank Farm Transition Stepped Approach for Zeolite Removal from 8D-1," memo # CA:97:0042, July, 1997.
8. Kumar, Shyam, "Table updated - added Assessed Times for 99.9% from Fred Damerow 2/17/98" (Fax received on 2/21/98).
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.*

17. "Update of 'Decision Analysis to Support West Valley Tank Farm Transition End Point Development for HLW Tank Cleanup: Final Report' to Include the Most Recent Curie Transfer Data." (letter report), September 30, 1998. Westinghouse STC.

18. "Decision Analysis to Support West Valley Tank Farm Transition End Point Development for HLW Tank Cleanup: Final Report" (October 22, 1998), Westinghouse STC. Work performed for WVNS under P.O. 18-91711-I-LH.

Software:

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

Appendix
Table of Contents

	Page #
Record of Interviews Conducted at West Valley on December 14, 1998	28
Analysis of Vitrification Operations Costs	32
Summary Output (Regression Synopsis)	34
W:\Kumar2\... (Transfer History)	35

Record of Interviews Conducted at West Valley on December 14, 1998
R. K. Perdue

Introduction

Interviews were conducted by Bob Perdue and Shyam Kumar at WVNS on December 14, 1998 to update information for the Decision Analysis of Waste Tank Farm Endpoints, including changes in inputs for the WVNS Tank Farm Economic Evaluation Computer Model[1]. Information was sought on the following variables:

- Technology Options, including status of options and projected deployment dates.
- Expert assessments on "Time to" selected curie "Reduction Factors."
- Operating and Capitalized costs of technology options.
- Expert assessments of remaining melter life.
- Curies inventory and curies transfer history.

Changes in technology Options

Technology options were reviewed with Fred Damerow and John Fazio, and later with Dan Meess. A draft copy of the current schedule for deployment of equipment cross-referenced with both calendar time and level of waste remaining (in inches and curies) was obtained[2]. As compared to the Technology Options defined on pages 8-9 of the report referenced in endnote 1, the primary changes are:

a. The deletion of the Grinders option for 8D-1 (Hence, Augmented Baseline is now w/o grinders).
b. New dates for deployment of Mechanical Arm (approx. March 1999) and Tool Delivery System (end of FY 2001).

Mast mounted sluicer arms are on site. Regarding the use of oxalic acid, Damerow indicated that its use had been "moved out" and that it was unlikely to be used except for "supercleaning" (i.e., after "99.5%" of curies are already removed). Meess notes that acid may not dissolve the alpha emitters.

Expert Assessments on Time to Selected Reduction Factors

Although contractual terms have changed, for our purposes, a "transfer" still means moving curies from 8D-2 to the CFMT. New, independent assessments on calendar time (in months) to remove selected fractions - called reduction factors - of the initial inventory of curies were obtained from Bernie Connors, Fred Damerow and Dan Meess and are summarized in the following tables.

Connors (Months from 1/1/99)			
Technology Scenario	Low	Median	High
Baseline (to 98%)	18	24	36
Augmented Baseline (to 99.9%)	18	24	36
Augmented + TDS (to 99.9%)	34	36	48
Augmented +Acid @ 2% residue fraction (to 99.9%)	1 mo.after reaching 98%	"within 3mo.of reaching 98%"	6 mo.after reaching 98%
Aug. + TDS + Acid (to 99.9%)	Na	Na	Na

Damerow (Months from 1/1/99)			
Technology Scenario	Low	Median	High
Baseline (to 99%) Note:"99.9% not possible w/o arms."	6	8	15
Augmented Baseline (to 99.9%)	12	22	45
Augmented + TDS (to 99.9%)	20	28	36
Augmented +Acid @ 2% residue fraction (to 99.9%)	Na	Na	Na
Aug. + TDS + Acid (to 99.9%)	28	38	50

Mess (Months from 1/1/99) -"assume 2/3 equipment availability" (times to other RF given but not shown)			
Technology Scenario	Low	Median	High
Baseline (to 99.44%=0.08Mci)	36(FY2002)	48(FY2003)	72("add 50%")
Augmented Baseline (to 99.44%=0.08Mci)		subtract: low=6mo.med=9mo.high=18mo. From Baseline	
Augmented + TDS (to 99.44%=0.08Mci)		add: low=o mo.high=9mo.to Baseline	
Augmented +Acid @ 2% residue fraction (to 99.44%=0.08Mci)		subtract: low=12mo.,High=24mo.from Baseline	
Aug. + TDS + Acid (to 99.44%=0.08Mci)		Na	

New Operating and Capitalized Cost Data

Hal Morse and Jeannine Bordini subsequently compiled and provided new estimates for both vitrification facility operating costs (history and projection) and capitalized costs for the technology options. These cost estimates are detailed elsewhere.[3] The following table summarizes the new capital cost estimates for major equipment/technology options.

Capital & Selected Other Costs (000$)		
Equipment or Activity	FY1999	FY2000
Pumps (spare xfer/mob pumps)	700	0
Mechanical Arm w/effectors (+"Advanced Mob Equip")	2100	2150
"Total Tarzan"	1325	1500
Total Oxalic Acid (startup, labor, services, etc.)	2069	1800
Support Structures/Utilities ("for Mechanical Arms/Misc")	700	1250

Expert Assessments for Remaining Melter Life

Steve Barnes indicated that temperature-dependent corrosion is the limiting factor on melter life - a failure mechanism that is actually slowed when the melter is in use. Previous (implied, given passage of time) median estimate of 3.5 years remaining life for melter is "as reasonable as another."

Curies inventory and Curies Transfer History

A processing summary[4] dated 30 September 1998 was obtained and reflects the revised beginning inventory figure for Sr-90 (now =5.05E+6 rather than 5.81E+6). No changes have been made to Cesium. Further, since (according to Doug Wallen / Steve Barnes) other isotope inventories are scaled off of cesium (not strontium) they may not be impacted. Steve Barnes indicated he would get sample standard deviation on measured Sr and Cs. There have been two more transfers since the September 30 model update.[5]

End Notes:

1. See "Decision Analysis to Support West Valley Tank Farm Transition End Point Development for HLW Tank Cleanup: Final Report" (October 22, 1998), Westinghouse STC. Work performed for WVNS under P.O. 18-91711-I-LH.
2. "Anticipated Tank 8D-1/2 Status & Equipment Deployment: as of 12/03/98," J.M. Fazio.
3. "Updated Cost Data for Tech. & Econ. Analysis," email with attachments from S. Kumar dated January 13, 1999. Attachments (dated January 12, 1999) are spreadsheets for historical and projected vit operations costs and historical and projected costs of equipment and materials for technology options.
4. "Cesium and Strontium Processing Summary (As of September 30, 1998)."
5. "Update of 'Decision Analysis to Support West Valley Tank Farm Transition End Point Development for HLW Tank Cleanup: Final Report' to Include the Most Recent Curie Transfer Data." (letter report), September 30, 1998. Westinghouse STC.

File: w/kumar2/operdur1.wk4 January 12, 1999

ANALYSIS OF VITRIFICATION OPERATIONS COS
JULY 1996 THROUGH SEPTEMBER 1998

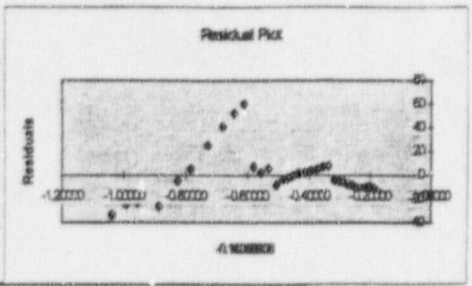
WBS '96/'97	WBS CURRENT	DESCRIPTION	TYPE	FY'96	FY'97	FY'98
101211089	101111089	Eng - Support	S/C	36	514	289
101211090	N/A	Syst Eng	Labor	243	4125	(in 090)
101241005	101111005	Sludge Mob	Mat'l	68	1559	2071
101241016	101111016	Vit Ops - General	Mat'l	874	1495	554
101241019	101111019	T&M Construction Support	Mat'l	1367	1372	1639
101241020	101111020	Chemicals	Mat'l	477	2191	611
101241024	101111024	Vit Spare Parts	Mat'l	(in 016)	1312	849
101241025	101111005	Canisters	Mat'l	76	501	433
101241090	101111090	Vit Labor	Labor	1369	5194	14642
101180090	N/A	Ops Support	Labor	691	1085	(in 090)
101A90002	N/A	Rad Prot Support	Labor	159	595	(in 090)
101A90003	N/A	QA Support	Labor	162	683	(in 090)
			Mat'l	0	85	N/A
101A90004	N/A	Analytical Labs Support	Labor	407	1759	(in 090)
101A90005	N/A	Maint Support	Labor	297	659	(in 090)
101A90008	N/A	Draft/Design Support	Labor	93	227	(in 090)
			Mat'l	84	242	N/A
101A90090	N/A	Proj Support	Labor	148	380	(in 090)
		($ THOUSANDS)		6571	24059	21098

VITRIFICATION OPERATION PLANNED/BUDGETED FY'99-FY'00

WBS	DESCRIPTION	BUDGET FY'99	ROUGH ESTIMATE FY'00	
101111005	Canisters	403	0	
101111005	Sludge Mob	1140	1000	
101111016	Vit Ops - General	1120	1000	
101111019	T&M Construction Support	869	800	
101111020	Chemicals	270	150	(ASSUMING NO OXALIC USE IN '00)
101111024	Vit Spare Parts	1055	500	
101111089	Eng Support	313	300	
101111090	Vit/Support Labor	11561	11000	
101111099	Vit Warehouse Restocking	598	600	
101111940	Escalation	400		
	TOTAL ($ THOUSANDS)	17729	15350	

Intentionally left blank

SUMMARY OUTPUT

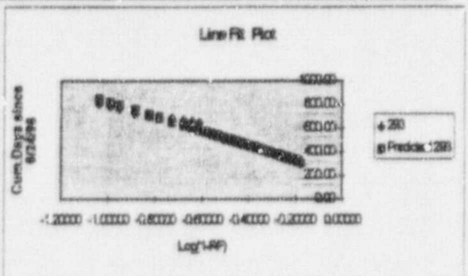


Regression Statistics	
Multiple R	0.991546
R Square	0.983163
Adjusted	0.982637
Standard	20.18205
Observati	34

ANOVA

	df	SS	MS	F	gnificance F
Regressio	1	761103.4	761103.4	1868.585	5.89E-30
Residual	32	13034.09	407.3153		
Total	33	774137.4			

	Coefficient	andard Er	t Stat	P-value	ower 95	pper 95	ower 95.0	pper 95.0%
Intercept	208.3194	7.762692	26.98479	1.42E-23	193.5073	225.1314	193.5073	225.1314
Log(1-RF)	-612.088	14.15981	-43.2271	5.89E-30	-640.931	-583.246	-640.931	-583.246



RESIDUAL OUTPUT

bservatic	edicted 2	Residuals
1	315.8907	-13.8907
2	322.9852	-10.9852
3	331.1715	-9.17154
4	339.4036	-10.4036
5	348.3207	-11.3207
6	357.8385	-10.8385
7	366.3307	-8.3307
8	375.4707	-7.47071
9	384.6046	-5.60461
10	393.971	-4.97101
11	402.9839	-3.98388
12	414.4989	7.501117
13	425.9427	7.057263
14	438.4632	4.546798
15	449.9983	4.001727
16	462.1439	1.856085
17	474.3449	1.655072
18	485.7406	-0.74058
19	495.8916	-2.89161
20	505.6439	-3.64386
21	518.3459	-8.34587
22	534.3558	5.644175
23	550.3981	1.903895
24	563.8735	7.126534
25	583.5723	60.42766
26	602.5084	52.49158
27	624.9673	41.03269
28	654.6045	25.39553
29	687.9466	5.053194
30	714.2549	-5.25495
31	750.5854	-26.5854
32	792.2718	-23.2718
33	815.5264	-24.5264
34	844.4617	-33.4617

FILE:
W:\KUMAR2\TXR58.XLS
January
19,1999

WQR 1996 90-Sr:	5.05E+06	[Revised]
WQR 1996 137-Cs:	6.29E+06	

Assumed date for WQR Curie data used for this analysis:	01/01/96

Transfer	Batch	Tx Date	Tx Ci 90-Sr	Tx Ci 137-Cs	Sr + Cs Tx Total	Sr + Cs Tx Cumul.
1	10	06/24/96	23450	25160	48610	48610
2	11	07/05/96	30295	37184	67479	116089
3	12	07/14/96	44129	48151	92280	208369
4	13	07/28/96	59667	61552	121219	329588
5	14	08/09/96	60983	63897	124880	454468
6	15	08/20/96	78896	67461	146357	600825
7	16	08/29/96	41808	41594	83402	684227
8	17	09/06/96	57853	60376	118229	802456
9	18	09/16/96	52197	60806	113003	915459
10	19	09/25/96	64085	72300	136385	1031844
11	20	10/06/96	55338	58211	113549	1165393
12	21	10/16/96	67816	65607	133423	1298816
13	22	10/23/96	97893	70305	168198	1467014
14	23	11/04/96	60137	75597	135734	1602748
15	24	11/12/96	59509	54074	113583	1716331
16	25	11/27/96	77629	86687	164316	1880647
17	26	12/07/96	97262	111257	208519	2089166
18	27	12/17/96	92393	112592	204985	2294151
19	28	12/30/96	85438	91275	176713	2470864
20	29	01/08/97	111573	113350	224923	2695787
21	30	01/23/97	92652	99369	192021	2887808
22	31	02/27/97	85340	111927	197267	3085075
23	32	03/10/97	107439	132916	240355	3325430
24	33	04/13/97	83971	97674	181645	3507075
25	34	04/22/97	104662	133175	237837	3744912
26	35	05/02/97	88616	111390	200006	3944918
27	36	05/10/97	102436	121814	224250	4169168
28	37	05/19/97	108653	109990	218643	4387811
29	38	05/27/97	104754	124571	229325	4617136
30	39	06/06/97	102219	134215	236434	4853570
31	40	06/18/97	87964	115961	203925	5057495
32	41	06/28/97	90632	121692	212324	5269819
33	42	07/09/97	88716	116297	205013	5474832
34	43	07/19/97	91103	111939	203042	5677874
35	44	07/29/97	87206	101533	188739	5866613
36	45	08/21/97	107358	124652	232010	6098623
37	46	09/01/97	82615	138216	220831	6319454
38	47	09/11/97	105761	125020	230781	6550235
39	48	09/22/97	96978	106570	203548	6753783
40	49	10/02/97	99118	105688	204806	6958589
41	50	10/14/97	95854	100676	196530	7155119
42	51	10/23/97	86128	89459	175587	7330706
43	52	11/01/97	72231	77964	150195	7480901

44	53	11/10/97	67006	71986	138992	7619893
45	54	11/18/97	83309	90244	173553	7793446
46	55	12/17/97	107188	100074	207262	8000708
47	56	12/29/97	91798	100159	191957	8192665
48	57	01/16/98	77639	81300	158939	8351604
49	58	03/30/98	98529	114879	213408	8565012
50	59	04/10/98	82461	108301	190762	8755774
51	60	04/21/98	95113	114208	209321	8965095
52	61	05/05/98	109093	141403	250496	9215591
53	62	05/18/98	116775	133590	250365	9465956
54	63	06/04/98	83165	93371	176536	9642492
55	64	06/19/98	98049	118725	216774	9859266
56	65	08/03/98	94009	120827	214836	10074102
57	66	08/25/98	49976	56014	105990	10180092
58	67	09/14/98	53675	65897	119572	10299664