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ICPP RADIOACTIVE LIQUID AND CALCINE WASTE TECHNOLOGIES EVALUATION INTERIM REPORT

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June 1994

Westinghouse Idaho Nuclear Company, Inc.

PREPARED FOR THE
DEPARTMENT OF ENERGY
IDAHO OPERATIONS OFFICE
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LIST OF ACRONYMS

AE	Architect Engineer
AMP	Ammonium Molybdophosphate
ANN	Aluminum Nitrate Nanohydrate
CFR	Code of Federal Regulations
CSSF	Calcined Solids Storage Facility
D&D	Decontamination and Decommissioning
DOE	Department of Energy
EH	Electrohydrolysis
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FC	Freeze Crystallization
FFCA	Federal Facilities Compliance Act
FUETAP	Formulated Under elevated Temperature And Pressure
FY	Fiscal Year
GTM	Generic TRUEX Model
HAW	High Activity Waste
HIP	Hot Isostatic Press
HLLWE	High-level Liquid Waste Evaporator
HLW	High-level Waste
ICPP	Idaho Chemical Processing Plant
IDHW	Idaho Department of Health and Welfare
INEL	Idaho National Engineering Laboratory
IX	Ion Exchange
LAW	Low Activity Waste
LDR	Land Disposal Restrictions
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
NWCF	New Waste Calcining Facility
NWPA	Nuclear Waste Policy Act
OMB	Office of Management and Budget
PDF	Production Development Facility
PUREX	Plutonium/Uranium Reduction Extraction
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision (for EIS)
SNF	Spent Nuclear Fuel
SREX	Crown Ether Strontium Extraction
SX	Crown Ether Sodium Extraction
TCLP	Toxicity Characteristic Leaching Procedure
TEAM	Technology Evaluation and Analysis Methodology
TRUEX	Transuranic Extraction
WIF	Waste Immobilization Facility
WINCO	Westinghouse Idaho Nuclear Company, Inc.

EXECUTIVE SUMMARY

The Department of Energy (DOE) has received spent nuclear fuel (SNF) at the Idaho Chemical Processing Plant (ICPP) for interim storage since 1951 and reprocessing since 1953. Until recently, the major activity of the ICPP has been the reprocessing of SNF to recover fissile uranium; however, changing world events have raised questions concerning the need to recover and recycle this material. In April 1992, DOE chose to discontinue reprocessing SNF for uranium recovery and shifted its focus toward the management and disposition of radioactive wastes accumulated through reprocessing activities. Currently, 1.8 million gallons of radioactive liquid wastes (1.5 million gallons of radioactive sodium-bearing liquid wastes and 0.3 million gallons of high-level liquid waste) and 3800 cubic meters (m^3) of calcine waste are in inventory at the ICPP.

Legal drivers and agreements exist obligating the INEL to develop, demonstrate, and implement technologies for safe and environmentally sound treatment and interim storage of radioactive liquid and calcine waste. A national policy, established by the Nuclear Waste Policy Act (NWPA), requires final disposal of radioactive waste in accordance with U.S. Environmental Protection Agency (EPA) and Nuclear Regulatory Commission (NRC) standards. This further obligates the INEL to prepare and qualify these materials for final disposal. Compliance with established mandates and development of technologies to properly manage and disposition radioactive liquid and calcine waste, along with current and future SNF inventories, is a high priority.

DOE Order 4700.1 outlines a formalized, logical systems engineering approach to problem definition and resolution. The radioactive liquid and calcine waste processing options are being evaluated using this systems engineering approach. Program goals were established to clearly define the evaluation objectives, and baseline requirements were developed to establish the boundaries or operating characteristics of the system within which the selected technologies must perform. Using program goals and baseline requirements as guides, potential alternatives were defined and further developed into combined technologies that held the potential to provide candidate processes for the treatment and disposition of radioactive liquid and calcine wastes. Candidate treatment processes and waste forms are being evaluated using the Technology Evaluation and Analysis Methodology (TEAM) Model. This process allows decision makers to (1) identify optimum radioactive waste treatment and disposal form alternatives; (2) assess tradeoffs between various optimization criteria; (3) identify uncertainties in performance parameters; and (4) focus development efforts on options that best satisfy stakeholder concerns.

The Systems Analysis technology evaluation presented in this document supports the DOE in selecting the most effective radioactive liquid and calcine waste management plan to implement in compliance with established regulations, court orders, and agreements. This is an interim report; criteria, units, and data may change as the evaluation and optimization of technologies progress and additional input is obtained. A document containing the completed data analyses and WINCO recommendations will be issued by September 30, 1994.

1.0 LEGAL DRIVERS AND AGREEMENTS

Several legal drivers and agreements exist which commit the INEL to develop, demonstrate, and implement technologies for safe, efficient, and environmentally sound treatment and interim storage of radioactive liquid and calcine waste. On December 22, 1993, Senior United States District Judge Harold L. Ryan issued an Order ratifying proposed modifications to the U.S. District Court's Opinion and Order of June 28, 1993. Subsequently, the Notice of Noncompliance Consent Order between the Idaho Department of Health and Welfare (IDHW) and DOE, signed April 3, 1992, was amended on March 22, 1994, to include mixed waste management stipulations outlined in the ratification Order dated December 22, 1993. The amended Consent Order requires DOE to take the following actions:

- "Calcine all high-level liquid radioactive waste that does not contain sodium on or before January 1, 1998."

- "Calcine or otherwise process as much sodium-bearing high-level liquid radioactive waste (sodium-bearing waste) as DOE and the Department [IDHW] mutually agree is practicable by January 1, 1998."

- ". . . evaluate and test Freeze Crystallization, Radionuclide Partitioning, and Precipitation, the sodium[-]bearing treatment technologies identified by DOE in a November 15, 1993 letter."

- "Select the sodium-bearing waste pre-treatment technology, if necessary, and calcine or processing technology by June 1, 1995."

- "Select a technology for converting calcined waste into an appropriate disposal form by June 1, 1995."

- within ninety (90) days following the selection of ". . . technologies for sodium-bearing waste calcination and calcine conversion, . . . enter into negotiations [with IDHW] on the construction schedule for any necessary facilities to implement the technologies."

- "On or before March 31, 2009 . . . permanently cease use of [tank farm tanks with pillar and panel vault construction] and all associated vaults; or . . . achieve compliance with all secondary containment requirements set forth in IDAPA § 16.01.5009 (40 C.F.R. § 265.193)."

- "On or before June 30, 2015 . . . permanently cease use of [all remaining tank farm tanks] and all associated vaults; or . . . achieve compliance with all secondary containment requirements set forth in IDAPA § 16.01.5009 (40 C.F.R. § 265.193)."

Additionally, the Federal Facilities Compliance Act (FFCA) requires DOE facilities to enter into binding agreements with their respective states as to how they will attain full compliance with all applicable Land Disposal Restriction (LDR) treatment requirements. An FFCA Conceptual Site Treatment Plan has been completed and includes a proposed schedule of commitments for processing radioactive liquid and calcine waste for final disposal. The Final Proposed Site Treatment Plan is to be submitted by February 1995.

A pre-evaluation of any new DOE actions must be made to assess what impact, if any, these actions will have on the environment, as required by the National Environmental Policy Act (NEPA). If impact levels are found significant, then an Environmental Impact Statement (EIS) must be prepared and a Record of Decision (ROD) published before proceeding with proposed activities. To meet the NEPA EIS requirements of the December 22, 1993 Order, the DOE will issue a draft EIS by June 30, 1994; a final EIS by April 30, 1995; and a ROD, based on the final EIS, no later than June 1, 1995.

This document discusses the process that is being employed to identify and assess alternatives for meeting all legal drivers and agreements.

2.0 SYSTEMS ANALYSIS APPROACH

DOE Order 4700.1 outlines a logical systems engineering approach to problem evaluation. Radioactive liquid and calcine waste processing options are being evaluated by the Systems Analysis Section at WINCO using a similar two-fold approach: (1) the following of a formal systems engineering process; and (2) the application of systems analysis tools and techniques to support informed decision making throughout the process. The formal systems engineering process consists of six principle steps:

- Define the Problem and Establish the Program Goal
- Determine the Functional (Baseline) Requirements
- Identify Alternatives that Meet the Functional Requirements
- Develop and Evaluate the Alternatives
- Optimize the Alternatives
- Recommend Preferred Alternatives for Selection and Implementation

Systems Analysis functions in support of systems engineering efforts include:

- Enhancing program integration and coordination by applying systems thinking and organizational learning concepts, tools, and techniques (i.e., Hexagon

Idea Modelling, mind maps, decision trees, causal loops, etc.) to clarify and maintain focus on program objectives, to facilitate group interaction, and to support informed selection of optimum strategies and technologies.

- Providing systems modeling capabilities, such as developing flowsheets and computer simulations (models).

- Conducting Performance Assessments to help establish waste acceptance criteria and estimate final product performance.

The Systems Analysis approach to analyzing the processing (meaning all treatments necessary to prepare waste for final disposition), storage, and disposal of radioactive liquid and calcine waste at the ICPP was implemented to facilitate informed decision making and understanding in the resolution of stakeholder issues. This approach evaluates candidate processes and disposal forms using a consistent set of assumptions and data. Additionally, the potential impacts of existing uncertainties are being evaluated, resulting in the recommendation of programs to investigate and resolve those uncertainties.

3.0 EVALUATION PROCESS

3.1 Program Goal

Through a series of facilitated meetings, Systems Analysis personnel considered the need to provide viable radioactive liquid and calcine waste treatment options which utilize both existing and new facilities and technologies. Established legal drivers and agreements were also reviewed to better determine the Systems Analysis role within the technology selection process. Varying perspectives were debated in regard to project milestones and overall desired results before a consensus was reached. As a result, the following program goal has been established for the evaluation of technologies for radioactive liquid and calcine waste treatment and disposition:

> To support DOE in developing a strategic plan for ICPP radioactive liquid and calcine waste management by gathering, evaluating, optimizing, and presenting performance data (including a recommendation of preferred treatment options and waste disposal forms) for viable candidate processes and technologies.

3.2 Baseline Requirements

Following definition of the program goal, Systems Analysis personnel solicited assistance from other Westinghouse Idaho Nuclear Company, Inc. (WINCO) departments involved in the ICPP radioactive liquid and calcine waste technologies evaluation and selection process to gather preliminary data and establish baseline requirements for the evaluation of candidate

waste treatment technologies. In conjunction with Systems Analysis, the Applied Technology Senior Staff, the Liquid and Gaseous Effluent (Sodium Waste) Technologies Section, the Calcine Immobilization Section, Facility Support, and the Environmental Permitting and Regulations Section reviewed legal drivers, analyzed radioactive waste stream compatibility with candidate technologies, and evaluated project schedules and milestones. Subsequently, the following items were established as baseline requirements for the technologies evaluation and optimization process.

1) Meet all current federal and state regulations, court orders, and agreements between DOE and the State of Idaho, or the EPA.

   (see Section 1.0, Legal Drivers and Agreements)

2) Treatment alternatives must be able to ultimately immobilize both radioactive liquid and calcine waste.

   ICPP stores and produces radioactive liquid and calcine, and both must be immobilized. Though the capability of a particular process to effectively treat both radioactive liquid and calcine waste is not required by regulation, preliminary analysis indicates that those combinations of technologies which can handle both waste types have an advantage over other options. For that reason, dual processing capability is being evaluated for all waste treatment alternatives.

3) Treatment alternatives must immobilize High Activity Waste (HAW)* using vitrification (glass or glass-ceramic). Treatment technologies other than vitrification would require an equivalency, determination, or variance.

   Vitrification is the specified treatment technology for the toxic metal and corrosive characteristic of mixed radioactive high-level liquid wastes generated during the reprocessing of SNF, per RCRA LDR [*40 CFR 268.42*]. Listed waste codes will require an equivalency, determination, or variance.

4) Treatment alternatives must stabilize Low Activity Waste (LAW)* to meet concentration-based standards, or seek equivalencies, determinations, or variances.

   Current RCRA regulations require that specified constituents in stabilized LAW be below established concentration levels in order to meet LDR.

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* It is assumed that a determination will be made by the appropriate agency that HAW is actually high-level waste and LAW is actually low-level waste, per NRC, EPA, and DOE classifications. The RCRA regulatory analysis depends on such a determination.

5) Treatment alternatives must be compatible with future radioactive liquid waste generated at ICPP.

To avoid accumulating an inventory of liquid waste that cannot be processed at ICPP, compatibility with all anticipated radioactive waste streams must be ensured.

6) Accommodate on-site interim storage of immobilized waste.

To maintain maximum flexibility in disposing of LAW and HAW, on-site interim storage of immobilized waste must be provided. The DOE has not yet designated a federal repository for HAW, requiring that immobilized radioactive waste be stored until a repository is available.

3.3 Identify Alternatives

After the decision in April 1992 to change the ICPP mission and discontinue reprocessing of DOE-owned SNF, an initiative was undertaken to identify and develop technologies, through laboratory testing and detailed investigation, for dispositioning INEL spent nuclear fuels and radioactive wastes. Through mid 1993, extensive investigations were conducted to identify potential technologies that could be employed at the ICPP to treat and dispose of radioactive liquid and calcine wastes. Several candidate technologies, described in Table 1, were identified and combined into processing systems (flowsheets) capable of handling radioactive liquid and calcine wastes at the ICPP.

NOTE: While some separations technologies can be employed as pre-treatment processes, pre-treatment is used in the tables below to indicate those non-separations technologies necessary for further processing or immobilization. Separations is used to indicate all separations technologies under consideration, whether used as a pre-treatment or not.

Table 1: Initial Candidate Technologies

Alternatives	Description	Application
Pre-treatment		
ANN or Silica Addition	Preparation of a high sodium solution for calcination by addition of ANN or activated silica to maintain the fluidized bed operation.	Calcination of Radioactive Liquid Waste
Calcination	Conversion of a radioactive liquid waste to a granular solid form.	Radioactive Liquid Waste Treatment
Dissolution	Conversion of solid radioactive waste to a liquid by chemical reaction with acid.	Calcine Treatment

Table 1: Initial Candidate Technologies		
Alternatives	**Description**	**Application**
Separations		
Halide Volatility	Conversion of an element to a halide gas which can then be preferentially separated by trapping the gas at different temperatures.	Calcine Treatment
Oxidation / Reduction	Conversion of elemental valences for use with preferential separation methods, such as precipitation, extraction, etc.	Radioactive liquid and calcine waste treatment
Radionuclide Partitioning by Liquid-Liquid Solvent Extraction (TRUEX, SrEX, NaEX)	Process using counter-current aqueous and organic streams to selectively remove components from the aqueous solution. Extractants being investigated are CMP and CMPO for transuranics (generically called TRUEX in this report) and crown ethers for both strontium and sodium removal (SrEX and NaEX, respectively).	Radioactive liquid and dissolved calcine waste treatment
Electrohydrolysis	Process which separates components using a chemical transformation driven by electrical current or voltage.	LAW from Freeze Crystallization or Precipitation by Neutralization
Fractional Condensation	Process which uses the differential ability of certain components to leave a gaseous state and form a solid or liquid as temperature is reduced.	Product from Halide Volatility
Freeze Crystallization (FC)	Separation of crystallized water and saturated sodium nitrate, which currently limits the efficiency of the New Waste Calcining Facility (NWCF) from radioactive liquid wastes by freezing. This results in a smaller waste volume of HAW than would occur if processed directly into calcine.	Radioactive liquid waste treatment only, specifically the sodium nitrate
Ion Exchange (IX)	Process which uses an organic resin or inorganic clay to preferentially remove ions in exchange for other ions pre-deposited on these surfaces.	To remove cesium (via CsIX) from waste streams in liquid form
Off-Gas Treatment	Filtration or chemical process to remove hazardous and/or radioactive contaminants from the process off-gas.	Will be used in all process as needed to control effluents
Precipitation (PPT) by neutralization	Process which uses the solubility properties of certain components to segregate those that do not form a solid.	Radioactive liquid and dissolved calcine waste treatment
Pyrochemical / Pyrometallurgical	High temperature processes which converts a solid to a vapor or metallic liquid form.	Calcine waste
Selective Leaching	Selective dissolution of radioactive solids into liquid by chemical reaction For example, the dissolution of cesium from calcine with water.	Calcine waste

Table 1: Initial Candidate Technologies		
Alternatives	**Description**	**Application**
Supported Liquid Membranes	Membrane filter used to separate target elements from an aqueous solution.	Radioactive liquid and dissolved calcine waste treatment
Volatilization / Distillation	Process using the differential ability of certain components to enter a vapor phase upon heating.	Calcine waste; part of a Pyrochemistry methodology
Immobilization		
Canning	Sealing waste inside a metal container.	Final waste forms and potentially calcine
Cementation/ Grouting	Incorporation of waste into a matrix of solidified hydrated oxides.	LAW immobilization alternative
Glass	Incorporation of waste into a matrix of non-crystalline solidified liquid.	Both LAW and HAW immobilization alternatives
Glass-Ceramic	Incorporation of waste into a form which contains some glass, but which also contains a large portion of crystalline matrix.	Both LAW and HAW immobilization alternatives

3.4 Develop Alternatives

Mass balance calculations resulting from literary studies and laboratory testing (see Appendix A) were made for processing systems compatible with ICPP radioactive liquid and calcine wastes. Radioactive waste compositions of current and projected inventories were used as inputs. Mass balances were then used to evaluate candidate technology flowsheet performance relative to ICPP radioactive waste streams and to develop estimates of cost, schedule, throughputs, and radioactive waste volumes. Additionally, a panel of outside experts evaluated the technical maturity of each candidate technology. Processes that did not fulfill the baseline requirements, could not be developed in time to meet regulatory requirements, or were viewed as technically inferior to other technologies were eliminated from further consideration. Processes that still showed promise following initial development were advanced to the next stage of analysis.

Radioactive liquid and calcine wastes contain many elemental components; separating some components prior to final immobilization results in smaller volume of HAW requiring immobilization and disposal. The following technologies (see Table 2), along with direct vitrification, provide twenty-seven potential combinations of technologies (each with their own immobilization and waste form options) that meet the baseline requirements and support the program goal.

Table 2: Technologies Under Evaluation		
Technology	**Technology Use**	**Decision Node(s) from Section 3.4.1**
Pre-treatment		
ANN or Silica Addition	added directly to radioactive liquid waste or to the resulting HAW fraction from FC or PPT	3
Calcination	conversion of sodium-bearing liquid plus additive to granular solid form	3 & 4
Dissolution	used on all calcine wastes	4
Separations		
Freeze Crystallization (FC)	used on radioactive liquid waste with high sodium concentrations	2
Precipitation (PPT) by neutralization	used on both radioactive liquid and calcine wastes	2 & 4
Radionuclide Partitioning by Liquid-Liquid Solvent Extraction (TRUEX, SrEX)	used on radioactive liquid and dissolved calcine wastes, to extract transuranics (TRU) and strontium	2 & 4 for TRU; 7 for strontium
Electrohydrolysis	used on the LAW fraction from PPT separation and, potentially, FC	2
Ion Exchange (IX)	used on the LAW fraction from FC, PPT, or TRU removal methods	7
Immobilization		
Cementation/ Grouting	Immobilization method for LAW	6
Glass	Immobilization method for HAW or LAW	6 & 7
Glass-Ceramic	Immobilization method for HAW or LAW	6 & 7
Canning	All final HAW forms	Assumed for all HAW forms

3.4.1 Decision Tree

Potential combinations of technologies are arranged according to seven identified key process decisions, the first four of which are presented in Figure 1. These seven decisions, referred to as nodes, are discussed below in greater detail.

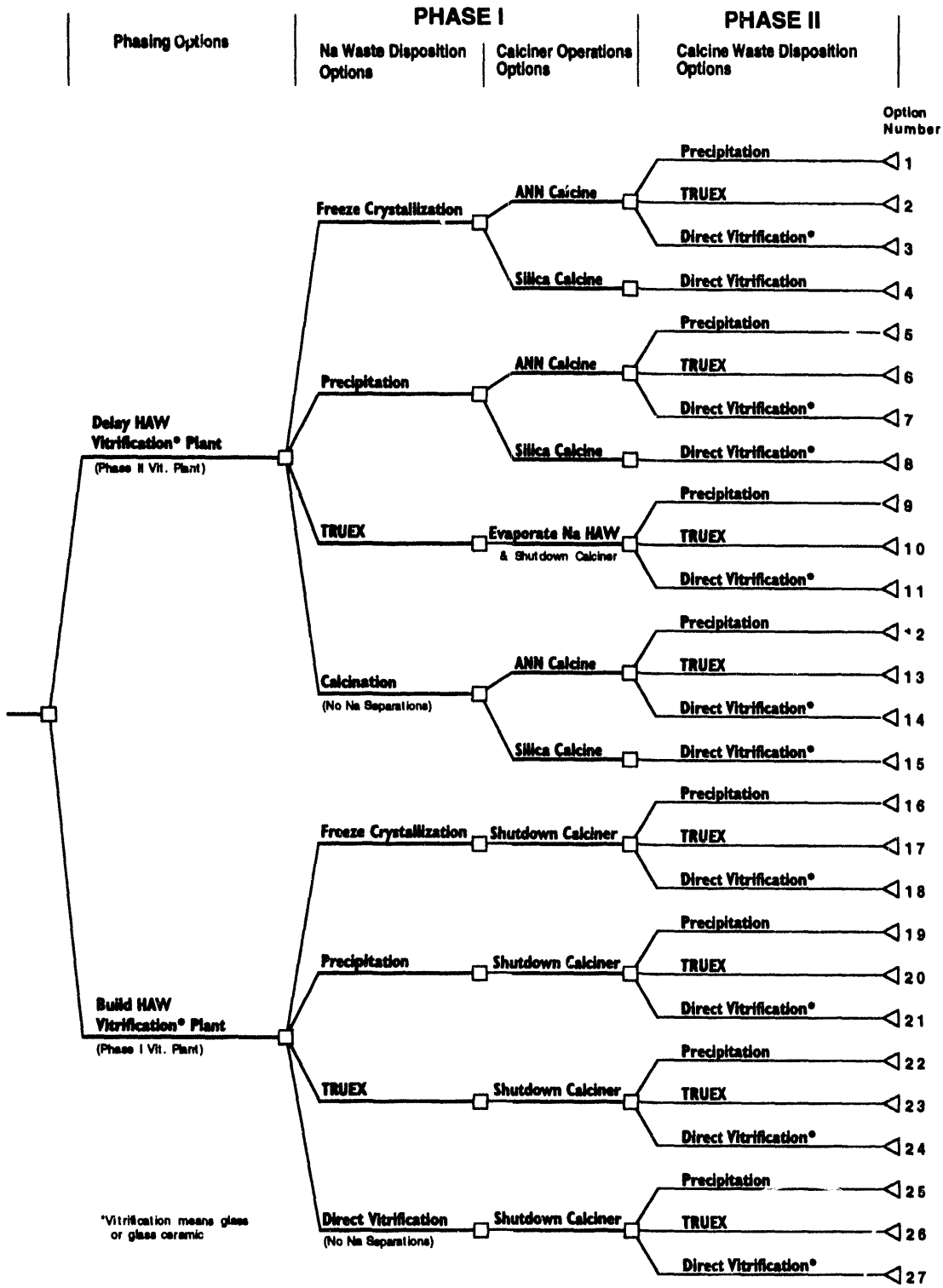


Figure 1: Decision Tree (Nodes 1 through 4) for Waste Treatment Technologies

The first node allows selection of whether the construction and operating expenditures for the HAW immobilization facility will be spent during the initial project phase, when the radioactive liquid waste is processed, or during the second phase of the project, where calcine processing occurs. By delaying the HAW immobilization unit until Phase II, the initial capital investment would be delayed; operations cost would be saved on that part of the project, but interim liquid to solid processing and interim storage would be required.

The second decision node deals with the radioactive liquid waste processing technology selection. Here, there are four possibilities: (1) Freeze Crystallization, (2) Precipitation through Neutralization, (3) TRUEX radionuclide partitioning, and (4) Non-separations processing, with each of the three separations technologies producing a LAW stream requiring immobilization. The Freeze Crystallization technology can be used only with the radioactive liquid waste whereas the other alternatives can be used for both liquid and calcine waste.

In the third decision node, the continued use of the existing NWCF is decided upon. Current inventories of radioactive sodium-bearing and high-level liquid waste cannot be calcined without the addition of either first-cycle raffinates from the reprocessing of SNF, nonradioactive aluminum nitrate nanohydrate (ANN), or silica. Raffinates from past reprocessing are now depleted, leaving blending with nonradioactive ANN or silica (both of which will significantly increase calcine waste volume) as the only methods to continue calcination. The NWCF is presently equipped for ANN calcination; if the decision is made, however, to use silica instead, major modification would be required to the calciner prior to performing calcination campaigns. Regardless of which additive is used, the decision whether or not to continue calcination varies according to the processing technology selected for the sodium-bearing liquid waste. For Freeze Crystallization, Precipitation, and Direct calcining, the calciner could be used to process the HAW stream using either ANN or silica; if, however, a HAW immobilization facility is built for Phase I operations, the calciner is no longer needed. Similarly, if TRUEX is used to process sodium-bearing liquid waste, continued calcine operations would not be cost effective based on estimates that the resulting volume of concentrated liquid would feed the calciner for only 45-60 days over a twelve year period.

Selection of technologies for processing calcine waste occurs in decision node four, resulting in twenty-seven potential technology combinations as mentioned above. Possible calcine waste processing options include Precipitation (through neutralization), TRUEX radionuclide separation, and Direct Immobilization of calcine into a HAW waste form.

The remaining three decision nodes do not appear on the decision tree shown, yet remain as integrated decisions regarding disposal form and waste classification options for each radioactive waste processing alternative. Decision node five involves selecting a HAW immobilization technology; HAW immobilization processes available are Glass are Glass-ceramic. LAW immobilization process selection, including: Glass; Glass-ceramic; normal Grout (Portland-type cement); and FUETAP (Formulated Under Elevated Temperature And

Pressure) Grout, is made in decision node six. The last decision node is used to select desired radioactivity levels for LAW according to waste class; currently, the NRC classification guide is used to distinguish the possibilities (i.e., Class A, B, C, or greater-than-class C). If a class A or B waste is selected, then strontium and cesium removal (via SrEX and CsIX, respectively) is required in addition to TRUEX actinide separations.

3.5 Optimize and Evaluate Alternatives

Within each of the twenty-seven processing combinations are additional variables which may affect the performance of any of the processing options in a variety of ways. Additional variables include waste immobilization techniques for the high and low level waste forms, low level waste classes, interim storage types utilized, and calciner operations. A computerized model was developed to assist in the evaluation and analysis of technologies, and each candidate process was optimally configured using a uniform basis for each cost element (see Appendix B, C, D, and E). This ensured an objective comparison of waste treatment alternatives by presenting each alternative in its most cost-effective configuration. The analysis also helps identify development activities needed to support technology evaluation, prioritize development efforts by identifying essential information needed prior to selecting a process, and establish relationships between available data and process selection criteria.

3.5.1 Technology Evaluation and Analysis Methodology (TEAM) Model

The TEAM Model computes the present value (in 10/94 dollars) for life-cycle costs of user specified treatment options for radioactive liquid and calcine waste. These costs include development; design, construction, and start-up; operations and maintenance; interim storage; disposal; and decontamination and decommissioning (D&D) costs associated with radioactive liquid and calcine waste treatment. Although the primary focus is on cost analyses of the various waste treatment options, other issues, such as the timing of expenditures and environmental impacts, are expected be important factors in the selection and implementation of waste treatment technologies. Consequently, the model also computes the cost-time profile of expenditures and the volumes of each waste type produced.

Determining the relative costs for each option is complicated by the interactions between the different cost components and by uncertainties in key parameters. For example, because each option generates both HAW and LAW, which have substantially different long term disposal costs, options which appear relatively inexpensive in regard to short term expenditures may be overshadowed by high disposal costs if they generate even a modest increase in the amount of resulting HAW. The model automatically selects the most cost-effective HAW and LAW immobilization processes and LAW waste classes, and includes a user's option to change the selected immobilization technology to explore other options where cost is not a primary driver or criteria (see Appendix D, Section D-7).

3.5.2 Strategy for Evaluation

To identify the most economical treatment alternatives, as well as key uncertainties in performance parameters, the TEAM Model will first be used to evaluate the cost of alternative processes and the relationships between cost and other related concerns (i.e., cost-time profiles, waste volumes, and characteristics of resulting waste streams) using base case parameters with user variation. Additionally, the model will be used to identify key sensitivities to help prioritize development work needed prior to the final decision.

3.5.2.1 Evaluating Processes and Tradeoffs

The evaluation process offers consistent comparison between the various treatment alternatives and identifies the factors that drive evaluation results. Initial comparisons of treatment alternatives will identify the (nominally) least expensive options and the cost differences between them. Additionally, tradeoffs between overall cost and waste volume can be assessed by comparing cost increase versus waste volume reduction ratios for each processing alternative. This information will be useful in identifying the alternatives with the greatest potential for meeting the radioactive liquid and calcine waste processing demands. Evaluative criteria, per baseline requirements and stakeholder concerns, have been identified to help focus on meaningful and comprehensible performance indicators.

Because the relative importance of evaluative criteria differ among individual stakeholders and decision makers, results of the TEAM Model can be displayed from various viewpoints to better help decision makers ultimately identify one or two preferred treatment and waste form alternatives. No one alternative is likely to satisfy all stakeholder concerns; therefore, alternatives are based on choices or tradeoffs between competing values. This approach makes trade-offs clearly visible while allowing individual values to be applied to the interpretation of technical data. Evaluative criteria, illustrated in Section 4.0, are as follows: (1) life-cycle costs, (2) life-cycle cost components, (3) waste volumes between alternatives, and (4) cost-time profiles. Identified tradeoffs will be discussed in greater detail as evaluation results are displayed.

3.5.2.2 Investigation of Uncertainty

As mentioned above, the evaluation is complicated by uncertainties in many of the performance parameters (e.g., efficiencies and costs of various candidate processes) which could have a major impact on the technology evaluation and selection process. To identify the parameters for which further investigation will be most valuable, the following procedure will be used. First, the range of uncertainty will be assessed, judgmentally if necessary, for each parameter of interest, and the high and low ends of that range will be defined. The model can then be rerun setting the specified parameter at each end of the established range. If setting the parameter at either one

end of the range or the other makes no significant difference in the choice of options, then further investigation of that particular parameter is not useful at this time, since it would not affect the outcome of the overall evaluation. If, however, variations in parameter settings do affect the choice of options, then it may be important to investigate the parameter further.

3.6 Stakeholder Involvement

Evaluation and selection of a treatment alternative for dispositioning ICPP radioactive liquid and calcine waste must include the consideration of stakeholder input to better identify and establish the relative importance of decision criteria. The basic premise is that technical experts can rank the performance of various alternatives against given parameters; however, the relative importance of each parameter is a value choice rather than a purely technical decision. For this reason, input will be solicited from various stakeholders (i.e., any person, organization, or group who has a vested interest in the specific issue or problem and in how the issue or problem is being solved) and considered in the decision making process.

3.7 Recommend Preferred Alternatives for Selection and Implementation

Current efforts focus primarily on verifying and presenting analysis data on all twenty-seven potential radioactive liquid and calcine waste treatment options for decision maker consideration. Preliminary cost and waste volume analyses regarding the twenty-seven potential technology combinations, discussed briefly in section 3.4, have already been presented to the WINCO Senior Staff and to personnel from both the DOE Idaho Operations Office and DOE Headquarters at Washington D.C. Presentations will continue routinely throughout the duration of the evaluation and optimization process in order to further verify data. As the evaluation process progresses and additional information becomes available, the scope of the evaluation will be narrowed to focus on the most promising technologies in greater detail. Candidate waste processing options will then be re-evaluated, re-optimized, and re-presented for decision makers' consideration until a final technology recommendation and selection is made. Systems Analysis personnel will periodically revisit the program goal and baseline requirements to confirm that evaluation efforts are moving in the desired direction and to ensure that the selection and implementation of optimal waste immobilization technologies is progressing according to schedule. It is important to note that this Systems Analysis process is recursive, incorporating, as appropriate, stakeholder concerns and subsequent directional modifications at any point along the way. A recommendation of preferred alternatives will be made to decision makers in the ICPP Radioactive Liquid and Calcine Waste Technologies and Disposal Form Evaluation report, to be issued September 30, 1994. Interface with stakeholders and decision makers will continue, following recommendation of alternatives, to ensure that a final selection is made by June 1, 1995, in conjunction with the ROD for the site-wide EIS as outlined in the Amended Court Order of December 22, 1993.

4.0 INTERPRETING EVALUATION DATA

Preliminary evaluations were performed for all twenty-seven options. Section 4 provides a brief overview of a number of optimization criteria, representative of diverse decision-maker concerns, and presents initial technology evaluation data as a function of those criteria.

Data for each of the twenty-seven waste treatment alternatives are graphically sub-divided into the following life-cycle expenditure components: Development costs; Phase I construction costs; Phase II construction costs; Operations costs; Interim storage costs; LAW disposal costs; HAW disposal costs; and D&D costs (see Appendix B). These components, discounted to the start of FY-95, are added together to give total life-cycle expenditures for each waste treatment option. Options are then categorically ranked according to the following criteria.

- Life-cycle Costs
- Development plus Phase I Construction Costs
- Life-cycle minus HAW Disposal Costs
- Cost-Time Profiles
- Five-year Costs
- HAW and LAW Waste Quantities prior to Immobilization

Such analyses allow decision makers to (1) identify optimum alternatives for individual criterion; (2) assess tradeoffs between various criteria; (3) identify uncertainties; and (4) focus investigation and evaluation efforts on options that best satisfy stakeholder concerns.

Data presented in the examples below are relative values based on available information. The graphic representations of radioactive waste treatment options are a consistent evaluative comparison and should not be considered as the actual cost required to implement a given alternative. As the evaluation progresses and more information becomes available data will be re-evaluated and updated.

4.1 Life-Cycle Costs

Life-cycle costs are measured in present value (in 10/94 dollars) and include all life-cycle expenditure components described above. Figure 2 shows the twenty-seven conditioning alternatives sorted according to the total life-cycle costs, with the most inexpensive options on the left of the graph.

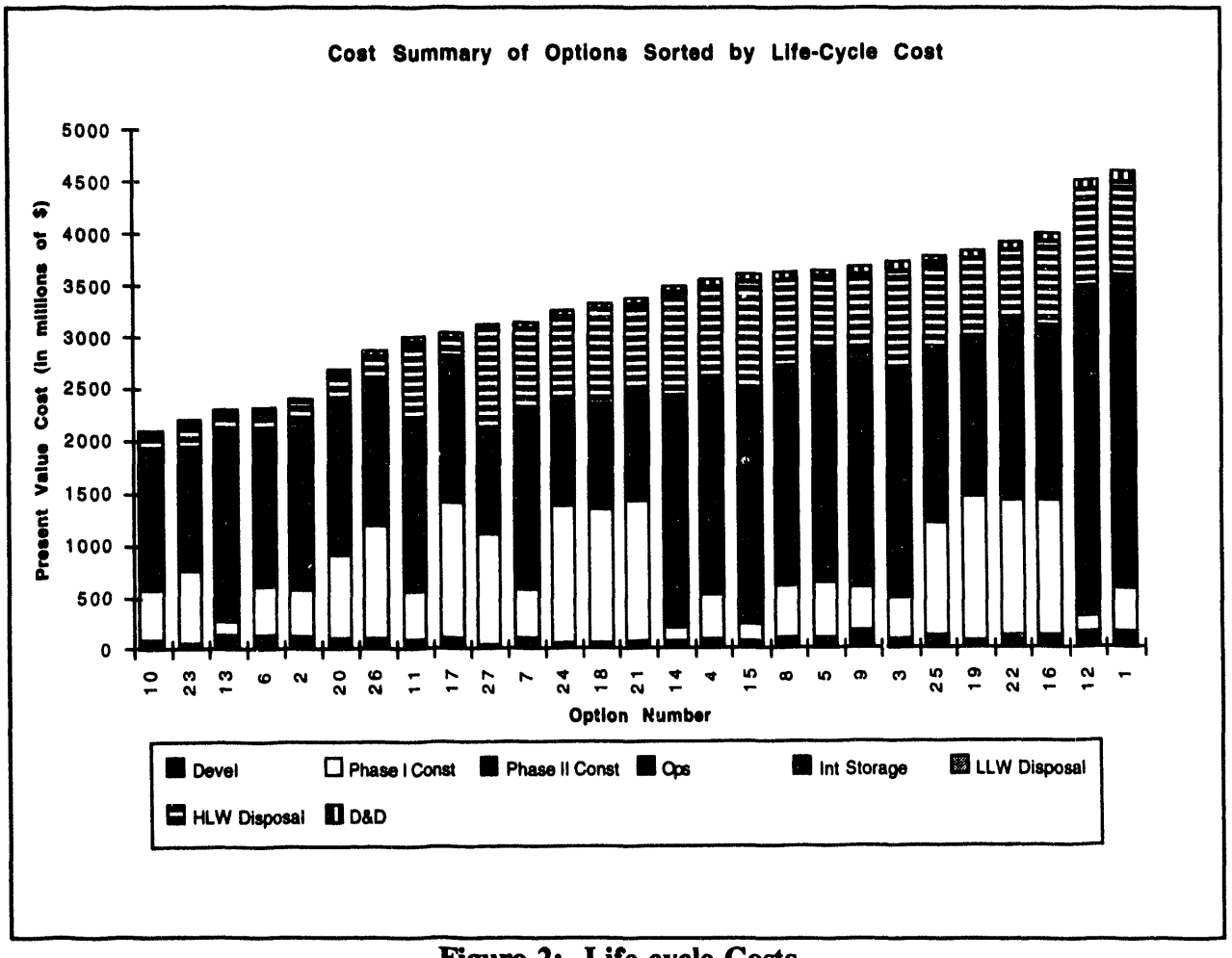


Figure 2: Life-cycle Costs

The Life-cycle Costs shown here provide the decision-maker with an understanding of the overall relative cost for each technology and of the range of life-cycle expenditures ($2 billion to $4.5 billion) for all 27 alternatives. Under this criterion, options 10, 23, 13, 6, and 2 are the most favorable.

4.2 Development Plus Phase I Construction Costs

An important criterion for the Department of Energy and the U.S. Government in general is the initial investment required to begin the immobilization process. Figure 3 shows the life-cycle cost of different options sorted by the sum of the development and phase I construction costs (illustrated by the bottom two divisions on each bar). Here, the initial investment is defined as the sum of the development and phase I construction costs required to deal with the radioactive liquid and calcine waste at the ICPP.

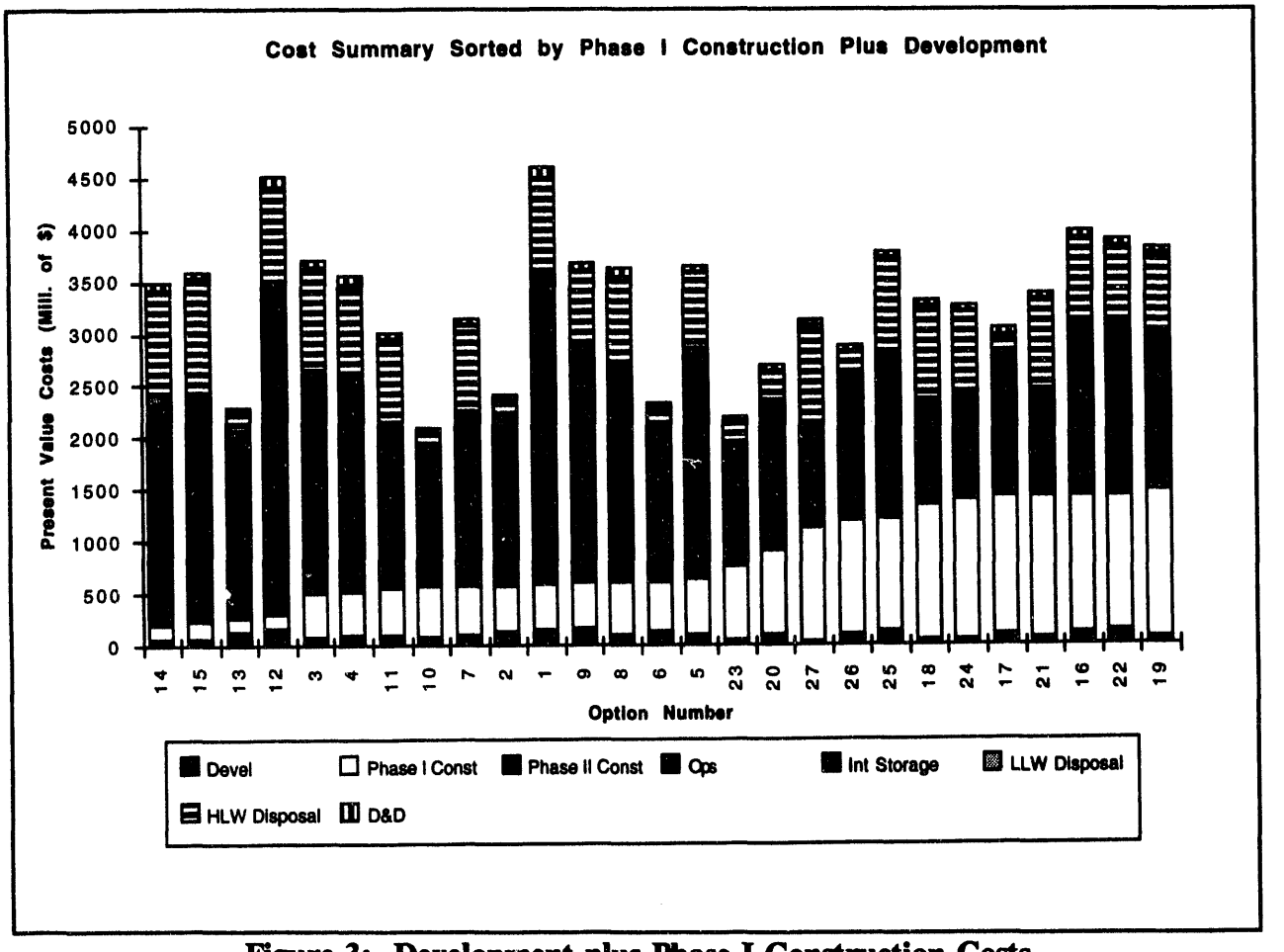


Figure 3: Development plus Phase I Construction Costs

The first four options utilize a new tank farm in the first phase and put all new technology implementation off until Phase II. The next group of options, between options 3 and 5, delay only the HAW immobilization plant until Phase II. Options implementing the HAW immobilization facility in Phase I are grouped at the far right of the graph beginning with option 23. Although options 14, 15, 13, 12, and 3 offer the lowest alternatives for Development plus Phase I Construction Costs, options 13, 10, 6, 2, and 23 provide optimum minimization of both Development plus Phase I Construction Costs and Life-cycle Costs.

4.3 Life-cycle Minus HAW Disposal Costs

The DOE Office of Civilian Radioactive Waste Management (OCRWM) has not yet selected a final high-level waste repository site. For that reason, the cost for disposal of HAW is an identified uncertainty. Current estimates place HAW disposal costs between 300 thousand and 2 million dollars per canister. The TEAM Model data presented below assumes a HAW disposal costs of 500 thousand dollars per canister for life-cycle cost calculations. This assumption, rounded up to the nearest 100 thousand, is based on present value estimates of HAW disposal costs published in the Federal Register. Figure 4 shows the life-cycle cost data for all options sorted by Life-cycle Costs minus HAW disposal.

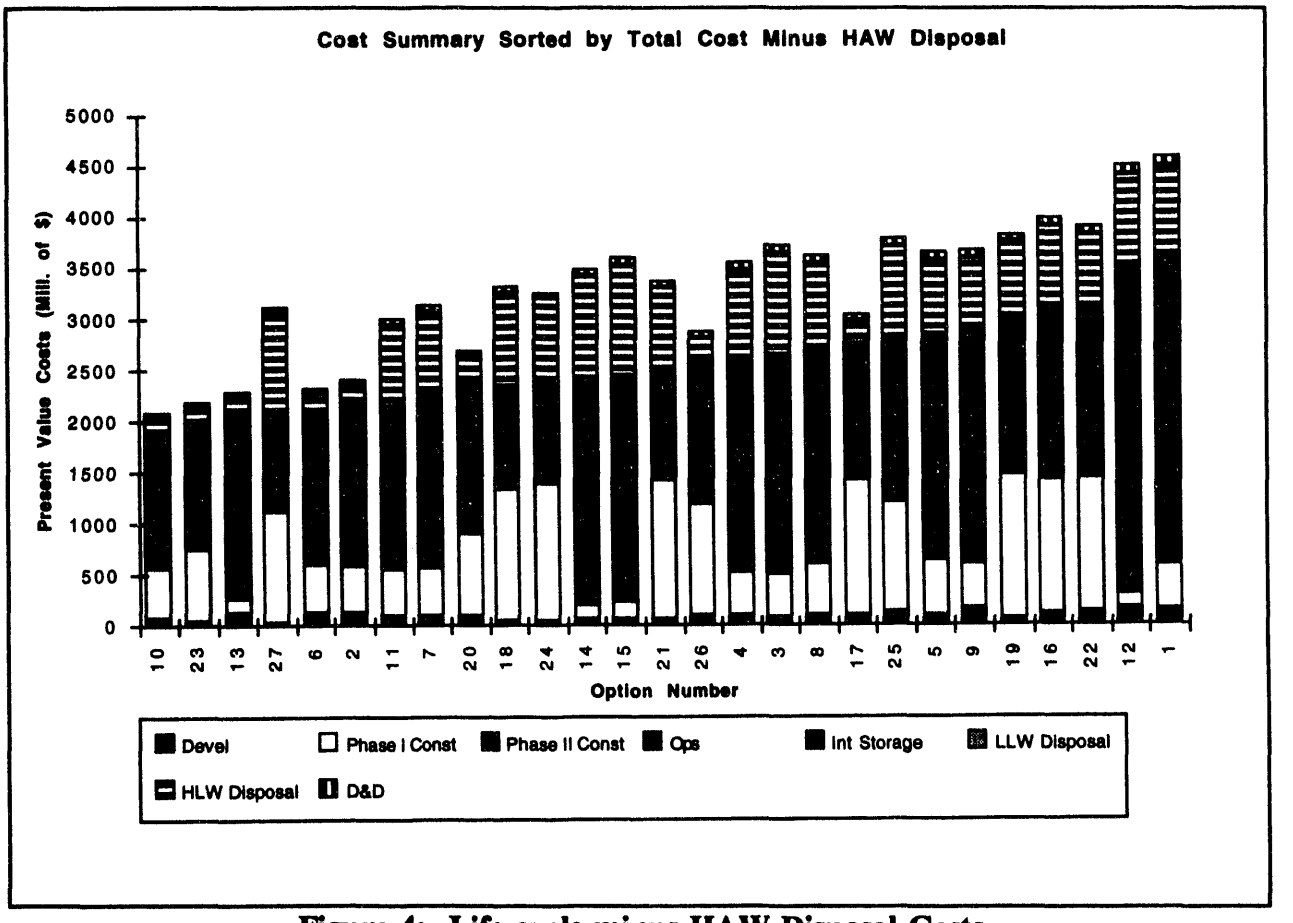


Figure 4: Life-cycle minus HAW Disposal Costs

Tradeoffs between the criteria show that options 10, 23, 13, 6, and 2 provide optimum minimization for both Life-cycle Costs and Life-cycle Costs minus HAW Disposal. Additionally, data seems to indicate that HAW disposal costs do not have a significant impact on the process selection, in that there is no significant difference in the ranking of options for the two criteria. This will be investigated further using the strategy outlined in Section 3.5.2.2

4.4 Cost-Time Profile

The timing of expenditures is an important aspect of budgeting for the DOE. If a process has large surges in funding (see Figure 5), priorities within the DOE complex must change to meet increased funding needs. Many DOE programs are short on funds; therefore, expenditures should be close to flat for the life time of a given process or the likelihood of success is reduced. Figure 5 shows a cost-time profile for option 14 where the ICPP continues to calcine radioactive liquid waste, then builds and operates a glass-ceramic plant to immobilize the calcine.

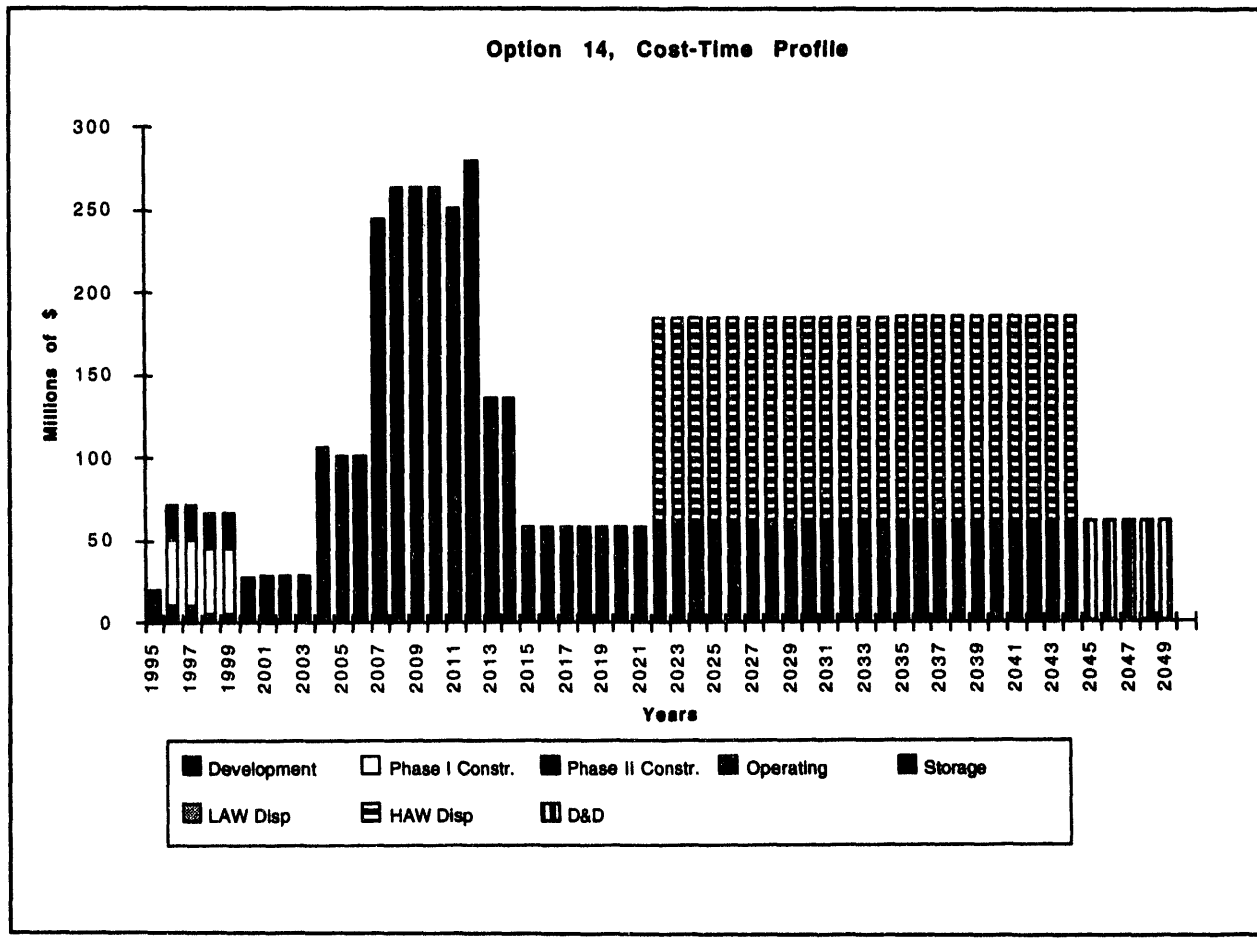


Figure 5: Cost-Time Profile for Option 14

If a new tank farm is built during Phase I, in accordance with Court Orders requiring that such a tank farm to be built by the year 2000, a funding spike occurs during Phase II as a result of increases in both glass-ceramic facility size and calcine waste volume. There are also large expenditures expected for HAW disposal, although these are minimized by utilizing the glass-ceramic process on this option. As mentioned, funding spikes like those shown in Figure 5 make the probability of success for funding this option minimal.

By comparison, option 10 (see Figure 6) spreads expenditures relatively evenly over the life-cycle of the process and a near flat cost-time profile is achieved.

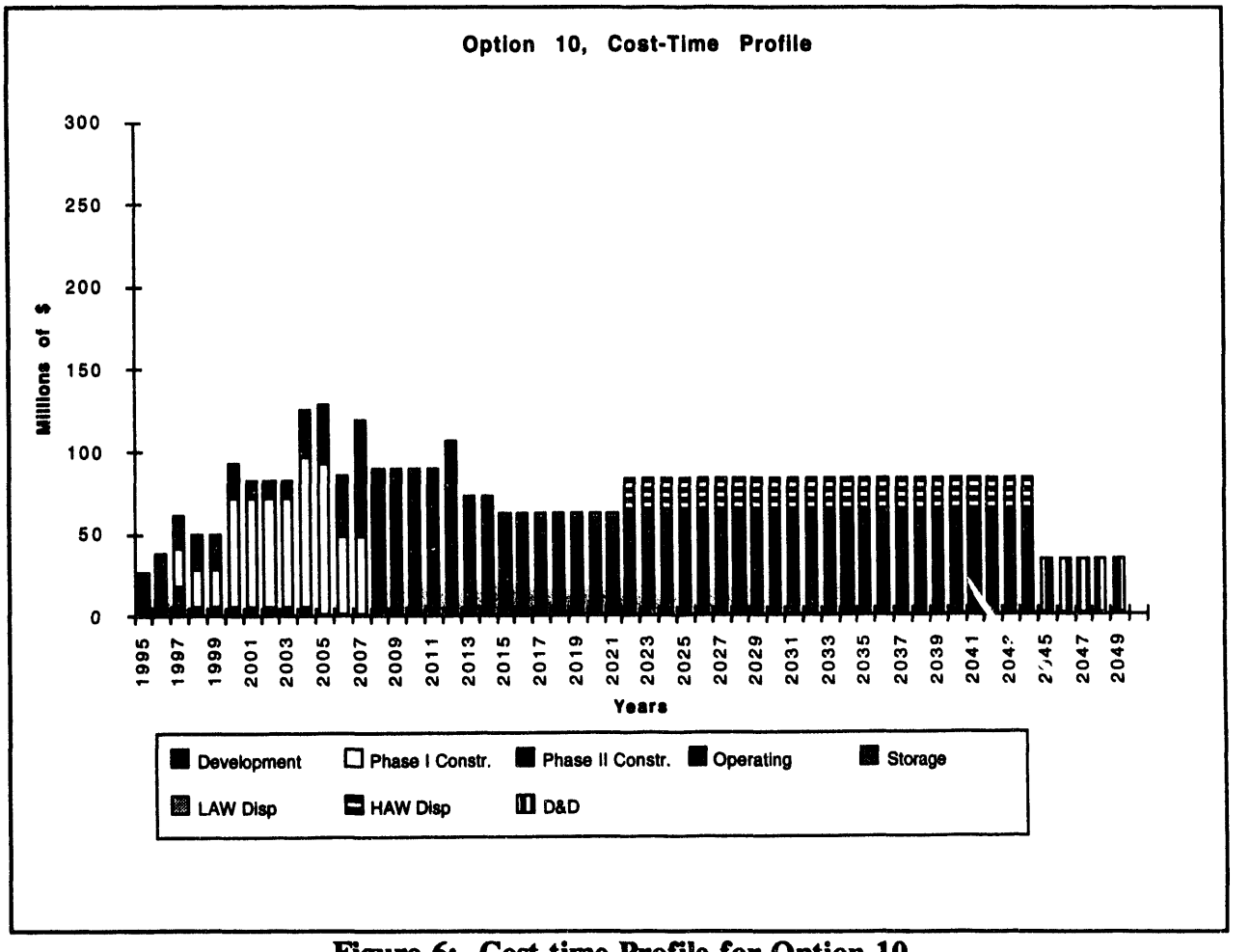


Figure 6: Cost-time Profile for Option 10

Other adjustments in time-phasing will be investigated during optimization to ensure that a good comparison between time-phasing and other concerns is achieved.

4.5 Five-year Costs

With the United States Government's budget tightening and requested budgets exceeding the amount of funding available, the next few years are critical to any implementation plan. By adding the first five bars on the cost-time profile, the present value of the five-year costs can be estimated.

Figure 7 shows all twenty-seven options with corresponding five-year costs (y-axis) as compared to corresponding life-cycle costs (x-axis). These options separate into four principle five-year versus life-cycle cost tradeoffs: low five-year with low life-cycle costs; low five-year with high life-cycle costs; high five-year with low life-cycle costs; and high five-year with high life-cycle costs.

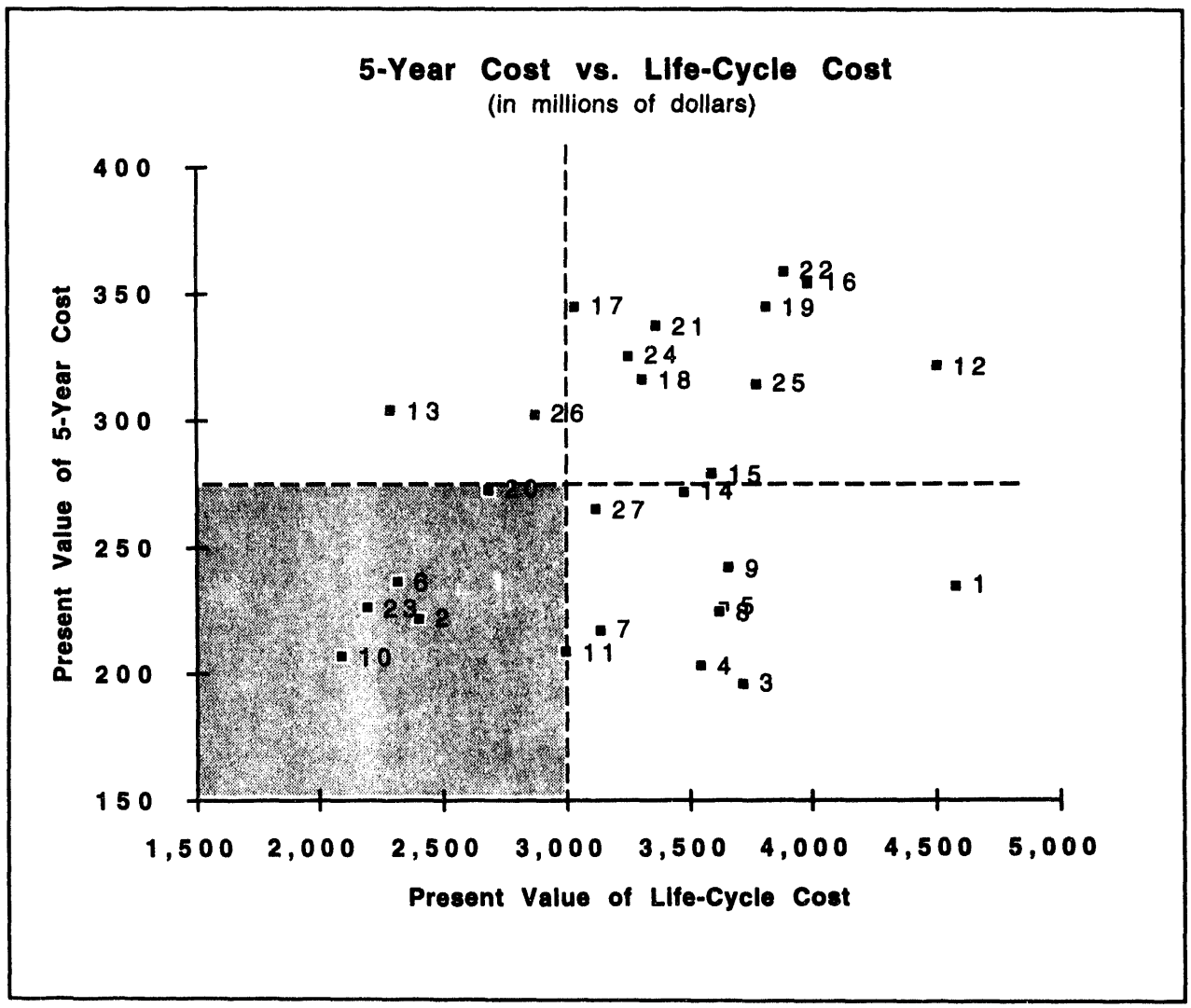


Figure 7: Five-year vs. Life-cycle Costs

Since options with either high five-year or high life-cycle costs may not be acceptable to decision-makers for which this is a vital criterion, the area of principle concern is the grouping where both low five-year and low life-cycle costs are achievable. This comparison shows that options 10, 23, 6, and 2 offer the best alternatives for reducing both short-term and long-term expenditures while satisfying baseline requirements for the treatment of radioactive liquid and calcine waste.

4.6 Waste Quantities

An important parameter in the technology selection is the quantity of waste that will result from the treatment of the radioactive liquid and calcine wastes. Some waste treatment options separate radionuclides from the inert chemicals used in the reprocessing of SNF. These chemicals, once removed from the fission products and transuranics, can be disposed of as LAW in a shallow land burial site following RCRA regulations, and possibly NRC guidelines for disposal. If separation is completed as is possible with some solvent extraction and ion exchange processes, the quantity of HAW requiring immobilization and disposal can be significantly reduced (see Options 2, 6, 10, 13, 17, 23, and 26 below). Figure 8 shows HAW and LAW waste quantities after radionuclide separations, if any, but prior to immobilization.

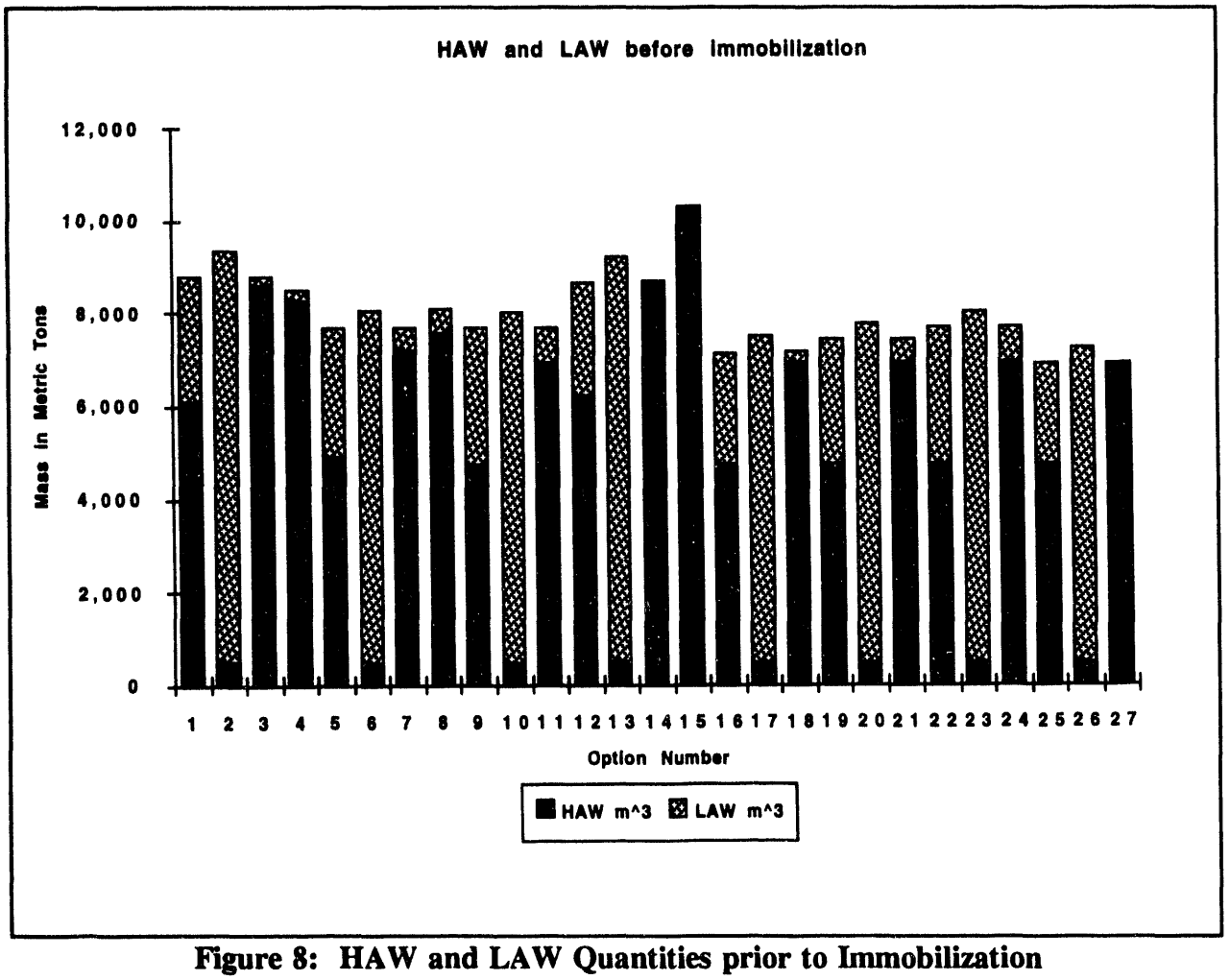


Figure 8: HAW and LAW Quantities prior to Immobilization

The waste quantities displayed in Figure 8 are shown as metric tons of metal oxide requiring immobilization. This value is the actual waste after the removal of water and volatile

chemicals, such as nitric acid, and the conversion of remaining metals to their oxide states. If volume is the primary driver and cost is secondary, then a glass-ceramic plant would be the most promising choice since this technology has the greatest potential for reducing HAW volume. If construction cost were the only driver, a low-grade Portland cement-type immobilization method might be used. When a final decision is made, this will be a matter of negotiations between the DOE and various stakeholders to ensure that all concerns are adequately weighed.

The quantities displayed show most of the options totalling between 7500 and 8000 metric tons. The options that show some additional calcine (1-4 and 12-15) are the result of calciner operations and the associated cold chemicals (ANN and Silica) used to process the radioactive liquid waste beyond the preferred two calcination campaigns. Of those options where separations are used, most of the cold chemicals used in the calcination process are immobilized with the LAW. However, for those processes that do not utilize separations technologies, cold chemicals added for calcination must be processed into the HAW immobilized product.

APPENDIX A: MASS BALANCE CALCULATIONAL BASES

A-1 Feed Material

1. Mass balance calculations are based on feed compositions as shown in Tables A-1 and A-2 *(BDMN-09-93, "Update of Sodium-Bearing Waste Tanks Composition and Volume and WINCO-1050, Inventories and Properties of ICPP Calcined High-Level Waste").*

2. Densities for aqueous solutions, unless otherwise noted, are calculated from apparent (partial) molar volumes of the components according to the following equation:

$$d = 1000. + \sum_i \frac{\left(\frac{MW_i}{1000.} - 1000.\ V_{\phi i}\right) N_i}{1000.}$$

Where

d	=	density, kg/m^3
1000	=	density of water, used as reference point
MW_i	=	Molecular weight of component i (g/mole)
$V_{\phi,i}$	=	Apparent (partial) molar volume of component i ($mole/m^3$)
N_i	=	Number of moles of component i

(Reference ANL-89/18)

Note: To properly calculate the density the cations must be charged balanced with the anions, listed in Table A-1, to determine the net apparent molar volumes.

3. Nitrate values in Table A-1 are based on a charge balance and not the analytical analysis value. The solution would be ionically unbalanced if this were not done.

4. There are two calcine feeds: (1) aluminum and (2) a zirconium and fluoride mixture representing 4 calcines (Zr, Zr-Na, Fluorinel-Na, and a 3-way blend of Al-Zr-Na). Inerts are from WINCO-1050 and BAS-1-93. Actinides are from WINCO-1050 with isotopes in the same ratio as IDO-10105, except for Np, which is taken from ICP-1189. Fission products Sr^{90}, Y^{90}, Cs^{137}, Ba^{137}, and Pm^{147} are from WINCO-1050, and the remaining isotopes are ratioed per IDO-10105.

Table A-1: Sodium Feed Composition			
Component	Apparent Molar Volume (m^3/mole)	Mass per m^3	
		gms	moles
Acid (H^+)	0	1,471.0	1,459.34
Hydroxide (OH^-)	-0.00000404	-	-
Boron (B^{3+})	0.00005575	167.3	15.48
Sodium (Na^+)	-0.00000121	30,468.9	1,3256.32
Aluminum (Al^{3+})	-0.0000422	14,504.1	537.56
Potassium (K^+)	0.00000902	5,979.3	152.92
Calcium (Ca^{2+})	-0.00001785	1,737.9	43.36
Chromium (Cr^{3+})	-0.0000395	298.5	5.74
Manganese (Mn^{2+})	-0.0000177	785.4	14.30
Iron (Fe^{2+})	-0.0000247	1,370.5	24.54
Nickel (Ni^{2+})	-0.000024	142.0	2.42
Zirconium (Zr^{4+})	0.000115.94	579.8	6.36
Molybdenum (Mo^{6+})	-0.0000395	59.6	0.62
Cadmium (Cd^{2+})	-0.00002	207.6	1.85
Lead (Pb^{2+})	-0.0000155	237.2	1.14
Mercury (Hg^{2+})	-0.0000193	403.1	2.01
Fluoride (F^-)	-0.00000116	1,219.5	64.19
Chloride (Cl^-)	0.00001783	813.6	22.95
Nitrate (NO_3^-)	0.000029	289,328.3	4,666.22
Phosphate (PO_4^{3-})	0.0000291	909.5	9.58
Sulphate (SO_4^{2-})	0.00001398	3,127.3	32.55
Undiss. Solids	-	1,653.8	-
Water (H_2O)	-	844,238.2	46,862.19
Density (kg/m^3)	-	1,240.97	
H-3 (Tritium)	0	0.00000709	0.00000236
Strontium-90	-0.00001816	0.54	0.006

Table A-1: Sodium Feed Composition			
Component	Apparent Molar Volume (m^3/mole)	Mass per m^3	
		gms	moles
Yttrium-90 *	0	-	-
Technetium-99	0.00002283	0.98	0.010
Iodine-129	0.00003622	135.52	1.05
Cesium-137	0.00002134	1.01	0.007
Barium-137 *	0	-	-
Actinides	0.00001591	106.86	0.45

* Yttrium-90 and Barium-137 are in secular equilibrium with Strontium-90 and Cesium-137 respectively. They are included here because they are needed in making heat calculations.

Table A-2: Calcine Feed Composition		
Component	Mass (Kg) per m^3	
	Aluminum	Zirc Mix
Boron (B)	2.046	14.321
Oxygen (O)	451.018	256.01
Sodium (Na)	25.301	33.601
Aluminum (Al)	526.921	142.726
Potassium (K)	--	7.44
Calcium (Ca)	--	472.018
Manganese (Mn)	--	0.197
Iron (Fe)	4.62	3.008
Zirconium (Zr)	--	233.609
Cadmium (Cd)	--	8.096
Mercury (Hg)	31.901	--
Fluoride (F)	--	355.214
Nitrate (NO_3)	44.992	67.523

Table A-2: Calcine Feed Composition		
Component	**Mass (Kg) per m³**	
	Aluminum	**Zirc Mix**
Phosphate (PO_4)	--	1.581
Sulphate (SO_4)	13.201	4.656
Density (kg/m³)	1,100.0	1,600.0
Radionuclides	**Ci/m³**	
Strontium-90	3,700.0	
Yttrium-90	3,700.0	
Technetium-99	--	
Cesium-137	4,200.0	
Barium-137	4,200.0	
Actinides	100.0	

A-1.1 Calcine Dissolution Values and Assumptions

The following specified values and assumptions were used to calculate the dissolution of calcine.

Values

Composition and density for aluminum calcine: as specified throughout this report
Composition and density for zirconium calcine: as specified throughout this report
Feed Acid concentration: 5M
Final free acid concentration for TRUEX feed: 3M
Final free acid concentration for precipitation feed: 0.5M

Assumptions

The dissolution assumptions (based on an understanding of basic chemistry and on results of dissolution experiments reported by Herst [*Letter to T. A. Todd, "Interim Report on Calcine Dissolution Studies, RSH-08-93, August 20, 1993*]) were as follows.

1) 99% of all calcine constituents dissolve with the following exceptions:

For zirconium calcine, calcium is assumed to be present as CaO and as CaF_2; fluoride is assumed to be present only as CaF_2. However, CaF_2, which is fairly

insoluble, is assumed to be present at a mass equivalent to 5% of the total starting weight of the calcine ; in other words, if 1 kg of calcine is dissolved, 50 g of CaF_2 will remain as undissolved solids.

2) The oxygen released during dissolution (99% of that listed as present) combines with free acid to form water.

3) The final volume used for molarity calculations was set equal to the initial volume plus the volume of water formed.

About twice the volume of acid is required to dissolve a cubic meter (m^3) of aluminum calcine as compared to a m^3 of zirconium calcine. This is because, on a volume basis, the oxygen content of alumina is about twice that of zirconium.

It should be noted that the amount of acid required to dissolve calcine is sensitive to the specification. For example, if the specifications are changed such that 8M acid is used instead of 5M acid, and for the case of TRUEX feed, the final free acid is changed to 1M instead of 3M, then the following acid volumes are required.

TRUEX feed: 8000 liters of Al and 4600 liters of Zr, a 70% reduction
Precipitation feed: 7500 liters of Al and 4250 liters of Zr, a 40% reduction

It should be noted that the assumption that a large amount of CaF_2 does not dissolve and that 1% of the remaining constituents do not dissolve are upper bounds on the solids. If only small quantities of insoluble crystalline alumina are present, and if blending of zirconium and aluminum calcine is used, than it is possible that the amount of solids will be negligible.

A-2 Actinide Removal

1. TRUEX process technology will be utilized for actinide removal. The waste feed composition is entered into the Generic TRUEX Model (GTM) software; components not considered in the model are assumed to reside in the raffinate.

2. The electrohydrolysis option for actinide removal raffinates is not valid since polyvalent cations (e.g., Ca^{+2}) will foul the membranes due to high concentrations of those cations *(BDMN-04-93, R. D. Boardman letter to D. V. Croson, "Technical Review of Sodium-Bearing Waste Treatment Alternatives," dated May 28, 1993).*

3. It is assumed that ammonium oxalate will be used as the strip solution.

4. Nitric acid will be used in the scrub.

5. The organic will be recycled and, at the end of operations, incinerated at a waste treatment facility.

6. The raffinate and organic wash streams will combine into one LAW stream.

7. The most probable valence state of Pu (i.e., +4) was chosen for extraction due to the oxidizing environment.

8. All feed stream components not included in the GTM are assumed to not extract; they will reside in the raffinate or LAW. A component distribution of greater than 99.9% is considered 100%.

9. The HAW stream containing the extraction products is concentrated to provide a nitrate concentration of 6M in the resulting solution.

10. Five extraction stages, four scrub stages, five strip stages, and a total of three organic wash stages using three different streams are modelled. The compositions are 0.2 M nitric acid for the scrub, 0.1 M oxalate for the strip, 0.25 M sodium carbonate for the first wash, and 0.1 M nitric acid for the second wash (stages and compositions determined by J. Law). The extraction has an aqueous to organic volume ratio of 3:1 and a strip aqueous to organic volume ratio of 5:3.

11. The feed volume must be prorated/normalized to 1 m^3 as 400 volumes are used; all other volumes are then ratioed accordingly.

A-3 Neutralization/Precipitation

1. Neutralization of the sodium-bearing waste produces two phases: solid and liquid. If the precipitate will be directly made into a glass, sodium hydroxide will be added to achieve a supernate having a pH of 13.5. Otherwise, a pH of 11 will be achieved to maximize aluminum precipitation.

2. No significant change of total volume (HAW plus LAW) results; 95% of the water (H_2O) stays in the LAW liquid stream and 5% with the HAW solid product. 100% solid/liquid separation is assumed.

3. Component removal % (See Table A-3, with references.)

4. Either fresh acid or the nitric acid from electrohydrolysis will be used to redissolve the precipitate prior to waste immobilization. Sufficient acid will be used to provide a redissolved HAW with a 1.6 M Al and 1.0 M H^+ concentration. If the desired immobilized product is a HAW glass, the precipitate would not be redissolved with nitric acid since direct vitrification would be possible.

5. Note that even though NaOH is recycled when electrohydrolysis is an operating option, the NaOH will eventually be immobilized as LAW.

Table A-3: Precipitation Removal Percentage

Component	Removal %
Aluminum+3 (D)	90
Fluoride-1 (G)	0
Nitrate-1 (G)	0
Potassium+1 (C)	0
Sodium+1 (C)	0
Sulfate-2 (G)	0
Undissolved Solids	100
Americium-241 (B)	100
Antimony-125 (F)	100
Arsenic+3 (A)	100
Barium+2 (A)	80
Boron+3 (F)	90
Cadmium+2 (A, E)	85
Calcium+2 (C)	50
Cerium-134 (E)	100
Cesium+1	0
Chloride-1 (G)	0
Chromium+3 (A)	92
Cobalt-60 (F)	100
Europium-154/5 (F)	100
Iodine-129 (G)	0
Iron+3 (E)	90
Lead+2 (A)	75
Manganese+2 (E)	90
Molybdenum+6 (F)	90
Mercury+2 (A)	70
Neptunium-237 (B)	100
Nickel+2 (A, E)	90
Phosphate-3 (G)	0
Plutonium (total) (B)	100
Selenium+4 (F)	100
Silver+1 (A)	90
Strontium-90	47
Technetium-99 (F)	90
Tritium-3 (H)	0
Uranium (total) (B)	100
Zirconium+4 (D, E)	85

References

A) R. W. Peters, Y. Ku, and D. Bhattacharyya, "Evaluation of Recent Treatment Techniques for Removal of Heavy Metals from Industrial Waste Waters," AIChE Symposium Series: Separation of Heavy Metals and Other Trace Contaminants, 81 (243) 1985: pp. 165-203.

B) N. A. Chipman, G. O. Engelgau, and J. R. Berreth, "An Evaluation of Alternative Methods for Processing Sodium-Bearing Waste," WIN-268, 1989.

C) R. H. Perry and C. H. Chilton, eds., *Chemical Engineers' Handbook*, New York: McGraw-Hill Book Co., 1973.

D) J. A. Nenni, JAN-06-93, to D. V. Croson, "Sodium-Bearing Waste Treatment Program Scoping Study Results," dated September, 28, 1993.

E) W. B. Kerr, "Studies on the Removal of Inerts from ICPP high-level liquid waste by Neutralization," WIN-168, 1985.

F) Estimation based on chemical similarity to other ions with published removal efficiency.

G) Removal of anions was based on the assumption that all cations would precipitate as hydroxide salts.

H) Tritium would be contained in the water stream due to the chemical similarities between tritiated water and water.

A-4 Electrohydrolysis (EH)

1. Electrohydrolysis (EH) results in three effluent streams: (1) an HNO_3 stream; (2) an NaOH stream; and (3) a dilute waste stream.

2. The Na^+ and NO_3^- is formed into NaOH and HNO_3 via electrolysis of the water by the following reactions:

   $2H_2O \text{--->} O_2\uparrow + 4H^+ + 4e^-$ Anode Reaction
   $2H_2O + 2e^- \text{--->} 2OH^- + H_2\uparrow$ Cathode Reaction

   The amount will be the NaOH required to do the neutralization in A-3 above.

3. 95 mole% of the anions transfer across the membrane and leave with the HNO_3 stream. 5 mole% of the anions remain in the dilute waste stream.

4. 95 mole% of the cations transfer across the membrane and leave with the NaOH stream. 5 mole% of the cations remain in the dilute waste stream.

5. Of the water (H_2O) remaining that is unsplit, 25 wt% leaves with the HNO_3 stream, 25 wt% leaves with the NaOH stream, and 50 wt% remains in the dilute waste stream.

A-5 Freeze Crystallization (FC)

1. Freeze crystallization (FC) results in three effluent streams: (1) a pure ice crystal stream which is later melted to liquid water; (2) a solid precipitate stream consisting of sodium nitrate crystals; and (3) a concentrated liquid stream consisting of all the original sodium-bearing waste components minus the water and sodium nitrate streams.

2. Two weight percent of the components in the feed stream (except water and sodium) will reside in the sodium nitrate precipitate as occlusions. To achieve Class A waste, two cycles of FC will be used. The precipitate from the first cycle will be dissolved in pure water to make an Na concentrate and then reprecipitated; this will result in a final precipitate phase having 0.07 wt% of the feed stream components (except for water and sodium). The liquor from the second cycle will be concentrated to achieve an Na concentration greater than the original feed, then be combined back into the original feed stream.

3. Water removal of 77 wt%, via ice, results for the freeze crystallization process in each cycle. The water removed from the second cycle liquor is recycled and used to dissolve the precipitate from the first cycle *("Test Plan for Development and Demonstration of Sodium Bearing Radioactive Liquid*

Solution Treatment by Freeze Crystallization," FTC Acquisition Corp., dated 8/18/93).

4. Na removal of 64 wt% is achieved as $NaNO_3$ precipitate for freeze crystallization in each cycle *(FAX transmission from FTC Acquisition Corp., dated 8/2/93).*

5. The refrigerant is liquid or two-phase nitrogen (N_2). Although this is a process additive, no secondary waste results from its use. Therefore, N_2 is not considered in the volume or mass calculations.

6. Ice crystal wash water is recycled and eventually evaporated; therefore, no additional LAW volume is assumed to be attributed from this wash.

7. Tritium will partition the same as the water.

A-6 Calcination

1. The sodium plus potassium blend ratio in the calcine is 8.4 mole % (mean of the 5.3% and 11.5% flowsheets) and calculated using the methodology documented in BHO-03-93, *"Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine."*

2. Sodium plus Potassium (Na+K) mole % in the calcine is calculated according to the following:

$$(Na + K)\ mol\% = \left(\frac{(Na + K)}{(Metals + O + NO_3^- + PO_4^{2-} + SO_4^{2-} + F^- + Cl^-)}\right)(100)$$

All concentrations are in moles, with Oxygen (O) being the number of moles associated with the metal oxides.

3. Calcine density for alumina-based calcines is 1.1 g/cm^3. The bulk density for a blend of Fluorinel and Sodium wastes is 1.6 g/cm^3. The bulk density of blends from the tanks is 1.4 g/cm^3 *(B. A. Staples, G. S. Pomiak, E. L. Wade, ICP-1189, "Properties of Radioactive Calcine Retrieved from the Second Calcined Solids Storage Facility at ICPP," March 1979; J. R. Berreth, WINCO-1050, "Inventories and Properties of ICPP Calcined High-Level Waste," February 1988.)*

4. For additives the following will be used:

Component	Molarity	Density
Aluminum Nitrate ($Al(NO_3)_3$)	2.2	1.3648
Boric Acid (H_3BO_3)	0.75	1.0143
Calcium Nitrate ($Ca(NO_3)_2$)	4.3	1.5284

NOTE: These are known physical properties

5. For all calcines a Ca to F mole ratio of 0.7 will be used, and a boron concentration of 0.15 M will be used for calcination with aluminum nitrate *(Known Limits)*.

A-7 Cesium Removal via Ion Exchange (IX) or Absorption

Cesium sorption onto sorbent materials is characterized by two parameters. The first parameter concerns the physical and/or theoretical capacity of the material at saturation (i.e., how much cesium it can hold). The capacities are usually reported in terms of the number of grams of cesium sorbed per kilogram of sorbent. The second parameter is a distribution coefficient that quantifies the amount of cesium sorbed when in equilibrium with the contacting solution. The distribution coefficient is commonly reported in units of milliliters of aqueous waste per gram of sorbent and is considered to be constant until saturation is approached. From the distribution coefficient and the capacity, one can estimate the cesium concentration where the material becomes saturated. Material saturation is not normally achieved because the aqueous cesium concentrations are well below the value where the saturation is approached. Typical operation of a sorbent column involves the termination of the process when a given breakthrough (discharge) cesium concentration is reached.

1. Engineered sorbent forms are ammonium molybdophosphate (AMP) in a silica gel matrix for acidic systems and crystalline silicotitanate (CST) in an inorganic matrix for basic systems *(Dan Trudell, Sandia Nat'l Lab. for CST)*.

2. Break-through sorbent capacity for AMP is 9.3 g Cs per kg of AMP.

3. Sorbent loading in the engineered forms is 20 wt% for AMP and 50 wt% for CST *(Kikuo Terada, et al., "Silica Gel As a Support for Inorganic Ion-Exchangers for the Determination of Caesium-137 in Natural Waters," Tantala 17(10) 1970: pp. 955-963)*.

4. Spent sorbents will not be regenerated; they will be incorporated into a HAW glass or glass-ceramic. Because the engineered sorbent forms contain SiO_2, the AMP-silica gel and CST matrices will supplement the SiO_2 requirements

for the glass or glass-ceramic. Spent sorbents will be vitrified, etc. in a blend with other wastes. The SiO_2 mass loading in the glass is 45 wt% and 25 wt% in the glass-ceramic. If the silica gel matrix provides too much SiO_2, then the SiO_2 must be diluted *(Process knowledge and conversations with B. Staples).*

5. Sorbents are selective for cesium unless actinides are present; then, both will exchange/load the exchanger. Cesium adsorption will be performed in columns *(LA-12654, "Distributions of 14 Elements on 60 Selected Absorbers from Two Simulant Solutions (Acid-Dissolved Sludge and Alkaline Supernate) for Hanford HLW Tank 102-SY").*

A-8 SREX: Strontium Extraction

1. The strontium extraction (SREX) process is an 18 crown 6 ether in an organic diluent as the Sr extractant.

2. The organic will be recycled and, at the end of operations, incinerated at a waste treatment facility.

3. 99.7% of the Sr and equal molar Ba, Zr, and Sr are extracted/removed per process cycle *(Verbal communication with Phil Horwitz, 10-27-93 (SREX inventor); G. J. Lumetta presentation at 8th Symposium on Separation science and Technology for Energy Applications, 10-24-93; R. G. Shuler, C. B. Bowers. Jr., K. E. Smith, Jr., V. Van Brunt, M. W. Davis, Jr., "The Extraction of Cesium and Strontium from Acidic High Activity Nuclear Waste Using a PUREX Process Compatible Organic Extractant," Solvent Extraction and Ion Exchange, 3(5) 1985: pp. 567-604).*

A-9 Waste Forms Overview

1. Grout density is 2.0 g/cm^3 *(FUETAP reference formula taken from Radioactive Waste Forms for the Future, Werner Lutze and Rodney C. Ewing, Editors, North-Holland, 1988).*

2. Excess LAW water is evaporated off; grout waste loading (solids) is 15 wt% of the total grout mass. Recognize that heavy metals are assumed to not be limiting *(FUETAP reference formula taken from Radioactive Waste Forms for the Future, Werner Lutze and Rodney C. Ewing, Editors, North-Holland, 1988).*

3. The LAW glassification process destroys all nitrates and hydroxides. Nitrate destruction is necessary in order to produce a stable LAW grout or LAW glass.

4. The ^{129}I and ^{3}H in the feed are volatilized during vitrification of the waste.

5. The LAW glass has the same density and loading as does the HAW glass.

A-9.1 Assumptions—HAW Glass and Glass-ceramic

1. The glass density is 2.6 g/cm^3 with a waste loading of 33 wt% solids *(WDB-4-93/LON-3-93, W. D. Bolon and L. O. Nelson letter to J. D. Herzog, "Estimated Immobilized Waste Volumes, Number of Canisters, and Metal Canister Mass Based on Current Waste Inventories", Dated September 8, 1993; D. A. Knecht, J. R. Berreth, "FY-88 Update: Strategy Planning Document for the Long-term Management of ICPP High-level Radioactive Waste,", WIN-225, September 1988; D. C. Stewart, Data for Radioactive Waste Management and Nuclear Applications, John Wiley and Sons, Table 5.18).*

2. The glass-ceramic density is 3.2 g/cm^3 with a waste loading of 70 wt% solids *(WDB-4-93/LON-3-93, W. D. Bolon and L. O. Nelson letter to J. D. Herzog, "Estimated Immobilized Waste Volumes, Number of Canisters, and Metal Canister Mass Based on Current Waste Inventories", Dated September 8, 1993).*

3. Although sodium concentration may limit glass or glass ceramic waste loading, it is assumed that sodium concentration will not affect waste loading.

4. The undissolved solids are assumed to be removed prior to separation processing via filtration or centrifugation for the TRUEX or FC processing options. The undissolved solids are added to the HAW fraction with no further waste processing ramifications; solid criticality concerns will have to be addressed.

5. The HAW uranium mass is determined as elemental uranium and not UO_2. The slight molecular weight difference is considered negligible for the spreadsheet calculations when considering the low molarity of the uranium.

6. The ^{129}I and ^{3}H in the feed are volatilized during denitration/calcination of the waste.

APPENDIX B COSTS

Appendix B provides the equations for all calculations used to obtain cost data for the TEAM Model. Life-cycle costs for each candidate option (C_{LC}) are the summation of the associated costs of a selected option and are computed as follows.

$$C_{LC} = C_{Td} + C_{Tdcs} + C_{Tops} + C_{Tstor} + C_{Tdisp} + C_{Tdd}$$

Where

C_{Td}	=	total cost for development of a selected option, from Section B-1
C_{Tdcs}	=	total costs for design, construction, and start-up of each phase of an option, from Section B-2
C_{Tops}	=	total operating costs of a selected option, from Section B-3
C_{Tstor}	=	total interim storage cost of a selected option, from Section B-4
C_{Tdisp}	=	total disposal cost of a selected option, from Section B-5
C_{Tdd}	=	total decontamination and decommissioning costs of a selected option, from Section B-6

Equations for each of the components of this calculation are provided in the sections that follow; data for each equation, along with their bases, are provided in Appendix E.

The WIF technology decision consists of two phases. Phase I processes radioactive liquid wastes and Phase II processes calcine waste. Using this phased approach, the TEAM Model calculates costs based on each phase. The default start dates and durations for phasing are given in Table B-1, but may be selected as user inputs in the model.

Table B-1: Phasing Summary (Default Values)		
Variable	**Description**	**Default**
DI_{dev}	Phase I development start date	1995
YI_{dev}	Phase I development duration, in years, equals DI_{con} plus one year for advanced conceptual design minus DI_{dev}	3
DI_{con}	Phase I construction start date	1997
YI_{con}	Phase I construction duration, in years	11
DI_{ops}	Phase I operation start date equals DI_{con} plus YI_{con}	2008
YI_{ops}	Phase I operating duration, in years	7
DII_{dev}	Phase II development start date, in years, equals DI_{dev} plus YI_{dev}	1998
YII_{dev}	Phase II development duration, in years, equals DII_{con} plus one year for advanced conceptual design minus DII_{dev}	7
DII_{con}	Phase II construction start date	2004
YII_{con}	Phase II construction duration, in years	11
DII_{ops}	Phase II operation start date equals DII_{con} plus YII_{con}	2015
YII_{ops}	Phase II operating duration, in years	30

B-1 Development Costs

C_{Td} is the total cost for development of a selected option and is calculated by the following equation.

$$C_{Td} = C_{dPI} + C_{dC} + C_{dPII} + C_{dHAW} + C_{dLAW}$$

Where

C_{dPI} = development cost for Phase I process, from Section B-1.1
C_{dC} = development cost for calciner, from Section B-1.1
C_{dPII} = development cost for Phase II process, from Section B-1.1
C_{dHAW} = development cost for HAW immobilization process, from Section B-1.1
C_{dLAW} = development cost for LAW immobilization process, from Section B-1.1

NOTE: If the same technology is used to process radioactive liquid and calcine waste, then C_{dPII} for Phase II is zero.

B-1.1 General Development Costs

Development costs (C_d) are the annual costs (investigators, development personnel, and non-labor) incurred during development of a selected option and are calculated by the following equation for C_{dPI}, C_{dC}, C_{dPII}, C_{dHAW}, and C_{dLAW}.

$$C_d = [(FTE)(F_{supp})(LR_{dev})](1 + F_{sm})(t_d) + C_{test}$$

Where

FTE	=	the number of principle investigators (full time equivalent person years) required for development, from Table E-1
F_{supp}	=	the ratio of support personnel to principle investigators needed to support technology development, from Table E-2
LR_{dev}	=	the fully burdened annual labor rate for development personnel, from Table E-2
F_{sm}	=	the factor of the labor budget expended for subcontract support and materials during technology development, from Table E-2
t_d	=	development time, from Section B-1.1.1
C_{test}	=	advanced testing costs, from Table E-1

B-1.1.1 Development Time

To calculate development time (t_d) for Phase I use the following.

$$t_d = YI_{dev}$$

Where

YI_{dev}	=	the Phase I development years, from Table B-1

To calculate development time (t_d) for Phase II use the following equation.

$$t_d = YI_{dev} + YII_{dev}$$

Where

YI_{dev}	=	the Phase I development years, from Table B-1
YII_{dev}	=	the Phase II development years, from Table B-1

B-2 Design, Construction, and Start-up Costs

C_{Tdcs} is the total cost incurred during the design, construction, and start-up of an option and is calculated by the following equation.

$$C_{Tdcs} = C_{dcsPI} + C_{dcsC} + C_{dcsPII} + C_{dcsHAW} + C_{dcsLAW}$$

Where

C_{dcsPI}	=	design, construction, and start-up cost for Phase I process, from Section B-2.1
C_{dcsC}	=	design, construction, and start-up cost for calciner, from Section B-2.1
C_{dcsPII}	=	design, construction, and start-up cost for Phase II process, from Section B-2.1
C_{dcsHAW}	=	design, construction, and start-up cost for HAW immobilization process, from Section B-2.1
C_{dcsLAW}	=	design, construction, and start-up cost for LAW immobilization process, from Section B-2.1

NOTE: In addition to the general C_{dcs} calculations outlined below, certain cases result in increased C_{dcs} costs. The associated costs for these cases are found in Table E-1 and need to be multiplied by F_{cp} (from Table E-2). Additional costs are as follows.

(1) Sodium transfer costs are added to Phase I C_{dcs} costs if any new facilities are used to process radioactive liquid waste from the tank farm. Sodium transfer costs are the costs to add a transfer line from the tank farm to the new facility.

(2) If the maximum value of surge capacity needed (Cp_{add}) is less than or equal to 300,000 gallons then surge capacity costs (from Table E-2) are added to Phase I C_{dcs} costs for any new process (i.e., any option that doesn't choose just calcination for Phase I). If calcination is chosen for Phase I, or Cp_{add} is greater than 300,000 gallons, then surge capacity costs are calculated by the following equation, from the ICPP Tank Farm Systems Analysis (WINCO-1192).

$$C_{sc} = [(1.35)(10)^{-11}](Cp_{add})^3 - [(8.32)(10)^{-5}](Cp_{add})^2 + (183)(Cp_{add}) + (3.76)(10)^7$$

Where

Cp_{add} = the maximum value of surge capacity needed as calculated in Section C-3

NOTE: The resulting value is discounted as outlined in Section D-3.2. C_{sc}, in this case, is not multiplied by F_{cp}.

(3) Utilities costs are added to Phase I C_{dcs} costs if a vitrification plant is planned in Phase I or a sodium separations process is chosen.

(4) Additional CSSF costs are added to Phase I C_{dcs} costs if additional calcine waste generated requires use of CSSF 8. This cost is discounted as specified in Section D-3.2.

(5) Calcine handling costs are always added to Phase II C_{dcs} costs and are the cost of the transfer line from the CSSF to the new facility.

(6) Support upgrade for delayed vitrification C_{dcs} costs are added to Phase II C_{dcs} costs if a vitrification plant is planned in Phase II. If no new process is chosen in Phase I both utilities and support upgrade costs are added to Phase II C_{dcs}.

(7) Separations upgrade for calcine costs are added to Phase II C_{dcs} costs if either Precipitation or TRUEX is used during Phase II.

(8) Additional calcine retrieval costs are added to Phase II C_{dcs} costs if CSSF 7 or 8 are used. If both CSSF 7 and 8 are used, then retrieval costs are added for both. These costs are discounted as specified in Section D-3.2.

B-2.1 General Design, Construction, and Startup Costs

The following equation is used to calculate C_{dcsPI}, C_{dcsC}, C_{dcsPII}, C_{dcsHAW}, and C_{dcsLAW} for either Phase I or II, except for Glass Ceramic (see Section B-2.3).

$$C_{dcs} = (F_{cp})(C_{const})\left(\frac{T_h}{T_b}\right)^{0.6}$$

Where

F_{cp} = the factor to adjust construction cost to design, construction, and start-up cost, Table E-2

C_{const} = the estimated construction costs for a facility capable of handling the baseline throughput, from Table E-1

T_h = the needed throughput, from Section B-2.2

T_b = baseline throughput used for estimating construction costs of processing equipment and facilities, from Table E-1

0.6 = throughput rates are obtained by scaling according to the six tenths rule (0.6) [Williams, *Chem. Eng.*, *54(12) 1947, p. 124*].

NOTE: When calculating for HAW and LAW immobilization, T_b must be multiplied by the weighted average weight percent loading (WT_{AVG}), from Section B-2.1.1. Also, when calculating C_{dcsC}, $T_h = T_b$.

B-2.1.1 Weighted Average Weight Percent Loading

To calculate general DCS costs for HAW and LAW immobilization, T_b must be multiplied by the weighted average weight percent loading (WT_{AVG}). To determine WT_{AVG} use the following equation.

$$WT_{AVG} = \frac{(WT_{Na})(Na_{MT})(Na_{sep}) + (WT_{Al})(Al_{calcine})(Al_{sep}) + (WT_{Zr})(Zr_{calcine})(Zr_{sep})}{(Na_{MT})(Na_{sep}) + (Al_{calcine})(Al_{sep}) + (Zr_{calcine})(Zr_{sep})}$$

Where

WT_{Na} = sodium-bearing liquid waste weight percent loading, from Table E-5

Na_{MT} = metric tons of sodium-bearing liquid waste, from Section C-1

Na_{sep} = the sodium-bearing liquid waste separation factor, from Table E-3. Use the HAW separations factor when calculating HAW (WT_{AVG}) and the LAW separations factor when calculating LAW (WT_{AVG})

WT_{Al} = Aluminum calcine weight percent loading, from Table E-5

Al_{sep} = the Aluminum calcine separation factor, from Table E-3. This will be the HAW separation factor when calculating C_{dcsHAW} and the LAW separation factor when calculating C_{dcsLAW}.

WT_{Zr} = Zirconium calcine weight percent loading, from Table E-5

Zr_{sep} = the Zirconium waste separation factor, from Table E-3. This will be the HAW separation factor when calculating C_{dcsHAW} and the LAW separation factor when calculating C_{dcsLAW}.

$Al_{calcine}$ = metric tons of aluminum calcine, from Section C-2.1

$Zr_{calcine}$ = metric tons of zirconium calcine currently in inventory, from Table E-2

B-2.2 Needed Throughput

T_h is the actual throughput necessary in order to complete processing on schedule and is calculated by the following equation.

$$T_h = \frac{W_i}{(OPS_t)(365.25)(24)(0.75)(0.5)}$$

Where

W_i	=	current and projected radioactive waste inventory to be processed through the facility based on the waste stream, from Section B-2.2.1
OPS_t	=	the number of years the facility is available for operation for either Phase I (YI_{ops}) or Phase II (YII_{ops}), from Table B-1
365.25	=	number of days in a year
24	=	number of hours in a day
0.75	=	process efficiency
0.5	=	on-line efficiency

NOTE: The 0.5 on-line efficiency factor is omitted from the equation when calculating T_h for glass-ceramic.

B-2.2.1 Radioactive Waste Inventory

Two types of radioactive waste streams are being evaluated for the proposed WIF: radioactive liquid (before separation) and solid (after separation but prior to immobilization) waste. Throughputs for these two radioactive waste streams are calculated in Section B-2.2, but the input for the radioactive waste inventory (W_i) variable is different, as explained below. If the same technology is being used to process both radioactive liquid and calcine waste, then the actual throughput necessary equals the greater T_h of Phase I or Phase II.

W_i for Phase I radioactive liquid waste is calculated in liters by the following equation.

$$W_i = (Na_{liq})(1000)$$

Where

Na_{liq}	=	cubic meters of sodium-bearing liquid waste, from Section C-1
1000	=	liters per cubic meter

W_i for Phase II dissolved calcine waste is calculated in liters by the following equation.

$$W_i = (Al_{calcine})(12{,}700) + (Zr_{calcine})(5{,}000)$$

Where

$Al_{calcine}$	=	the metric tons of Aluminum calcine, from Section C-2.1
12,700	=	the liters of nitric acid required to dissolve one metric ton of Aluminum calcine
$Zr_{calcine}$	=	the metric tons of Zirconium calcine, from Table E-2
5,000	=	the liters of nitric acid required to dissolve one metric ton of Zirconium calcine

W_i for Phase I immobilization is calculated in kilograms by the following equation.

$$W_i = (Na_{MT})\ (Na_{Sep})\ (1000)$$

Where

Na_{MT}	=	the metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor when calculating C_{dcsHAW} and the LAW separation factor when calculating C_{dcsLAW}.
1000	=	kilograms per metric ton

W_i for Phase II immobilization is calculated in kilograms by the following equation.

$$W_i = [(Al_{calcine})\ (Al_{Sep}) + (Zr_{calcine})\ (Zr_{Sep})]\ (1000)$$

Where

$Al_{calcine}$	=	the metric tons of Aluminum calcine, from Section C-2.1
Al_{sep}	=	the Aluminum calcine separation factor, from Table E-3. This will be the HAW separation factor when calculating C_{dcsHAW} and the LAW separation factor when calculating C_{dcsLAW}.
$Zr_{calcine}$	=	the metric tons of Zirconium calcine, from Table E-2
Zr_{sep}	=	the Zirconium waste separation factor, from Table E-3. This will be the HAW separation factor when calculating C_{dcsHAW} and the LAW separation factor when calculating C_{dcsLAW}.
1000	=	kilograms per metric ton

B-2.3 C_{dcs} for Glass-Ceramic

A different equation is used for Glass-Ceramic C_{dcs} costs because its costs are tied directly to the incremental equipment required to increase the input, namely the need for additional Hot Isostatic Presses (HIPs). C_{dcs} costs for Glass-Ceramic (C_{GCdcs}) facility are calculated by the following equation.

$$C_{GCdcs} = [C_{scale} + (N_{HIP})\ (C_{HIP}) + C_{fill}]\ (F_{waste})\ (F_{cp})$$

Where

C_{scale}	=	the cost for the scalable portion of a Glass-Ceramic facility, from Section B-2.3.1
N_{HIP}	=	the number of HIPs, based on throughput (T_h), from Section B-2.3.5
C_{HIP}	=	the cost of a HIP, from Table E-2
C_{fill}	=	the cost for additional filling stations, from Section B-2.3.2
F_{waste}	=	the waste classification factor, from Section B-2.3.3
F_{cp}	=	the factor to adjust construction cost to design, construction, and start-up cost, Table E-2

B-2.3.1 Scalable Portion of a Glass-Ceramic Facility Cost

C_{scale} is the cost for the scalable portion of a Glass-Ceramic facility and is calculated by the following equation.

$$C_{scale} = (C_{GC})\ (N_{HIP})^{0.6}$$

Where

C_{GC}	=	the scalable cost for a Glass-Ceramic facility, from Section B-2.3.4
N_{HIP}	=	the number of HIPs, based on throughput (T_h), from Section B-2.3.5
0.6	=	throughput rates are obtained by scaling according to the six tenths rule (**0.6**) (Williams, *Chem. Eng.*, *54(12) 1947: p. 124*)

B-2.3.2 Filling Station Cost

C_{fill} is the cost of adding additional filling stations to a facility and is determined as follows, where one filling station is required for every four HIPs present. The number of HIPs (N_{HIP}) required for a given facility is found in Section B-2.3.5.

If $0 \leq N_{HIP} < 5$, then C_{fill} equals 0

If $5 \leq N_{HIP} < 9$, then C_{fill} equals \$10,000,000
If $9 \leq N_{HIP} < 13$, then C_{fill} equals \$20,000,000
If $13 \leq N_{HIP} < 17$, then C_{fill} equals \$30,000,000
If $17 \leq N_{HIP}$, then C_{fill} equals \$40,000,000

B-2.3.3 Radioactive Waste Classification Factor

F_{waste} is the radioactive waste classification factor and is determined based on the following.

If the waste classification is Class A, then F_{waste} equals 0.75
If the waste classification is Class B, then F_{waste} equals 0.85
If the waste classification is Class C or HAW, then F_{waste} equals 1

Class A will have reduced shielding and will allow for hands-on maintenance due to low levels of radioactivity. This is expected to lower the costs by 25%. Class B will also have reduced shielding, although levels of radioactivity (though relatively low) will be high enough to require remote handling capabilities for maintenance. This is expected to reduce costs by 15%.

B-2.3.4 Glass-Ceramic Facility Scalable Cost

The Process Development Facility (PDF) feasibility study showed a throughput of 48.3 kg/hr for a Glass plant costing \$80 million. Of this \$80 million, \$5 million was used as the cost for the melter used in the facility. The scalable portion of the facility cost is found by eliminating the melter cost (\$80,000,000 - \$5,000,000 = \$75,000,000). This cost was scaled to a Glass-Ceramic facility (GC_{HIP}) containing one HIP by the following equation.

$$GC_{HIP} = \left(\frac{T_{GC}}{48.3}\right)^{0.6} (scale)$$

Where

T_{GC}	=	Glass-Ceramic facility throughput in kg/hr, from Table E-2
48.3	=	Glass facility throughput in kg/hr from the PDF feasibility study
0.6	=	throughput rates are obtained by scaling according to the six tenths rule (0.6) [Williams, Chem. Eng., 54(12) 1947: p. 124]
scale	=	the scalable portion of the cost for a Glass-Ceramic facility, from Table E-2

This value (GC_{HIP}) is increased by 25% for blending stations and feed vessels required to handle solids. The resulting value is increased by an additional 25% for a

stabilizer and grinder required for solids processing. Adding these costs results in the scalable costs for a Glass-Ceramic facility (C_{GC}) as outlined by the following equation.

$$C_{GC} = (GC_{HIP})\ (1.25)\ (1.25)$$

Where

GC_{HIP}	=	the Baseline scaled cost for Glass-Ceramic facility, from equation above
1.25	=	25% increase

B-2.3.5 Number of HIPs

The number of HIPs (N_{HIP}) required for the Glass-Ceramic facility is calculated by the following equation.

$$N_{HIP} = [INTEGER\ (\frac{T_h}{(T_b)\ (WT_{AVG})}) + 1]\ (2)$$

Where

INTEGER	=	the integer function which truncates the resulting value into an integer
T_h	=	the needed throughput, from Section B-2.2
T_b	=	baseline throughput used for estimating construction costs of processing equipment and facilities, from Table E-1
WT_{AVG}	=	the weighted average weight percent loading, from Section B-2.1.1. The note in section B-2.1 indicates that T_b must be mutiplied by WT_{AVG}.
1	=	an additional factor that allows integer function to always round up
2	=	factor to increase the number of HIPs to allow for 50% online efficiency

B-3 Operating Cost

The total operating costs (C_{Tops}) for a selected option are determined by the following equation.

$$C_{Tops} = C_{opsPl} + C_{opsC} + C_{opsPll} + C_{opsLAW} + C_{opsHAW} + C_{OTHER}$$

Where

C_{opsPI}	=	operating cost for Phase I process, from Section B-3.1
C_{opsC}	=	operating cost for calciner, from Section B-3.1
C_{opsPII}	=	operating cost for Phase II process, from Section B-3.1
C_{opsLAW}	=	operating cost for LAW immobilization process, from Section B-3.1
C_{opsHAW}	=	operating cost for HAW immobilization process, from Section B-3.2
C_{OTHER}	=	other additional operating costs as described in Section B-3.3

B-3.1 General Operating Cost

Operating cost (C_{ops}) for Phase I, the calciner, Phase II, and LAW immobilization (C_{opsPI}, C_{opsC}, C_{opsPII}, and C_{opsLAW} respectively) are calculated by the following equation.

$$C_{ops} = (C_{matls} + C_{labor})\ OPS_t$$

Where

C_{matls}	=	the annual cost of materials and supplies during operations, from Section B-3.1.1
C_{labor}	=	annual labor costs to operate the facility, from Section B-3.1.2
OPS_t	=	the time the facility is available for operation for either Phase I (YI_{ops}) or Phase II (YII_{ops}), from Table B-1

B-3.1.1 Material Cost

The cost of materials during operations (C_{matls}) is calculated as a proportion of the labor cost and the throughput by the following equation.

$$C_{matls} = (F_{matR})(F_{matB})(\frac{T_h}{T_b})$$

Where

F_{matR}	=	the ratio of materials expenses to baseline material cost for facility operations, from Table E-1
F_{matB}	=	annual baseline process material cost factor, from Table E-2
T_h	=	needed throughput, from Section B-2.2
T_b	=	baseline throughput used for estimating construction costs and materials cost factors of processing equipment and facilities, from Table E-1

NOTE: When calculating for HAW and LAW immobilization, T_b must be multiplied by the weighted average weight percent loading (WT_{AVG}), from Section B-2.1.1.

B-3.1.2 Labor Cost

C_{labor}, the annual cost of labor to operate the facility, is calculated by the following equation.

$$C_{labor} = (N_o + N_{ao})(C_{oper})$$

Where

N_o	=	number of operators per shift, from Table E-1
N_{ao}	=	the number of additional operators per shift is determined as noted below
C_{oper}	=	annual cost per operator, from Table E-2

NOTE: To determine the number of additional operators per shift (N_{ao}) use the following, except when calculating HAW and LAW immobilization. In that event, T_b must be multiplied by the weighted average weight percent loading (WT_{AVG}), from Section B-2.1.1.

If $0 \leq (T_h/T_b) < 2$ then N_{ao} equals 0, If $2 \leq (T_h/T_b) < 3$ then N_{ao} equals 1, ... If $n + 1 \leq (T_h/T_b) < n + 2$ then N_{ao} equals n.

Certain cases, listed below, incur additional operators. The number of additional operators (N_{ao}) for these cases are found in Table E-1.

(1) If a vitrification plant is planned in Phase II and Freeze Crystallization, Precipitation, or TRUEX is used in Phase I then sodium transfer operators are added to N_{ao} when calculating operating costs for Phase I (C_{opsPI}).

(2) If the vitrification plant is planned in Phase II and there are Phase I separations then surge capacity to process operators are added to N_{ao} when calculating operating costs for Phase I (C_{opsPI}).

(3) Calcine handling operators are always added to N_{ao} when calculating operating costs for Phase II (C_{opsPII}).

(4) If Precipitation or TRUEX is used during Phase II then separations upgrade for calcine operators are added to N_{so} when calculating operating costs for Phase II (C_{opsPII}).

B-3.2 HAW Operating Cost

For HAW immobilization C_{opsHAW} is determined by the following equation.

$$C_{opsHAW} = [\, C_{matls} + [(C_{can})(NC_Y) + \frac{(C_{MPC})(NC_Y)}{N_{can}}] + C_{maint} + C_{labor} \,]\ OPS_t$$

Where

C_{matls}	=	annual cost of materials and supplies during operations, from Section B-3.1.1
C_{can}	=	cost of a one cubic meter canister, from Table E-2
NC_Y	=	number of canisters of immobilized waste per year, from Section B-3.2.1 for Phase I and Section B-3.2.2 for Phase II
C_{MPC}	=	cost for a multi-purpose canister, from Table E-2
N_{can}	=	the number of one cubic meter canisters held by a multi-purpose canister (over-pack canister for the one cubic meter canisters), from Table E-2
C_{labor}	=	annual labor costs to operate the facility, from Section B-3.1.2
C_{maint}	=	annual maintenance expenses for a facility, from Section B-3.2.3
OPS_t	=	the time the facility is available for operation for either Phase I (YI_{ops}) or Phase II (YII_{ops}), from Table B-1

B-3.2.1 Phase I Canisters

Phase I number of canisters of immobilized waste produced annually (NC_Y) is calculated by the following equation.

$$NC_Y = \frac{[(Na_{MT})\ (Na_{sep})]\,(1000)}{(F_{ef})\ (WT_{Na})\ (D_{HAW})\ (YI_{ops})\ (V_{CAN})}$$

Where

Na_{MT}	=	the metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor.
1000	=	kilograms per metric tons
F_{eff}	=	the canister filling efficiency factor, from Table E-2

WT_{Na}	=	sodium-bearing liquid waste weight percent loading, from Table E-5
D_{HAW}	=	density of the immobilized HAW, from Table E-6
YI_{ops}	=	the Phase I operating years, from Table B-1
V_{CAN}	=	the canister volume, from Table E-2

B-3.2.2 Phase II Canisters

Phase II number of canisters of immobilized waste produced annually (NC_Y) is calculated by the following equation.

$$NC_Y = \frac{\left[\frac{(Al_{calcine})\ (Al_{sep})}{WT_{Al}} + \frac{(Zr_{calcine})\ (Zr_{sep})}{WT_{Zr}}\right](1000)}{(F_{eff})\ (D_{HAW})\ (YII_{ops})(V_{CAN})}$$

Where

$Al_{calcine}$	=	the metric tons of Aluminum calcine, from Section C-2.1
Al_{sep}	=	the Aluminum calcine separation factor, from Table E-3. This will be the HAW separation factor.
WT_{Al}	=	Aluminum calcine weight percent loading, from Table E-5
$Zr_{calcine}$	=	the metric tons of Zirconium calcine, from Table E-2
Zr_{sep}	=	the Zirconium waste separation factor, from Table E-3. This will be the HAW separation factor.
WT_{Zr}	=	Zirconium calcine weight percent loading, from Table E-5
1000	=	kilograms per metric ton.
F_{eff}	=	the canister filling efficiency factor, from Table E-2
D_{HAW}	=	density of HAW, from Table E-6
YII_{ops}	=	the Phase II operating years, from Table B-1
V_{CAN}	=	the canister volume, from Table E-2

B-3.2.3 Maintenance Cost

C_{maint}, the annual maintenance costs for a facility, is calculated by the following equations for Glass and Glass-ceramic.

For Glass use the following equation.

$$C_{maint} = \frac{(N_{melt})\,(C_{gm} + C_{Mrep})\,\left(\frac{T_h}{(T_{Sb})(WT_{AVG})}\right)^{0.6}}{M_{freq}}$$

Where

N_{melt}	=	the number of melters, from Table E-2
C_{gm}	=	the cost of a glass melter, from Table E-2
C_{Mrep}	=	the cost for replacing a glass melter, from Table E-2
T_h	=	the needed throughput, from Section B-2.2
T_{Sb}	=	the Savannah River baseline throughput that matches the baseline melter replacement costs, from Table E-2
M_{freq}	=	maintenance frequency, from Table E-2
WT_{AVG}	=	weighted average weight percent loading, from Section B-2.1.1

For Glass-Ceramic use the following equation.

$$C_{maint} = \frac{(N_{HIP})(C_{HIP} + C_{Hrep})}{M_{freq}}$$

Where

N_{HIP}	=	number of HIPs, based on throughput (T_h), from Section B-2.3.5
C_{HIP}	=	the cost of a HIP, from Table E-2
C_{Hrep}	=	the cost for replacing a HIP, from Table E-2
M_{freq}	=	maintenance frequency, from Table E-2

B-3.3 Other Additional Operating Costs

Other additional operating costs (C_{OTHER}) are calculated using the following equation.

$$C_{OTHER} = C_{RET} + C_{nTFops} + C_{TFops} + C_{OWops} + C_{ECops}$$

Where

C_{RET}	=	the retreival cost for a CSSF, from Section B-3.3.1
C_{nTFops}	=	new tank farm operating cost, from Table E-2. If no new tank farm is needed, then $C_{nTFops} = 0$.
C_{TFops}	=	existing tank farm operating costs, from Table E-2
C_{OWops}	=	other waste operating costs, from Table E-2
C_{ECops}	=	cost of early calcination campaigns, from Section B-3.3.2

NOTE: These variables are discounted in Section D-3.3.

B-3.3.1 Retreival Operating Costs

Retrieval operating costs (C_{RET}) are determined by the following.

If neither CSSF 7 or 8 is used then C_{RET} equals zero.
If CSSF 7 is used then C_{RET} equals C_{Bops}, from Table E-2.
If CSSF 7 and 8 are used then C_{RET} equals two times C_{Bops}, from Table E-2.

To determine which CSSF's are used, see Section C-4. Retreival operating costs are discounted as described in Section D-3.3.

B-3.3.2 Early Calcination Operating Costs

Operating costs for early calcine campaigns (C_{ECops}) are calculated using the following equation.

$$C_{ECops} = [(F_{matR})(F_{matB}) + (N_o)(C_{oper})](Y_{endcal} - 1996)$$

Where

F_{matR}	=	the ratio of materials expenses to baseline material costs for facility operations, from Table E-1
F_{matB}	=	the annual baseline process material cost factor, from Table E-2
N_o	=	number of operators per shift, from Table E-1
C_{oper}	=	annual cost per operator, from Table E-2
Y_{endcal}	=	year early calcination ends, from Section C-5
1996	=	start date for early calcination

B-4 Interim Storage Cost

The interim storage costs (C_{Tstor}) are calculated based on the type of radioactive waste, years of storage, and capacity of the waste storage facility. The TEAM Model uses a default value of 7 for the years of storage. The waste storage facility will be sized to store the greater of the radioactive waste volume produced by either Phase I or II. Disposal cost ratios for the different waste classes were used to determine the effects of changes in radioactivity to the interim storage cost. This ratio is used to determine the operating costs for greater-than-Class A wastes. C_{Tstor} is calculated using the following equation.

$$C_{Tstor} = (OS_L)\ (Y_{Lstor}) + CS_L + (OS_H)\ (Y_{Hstor}) + CS_H$$

Where

OS_L = the annual interim storage operating cost for LAW, from Section B-4.1, B-4.2, and B-4.3

Y_{Lstor} = the number of operating years of the LAW storage facility, from Section B-4.4

CS_L = the interim storage capital cost for LAW, from Section B-4.5, B-4.6, and B-4.7

OS_H = the annual interim storage operating cost for HAW, from Section B-4.8

Y_{Hstor} = number of operating years of the HAW storage facility, from Section B-4.9

CS_H = the interim storage capital cost for HAW, from Section B-4.10

NOTE: Since there are three different LAW classifications, OS_L and CS_L are calculated based on the chosen waste classification as outlined below.

B-4.1 Class A Interim Storage Operating Cost

The interim storage operating cost for Class A wastes (OS_{LA}) is based on curve fit of data from *Waste Management Facilities Cost Information Report (EGG-WTD-10443)* and is calculated using the following equation.

$$OS_{LA} = 7.14(10^{-15})(V_{Lstor})^4 + 3.82(10^{-9})(V_{Lstor})^3 - 7.38(10^{-4})(V_{Lstor})^2 + 65.3(V_{Lstor}) + 1.51(10^5)$$

Where

V_{Lstor} = LAW storage volume available in cubic meters, from Section B-4.1.1

B-4.1.1 LAW Storage Volume

The maximum volume of LAW, in cubic meters, that can be stored by the interim storage facility (V_{Lstor}) is calculated by the following equation.

$$V_{Lstor} = \max\left[\frac{(V_{ILAW})(YS_{LCap})}{(YI_{ops})}, \frac{(V_{IILAW})(YS_{LCap})}{(YII_{ops})}\right]$$

Where

V_{ILAW} = the total volume of LAW produced, in cubic meters, during Phase I, from Section B-4.1.1.1

V_{IILAW} = the total volume of LAW produced, in cubic meters, during Phase II, from Section B-4.1.1.2

YI_{ops} = years duration of Phase I operations, from Table B-1

YII_{ops} = years duration of Phase II operations, from Table B-1
YS_{LCap} = number of years of storage capacity for LAW, from Table E-2

B-4.1.1.1 Total Phase I LAW Volume Produced

The total volume of immobilized LAW produced during Phase I (V_{ILAW}) operations is calculated by the following equation.

$$V_{ILAW} = \frac{(Na_{MT})\ (Na_{sep})\ (1000)}{(WT_{Na})\ (D_{LAW})}$$

Where

Na_{MT} = the metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep} = the sodium-bearing liquid waste separation factor, from Table E-3. This will be the LAW separation factor.
1000 = kilograms per metric ton
WT_{Na} = the weight loading for sodium-bearing liquid waste, from Table E-5
D_{LAW} = the density of LAW, from Table E-6

B-4.1.1.2 Total Phase II LAW Volume Produced

The total volume of immobilized LAW (m^3) produced during Phase II (V_{IILAW}) operations is calculated using the following equation.

$$V_{IILAW} = \frac{(Zr_{calcine})(Zr_{Sep})(1000)}{(WT_{Zr})(D_{LAW})} + \frac{(Al_{calcine})(Al_{Sep})(1000)}{(WT_{Al})(D_{LAW})}$$

Where

$Zr_{calcine}$ = the metric tons of Zirconium calcine, from Table E-2
Zr_{sep} = the Zirconium calcine separation factor, from Table E-3. This will be the LAW separation factor.
1000 = kilograms per metric ton
WT_{Zr} = the weight loading for Zirconium calcine, from Table E-5
D_{LAW} = the density of LAW, from Table E-6
$Al_{calcine}$ = the metric tons of Aluminum calcine, from Section C-2.1
Al_{sep} = the Aluminum calcine separation factor, from Table E-3. This will be the HAW separation factor.
WT_{Al} = the weight loading for Aluminum calcine, from Table E-5

B-4.2 Class B Interim Storage Operating Cost

Class B interim storage operating cost for LAW (OS_{LB}) is determined based on the ratio of Class B to Class A disposal costs. Disposal costs are \$20,000/m^3 for Class B and \$10,000/m^3 for Class A (a 2:1 ratio). Based on this ratio Class B annual storage operating costs are calculated as follows.

$$OS_{LB} = 2(OS_{LA})$$

B-4.3 Class C Interim Storage Operating Cost

Class C interim storage operating cost for LAW (OS_{LC}) is determined based on the ratio of Class C to Class A disposal costs. Disposal costs are \$110,000/m^3 for Class C and \$10,000/m^3 for Class A (an 11:1 ratio). Because this ratio gives a higher cost than HAW annual storage operating cost, OS_{LC} is based on the same curve fit of data, from the *Waste Management Facilities Costs Information Report for Greater-Than-Class C and DOE Equivalent Special Case Waste (EGG-WM-10701)*, as the HAW annual storage operating cost. OS_{LC} is calculated by the following equation.

$$OS_{LC} = 688(V_{Lstor}) + 3{,}170{,}000$$

Where

V_{Lstor} = the LAW volume produced in cubic meters, from Section B-4.1.1

B-4.4 Interim Storage Operating Years for LAW

Interim storage operating years for LAW facilities (Y_{Lstor}) are calculated by the following.

If a separation process is used in Phase I and Phase II then

$$Y_{Lstor} = DII_{ops} - DI_{ops} + YII_{ops}$$

Where

DII_{ops} = Phase II operation start date, from Table B-1
DI_{ops} = Phase I operation start date, from Table B-1
YII_{ops} = Phase II operating duration in years, from Table B-1

If Phase I has no separation processes and Phase II uses a separation process then

$$Y_{Lstor} = YII_{ops}$$

Where

YII_{ops} = Phase II operating duration in years, from Table B-1

If Phase II has no separation processes and Phase I uses a separation process then

$$Y_{Lstor} = DII_{ops} - DI_{ops} + YS_{LCap}$$

Where

DII_{ops} = Phase II operation start date, from Table B-1
DI_{ops} = Phase I operation start date, from Table B-1
YS_{LCap} = years of LAW storage capacity, from Table E-2

If no separation processes are used in Phase I or Phase II then

$$Y_{Lstor} = 0$$

B-4.5 Interim Storage Capital Cost for Class A

Interim storage capital costs for Class A LAW (CS_{LA}) are based on curve fit of data from *Waste Management Facilities Cost Information Report (EGG-WTD-10443)*. They are calculated using the following equation.

$$CS_{LA} = 1{,}130(V_{Lstor}) + 20{,}000{,}000$$

Where

V_{Lstor} = the LAW volume produced in cubic meters, from Section B-4.1.1

B-4.6 Interim Storage Capital Cost for Class B

Class B interim storage capital costs for LAW (CS_{LB}) are determined based on the ratio of Class B to Class A disposal costs. Disposal costs are \$20,000/m^3 for Class B and \$10,000/m^3 for Class A (a 2:1 ratio). Based on this ratio CS_{LB} is calculated as follows.

$$CS_{LB} = 2(CS_{LA})$$

B-4.7 Interim Storage Capital Cost for Class C

Interim storage capital costs for Class C waste (CS_{LC}), is based on the same curve fit of data, from the *Waste Management Facilities Costs Information Report for Greater-Than-Class C and DOE Equivalent Special Case Waste (EGG-WM-10701)*, as the HAW annual storage operating cost. CS_{LC} is calculated by the following equation.

$$CS_{LC} = 31{,}500(V_{Lstor}) + 42{,}100{,}000$$

Where

V_{Lstor} = the LAW volume produced in cubic meters, from Section B-4.1.1

B-4.8 HAW Interim Storage Operating Cost

The interim storage operating cost for HAW (OS_H) is based on curve fit of data from *Waste Management Facilities Costs Information Report for Greater-Than-Class C and DOE Equivalent Special Case Waste (EGG-WM-10701)* and is calculated by the following equation.

$$OS_H = 688(CAN_{Hstor}) + 3{,}170{,}000$$

Where

CAN_{Hstor} = number of HAW canisters filled, from Section B-4.8.1

B-4.8.1 HAW Canisters Produced

The maximum number of canisters of HAW that can be stored by the interim storage facility (CAN_{Hstor}) is calculated by the following equation.

$$CAN_{Hstor} = \frac{\max\left[\dfrac{(V_{IHAW})(YS_{Hcap})}{(YI_{ops})}, \dfrac{(V_{IIHAW})(YS_{Hcap})}{(YII_{ops})}\right]}{F_{ef}}$$

Where

V_{IHAW} = the volume of HAW produced, in cubic meters, during Phase I, from Section B-4.8.1.1

V_{IIHAW} = the volume of HAW produced, in cubic meters, during Phase II, from Section B-4.8.1.2

YI_{ops} = years duration of Phase I operations, from Table B-1

YII_{ops} = years duration of Phase II operations, from Table B-1

YS_{HCap} = number of years of storage capacity for HAW, from Table E-2
F_{eff} = canister filling efficiency, from Table E-2

B-4.8.1.1 Phase I HAW Volume

The volume of immobilized HAW (m^3) produced during Phase I operations (V_{IHAW}) is calculated by the following equation.

$$V_{IHAW} = \frac{(Na_{MT})(Na_{Sep})(1000)}{(WT_{Na})(D_{HAW})}$$

Where

Na_{MT} = the metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep} = the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor.
1000 = kilograms per metric ton
WT_{Na} = the weight loading for sodium-bearing liquid waste, from Table E-5
D_{HAW} = the density of HAW, from Table E-6

B-4.8.1.2 Phase II HAW Volume

The volume of immobilized HAW (m^3) produced during Phase II (V_{IIHAW}) operations is calculated by the following equation.

$$V_{IIHAW} = \frac{(Zr_{calcine})(Zr_{Sep})(1000)}{(WT_{Zr})(D_{HAW})} + \frac{(Al_{calcine})(Al_{Sep})(1000)}{(WT_{Al})(D_{HAW})} + T_{si} + \frac{(Na_{MT})(Na_{Sep})(1000)}{(WT_{Na})(D_{HAW})}$$

Where

$Zr_{calcine}$ = the metric tons of Zirconium calcine, from Table E-2
Zr_{sep} = the Zirconium calcine separation factor, from Table E-3. This will be the HAW separation factor.
1000 = kilograms per metric ton
WT_{Zr} = the weight loading for Zirconium calcine, from Table E-5
D_{HAW} = the density of HAW, from Table E-6
$Al_{calcine}$ = the metric tons of Aluminum calcine, from Section C-2.1
Al_{sep} = the Aluminum calcine separation factor, from Table E-3. This will be the HAW separation factor.

WT_{Al}	=	the weight loading for Aluminum calcine, from Table E-5
T_{si}	=	if a silica calciner is used to solidify HAW from Phase I, then the total silica calcine produced is calculated as outlined in Section C-2.2, otherwise T_{si} equals zero.
Na_{MT}	=	if a Vitrification facility is planned for Phase I and the selected technology for Phase I is TRUEX, then the metric tons of sodium-bearing liquid waste is calculated as outlined in Section C-1, otherwise Na_{MT} equals zero.
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor.

B-4.9 Interim Storage Operating Years for HAW (YH_{stor})

If the HAW vitrification plant is built in Phase I then

$$Y_{Hstor} = DII_{ops} - DI_{ops} + YII_{ops}$$

Where

DII_{ops}	=	Phase II operation start date, from Table B-1
DI_{ops}	=	Phase I operation start date, from Table B-1
YII_{ops}	=	Phase II operating duration, in years, from Table B-1

If the HAW vitrification plant is built in Phase II then

$$Y_{Hstor} = YII_{ops}$$

Where

YII_{ops}	=	Phase II operating duration, in years, from Table B-1

B-4.10 Interim Storage Capital Cost for HAW

For HAW interim storage capital costs (CS_H) filling efficiencies of 0.85 for Glass and 0.775 for Glass-Ceramic are assumed *(WDB-08-92, "Estimated Immobilized HLW and Sodium-bearing Waste Volumes Based on Current Waste Inventories")*. CS_H is based on curve fit of data from *Waste Management Facilities Costs Information Report for Greater-Than-Class C and DOE Equivalent Special Case Waste (EGG-WM-10701)* and is calculated by the following equation.

$$CS_H = [31{,}500(CAN_{Hstor}) + 42{,}100{,}000]\ (N_{fac})$$

Where

CAN_{Hstor}	=	number of HAW canisters filled, from Section B-4.8.1
N_{fac}	=	the number of HAW interim storage facilities required as summarized in Section B-4.10.1

B-4.10.1 Number of HAW Storage Facilities

N_{fac} is determined by the following equation.

$$N_{fac} = INTEGER\ [\frac{(Y_{rep} - DII_{ops})}{YS_{HCap}}] + 1$$

Where

INTEGER	=	the integer function which truncates the resulting value into an integer
Y_{rep}	=	the date the HAW repository opens, from Table E-2
DII_{ops}	=	Phase II operations start date, from Table B-1
YS_{HCap}	=	years of HAW storage capacity, from Table E-2

B-5 Disposal Costs

Total disposal costs (C_{Tdisp}) for immobilized waste from a selected option were determined by the following equation.

$$C_{Tdisp} = (\frac{WASTE}{DUR})\ (C_{waste}) \sum_{Y_c = SD}^{SD + DUR} [1 + (Y_c - 1995)(F_{incr})]$$

Where

WASTE	=	total amount of radioactive waste to be immobilized (m^3), from Section B-5.1
DUR	=	the duration of disposal in years, from Section B-5.1
C_{waste}	=	cost of waste disposal per m^3, from Table E-7
SD	=	the start date of disposal, from Section B-5.1
Y_c	=	current year for which disposal costs are calculated (Y_c ranges from SD to SD + DUR)
F_{incr}	=	annual increase factor, from Table E-7

NOTE: C_{Tdisp} for HAW includes an additional charge for transporting the final waste form to an approved disposal site (C_{trans}). C_{trans} is calculated by the following equation, then added to the C_{tdisp} equation above, for HAW disposal only .

$$C_{trans} = \frac{\left(\frac{V_{IHAW} + V_{IIHAW}}{0.0283}\right)}{50} 4.9\ (760) + 2480\ \frac{\left(\frac{V_{IHAW} + V_{IIHAW}}{0.0283}\right)}{50}$$

Where

V_{IHAW} = the volume of HAW produced, in cubic meters, during Phase I, from Section B-4.8.1.1

V_{IIHAW} = the volume of HAW produced, in cubic meters, during Phase II, from Section B-4.8.1.2

The transportation costs equation was taken from *Waste Management Facilities Cost Information for Transportation of Radioactive Materials (EGG-WM-10877)*. Numerical values used in the equation are defined below.

- 0.0283 converts m^3 to ft^3
- 50 ft^3 of immobilized waste per shipment
- 4.9 dollars per mile to transport the immobilized waste
- 760 miles to Yucca Mountain from the ICPP
- 2480 dollars of fixed costs per shipment

B-5.1 Disposal Timing

The disposal timing for LAW and HAW is determined by the following.

For LAW

If there is Phase I separations and no Phase II separations, then:

SD = DI_{LDisp}, from Section D-5.5
DUR = YI_{LDisp}, from Section D-5.5
WASTE = V_{ILAW}, from Setion B-4.1.1.1

If there is Phase II separations and no Phase I separations, then:

SD = DII_{LDisp}, from Section D-5.5
DUR = YII_{LDisp}, from Section D-5.5
WASTE = V_{IILAW}, from Setion B-4.1.1.2

If there is Phase I and II separations, then add the disposal costs for Phase I and II.

For HAW

If the HAW vitrification facility is planned for Phase I, then the total disposal cost (C_{Tdisp}) equals the sum of Phase I and Phase II C_{Tdisp}, as calculated in Section B-5. If the HAW vitrification facility is planned for Phase II, then C_{Tdisp} equals Phase II C_{Tdisp} only.

For Phase I HAW disposal cost

SD	=	DI_{HDisp}, from Section D-4.5
DUR	=	YI_{HDisp}, from Section D-4.5
WASTE	=	V_{IHAW} divided by F_{eff}, from Setion B-4.8.1.1 and Table E-2, respectively

For Phase II HAW disposal cost

SD	=	DII_{HDisp}, from Section D-4.5
DUR	=	YII_{HDisp}, from Section D-4.5
WASTE	=	V_{IIHAW} divided by F_{eff}, from Setion B-4.8.1.2 and Table E-2, respectively

B-6 Decontamination and Decommissioning Costs

The Decontamination and Decommissioning (D&D) expenditure is spread over five years starting at the conclusion of operations. The D&D cost (C_{Tdd}) for a selected option is estimated as 18% of Design, Construction, and Start-up costs using the following equation.

$$C_{Tdd} = (F_{dd})(C_{Tdcs})$$

Where

F_{dd}	=	the D&D factor, from Table E-2
C_{Tdcs}	=	the total cost for design, construction, and start-up, from Section B-2

APPENDIX C: RADIOACTIVE WASTE VOLUMES

C-1 Amount of Sodium-bearing Liquid Waste

The cubic meters of Sodium-bearing liquid waste to be processed (Na_{liq}) by the selected option is calculated by the following equation.

$$Na_{liq} = \frac{(V_{TF} + V_{Igen})\ (3.785)}{1000}$$

Where

V_{TF}	=	tank farm volume from Section C-1.1
V_{Igen}	=	volume of waste generated between startup of Phase I and startup of Phase II, from Section C-1.2
3.785	=	liters per gallon
1000	=	liters per cubic meter

Removing the water and nitrates, the mass of metal oxides, in metric tons, in the Sodium-bearing liquid waste (Na_{MT}) is calculated by the following equation.

$$Na_{MT} = (Na_{liq})\ (0.1192)$$

Where

Na_{liq}	=	the cubic meters of Sodium-bearing liquid waste, from equation above
0.1192	=	the metric tons of metal oxides per cubic meter of Sodium-bearing liquid waste

C-1.1 Current Tank Farm Volumes

Tank Farm volumes (V_{TF}, in gallons) during the life-cycle of a selected option are calculated using the following equation.

$$V_{TF} = INV_{TF} - V_{pcal} + \sum_{1994}^{Y_{endcal}} V_{add}$$

Where

INV_{TF}	=	current Tank Farm inventory after evaporation by the High-level Liquid Waste Evaporator (HLLWE), from Table E-2
V_{pcal}	=	volume processed by the calciner, from Section C-1.1.2

Y_{endcal} = the year early calcination ends, from Section C-5
V_{add} = waste volume added, from Section C-1.1.1

C-1.1.1 Annual Volume Added

The annual volume added (V_{add}, in gallons) to existing radioactive waste inventory for a specific year, is calculated by the following equation.

$$V_{add} = \frac{V_{WNa}}{R_{FNa}} + \frac{V_{WH+}}{R_{FH+}} + V_{addc} + V_{FL}$$

Where

V_{WNa} = Sodium waste volume, from Table E-8
R_{FNa} = Sodium waste reduction factor, from Table E-8
V_{WH+} = acid volume, from Table E-8
R_{FH+} = acid reduction factor, from Table E-8
V_{addc} = solution generated as a result of calciner operations from Section C-1.1.1.1
V_{FL} = volume of waste generated by the filter leach process, from Section C-1.1.1.2

C-1.1.1.1 Annual Solution Generated

Annual solution generated (V_{addc}, in gallons) is calculated by the following equation.

$$V_{addc} = (C_{dep})\ (T_{cm}) + (T_{cm})\ (\frac{N_{bd}}{T_{camp}})\ (V_{bed})$$

Where

C_{dep} = gallons per month deep recycle returned to calciner, from Table E-2
T_{cm} = calciner operating months during a given calendar year, from Table E-8
N_{bd} = number of calciner bed dissolution per campaign, from Table E-2
T_{camp} = number of months the calciner campaign occurs, from Table E-2
V_{bed} = the gallons per bed dissolution, from Table E-2

C-1.1.1.2 Filter Leach Volume

The volume of radioactive waste generated by the filter leach process (V_{FL}, in gallons) for a specific year is calculated by the following equation.

$$V_{FL} = N_{EF} \left(\frac{420}{13.14}\right) + (N_{OF} + N_{CF}) \left(\frac{420}{15.71}\right)$$

Where

N_{EF}	=	the number of existing filters (as of 1993) processed during the year being calculated, from Table E-4
420	=	the volume (in gallons) generated by processing one filter
13.14	=	the evaporation factor for existing filters
N_{OF}	=	the number of other filters generated for a specific year, from Table E-4
N_{CF}	=	the number calcine filters generated for a specific year, from Table E-4
15.71	=	the evaporation factor for newly generated filters

C-1.1.2 Volume Processed by Calciner

The volume processed by the calciner (V_{pcal}, in gallons) during the life-cycle of a selected option is calculated by the following equation.

$$V_{pcal} = (R_1)\,(T_{camp})\,(30.4)\,(24) + (R_2)\,(T_{camp})\,(30.4)\,(24)\,(N_{camp} - 1)$$

Where

R_1	=	net processing rate for the first calciner campaign in gallons per hour, from Section C-1.1.2.1
T_{camp}	=	number of months a calciner campaign is run, from Table E-2
30.4	=	days per month
24	=	hours per day
R_2	=	net processing rate for any calcine campaigns following the first, from Section C-1.1.2.2
N_{camp}	=	number of calciner campaigns, from Table E-2

C-1.1.2.1 Net Processing Rate for First Calciner Campaign

The net processing rate for the first calciner campaign (R_1) beyond the 1993 campaign, in gallons per hour, is a weighted average.

It is calculated using the following equation.

$$R_1 = \frac{(R_{B1})\ (P_{B1}) + (R_{B2})\ (P_{B2}) + (R_{B3})\ (P_{B3})}{P_{B1} + P_{B2} + P_{B3}}$$

Where

R_{B1}	=	rate of blend 1 for first campaign, from Section C-1.1.2.1.1
P_{B1}	=	gallons of blend 1 processed during first campaign, from Section C-1.1.2.1.2
R_{B2}	=	rate of blend 2 for first campaign, from Section C-1.1.2.1.1
P_{B2}	=	gallons of blend 2 processed during first campaign, from Section C-1.1.2.1.2
R_{B3}	=	rate of blend 3 for first campaign, from Section C-1.1.2.1.1
P_{B3}	=	gallons of blend 3 processed during first campaign, from Section C-1.1.2.1.2

C-1.1.2.1.1 Blend Rate Calculations

The following equations are used to calculate the three blend rates used during the first campaign, in gallons per hour.

Blend rate 1 (R_{B1})

$$R_{B1} = \frac{(G_r)\ (0.75) - (G_r)\ (0.75)\ (0.15)}{B1_r}$$

Where

G_r	=	the gross feed rate, from Table E-2
0.75	=	the calciner efficiency
0.15	=	the internal calciner recycle for sodium-bearing liquid waste
$B1_r$	=	blend rate 1, from Table E-2

Blend rate 2 (R_{B2})

$$R_{B2} = \frac{(G_r)\ (0.75) - (G_r)\ (0.75)\ (0.15)}{B2_r}$$

Where

G_r	=	the gross feed rate, from Table E-2
0.75	=	the calciner efficiency
0.15	=	the internal calciner recycle for sodium-bearing liquid waste
$B2_r$	=	blend rate 2, from Table E-2

Blend rate 3 (R_{B3})

$$R_{B3} = \frac{(G_r)\ (0.75)\ -\ (G_r)\ (0.75)\ (0.15)}{B3_r}$$

Where

G_r	=	the gross feed rate, from Table E-2
0.75	=	the calciner efficiency
0.15	=	the internal calciner recycle for sodium-bearing liquid waste
$B3_r$	=	blend rate 3, from Table E-2

C-1.1.2.1.2 Gallons Processed

The following equations are used to calculate the gallons processed for each of the three blend rates during the first campaign.

Gallons of blend 1 processed (P_{B1})

$$P_{B1} = (B1_{er})\,[(B_r)\ (V_{183}) + V_{183}]$$

Where

$B1_{er}$	=	the rate of evaporation for blend 1, from Table E-2
B_r	=	the blend ratio of WM189 to WM183, from Table E-2
V_{183}	=	the volume of waste currently in WM183 tank, from Table E-2

Gallons of blend 2 processed (P_{B2})

$$P_{B2} = [V_{189} - (B_r)\ (V_{183})] + [\frac{V_{189} - (B_r)\ (V_{183})}{B_r}]\ (B2_{er})$$

Where

V_{189}	=	the volume of waste currently in WM189 tank, from Table E-2
B_r	=	the blend ratio of WM189 to WM183, from Table E-2
V_{183}	=	the volume of waste currently in WM183 tank, from Table E-2
$B2_{er}$	=	the rate of evaporation for blend 2, from Table E-2

Gallons of blend 3 processed (P_{B3})

$$P_{B3} = [(T_{camp})(30.4)(24) - (\frac{P_{B1}}{R_{B1}} + \frac{P_{B2}}{R_{B2}})]\ (R_{B3})$$

Where

T_{camp}	=	number of months a calciner campaign runs, from Table E-2
P_{B1}	=	the gallons of blend 1 processed, from section C-1.1.2.1.2
R_{B1}	=	blend 1 rate, from section C-1.1.2.1.1
P_{B2}	=	the gallons of blend 2 processed, from section C-1.1.2.1.2
R_{B2}	=	blend 2 rate, from section C-1.1.2.1.1
30.4	=	days per month
24	=	hours per day
R_{B3}	=	blend 3 rate, from section C-1.1.2.1.1

C-1.1.2.2 Net Processing Rate for Any Additional Campaigns

The net processing rate for any additional calciner campaigns (R_2, in gallons per hour) is calculated using the following equation.

$$R_2 = \frac{(G_r)\ (0.75) - (G_r)\ (0.75)\ (0.015)}{B3_r}$$

Where

G_r	=	the gross feed rate, from Table E-2
0.75	=	the calciner efficiency
0.015	=	the internal calciner recycle for sodium-bearing liquid waste
$B3_r$	=	the blend rate 3, from Table E-2

C-1.2 Volume of Radioactive Wastes Generated

The volume of radioactive waste generated (in gallons) between startup of Phase I and startup of Phase II is calculated by the following equation.

$$V_{lgen} = \sum_{DI_{ops}}^{DII_{ops}} \left[\frac{V_{WNa}}{R_{FNa}} + \frac{V_{WH+}}{R_{FH+}} + V_{FL} \right]$$

Where

DII_{ops}	=	Phase II operation start date, from Table B-1
DI_{ops}	=	Phase I operation start date, from Table B-1
V_{WNa}	=	Sodium waste volume, from Table E-8
R_{FNa}	=	Sodium waste reduction factor, from Table E-8
V_{WH+}	=	acid volume, from Table E-8
R_{FH+}	=	acid reduction factor, from Table E-8
V_{FL}	=	volume of waste generated by the filter leach process, from Section C-1.1.1.2

C-2 Annual and Accumulated New Calcine Waste Inventories

There are two possible accumulated new calcine waste inventories. First is the inventory generated from Aluminum calcine (Section C-2.1) and second is the inventory generated from Silica calcine (Section C-2.2).

C-2.1 Total Aluminum Calcine Generated

The total amount of Aluminum calcine ($Al_{calcine}$), metric tons, generated is calculated by the following equation.

$$Al_{calcine} = (Al_{INV} + Al_{new})\ (1.1)$$

Where

Al_{INV}	=	cubic meters of Aluminum calcine in current inventories (CSSF 1 & 2), from Table E-2
Al_{new}	=	the additional calcine generated using Aluminum nitrate, from Section C-2.1.1
1.1	=	the density of Aluminum calcine in metric tons per cubic meter

C-2.1.1 Additional Calcine Waste Generated

The additional calcine waste generated (Al_{new}), in metric tons, using Aluminum nitrate is calculated by the following equation.

$$Al_{new} = [Calc_{c1} + (Calc_{c2})\ (N_{camp} - 1)]\ (1.1) + Calc_{nt}$$

Where

$Calc_{c1}$	=	calcine generated annually during the first calciner campaign, from Section C-2.1.1.1
$Calc_{c2}$	=	calcine generated annually during the second calciner campaign, from Section C-2.1.1.2
N_{camp}	=	number of calciner campaigns, from Table E-2
1.1	=	metric tons per cubic meter
$Calc_{nt}$	=	calcine generated form new technology, from Section C-2.1.1.3

C-2.1.1.1 Calcine Waste Generated During First Campaign

The calcine waste generated annually during the first calciner campaign ($Calc_{c1}$, in cubic meters) is calculated using the following equation.

$$Calc_{c1} = \left[\frac{(P_{B1})\ (C_{B1}) + (P_{B2})\ (C_{B2}) + (P_{B3})\ (C_{B3})}{P_{B1} + P_{B2} + P_{B3}}\right] \left[\frac{(T_{camp})\ (24)\ (30.4)\ (3.785)\ (R_1)}{1000}\right]$$

Where

P_{B1}	=	gallons of blend 1 processed, from section C-1.1.2.1.2
C_{B1}	=	number of liters of calcine generated for each liter of waste processed during campaign 1, from Table E-2
P_{B2}	=	gallons of blend 2 processed, from section C-1.1.2.1.2
C_{B2}	=	number of liters of calcine generated for each liter of waste processed during campaign 2, from Table E-2
P_{B3}	=	gallons of blend 3 processed, from section C-1.1.2.1.2
C_{B3}	=	number of liters of calcine generated for each liter of waste processed during campaign 3, from Table E-2
T_{camp}	=	number of months a calciner campaign is run, from Table E-2
24	=	hours per day
30.4	=	days per month
3.785	=	liters per gallon
R_1	=	net processing rate for the first calciner campaign in gallons per hour, from Section C-1.1.2.1
1000	=	liters per cubic meter

C-2.1.1.2 Calcine Waste Generated During Second Campaign

The calcine waste generated annually during the second calciner campaign ($Calc_{c2}$, in cubic meters) is calculated using the following equation.

$$Calc_{c2} = \frac{(C_{B3})\ (T_{camp})\ (24)\ (30.4)\ (3.785)\ (R_2)}{1000}$$

Where

C_{B3}	=	number of liters of calcine generated for each liter of waste processed during campaign 3, from Table E-2
T_{camp}	=	number of months a calciner campaign is run, from Table E-2
24	=	conversion from days to hours
30.4	=	days per month
3.785	=	liters per gallon

R_2	=	The net processing rate for any calciner campaigns beyond the first, from Section C-1.1.2.2
1000	=	liters per cubic meter

C-2.1.1.3 Calcine Waste Generated From New Technology

Calcine waste generated from new technology ($Calc_{nt}$, in metric tons) is calculated by the following equation.

$$Calc_{nt} = (Na_{MT})\ (Na_{sep})\ (M_{ac})$$

Where

Na_{MT}	=	metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor.
M_{ac}	=	Aluminum calcine multiplier, from Table E-2

C-2.2 Silica Calcine

If a silica calciner is used to solidify HAW from Phase 1, the total immobilized silica calcine produced (T_{si}, in cubic meters) is calculated using the following equations, otherwise T_{si} equals zero.

If the amount of silica needed for immobilization (M_{silica}) > the amount of silica from silica calcine ($Si_{calcine}$), then

$$T_{si} = \frac{(Na_{MT})(Na_{Sep})(1000)}{(WT_{Zr})(D_{HAW})}$$

If, however, $M_{silica} \leq Si_{calcine}$, then

$$T_{si} = \frac{[(M_{MTform}) + (Si_{calcine} - M_{silica})]\ (1000)}{(WT_{si})(D_{HAW})}$$

Where

M_{silica}	=	kgs of silica needed for immobilization, from Section C-2.2.1
$Si_{calcine}$	=	amount of silica from silica calcine, from Section C-2.2.3
Na_{MT}	=	metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor.
1000	=	kilograms per metric ton
WT_{Zr}	=	the weight loading for Zirconium calcine, from Table E-5

D_{HAW} = the density of HAW, from Table E-6
M_{MTform} = metric tons of waste form to be silica calcined, from Section C-2.2.2
WT_{Si} = the weight loading from silica calcine, from Table E-5

C-2.2.1 Silica Needed

The amount of silica needed, in kgs, is calculated by the following equation.

$$M_{silica} = (M_{MTform})(WT_{si})(1000)$$

Where

M_{MTform} = metric tons of waste form to be calcined, from Section C-2.2.2
WT_{Si} = the weight loading for silica calcine, from Table E-5
1000 = kilograms per metric ton

C-2.2.2 Amount of Radioactive Waste Form to be Silica Calcined

The amount of radioactive waste form to be silica calcined, in metric tons, is calculated by the following equation.

$$M_{MTform} = \frac{(Na_{MT})(Na_{Sep})}{WT_{si}} + \left(\frac{Al_{calcine}}{WT_{Al}}\right) + \left(\frac{Zr_{calcine}}{WT_{Zr}}\right)$$

Where

Na_{MT} = metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep} = the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor.
WT_{Si} = the weight loading for silica calcine, from Table E-5
$Al_{calcine}$ = metric tons of aluminum calcine, from Section C-2.1
WT_{Al} = the weight loading of aluminum calcine, from Table E-5
$Zr_{calcine}$ = amount of zirconium calcine in metric tons, from Table E-2
WT_{Zr} = the weight loading for zirconium calcine, from Table E-5

C-2.2.3 Silica From Silica Calcine

The amount of silica from silica calcine, in metric tons, is calculated by the following equation.

$$Si_{calcine} = (M_{sc} - 1)(Na_{MT})(Na_{Sep})$$

Where

M_{sc}	=	silica calcine multiplier, from Table E-2
Na_{MT}	=	metric tons of sodium-bearing liquid waste, from Section C-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table E-3. This will be the HAW separation factor.

C-3 Additional Needed Surge Capacity

Additional needed surge capacity (Cp_{add}, in gallons) is the maximum value of surge capacity needed annually (Cp_{na}, in gallons) which is calculated by the following equation.

$$Cp_{na} = V_{TF} - Cp_{TF}$$

Where

V_{TF}	=	the current Tank Farm volume, from Table C-1.1
Cp_{TF}	=	the current Tank Farm capacity, from Section C-3.1

The year the new tank farm space is needed (TF_Y) is calculated by steping through and calculating Cp_{na} for 1995, 1996, ... and so on. The year Cp_{na} becomes positive is the year the new tank farm space or surge capacity is needed (TF_Y).

C-3.1 Current Tank Farm Capacity

The current Tank Farm capacity (Cp_{TF}, in gallons) for a given year is calculated by the following equation.

$$Cp_{TF} = (N_{tnks})\ (285{,}000) + Cp_{st}$$

Where

N_{tnks}	=	number of available tanks currently on-line in the Tank Farm, from Table E-8
285,000	=	current ICPP single tank capacity, gal/tank
Cp_{st}	=	the additional available capacity of the selected technology, from Section C-3.1.1

C-3.1.1 Available Capacity from Selected Technology

The available capacity of the selected technology (Cp_{st}) is determined by the following.

> Any new technology built during Phase I will contain a 300,000 gallon surge capacity in Phase I. This surge capacity is added in the year Phase I operations start (DI_{opt}). If new technology is not built during Phase I, then no surge capacity will be added.

C-4 CSSF 7 and 8

As Tank Farm volumes (V_{TF}) are processed by the calciner, CSSF 6, 7, and 8 , in that order, are filled. Based on the needed volumes, the TEAM Model returns a value of "yes" or "no" for each of the two new CSSF (7 & 8). Currently CSSF 6 has a remaining capacity of 1449 cubic meters (1594 metric tons). CSSF 7 construction is complete and CSSF 8 does not yet exist, but would be constructed in time to meet additional storage needs. Both CSSF 7 and 8 have current capacities of 1784 cubic meters (1962 metric tons). The years that CSSF 7 and 8 are needed are calculated and then used in the cost calculations to properly distribute the operations, retrieval, and D&D costs throughout the life cycle of a selected option.

Use of CSSF 7 is determined by comparing Al_{new} to 1594 metric tons. If Al_{new} is greater than or equal to 1594 metric tons, then CSSF 7 is going to be used. If Al_{new} is greater than or equal to 3556 metric tons then CSSF 8 will be built and used.

If CSSF 8 needs to be used, $B8_Y$ is determined by using the equation for Al_{new} in Section C-2.1.1. Calculate Al_{new} for N_{camp} = 1, 2, 3, ... until Al_{new} is greater than or equal to 3556 metric tons. Then use N_{camp} to look up the year that campaign number starts in Table E-8. The year that campaign number ends is $B8_Y$.

C-5 Year Early Calcination Ends

The year early calcination ends is determined from Table E-8. The number of early calcination campaigns is a user input to the model (N_{camp}). This campaign number is shown as a column in Table E-8. The year corresponding to the last occurance of the desired campaign number is Y_{endcal}. (For example, for 2 campaigns, Y_{endcal} = 2000.)

APPENDIX D: TIME DISCOUNTING OF COSTS

This appendix provides discussion on time discounting of costs and provides the equations and methodology for discounting. DOE Order 1360.8A (Analysis of Benefits and Costs for Information Technology Resources Initiatives) recommends following the Office of Management and Budget (OMB) directions for time discounting dollars, and the OMB circular A-11 recommends using a real discount rate of 2.8% for a cost analysis spanning 30 years or more. The analysis performed by the TEAM Model, based on a 2.8% discount rate as recommended by OMB, is a real cost analysis, meaning inflation is left out. Section D-1 provides the basis for present value calculations; the remainder of Appendix D outlines calculations for determining when costs will be incurred. This enables construction of cost time profiles and time discounting of costs to enable present value (1995 dollars) comparisons of candidate radioactive waste treatment processes.

D-1 Present Value Discounting

D-1.1 Future Value to Present Value

The equation below is used to discount a future value to a present value.

$$PV = (FV)\ \frac{1}{(1 + i)^n}$$

Where

PV	=	present value
FV	=	future value
i	=	discount rate (0.028, per period)
n	=	number of periods

D-1.2 Annuity to Present Value

A series of equal payments over several years (i.e., an annuity) can also be discounted to present value using the following equation.

$$PV = (A)\ \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

Where

PV	=	present value
A	=	annuity
i	=	discount rate (0.028, per period)
n	=	number of periods

Several dates and years are used in the model to calculate years when costs are incurred. Figure D-1 shows a summary of these timing variables as defined in Table B-1.

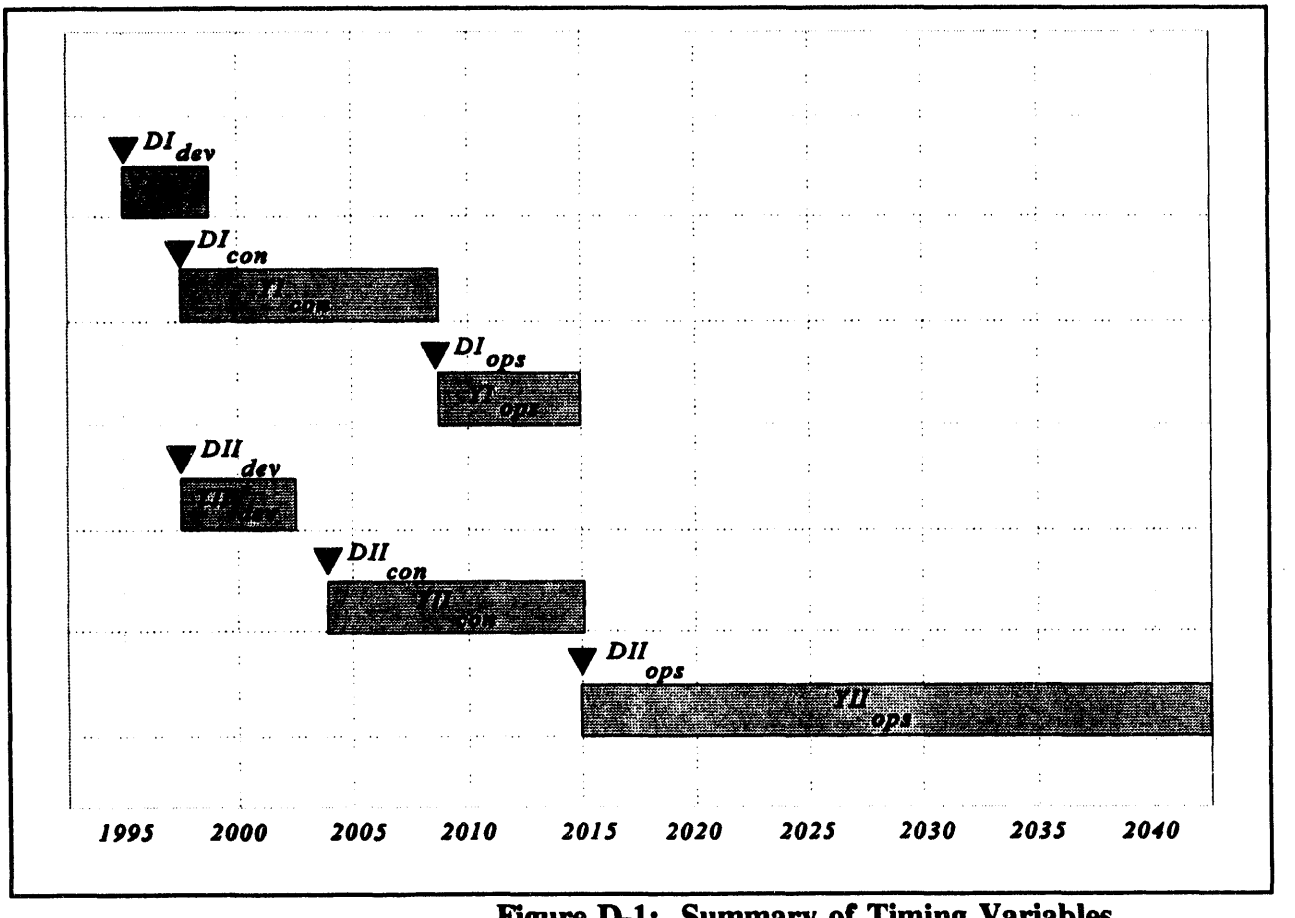


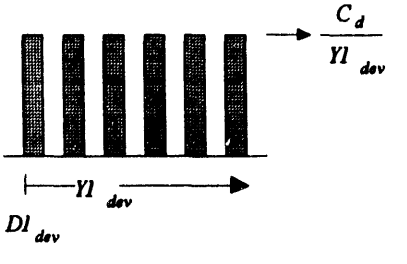
Figure D-1: Summary of Timing Variables

D-2 Time Discounting for Radioactive Liquid and Calcine Waste Processing

Time discounting for radioactive liquid and calcine waste processing can be performed by multiplying the total cost for a particular year by the discount factor for that year (see Section D-1). This same method is used to calculate time discounting for the Calciner (section D-3) and for HAW and LAW Immobilization (Sections D-4 and D-5).

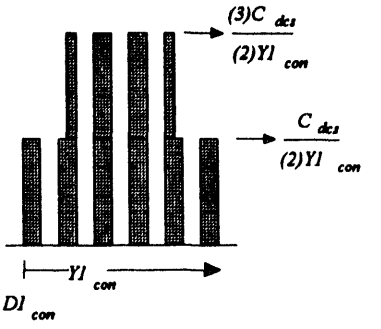
D-2.1 Phase I (Sodium Processing) Development Costs

The Phase I development costs are spread evenly over the YI_{dev} time period starting in the DI_{dev} year, per Table B-1, and can be calculated by dividing development costs (C_d) from Section B-1.1, by years of development (YI_{dev}) for Phase I.



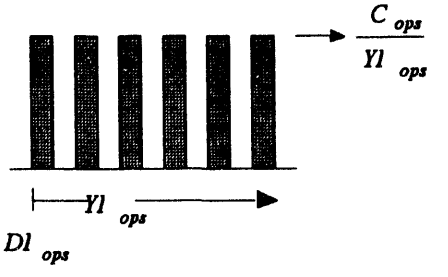
D-2.2 Phase I (Sodium Processing) Design, Construction, and Startup Costs

The Phase I design, construction, and startup costs are spread over the YI_{con} time period starting in the DI_{con} year, per Table B-1. Half of the cost (C_{dcs}) from Section B-2.1, are spread out evenly over YI_{con} lifetime, and the other half are spread over the middle half of YI_{con}. This cost profile approximates the spending over a typical construction period.



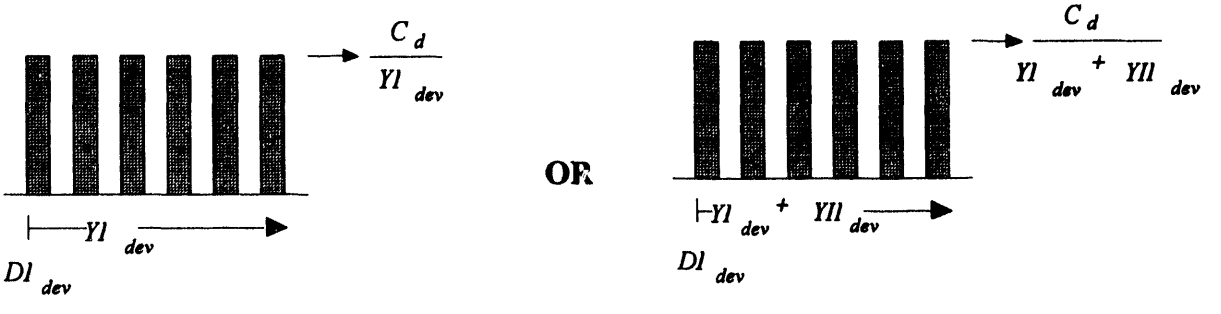
D-2.3 Phase I (Sodium Processing) Operating Costs

The Phase I operating costs are spread evenly over the YI_{ops} time period starting in the DI_{ops} year, per Table B-1, and can be calculated by dividing operating costs (C_{ops}) from Section B-3.1, by years of operation (YI_{ops}) for Phase I.



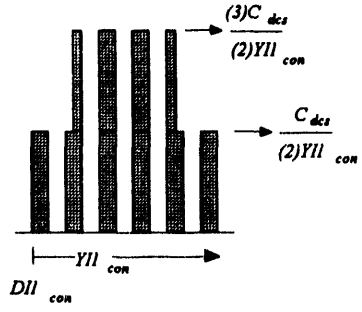
D-2.4 Phase II (Calcine Processing) Development Costs

The Phase II development costs (C_d) from Section B-1.1, are spread out evenly over Phase I (YI_{dev}) and/or Phase II (YII_{dev}) development time periods, per Table B-1. If the Phase II process is utilized for Phase I processing, then all development costs are accrued in Phase I and the Phase II development cost is zero. If, however, the Phase II process is not used during Phase I, then development occurs and development costs are charged during both Phase I and Phase II time periods.



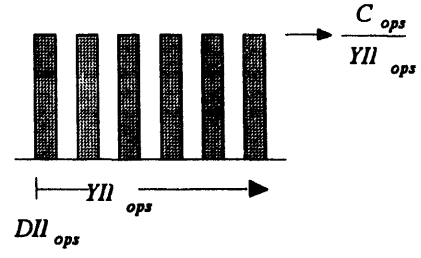
D-2.5 Phase II (Calcine Processing) Design, Construction, and Startup Costs

The Phase II design, construction, and startup costs are spread over the YII_{con} time period starting in the year DII_{con}, per Table B-1. Half of the DCS costs (C_{dcs}) from Section B-2.1 are spread evenly over YII_{con}, and the other half are spread over the middle half of YII_{con}. This cost profile approximates the spending over a typical construction period.



D-2.6 Phase II (Calcine Processing) Operating Costs

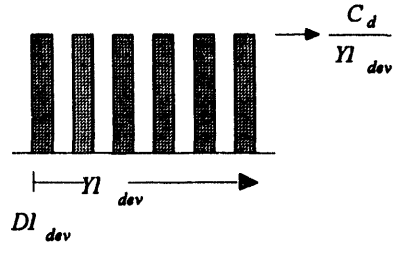
The Phase II operating costs are spread evenly over the YII_{ops} time period starting in the year DII_{ops}, per Table B-1, and can be calculated by dividing operating costs (C_{ops}) from Section B-3.1, by the operations years (YII_{ops}) for Phase II.



D-3 Calciner Time Discounting

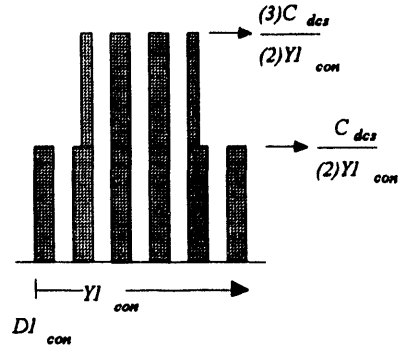
D-3.1 Calciner Development Costs

The calciner development costs are spread evenly over the YI_{dev} time period starting in the DI_{dev} year, per Table B-1, and can be calculated by dividing development costs (C_d) from Section B-1.1, by years of calciner development (YI_{dev}). Since solidification of HAW into calcine is a Phase I process, Phase I time periods and start-up dates are utilized for calciner calculations.



D-3.2 Calciner Design, Construction, and Startup Costs

The Calciner design, construction, and startup costs are spread over the YI_{con} time period starting in the DI_{con} year, per Appendix B, Table B-1. Half of the costs (C_{dcs}) from Section B-2.1 are spread evenly over the YI_{con} lifetime and the other half are spread over the middle half of YI_{con}. This cost profile approximates the spending over a typical construction period.



Additional C_{dcs} costs are incurred as follows.

1) Additional surge capacity costs (C_{sc}) are divided evenly over the number of years necessary to build a CSSF or tank farm (BT_Y) starting in the year the surge capacity (or new tank farm) is needed (TF_Y). If there is a new process in phase I, then C_{sc} = $100,000,000 (the cost for 300,000 gal. surge capacity, from Table E-1). If, however, there is no new process in Phase I, then C_{sc} are determined by the equation in section B-2, Note (2).

   The date upon which additional C_{sc} costs begin to incur is determined as follows.

$$StartDate = TF_Y - BT_Y$$

   Where

   TF_Y = the year surge capacity (or new tank farm) is needed, from Section C-3

   BT_Y = the number of years to build a CSSF or tank farm, from Table E-2

2) If CSSF 8 is used, then additional CSSF costs (Section B-2, note 4) are divided evenly over the number of years to build a CSSF or tank farm (BT_Y), starting in the year CSSF 8 is needed ($B8_Y$). The date upon which costs begin to incur is determined as follows.

$$StartDate = B8_Y - BT_Y$$

   Where

   $B8_Y$ = the year CSSF 8 is needed, from Section C-4

   BT_Y = the number of years to build a CSSF or tank farm, from Table E-2

3) Also, if CSSF 8 is used, then the calcine retrieval costs are divided evenly over the number of years of calcine retrieval (CR_Y), starting at the end of Phase II operations. The date upon which costs begin to incur is determined as follows.

$$StartDate = DII_{ops} + YII_{ops} - CR_Y$$

   Where

   DII_{ops} = the date Phase II operations start, from Table B-1

   YII_{ops} = the years of duration of Phase II operations, from Table B-1

   CR_Y = the number of years of calcine retrieval, from Table E-2

4) If CSSF 7 is used, then the calcine retrieval costs are divided evenly over the number of years of calcine retrieval (CR_Y) starting at the end of Phase II operations. The date upon which costs begin to incur is determined as follows.

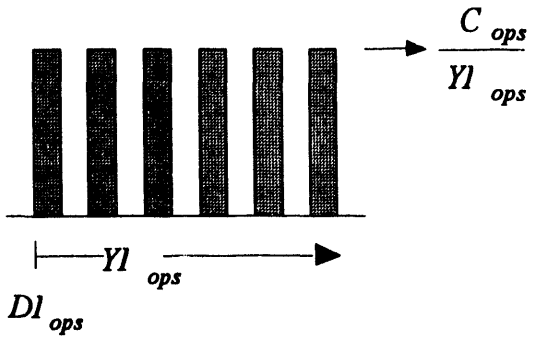
$$StartDate = DII_{ops} + YII_{ops} - CR_Y$$

Where

DII_{ops} = the date Phase II operations start, from Table B-1
YII_{ops} = the years of duration of Phase II operations, from Table B-1
CR_Y = the number of years of calcine retrieval, from Table E-2

D-3.3 Calciner Operating Costs

The Phase I operating costs are spread evenly over the YI_{ops} time period starting in the DI_{ops} year, per Table B-1, and can be calculated by dividing operating costs (C_{ops}) from Section B-3.1, by the calciner operations years (YII_{ops}).



NOTE: Additional calciner operating costs are incurred via the following circumstances and are discounted as specified below.

1) If CSSF 7 is used, then the CSSF retrieval operating costs (C_{Bops}) are divided evenly over the number of years of calcine retrieval (CR_Y) starting at the end of Phase II operations. The date upon which C_{Bops} begin to incur is determined as follows.

$$StartDate = DII_{ops} + YII_{ops} - CR_Y$$

Where

DII_{ops} = date Phase II operations start, from Table B-1
YII_{ops} = years of duration of Phase II operations, from Table B-1
CR_Y = number of years of calcine retrieval, from Table E-2

2) If CSSF 8 is used, then the CSSF retrieval operating cost (C_{Bops}) is divided evenly over the number of years of calcine retrieval (CR_Y) starting at the end of Phase II operations. The date upon which C_{Bops} begin to incur is determined as follows.

$$StartDate = DII_{ops} + YII_{ops} - CR_Y$$

Where

DII_{ops} = date Phase II operations start, from Table B-1
YII_{ops} = years of duration of Phase II operations, from Table B-1
CR_Y = number of years of calcine retrieval, from Table E-2

3) If the additional surge capacity needed (Cp_{add}) is greater than 300,000 gallons, then new tank farm operating costs (C_{nTFops}), from Table E-2, are incurred over the number of years difference between the end of operations and the year the tank farm is needed (TF_Y) starting in the year the tank farm is needed (TF_Y). End of operations is determined by adding the Phase II start date (DIIops) to the number of Phase II operations years (YII_{ops}); hence, the number of years over which C_{nTFops} are incurred is determined as follows.

$$Number\ of\ Years = (DII_{ops} + YII_{ops}) - TF_Y$$

Where

DII_{ops} = Phase II operations start date, from Table B-1
YII_{ops} = years of duration of Phase II operations, from Table B-1
TF_Y = year new tank farm space is needed. This equals 2000 unless user chooses not to comply with the Court Order; in that event TF_y is equal to the values from Section C-3.

4) Existing Tank Farm operating costs (C_{TFops}), from Table E-2, are incurred over the number of years difference between the year the existing Tank Farm goes out of commission (Y_{TFout}) and 1995 via the following equation.

$$Number\ of\ Years = Y_{TFout} - 1995$$

Where

1995 = start date for incurred costs

Y_{TFout} = year existing Tank Farm goes out of commission, from Table E-2

5) Other waste operating costs (C_{OWops}), from Table E-2, are incurred over the number of years difference between 1995 and the end of Phase II operations. End of operations is determined by adding the Phase II start date (DIIops) to the number of Phase II operations years (YII_{ops}); hence, the number of years over which C_{OWops} are incurred is determined as follows.

$$Number\ of\ Years = (DII_{ops} + YII_{ops}) - 1995$$

Where

1995 = start date for incurred costs

DII_{ops} = Phase II operations start date, from Table B-1

YII_{ops} = years of duration of Phase II operations, from Table B-1

6) Early calcination operating costs (C_{ECops}, from Section B-3.3.2) are incurred over the number of years difference between the start date of the next calcination campaign (1996) and the end of early calcination (Y_{endCal}), per the following equation.

$$Number\ of\ Years = Y_{endcal} - 1996$$

Where

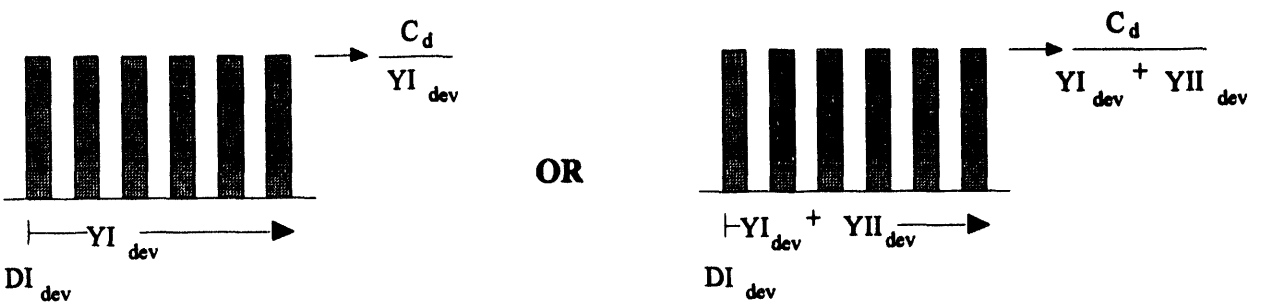
Y_{endcal} = end of early calcine campaigns, from Section C-5

1996 = start date of early calcination campaigns

D-4 HAW Immobilization Time Discounting

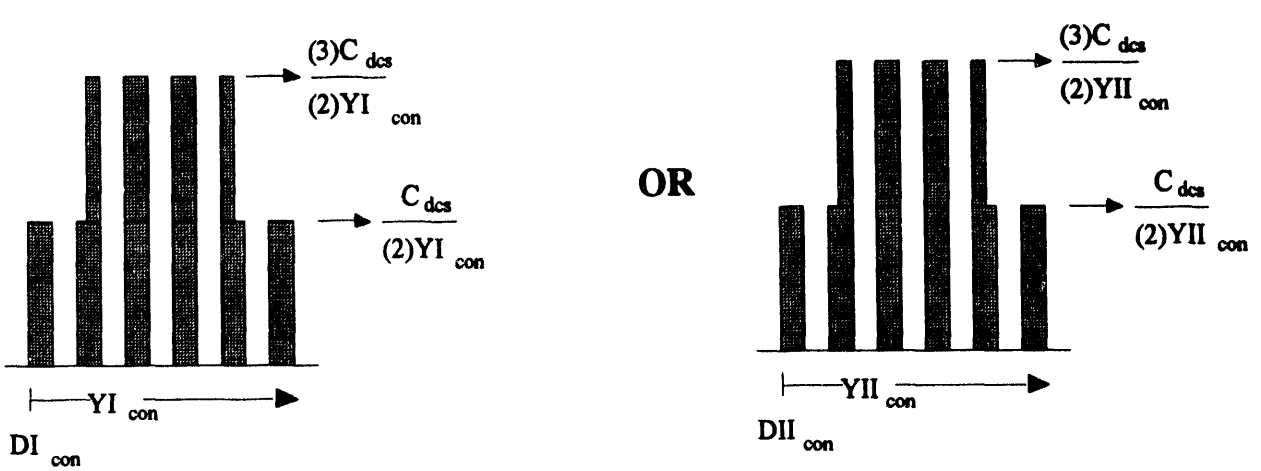
D-4.1 HAW Immobilization Development Costs

The HAW immobilization development costs (C_d) from Section B-1.1, are spread out evenly over Phase I (YI_{dev}) and/or Phase II (YII_{dev}) development time periods, per Table B-1. If the vitrification plant is planned for Phase II, then the development costs are charged for Phase I and Phase II. If, however, the vitrification plant is planned for Phase I, then development costs are charged for Phase I only.



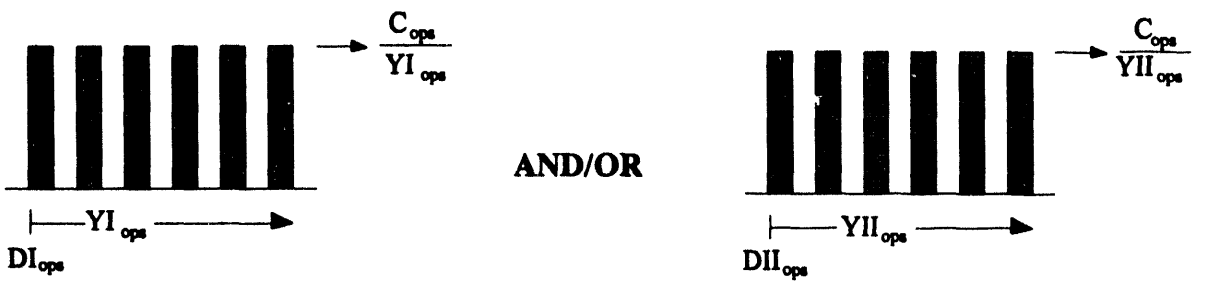
D-4.2 HAW Immobilization Design, Construction, and Startup Costs

Design, construction, and startup costs for HAW immobilization are spread over either the Phase I or the Phase II construction time period depending upon which phase the HAW immobilization facility is planned for. The design, construction, and startup costs are distributed the same as C_{dcs} shown previously, half over the YI_{con} or YII_{con} lifetime and the other half over the middle years only.



D-4.3 HAW Immobilization Operating Costs

The HAW Immobilization operating costs are spread evenly over the Phase I or the Phase II construction time period depending on which phase the HAW immobilization plant is planned for. If the vitrification plant is planned for Phase I, then operating cost are charged for Phase I and Phase II. If, however, the vitrification plant is planned for Phase II, then operating cost are charged for Phase II only.



D-4.4 HAW Immobilization Interim Storage Costs

D-4.4.1 HAW Interim Storage Capital Costs

The HAW interim storage capital costs (CS_H) from Section B-4.10 are charged out over the number of interim storage construction years prior to start-up of storage facility operations (Y_{sCon}). The date upon which CS_H begins to incur is determined as follows.

If a vitrification plant is planned for Phase I, then

$$StartDate - DI_{ops} - Y_{sCon}$$

Where

DI_{ops} = start date for Phase I operations, from Table B-1
Y_{sCon} = years of interim storage construction, from Table E-2

If a vitrification plant is planned for Phase II, then

$$Start\ Date - DII_{ops} - Y_{sCon}$$

Where

D_{IIops} = start date for Phase II operations, from Table B-1
Y_{sCon} = years of interim storage construction, from Table E-2

HAW interim storage capital costs (CS_H) from Section B-4.10 are divided by the years of storage construction (Y_{sCon}), from Table E-2, to determine per year capital expenses.

D-4.4.2 HAW Interim Storage Operating Costs

The yearly HAW storage operating costs (OS_H) from Section B-4.8 are charged out over the years of operations as follows.

If a vitrification plant is planned for Phase I, then OS_H costs begin to incur on the Phase I operations start date (DI_{ops}) and continue to the end of Phase II operations. The total number of years over which OS_H costs are charged out is determined by the following equation.

$$Number\ of\ Years = (DII_{ops} - DI_{ops}) + YII_{ops}$$

Where

DII_{osp} = start date for Phase II operations, from Table B-1
DI_{ops} = start date of Phase I operations, from Table B-1
YII_{ops} = years of Phase II operations, from Table B-1

If a vitrification plant is planned for Phase II, then OS_H costs begin to incur on the Phase II start date (DII_{ops}) and continue throughout Phase II operations years (YII_{ops}).

D-4.5 HAW Disposal Costs

HAW disposal costs have an annual increase factor (F_{incr}) based on the increasing cost of regulatory requirements. For each year disposal costs are incurred, the additional disposal cost (C_{add}) for the respective year is added to the disposal cost per cubic meter of radioactive waste (C_{waste}). C_{add} starts at 0 in 1995 and increases by F_{incr} each of the following years.

If a vitrification plant is planned for Phase I, yearly disposal costs are incurred for Phase I and for Phase II as described later in this section. Phase I disposal costs are calculated via the following equation.

$$Yearly\ Disposal\ Cost = \frac{(V_{IHAW})}{(F_{eff})(YI_{HDisp})}(C_{waste})\,[1 + (Y_c - 1995)(F_{incr})]$$

Where

V_{IHAW}	=	the volume of HAW produced, in cubic meters, during Phase I, from Section B-4.8.1.1
F_{eff}	=	canister filling efficiency, from Table E-2
YI_{HDisp}	=	number of years of Phase I HAW disposal as defined below
C_{waste}	=	cost of waste disposal per m^3, from Table E-7
Y_c	=	current year for which disposal cost is being calculated
F_{incr}	=	annual increase factor, from Table E-7

The date upon which HAW disposal costs begin to incur (DI_{HDisp}) is determined by adding the start date of Phase I operations (DI_{ops}) from Table B-1 to the years of storage capacity for HAW (YS_{HCap}) from Table E-2 as follows.

$$DI_{HDisp} = DI_{ops} + YS_{HCap}$$

The number of years over which disposal costs are incurred, in the event of a Phase I vitrification plant (YI_{HDisp}), is then determined by the following equation.

$$YI_{HDisp} = DI_{ops} + YI_{ops} - DI_{HDisp}$$

Where

DI_{ops}	=	start date for Phase I operations, from Table B-1
YI_{ops}	=	years of Phase I operations, from Table B-1
DI_{HDisp}	=	date when HAW disposal costs begin, from Section D-4.5 (above)

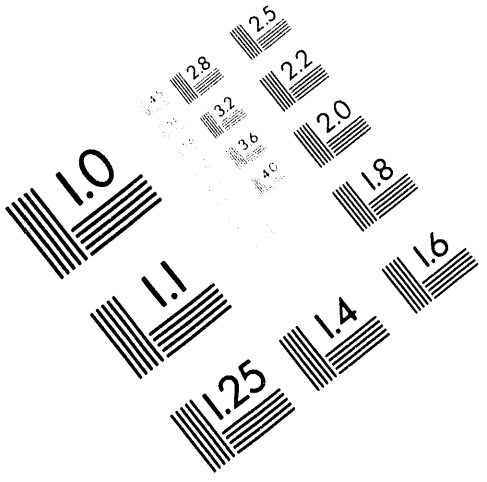
NOTE: If the repository is not open by the start date of disposal, then the start date slips until the repository is open ($DI_{HDisp} = Y_{rep}$, from Table E-2). The minimum YI_{HDisp} is 2.

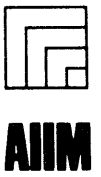
Phase II disposal costs are always incurred. Yearly disposal costs for Phase II are calculated via the following equation.

$$Yearly\ Disposal\ Cost = \frac{(V_{IIHAW})}{(F_{eff})(YII_{HDisp})}(C_{waste})\,[1 + (Y_c - 1995)(F_{incr})]$$

Where

V_{IIHAW}	=	the volume of HAW produced, in cubic meters, during Phase I, from Section B-4.8.1.2
F_{eff}	=	canister filling efficiency, from Table E-2
YII_{HDisp}	=	number of years of Phase I HAW disposal as defined below
C_{waste}	=	cost of waste disposal per m^3, from Table E-7





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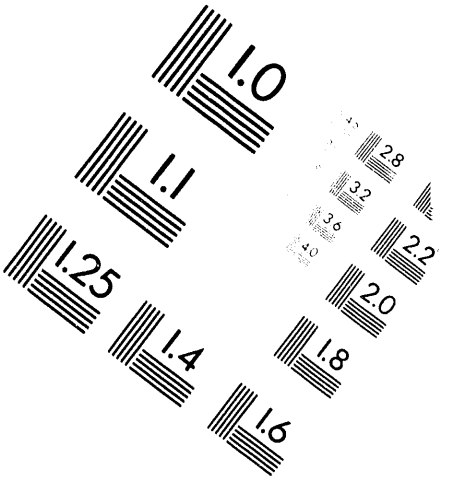

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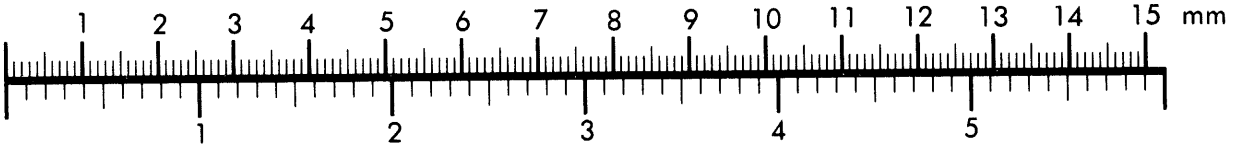
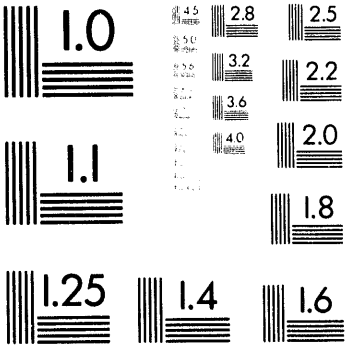
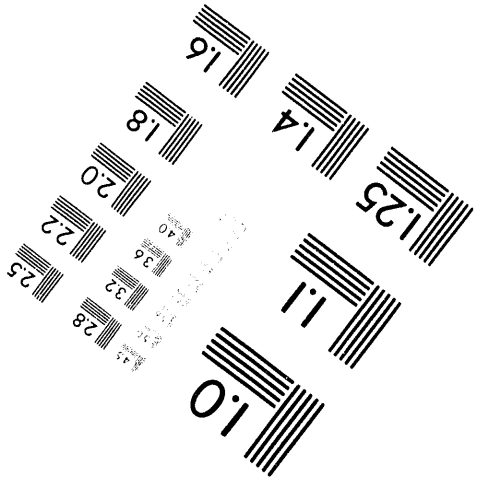
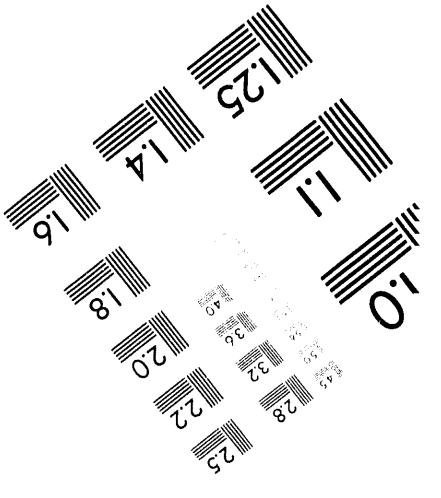


Inches







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Y_c = current year for which disposal cost is being calculated
F_{incr} = annual increase factor, from Table E-7

The date upon which HAW disposal costs begin to incur (DII_{HDisp}) is determined by adding the start date of Phase II operations (DII_{ops}) from Table B-1 to the years of storage capacity for HAW (YS_{HCap}) from Table E-2 as follows.

$$DII_{HDisp} = DII_{ops} + YS_{HCap}$$

The number of years over which disposal costs are incurred (YII_{HDisp}), in the event of a Phase II vitrification plant, is by subtracting YS_{HCap} from the years of Phase II operations (YII_{ops}) as follows.

$$YII_{HDisp} = DII_{ops} + YII_{ops} - DII_{HDisp}$$

Where
DII_{ops} = start date for Phase II operations, from Table B-1
YII_{ops} = years of Phase II operations, from Table B-1
DII_{HDisp} = start date for HAW disposal costs, from Section 4.5 (above)

NOTE: If the repository is not open by the start date of disposal, then the start date slips until the repository is open ($DII_{HDisp} = Y_{rep}$, from Table E-2). The minimum YII_{HDisp} is 2.

D-4.5.1 Transportation Costs

The transportation cost (C_{trans}) portion of HAW disposal costs are discounted differently than overall disposal costs. C_{trans} is divided evenly over the number of years for which transportation costs are incurred.

$$Number\ of\ Years = YII_{ops} - YS_{HCap}$$

Where
YII_{ops} = number of years of Phase II operations, from Table B-1
YS_{HCap} = years of HAW storage capacity, from Table E-2

The date upon which transportation costs begin to incur is determined by the following equation.

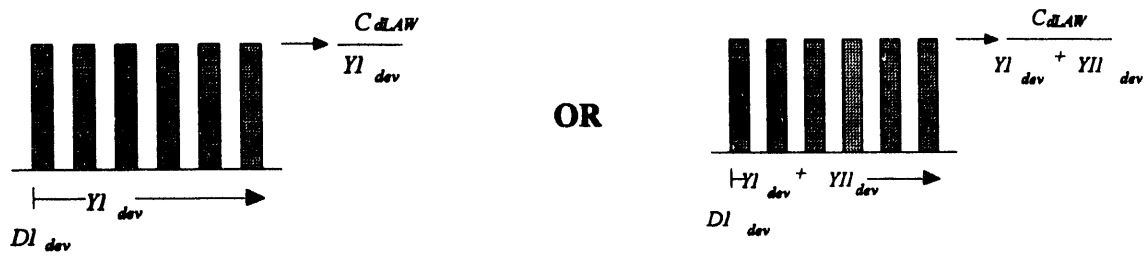
$$Start\ Date = DII_{ops} + YS_{HCap}$$

Where
DII_{ops} = Start Date of Phase II operations, from TableB-1
YS_{HCap} = years of HAW storage capacity, from Table E-2

D-5 LAW Immobilization Time Discounting

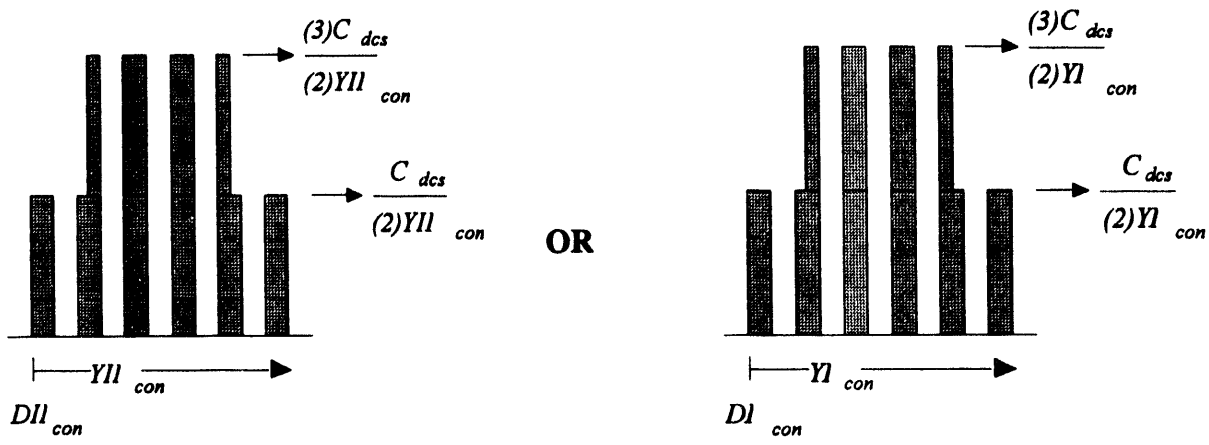
D-5.1 LAW Immobilization Development Costs

LAW immobilization development costs (C_d) from Section B-1.1, are spread out evenly over Phase I (YI_{dev}) and/or Phase II (YII_{dev}) development time periods, per Table B-1. If a separation process is planned for Phase I, then development costs are charged for Phase I only. If, however, a separation process is planned for Phase II and not Phase I, then development costs are charged for both Phase I and Phase II.



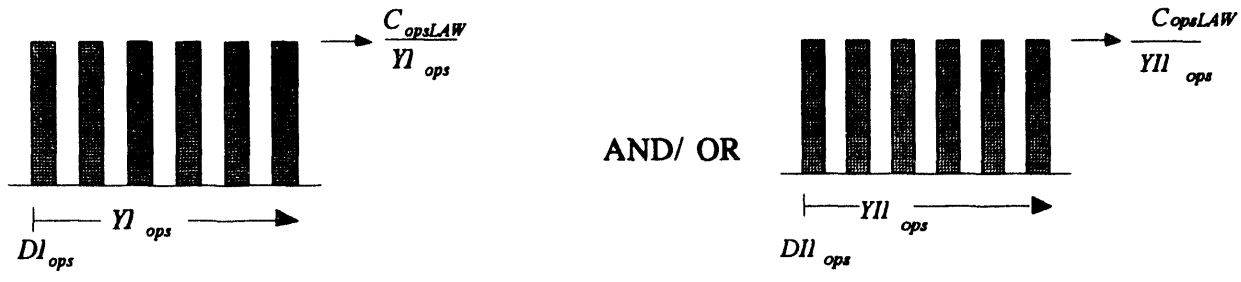
D-5.2 LAW Immobilization Design, Construction, and Startup Costs

LAW immobilization design, construction, and startup costs, per Section B-2.1, are spread over either the Phase I or the Phase II construction time period depending on whether or not a separations process is used in Phase I. If Phase I uses a separation process then the DCS cost (C_{dcs})is charged over the Phase I construction period. If Phase I does not use a separation process and Phase II does, then C_{dcs} is charged over the Phase II construction period. If no separation process is used, then there is no construction cost. The design, construction, and startup costs are distributed the same as shown previously, half over the YI_{con} or YII_{con} lifetime and the other half over the middle years only.



D-5.3 LAW Immobilization Operating Costs

LAW immobilization operating costs (C_{ops}), per Section B-3.1, are spread over the Phase I or the Phase II construction time period depending on whether or not a separations process is used in Phase I. If Phase I uses a separation process, then the operating cost is charged over the Phase I operating period only. If Phase I does not use a separation process and Phase II does, then the operating cost is charged over the Phase II operating time period only. If, however, there is a separation process in Phase I and Phase II, then the operating cost is charged over both Phases. If no separation process is used then there is no operating cost.



D-5.4 LAW Immobilization Interim Storage Costs

D-5.4.1 LAW Interim Storage Capital Costs

The LAW interim storage capital costs (CS_L) from Sections B-4.5, B-4.6, and B-4.7 are charged out over the number of interim storage construction years prior to start-up of storage facility operations (Y_{sCon}). The date upon which CS_L begin to incur is determined as follows.

If a separations process is used during Phase I, then

$$StartDate - DI_{ops} - Y_{sCon}$$

Where

DI_{ops} = start date for Phase I operations, from Table B-1
Y_{sCon} = number of interim storage construction years, from Table E-2

If a separations process is used during Phase II, but not during Phase I, then

$$Start\ Date - DII_{ops} - Y_{sCon}$$

Where

D_{IIops} = start date for Phase II operations, from Table B-1
Y_{sCon} = number of interim storage construction years, from Table E-2

LAW interim storage capital costs (CS_L) from Sections B-4.5, B-4.6, and B-4.7 are divided by the years of storage construction (Y_{sCon}), from Table E-2, to determine per year capital expenses.

D-5.4.2 LAW Interim Storage Operating Costs

The yearly LAW interim storage operating costs (OS_L) from Sections B-4.1, B-4.2, and B-4.3 are charged out over the years of operations as follows.

If a separations process is used during Phase I, then OS_L costs begin to incur on the Phase I operations start date (DI_{ops}) and continue to the end of Phase II operations. The total number of years over which OS_L costs are charged out is determined by the following equation.

$$Number\ of\ Years = (DII_{ops} - DI_{ops}) + YII_{ops}$$

Where

DII_{ops} = start date for Phase II operations, from Table B-1
DI_{ops} = start date of Phase I operations, from Table B-1
YII_{ops} = years of Phase II operations, from Table B-1

If a separations process is used during Phase II, then OS_L costs begin to incur on the Phase II start date (DII_{ops}) and continue throughout Phase II operations years (YII_{ops}).

D-5.5 LAW Disposal Costs

LAW disposal costs have an annual increase factor (F_{incr}) based on the increasing cost of regulatory requirements. For each year disposal costs are incurred, the additional disposal cost (C_{add}) for the respective year is added to the disposal cost per cubic meter of radioactive waste (C_{waste}). C_{add} starts at 0 in 1995 and increases by F_{incr} each of the following years. If a separations process is used in Phase I, then the yearly disposal costs for Phase I are calculated via the following equation.

$$Yearly\ Disposal\ Cost = \frac{(V_{ILAW})}{(YI_{LDisp})}(C_{waste})[1 + (Y_c - 1995)(F_{incr})]$$

Where

V_{ILAW}	=	the total volume of LAW produced, in cubic meters, during Phase I, from Section B-4.1.1.1
YI_{LDisp}	=	the number of years of Phase I LAW disposal as described below
C_{waste}	=	cost of waste disposal per m^3, from Table E-7
Y_c	=	current year for which disposal cost is being calculated
F_{incr}	=	annual increase factor, from Table E-7

The date upon which Phase I LAW disposal costs begin to incur (DI_{LDisp}) is determined by adding the start date of Phase I operations (DI_{ops}) from Table B-1 to the years of storage capacity for LAW (YS_{LCap}) from Table E-2 as follows.

$$DI_{LDisp} = DI_{ops} + YS_{LCap}$$

The number of years over which disposal costs are incurred (YI_{LDisp}), in the event of a Phase I separations process, is then determined by the following equation.

$$YI_{LDisp} = DII_{ops} - DI_{ops}$$

Where

DII_{ops}	=	start date for Phase II operations, from Table B-1
DI_{ops}	=	start date for Phase I operations, from Table B-1

If a separations process is used in Phase II, then the yearly disposal costs for Phase II are calculated via the following equation.

$$Yearly\ Disposal\ Cost = \frac{(V_{IILAW})}{(YII_{LDisp})}(C_{waste})\,[1 + (Y_c - 1995)(F_{incr})]$$

Where

V_{IILAW}	=	the total volume of LAW produced, in cubic meters, during Phase II, from Section B-4.1.1.2
YII_{LDisp}	=	the number of years of Phase II LAW disposal as described below
C_{waste}	=	cost of waste disposal per m^3, from Table E-7
Y_c	=	current year for which disposal cost is being calculated
F_{incr}	=	annual increase factor, from Table E-7

The date upon which LAW disposal costs begin to incur (DII_{LDisp}) is determined by adding the start date of Phase II operations (DII_{ops}) from Table B-1 to the years of storage capacity for LAW (YS_{LCap}) from Table E-2 as follows.

$$DII_{LDisp} = DI_{ops} + YS_{LCap}$$

The number of years over which disposal costs are incurred (YII_{LDisp}), in the event of a Phase II vitrification plant, is by subtracting YS_{LCap} from the years of Phase II operations (YII_{ops}) as follows.

$$YII_{LDisp} = YII_{ops} - YS_{LCap}$$

Where

YII_{ops} = Phase II operations years, from Table B-1
YS_{LCap} = years of storage capacity for LAW, from Table E-2

D-6 Decontamination and Decommissioning (D&D) Costs

The D&D costs of all newly constructed facilities are divided evenly over 5 years beginning at the end of Phase II operations. The date upon which D&D costs begin to incur is determined as follows.

$$Start\,Date = DII_{ops} + YII_{ops}$$

Where

DII_{ops} = start date of Phase II operations, from Table B-1
YII_{ops} = years of Phase II operations, from Table B-1

D-7 Process for Choosing Best Immobilization and Classification

The TEAM Model chooses, by default, the best HAW and LAW immobilization process and waste class on the basis of minimum cost. Calculations for immobilization process and waste class selection are as follows.

D-7.1 HAW Immobilization Process Selection

The first step in selecting the optimum immobilization process is to calculate the total discounted cost for HAW Glass and the total discounted cost for HAW Glass Ceramic. The total discounted cost is the sum of the discounted development costs (sect. D-4.1); the discounted design, construction, and startup costs (sect. D-4.2); the discounted operating costs (sect. D-4.3); the discounted storage costs (sect. D-4.4); and the discounted disposal costs (sect. D-4.5). Since the HAW immobilization is independent of LAW immobilization

and LAW classification, the best HAW immobilization process is determined by simply taking the lowest of the total discounted cost for HAW Glass and the total discounted cost for HAW Glass Ceramic.

D-7.2 LAW Immobilization Process and Waste Class Selection

The first step in selecting the best immobilization process and waste class for LAW is to calculate the total discounted cost for the Phase I process for class A, B, and C waste types and the total discounted cost for the Phase II process for class A, B, and C waste types. The total discounted cost for both the Phase I and II processes consists of the sum of the discounted development costs (sect. D-1.1, 2.1); the discounted design, construction, and startup cost (sect. D-1.2, 2.2): and the discounted operating costs (sect. D-1.3, 2.3).

Next, the total discounted cost is calculated for each LAW immobilization process and waste classes by adding the discounted development costs (sect. D-5.1); the discounted design, construction, and startup costs (sect. D-5.2); the discounted operating costs (sect. D-5.3); the discounted storage costs (sect. D-5.4); and the discounted disposal cost (sect. D-5.5). LAW immobilization processes and corresponding waste classes are as follows.

1)	Glass, class A	7)	Grout, class A
2)	Glass, class B	8)	Grout, class B
3)	Glass, class C	9)	Grout, class C
4)	Glass Ceramic, class A	10)	Grout (FUETAP), class A
5)	Glass Ceramic, class B	11)	Grout (FUETAP), class B
6)	Glass Ceramic, class C	12)	Grout (FUETAP), class C

The minimum of all the class A immobilizations (1, 4, 7, 10); all the class B immobilizations (2, 5, 8, 11) ; and all the class C immobilizations (3, 6, 9, 12) is identified as the best immobilization process for each class.

Next, total discounted costs for class A are calculated by summing the best LAW immobilization discounted cost, the total discounted cost for the Phase I process, and the total discounted cost for the Phase II process for classes. The same is then done for classes B and C, and discounted costs for all three waste classes are compared. The lowest of the total discounted cost determines the best waste class for LAW disposal. The best LAW immobilization process is then selected from the twelve options above as the one corresponding to the waste class selected from the waste class discounted cost comparison.

Although set as default calculations, model users may, if they desire, over-ride the default selection process to further explore waste immobilization and disposal class options.

APPENDIX E: VARIABLES FROM EQUATIONS

Table E-1: Process Unit Cost Factors

Process Unit	*Baseline Throughput (T_b)*	*Advanced Testing Costs (C_{test})*	*Persons Needed (FTE)*	*Construction Costs (C_{const})*	*Material Cost Factor (F_{matR})*	*Number of Operators/Shift (N_o)*
Separations Options						
TRUEX Class A	700 L/hr	850,000	5	58,000,000	3	14
TRUEX Class B	700 L/hr	850,000	5	55,000,000	3	13
TRUEX Class C	700 L/hr	500,000	1.5	46,000,000	1	9
Precipitation Class A	500 L/hr	1,000,000	7.5	65,000,000	6	14
Precipitation Class B	500 L/hr	1,000,000	7.5	62,000,000	6	13
Precipitation Class C	500 L/hr	750,000	4	50,000,000	4	8
Freeze Crystallization Class A	500 L/hr	1,350,000	6	57,000,000	4	13
Freeze Crystallization Class B	500 L/hr	1,000,000	2.5	48,000,000	2	9
Calciner Options						
ANN Calcine	76 L/hr	200,000	1.5	0	1	11
Silica Calcine	510 L/hr	500,000	2.5	6,000,000	1	11

Table E-1: Process Unit Cost Factors						
Process Unit	*Baseline Throughput (T_b)*	*Advanced Testing Costs (C_{test})*	*Persons Needed (FTE)*	*Construction Costs (C_{const})*	*Material Cost Factor (F_{matR})*	*Number of Operators/Shift (N_o)*
HAW Evaporator Storage	150,000 gal	750,000	1.5	3,900,000	1	0
Shutdown	0	0	0	0	1	11
Immobilization Options						
Glass HAW Liquid	45.3 Kg/hr	7,000,000	4.5	80,000,000	2	8
Glass HAW Liquid Solid	45.3 Kg/hr	10,000,000	5	100,000,000	2	9
Glass-Ceramic HAW	57 Kg/hr	10,000,000	5	n/a	2	14
Glass LAW	45.3 Kg/hr	5,000,000	3.5	60,000,000	2	8
Grout LAW (A)	628 Kg/hr	500,000	2.5	38,000,000	2	10
Grout LAW (>A)	628 Kg/hr	750,000	3.5	47,500,000	2	10
Grout LAW (FUETAP A)	628 Kg/hr	500,000	2.5	47,500,000	2	11
Grout LAW (FUETAP >A)	628 Kg/hr	750,000	3.5	59,400,000	2	11
Glass-Ceramic LAW	49 Kg/hr	5,000,000	5	n/a	2	14
Glass-Ceramic LAW (>A)	49 Kg/hr	7,000,000	5	n/a	2	14
Sodium Add-ons Phase I						
Sodium Transfer	n/a	n/a	n/a	5,000,000	n/a	1

Table E-1: Process Unit Cost Factors						
Process Unit	***Baseline Throughput (T_b)***	***Advanced Testing Costs (C_{test})***	***Persons Needed (FTE)***	***Construction Costs (C_{const})***	***Material Cost Factor (F_{matR})***	***Number of Operators/Shift (N_o)***
Surge Capacity	n/a	n/a	n/a	20,000,000	n/a	1
Utilities	n/a	n/a	n/a	30,000,000	n/a	0
Additional CSSF	n/a	n/a	n/a	3,900,000	n/a	0
Calcine Add-ons Phase II						
Calcine Handling	n/a	n/a	n/a	11,000,000	n/a	1
Support Upgrade/Delayed Vitrification	n/a	n/a	n/a	5,000,000	n/a	0
Separations Upgrade/Calcine	n/a	n/a	n/a	6,000,000	n/a	1
Calcine Retrieval Costs	n/a	n/a	n/a	2,200,000	n/a	n/a

Table E-2: Equation Constants		
Symbol	***Value***	***Basis***
Al_{INV}	460	cubic meters of aluminum calcine in inventory currently
$B1_{er}$	0.52	The rate of evaporation for blend 1, from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
$B1_r$	2.18	The blend rate 1 (1.18 ANN + 1.0 blend), from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
$B2_{er}$	0.617	The rate of evaporation for blend 2, from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
$B2_r$	2.82	The blend rate 2 (1.82 ANN + 1.0 blend), from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
$B3_r$	4.15	The blend rate 3 (3.15 ANN + 1.0 blend), from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
B_r	0.625	The blend ratio of WM189 to WM183, from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
BT_Y	4	the number of years to build a CSSF or tank farm
C_{B1}	0.274	The number of liters of calcine generated for each liter of waste processed during campaign 1, from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
C_{B2}	0.379	The number of liters of calcine generated for each liter of waste processed during campaign 2, from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
C_{B3}	0.520	The number of liters of calcine generated for each liter of waste processed during campaign 3, from Draft of Updated Method for Calculation of Weight of Calcined Solids and Sodium Plus Potassium Content of Calcine (BHO-03-93).
C_{Bops}	14,600,000	Operations cost for each CSSF retrieval.
C_{can}	9000	The cost of a one cubic meter canister is $9,000 (per phone conversation with Jim Spruill, Savannah River Site).
C_{dep}	3000	gallons per month deep recycle returned to calciner

Table E-2: Equation Constants		
Symbol	***Value***	***Basis***
C_{gm}	25,000,000	Bench marking with the Savannah River Plant.
C_{HIP}	11,500,000	The cost for a HIP ($3,000,000) was increased by a factor of 3.33 ($10,000,000) to account for remote operation capabilities. Each HIP will also require 1500 cubic feet of Hot Cell space. Hot Cell space costs $972 per cubic foot, which results in a cost of $1,500,000 for each HIP. The summation of these two numbers results in an additional cost of $11,500,000. This information is from the PDF feasibility study, and numerical values are rounded to three significant digits.
C_{Hrep}	10,000,000	The cost for a HIP ($3,000,000) was increased by a factor of 3.33 ($10,000,000) to account for remote operation capabilities.
C_{MPC}	211,000	The cost for a multi-purpose canister is $211,000 (Life Cycle Cost Comparison for the Multi-purpose Canister System, DOE ID: A00000000-01717-0200-00008 REV 0 and Commercially Available Dry Storage Systems for Storage of Irradiated Fuel on the Hanford Site, WHC-SD-CP-ES-155, REV 0).
C_{Mrep}	25,000,000	Bench marking with the Savannah River Plant.
C_{nTFops}	$1,500,000/yr	yearly operating costs for new tank farm.
C_{oper}	732,160	Annual cost per operator, per the following calculation. C_{oper} = (43)(8320) + (60)(2080): Labor costs per person ($43/hr for hourly and $60/hr for exempt employees) are based on current production labor and support services costs at the ICPP for FY 94. Total hourly work hours a year (8320) equals 4 crews times 40 hours times 52 weeks. Total exempt work hours a year (2080) equals 40 hours a week times 52 weeks a year.
C_{OWops}	$1,500,000/yr	yearly operating costs for other waste operations (i.e., process equipment waste, liquid effluent treatment and disposal, atmospheric protection system, service waste).
CR_Y	10	The number of years of calcine retrieval for CSSF 7 and 8, if used.
C_{sc}	$100,000,000	The design, construction, and startup costs for 300,000 gallons of surge capacity. This is calculated as five times the construction cost from Table E-1. This adjustment is consistent with the WINCO cost estimating basis for determining total project costs.
C_{TFops}	$1,500,000/yr	yearly operating costs for existing tank farm.
F_{cp}	5	To obtain total costs, including design, start-up, Operational Readiness Review, project management, and overhead, the construction costs are multiplied by a factor of 5. This adjustment is a conservative value and could range from 2 to 5. It has been identified as an uncertainty to be further evaluated.

Table E-2: Equation Constants		
Symbol	***Value***	***Basis***
F_{dd}	0.18	Based on the estimated D&D costs associated with buildings CPP-601, CPP-603, CPP-633, and CPP-640. D&D costs were averaged and divided by the average Design, Construction, and Start-up costs for these buildings. This showed that the average D&D costs will be about 18% of the Design, Construction, and Start-up Costs.
F_{eff}	0.85 / 0.775	for Glass and Glass-Ceramic, respectively.
F_{matB}	2,800,000	The material cost of NWCF in 1993 with 12 months of operations.
F_{sm}	0.52	F_{sm} equals the subcontractor ratio plus the non-labor ratio. The subcontractor ratio (0.36) is from FY 94 costs and is determined by dividing the subcontractor costs by the development personnel costs. The non-labor ratio (0.16) is from FY 94 costs and is the costs for non-labor items needed to support development personnel.
F_{supp}	5.5	The number of development personnel required to support the principle investigators is 5.5. This number includes technicians, secretaries, design and test engineers, management, analytical and health physics support, systems analysis, and performance assessment.
G_r	150 gal/hr	Gross calciner feed rate
INV_{TF}	1,237,996	current Tank Farm inventory after evaporation by HLLWE in gallons
LR_{dev}	$124,800/yr	LR_{dev} = ($60/hr)(2080 hr/yr): Labor rate per person ($60/hr for exempt employees) is based on current support services costs at the ICPP for FY 94. Total exempt work hours a year (2080) equals 40 hours a week times 52 weeks a year.
M_{ac}	1, 3.1, 4.15	The aluminum calcine multiplier for precipitation, freeze crystallization, and no separations respectively
M_{freq}	2 yrs/5 yrs	Number of years between HIP or melter change-out: two years for Glass, and five years for Glass-Ceramic.
M_{sc}	2.5	Silica calcine multiplier.
N_{bd}	2	number of calciner bed dissolution per campaign
N_{camp}	2	number of pre-phase I calciner campaigns. This is an input by the user into the model. The default value is 2 campaigns.
N_{can}	4	4 is the number of one cubic meter canisters held by a multi-purpose canister (over-pack canister for the one cubic meter canisters).
N_{melt}	2	The number of melters as determined by the Architect Engineer (AE) feasibility study.

Table E-2: Equation Constants		
Symbol	***Value***	***Basis***
N_r	96.625 g/hr	The net feed rate determined by gross feed rate (in gallons per hour) times the efficiency of the calciner (when it is operating) minus the gross feed rate times the efficiency minus the internal recycle for sodium waste (N_r = gross feed rate * 0.75 - (gross feed rate * 0.75) * 0.015
scale	$ 75,000,000	scaleable portion of a glass-ceramic facility
$Si_{calcine}$		the metric tons of Silica calcine in current inventories
T_{GC}	49 kg/hr 57 kg/hr	Baseline throughput for a Glass-Ceramic facility. It is different for HAW and LAW because of density differences. 49 kg/hr is for a LAW facility, and 57 kg/hr for a HAW facility.
T_{camp}	18	number of months the campaign is run
T_{Sb}	100 kg/hr	the baseline throughput for a glass plant at Savannah River Site
V_{183}	273,700	the volume of waste currently in WM183 tank, in gallons
V_{185}	189,100	the volume of waste currently in WM185 tank, in gallons
V_{189}	274,300	the volume of waste currently in WM189 tank, in gallons
V_{bed}	25,000	gallons per bed dissolution
V_{CAN}	1 m^3/canister	volume of HAW canister
Y_{sCon}	3	The years needed to construct a storage facility.
YS_{HCap}	7	This is the default value for years of storage for HAW.
YS_{LCap}	7	This is the default value for years of storage for LAW.
Y_{rep}	2015	The year the HAW repository is open. This is an input by the user and is set at a default of the year 2015.
Y_{TFout}	2015	The year existing Tank Farm goes out of commission.
$Zr_{calcine}$	5166	Metric tons of Zirconium calcine in current inventories.

Table E-3: Fractions		
Fractions of HAW After Sodium Separation (Na_{sep}) [4]		
Freeze Crystallization [1]	0.67	
Precipitation [1]	0.32	
TRUEX [2]	0.027	
NONE [3]	1	
Fractions of LAW After Sodium Separation (Na_{sep}) [4]		
Freeze Crystallization [1]	0.32	
Precipitation [1]	0.67	
TRUEX [2]	1	
NONE [3]	0	
Fractions of HAW Separated From Calcine Process		
	Aluminum Calcine (Al_{sep})	*Zirconium Calcine (Zr_{sep})*
Precipitation [1]	0.85	0.62
TRUEX [2]	0.025	0.073
NONE [3]	1	1
Fractions of LAW Separated From Calcine Process		
	Aluminum Calcine (Al_{sep})	*Zirconium Calcine (Zr_{sep})*
Precipitation [1]	0.14	0.38
TRUEX [2]	1.1	0.95
NONE [3]	0	0

1 - Flowsheets for Sodium-Bearing Waste Processing Alternatives (KMW-2-94)

2 - TRUEX Flowsheets for Sodium-Bearing Waste and Calcine Technology Selection Process (JLAW-05-94)

3 - None is used here to designate no separations will occur. This will leave all waste in HAW form.

4 - Composite Compositions of Sodium Waste in Tank Farm after NWCF Campaign H-4 (RJR-04-94)

Table E-4: Filters					
Year	[1] Number of existing filters, N_{EF}	Number of other filters, N_{OF}	[2] Number of calcine filters, N_{CF}	Processing limit (filters/yr)	Backlog at year end
1994	2	14	0	16	238
1995	36	14	0	50	202
1996	37	14	24	75	165
1997	0	14	61	75	176
1998	0	75	0	75	217
1999	1	14	60	75	216
2000	13	14	48	75	203
2001	37	14	24	75	166
2002	0	14	61	75	177
2003	49	14	12	75	128
2004	61	14	0	75	67
2005	61	14	0	75	6
2006	1	14	60	75	5
2007	5	14	48	75	0
2008	0	14	24	75	0
2009	0	14	61	75	11
2010	11	14	12	75	0
2011	0	14	60	75	0
2012	0	14	48	75	0
2013	0	14	0	75	0
2014	0	14	0	75	0
2015	0	14	24	75	0
2016	0	14	61	75	11
2017	11	14	24	75	0

[1] The number of filters currently in inventory is 240 (NWCF: 180, FDP: 17, WCF: 10, LET&D: 3, and RWMC: 30). These filters are processed according to the processing limit.

[2] The number of calciner filters generated during a given year equals six times the number of months the calciner is operating (T_{cm}).

Table E-5: Weight Percent Loading						
Technology	**Waste Type**	**Matrix**	**Sodium Waste (WT_{Na})**	**Aluminum Calcine (WT_{Al})**	**Zirconium Calcine (WT_{Zr})**	**Silica Calcine (WT_{Si})**
Freeze Crystallization	LAW	Glass	0.15	N/A	N/A	N/A
		Glass-Ceramic	0.4	N/A	N/A	N/A
		Grout	0.12	N/A	N/A	N/A
		Grout (FUETAP)	0.15	N/A	N/A	N/A
	HAW	Glass	0.25	N/A	N/A	0.5
		Glass-Ceramic	0.55	N/A	N/A	0.25
Precipitation	LAW	Glass	0.2	0.25	0.2	N/A
		Glass-Ceramic	0.5	0.5	0.5	N/A
		Grout	0.12	0.2	0.2	N/A
		Grout (FUETAP)	0.15	0.25	0.25	N/A
	HAW	Glass	0.3	0.25	0.2	0.5
		Glass-Ceramic	0.5	0.5	0.5	0.25
TRUEX	LAW	Glass	0.2	0.15	0.2	N/A
		Glass-Ceramic	0.4	0.65	0.65	N/A
		Grout	0.12	0.4	0.3	N/A
		Grout (FUETAP)	0.15	0.6	0.5	N/A
	HAW	Glass	0.1	0.15	0.2	0.5
		Glass-Ceramic	0.65	0.65	0.65	0.25
NONE	LAW	Glass	0	0	0	N/A
		Glass-Ceramic	0	0	0	N/A
		Grout	0	0	0	N/A
		Grout (FUETAP)	0	0	0	N/A
	HAW	Glass	0.3	0.15	0.2	0.5
		Glass-Ceramic	0.5	0.65	0.65	0.25

Low-Level Waste Loadings and Volume Determinations for Cement-Based [Grout and FUETAP Grout] Waste Forms (JAN-02-94)

Table E-6: Densities		
D_{LAW}	Glass	2,450 kg/m^3
	Glass-Ceramic	2,660 kg/m^3
	Grout	1,400 kg/m^3
	Grout (FUETAP)	2,000 kg/m^3
D_{HAW}	Glass	2,523 kg/m^3
	Glass-Ceramic	3,005 kg/m^3

Glass and Glass-ceramic waste formulations (KV-06-94)

Table E-7: Disposal Costs		
Waste Class	**Cost of Waste (C_{waste} \$/m^3)**	**Annual Increase Factor (F_{incr})[3]**
Class A[1]	10,000	0
Class B[1]	20,000	0
Class C[1]	110,000	0
HAW Glass[2]	500,000	0
HAW Glass-Ceramic[2]	500,000	0

1 - LLW disposal cost schedule from Barnwell (Chem-Nuclear Systems, Inc., effective August 1, 1993.

2 - For SRS-type 24" diameter canisters

3 - This can be changed by the user to make an annual increase.

Table E-8: Waste Volumes							
Year	Sodium Waste Volume (V_{WNa}), in gallons	Sodium Waste Reduction Factor (R_{FNa})	Acid Volume (V_{WH+}), in gallons	Acid Reduction Factor (R_{FH+})	Campaign Number	Calciner Schedule (T_{cm})	Number of Available Tanks (N_{tanks})
1994	62025	1.84	24200	1.09	0	0	10
1995	50725	1.80	11500	1.21	0	0	10
1996	46850	1.97	15500	1.14	1	4	10
1997	49583	1.97	118500	1.60	1	12	10
1998	47216	1.97	18500	1.28	1	2	10
1999	46400	1.97	4000	1	2	10	10
2000	46400	1.97	4000	1	2	8	9
2001	58400	1.97	4000	1	3	4	9
2002	58400	1.97	4000	1	3	12	8
2003	57767	1.97	4000	1	3	2	8
2004	106567	3.11	11500	1	4	0	8
2005	102567	3.18	19000	1	4	0	7
2006	97567	3.28	19000	1	4	10	7
2007	97567	3.28	19000	1	4	8	6
2008	97567	3.28	19000	1	5	4	6
2009	97567	3.28	19000	1	5	12	4
2010	97400	3.28	19000	1	5	2	4
2011	97400	3.28	19000	1	6	10	2
2012	97400	3.28	4000	1	6	8	2
2013	97400	3.28	4000	1	7	0	0
2014	97400	3.28	4000	1	7	0	0
2015	45600	1.97	4000	1	7	4	0
2016	45600	1.97	4000	1	7	12	0
2017	45600	1.97	4000	1	7	2	0
2018	45600	1.97	4000	1	8	10	0
2019	45600	1.97	4000	1	8	8	0
2020	45600	1.97	4000	1	9	4	0
2021	45600	1.97	4000	1	9	12	0
2022	45600	1.97	4000	1	9	2	0

DATE

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7/26/94

END