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ICPP Radioactive Liquid and Calcine Waste Technologies Evaluation Final Report and Recommendation

*High-Level Waste Processing,
Engineering and Project
Management Department*

Lockheed
Idaho Technologies Company

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Radioactive Liquid and Calcine Waste
Technologies Evaluation
Final Report and Recommendation**

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Engineering and Project Management Department**

April 1995

**PREPARED FOR THE
DEPARTMENT OF ENERGY
IDAHO OPERATIONS OFFICE
UNDER CONTRACT DE-AC07-94ID13223**

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CONTENTS

TABLES AND FIGURES	xi
ACRONYMS	xiii
ABSTRACT	xv
EXECUTIVE SUMMARY	xvii
1. LEGAL DRIVERS AND AGREEMENTS	1
2. SYSTEMS ANALYSIS APPROACH	2
3. EVALUATION PROCESS	3
3.1 Program Goal	3
3.2 Baseline Requirements	4
3.3 Identify Alternatives	5
3.4 Develop Alternatives	7
3.4.1 Decision Tree of Treatment Alternatives	9
3.4.2 Decision Tree of Immobilization Technologies	11
3.5 Optimize and Evaluate Alternatives	12
3.5.1 Technology Evaluation and Analysis Methodology (TEAM) Model	13
3.5.2 Strategy for Evaluation	13
3.5.2.1 Investigation of Uncertainty	14
3.6 Technical Peer Reviews	14
3.7 Stakeholder Involvement	15
4. EVALUATION DATA	16
4.1 Quantitative Evaluation Data	17
4.1.1 Life-Cycle Costs	18
4.1.2 Cost-Time Profile	18
4.1.3 Five-year Costs	20
4.1.4 Waste Quantities Before Immobilization	21
4.1.5 Waste Volumes After Immobilization	22
4.2 Qualitative Evaluation Data	24
4.2.1 Health & Safety	24
4.2.2 Non-Proliferation Issues	24
4.2.3 SNF Processing Capabilities	25
4.2.4 Low-Level Waste Radioactivity	25
4.2.5 Technical Maturity	25
4.3 Variable Inputs	26
4.3.1 Operations Start Date	26
4.3.2 Operations Completion Date	26
4.3.3 Calcliner Campaigns Run Prior to Facility Startup	27

5. EVALUATION RESULTS	29
5.1 Quantitative Results	29
5.1.1 Treatment Technologies	29
5.1.2 Immobilization Technologies	32
5.2 Qualitative Evaluation Results	33
5.3 Comparison to Hanford's Waste Management Process	35
6. TECHNICAL RECOMMENDATION	38
6.1 Path Forward	39
APPENDIX A: TECHNOLOGY DESCRIPTIONS	A-1
A-1 Treatment Technologies	A-1
A-1.1 Calcination	A-1
A-1.2 Calcine Dissolution	A-2
A-1.3 Radionuclide Partitioning	A-4
A-1.3.1 Actinide Removal via Transuranic Extraction (TRUEX)	A-4
A-1.3.2 Strontium Extraction (SREX)	A-5
A-1.3.3 Cesium Removal via Ion Exchange (IX)	A-6
A-1.4 Freeze Crystallization (FC)	A-8
A-1.5 Precipitation / Neutralization	A-9
A-1.6 Electrohydrolysis (EH)	A-11
A-2 Immobilization Technologies	A-13
A-2.1 Grouting	A-13
A-2.2 Glass (Vitrification)	A-16
A-2.3 Glass-Ceramic	A-19
APPENDIX B: MASS BALANCE CALCULATIONAL BASES	B-1
B-1 Feed Material	B-1
B-2 Actinide Removal	B-5
B-3 Neutralization/Precipitation	B-6
B-4 Electrohydrolysis (EH)	B-8
B-6 Calcination	B-9
B-7 Cesium Removal via Ion Exchange (IX) or Absorption	B-10
B-8 SREX: Strontium Extraction	B-11
B-9 Waste Forms Overview	B-11
B-9.1 Assumptions—HAW Glass and Glass-ceramic	B-12
APPENDIX C: COSTS	C-1
C-1 Development Costs	C-2
C-1.1 General Development Costs	C-3
C-1.1.1 Development Time	C-3
C-1.1.2 Waste Qualification Development	C-4
C-2 Design, Construction, and Start-up Costs	C-4
C-2.1 General Design, Construction, and Startup Costs	C-6

C-2.1.1	Weighted Average Weight Percent Loading	C-7
C-2.2	Needed Throughput	C-7
C-2.2.1	Radioactive Waste Inventory	C-8
C-2.3	C_{dcs} for Glass-Ceramic	C-10
C-2.3.1	Scalable Portion of a Glass-Ceramic Facility Cost	C-10
C-2.3.2	Filling Station Cost	C-11
C-2.3.3	Radioactive Waste Classification Factor	C-11
C-2.3.4	Glass-Ceramic Facility Scalable Cost	C-11
C-2.3.5	Number of HIPs	C-12
C-2.4	C_{dcs} for Glass Immobilization	C-13
C-2.4.1	Number of Glass Melters	C-15
C-3	Operating Cost	C-15
C-3.1	General Operating Cost	C-16
C-3.1.1	Material Cost	C-16
C-3.1.2	Labor Cost	C-17
C-3.2	HAW Operating Cost	C-18
C-3.2.1	Phase I Canisters	C-18
C-3.2.2	Phase II Canisters	C-19
C-3.2.3	Maintenance Cost	C-20
C-3.3	Other Additional Operating Costs	C-21
C-3.3.1	Retrieval Operating Costs	C-21
C-3.3.2	Early Calcination Operating Costs	C-21
C-4	Interim Storage Cost	C-22
C-4.1	Class A Interim Storage Operating Cost	C-22
C-4.1.1	LAW Storage Volume	C-23
C-4.1.1.1	Total Phase I LAW Volume Produced	C-23
C-4.1.1.2	Total Phase II LAW Volume Produced	C-24
C-4.2	Class B Interim Storage Operating Cost	C-24
C-4.3	Class C Interim Storage Operating Cost	C-25
C-4.4	Interim Storage Operating Years for LAW	C-25
C-4.5	Interim Storage Capital Cost for Class A	C-26
C-4.6	Interim Storage Capital Cost for Class B	C-26
C-4.7	Interim Storage Capital Cost for Class C	C-26
C-4.8	HAW Interim Storage Operating Cost	C-27
C-4.8.1	HAW Canisters Produced	C-27
C-4.8.1.1	Phase I HAW Volume	C-28
C-4.8.1.2	Phase II HAW Volume	C-28
C-4.9	Interim Storage Operating Years for HAW (YH_{stor})	C-29
C-4.10	Interim Storage Capital Cost for HAW	C-30
C-4.10.1	Number of HAW Storage Facilities	C-30
C-5	Disposal Costs	C-31
C-5.1	Disposal Timing	C-32
C-6	Decontamination and Decommissioning Costs	C-33

APPENDIX D: RADIOACTIVE WASTE VOLUMES	D-1
D-1 Amount of Sodium-bearing Liquid Waste	D-1
D-1.1 Current Tank Farm Volumes	D-1
D-1.1.1 Annual Volume Added	D-2
D-1.1.1.1 Annual Solution Generated	D-2
D-1.1.1.2 Filter Leach Volume	D-3
D-1.1.2 Volume Processed by Calciner	D-4
D-1.1.2.1 Net Processing Rate for First Calciner Campaign ..	D-5
D-1.1.2.1.1 Blend Rate Calculations	D-5
D-1.1.2.1.2 Gallons Processed	D-6
D-1.1.2.2 Net Processing Rate for Any Additional Campaigns	D-8
D-2 Annual and Accumulated New Calcine Waste Inventories	D-9
D-2.1 Total Aluminum Calcine Generated	D-9
D-2.1.1 Additional Calcine Waste Generated	D-10
D-2.1.1.1 Calcine Generated During First Campaign	D-10
D-2.1.1.2 Calcine Generated During Second Campaign	D-11
D-2.1.1.3 Calcine Generated From New Technology	D-11
D-2.2 Silica Calcine	D-12
D-2.2.1 Amount of Radioactive Waste Form to be Silica Calcined ..	D-12
D-2.2.2 Silica From Silica Calcine	D-13
D-3 Additional Needed Surge Capacity	D-13
D-3.1 Current Tank Farm Capacity	D-14
D-3.1.1 Available Capacity from Selected Technology	D-14
D-4 CSSF 7 and 8	D-14
D-5 Year Early Calcination Ends	D-15

APPENDIX E: TIME DISCOUNTING OF COSTS	E-1
E-1 Present Value Discounting	E-1
E-1.1 Future Value to Present Value	E-1
E-1.2 Annuity to Present Value	E-1
E-2 Time Discounting for Radioactive Liquid and Calcine Waste Processing	E-2
E-2.1 Phase I (Sodium Processing) Development Costs	E-2
E-2.2 Phase I (Sodium Processing) Design, Construction, and Startup Costs ..	E-3
E-2.3 Phase I (Sodium Processing) Operating Costs	E-3
E-2.4 Phase II (Calcine Processing) Development Costs	E-3
E-2.5 Phase II (Calcine Processing) Design, Construction, and Startup Costs ..	E-4
E-2.6 Phase II (Calcine Processing) Operating Costs	E-4
E-3 Calciner Time Discounting	E-4
E-3.1 Calciner Development Costs	E-4
E-3.2 Calciner Design, Construction, and Startup Costs	E-4
E-3.3 Calciner Operating Costs	E-6
E-4 HAW Immobilization Time Discounting	E-8
E-4.1 HAW Immobilization Development Costs	E-8
E-4.2 HAW Immobilization Design, Construction, and Startup Costs	E-9
E-4.3 HAW Immobilization Operating Costs	E-9

E-4.4	HAW Immobilization Interim Storage Costs	E-9
E-4.4.1	HAW Interim Storage Capital Costs	E-9
E-4.4.2	HAW Interim Storage Operating Costs	E-11
E-4.5	HAW Disposal Costs	E-11
E-4.5.1	Transportation Costs	E-14
E-5	LAW Immobilization Time Discounting	E-14
E-5.1	LAW Immobilization Development Costs	E-14
E-5.2	LAW Immobilization Design, Construction, and Startup Costs	E-15
E-5.3	LAW Immobilization Operating Costs	E-15
E-5.4	LAW Immobilization Interim Storage Costs	E-16
E-5.4.1	LAW Interim Storage Capital Costs	E-16
E-5.4.2	LAW Interim Storage Operating Costs	E-16
E-5.5	LAW Disposal Costs	E-17
E-6	Decontamination and Decommissioning (D&D) Costs	E-19
E-7	Process for Choosing Best Immobilization and Classification	E-19
E-7.1	HAW Immobilization Process Selection	E-19
E-7.2	LAW Immobilization Process and Waste Class Selection	E-19

APPENDIX F:	VARIABLES FROM EQUATIONS	F-1
-------------	--------------------------	-----

APPENDIX G:	TECHNICAL REVIEW COMMENTS AND RESOLUTIONS	G-1
-------------	---	-----

G-1:	<u>Evaluation and Selection of Aqueous-Based Technology for Partitioning Radionuclides from ICPP Calcine</u>	G-1
G-2:	<u>ICPP Sodium Waste Alternative Technologies Peer Review</u>	G-5
G-3:	<u>Report of the Technical Peer Review of the Idaho Chemical Processing Plant High-Level Waste Treatment Program</u>	G-7
G-4:	<u>ICPP Radioactive Waste HLW Immobilization Treatment Technologies: NUMATEC Comments and Recommendations</u>	G-13

APPENDIX H:	PUBLIC PARTICIPATION IMPLEMENTATION PLAN FOR THE ICPP RADIOACTIVE LIQUID AND CALCINE WASTE TECHNOLOGY EVALUATION PROGRAM	H-1
H-1:	Vision	H-1
H-2:	Background	H-1
H-3:	Requirements / Drivers	H-2
H-4:	Objectives	H-2
H-5:	Primary Audience	H-3
H-6:	Strategy	H-3
H-7:	Products / Deliverables	H-4
H-8:	Schedule	H-5
H-9:	Roles / Responsibilities	H-5

Attachment H-A:	Stakeholder Involvement Strategic Planning	H-6
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Attachment H-B:	DOE Preliminary Approval (Letter to the INEL/EM-SSAB)	H-8
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TABLES AND FIGURES

Tables

Table 1: Initial Candidate Technologies	6
Table 2: Technologies Presented on Decision Trees	8
Table 3: Summary of Criteria Performance	29
Table 4: Summary of Accumulated Option Points	30
Table 5: Direct Comparison of Options to Option 10	31
Table 6: Comparative Evaluation of Immobilization Technologies	32
Table 7: Comparative Qualitative Evaluation Results	34
Table B-1: Sodium Feed Composition	B-2
Table B-2: Calcine Feed Composition	B-3
Table B-3: Precipitation Removal Percentage	B-7
Table C-1: Phasing Summary (Default Values)	C-2
Table F-1: Process Unit Cost Factors	F-1
Table F-2: Equation Constants	F-4
Table F-3: Fractions	F-8
Table F-4: Weight Percent Loading	F-9
Table F-5: Densities	F-10
Table F-6: Disposal Costs	F-11
Table F-7: Waste Volumes	F-11
Table G-1.1: Evaluation and Selection of Aqueous-Based Technology	G-1
Table G-2.1: ICPP Sodium Waste Alternative Technologies Peer Review	G-6
Table G-3.1: Technical Peer Review of the ICPP High-Level Waste Treatment Program ...	G-8
Table G-4.1: NUMATEC Comments and Recommendations	G-13

Figures

Figure 1: Decision Tree (Nodes 1 through 4) for Waste Treatment Technologies	9
Figure 2: Decision Tree (Nodes 5, 6, and 7) for Disposal Form and Waste Classification	11
Figure 3: Values Assessment Workshop Results	15
Figure 4: Life-Cycle Costs	18
Figure 5: Cost-Time Profile for Option 14	19
Figure 6: Comparative Evaluation of Cost-Time Profiles	20
Figure 7: Five-Year vs. Life-Cycle Costs	21
Figure 8: HAW and LAW Quantities Before Immobilization	22
Figure 9: HAW and LAW Volumes After Immobilization	23
Figure 10: Option 10 Facility Size per End Date	26
Figure 11: Option 10 Life-Cycle and Peak Annual Costs per Calciner Campaigns	27
Figure 12: Option 10, Proposed Phased WIF	38
Figure A-1: Calcination	A-1
Figure A-2: Calcine Dissolution	A-3
Figure A-3: Actinide Removal via TRUEX	A-4

Figure A-4: Strontium Extraction (SREX)	A-6
Figure A-5: Cesium Removal via Ion Exchange (IX)	A-7
Figure A-6: Freeze Crystallization	A-8
Figure A-7: Precipitation by Neutralization	A-10
Figure A-8: Electrohydrolysis	A-12
Figure A-9: Grout via Batch Mixing	A-14
Figure A-10: Grout via In-line Mixing	A-14
Figure A-11: Grout via In-container Mixing	A-15
Figure A-12: Glass (Vitrification)	A-16
Figure A-13: Glass-Ceramic	A-19
Figure E-1: Summary of Timing Variables	E-2

ACRONYMS

AE	Architect Engineer
AMP	Ammonium Molybdophosphate
ANN	Aluminum Nitrate Nonahydrate
APS	Atmospheric Protection System
CFR	Code of Federal Regulations
CSSF	Calcined Solids Storage Facility
DCS	Design, construction, and start-up
D&D	Decontamination and Decommissioning
DOE	Department of Energy
EH	Electrohydrolysis
EIS	Environmental Impact Statement
EM	Environmental Restoration and Waste Management
EPA	Environmental Protection Agency
FC	Freeze Crystallization
FFCAct	Federal Facilities Compliance Act
FUETAP	Formulated Under elevated Temperature And Pressure
FY	Fiscal Year
GTM	Generic TRUEX Model
HAW	High Activity Waste
HEPA	High-efficiency Particulate Air
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
KD	Key Decision
LAW	Low Activity Waste
LDR	Land Disposal Restrictions
LLW	Low-level Waste
NaEX	Crown Ether Sodium Extraction
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
NWCF	New Waste Calcining Facility
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
OMB	Office of Management and Budget
PPT	Precipitation
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision (for EIS)
SNF	Spent Nuclear Fuel

SREX	Crown Ether Strontium Extraction
SSAB	Site-Specific Advisory Board
TCLP	Toxicity Characteristic Leaching Procedure
TEAM	Technology Evaluation and Analysis Methodology
TPA	Tri-Party Agreement
TRU	Transuranics
TRUEX	Transuranic Extraction
WAPS	Waste Acceptance Preliminary Specifications
WIF	Waste Immobilization Facility

ABSTRACT

Using a formalized Systems Engineering approach, the Lockheed Idaho Technologies Company developed and evaluated numerous alternatives for treating, immobilizing, and disposing of radioactive liquid and calcine wastes at the Idaho Chemical Processing Plant. Based on technical analysis data as of March, 1995, it is recommended that the Department of Energy consider a phased processing approach—utilizing Radionuclide Partitioning for radioactive liquid and calcine waste treatment, FUETAP Grout for low-activity waste immobilization, and Glass (Vitrification) for high-activity waste immobilization—as the preferred treatment and immobilization alternative.

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EXECUTIVE SUMMARY

Legal drivers and agreements exist obligating the Idaho National Engineering Laboratory (INEL) to develop, demonstrate, and implement technologies for safe and environmentally sound treatment and interim storage of radioactive liquid and calcine waste. In addition, 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 those technologies that support compliance activities explicit to the proper management and dispositioning of radioactive liquid and calcine waste is a high priority.

Department of Energy (DOE) Order 4700.1 outlines a formalized, logical systems engineering approach to problem definition and resolution. Numerous radioactive liquid and calcine waste processing options were 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 were then evaluated using the Technology Evaluation and Analysis Methodology (TEAM) Model. This process allowed decision makers to (1) identify optimum radioactive waste treatment and disposal form alternatives; (2) assess tradeoffs between various optimization criteria; (3) identify and measure significance of uncertainties in performance parameters; and (4) focus development efforts on options that best satisfy technical needs.

As a part of the Spent Fuel and Waste Management Technologies Development Program, the INEL has a commitment to recommend to DOE the preferred technologies for radioactive liquid and calcine waste treatment and low-activity waste (LAW) and high-activity waste (HAW) disposal. This document discusses the process employed to identify, assess, and recommended alternatives for meeting all legal drivers and agreements regarding the management of radioactive liquid and calcine waste, particularly the selection of a preferred treatment alternative in conjunction with the Environmental Impact Statement (EIS) Record of Decision (ROD) as required by the March 22, 1994, Modified Notice of Non-compliance (NON) Consent Order. Based on technical analysis data as of March, 1995, it is recommended that DOE consider a phased processing approach—utilizing Radionuclide Partitioning for radioactive liquid and calcine waste treatment, FUETAP Grout for LAW immobilization, and Glass (Vitrification) for HAW immobilization—as the preferred alternative for the treatment and immobilization of radioactive liquid and calcine waste at the ICPP.

The assumptions, supporting data, plans, and recommendations presented herein are based solely on technological development and evaluations completed to date. Current efforts to integrate all Environmental Restoration and Waste Management (EM) activities at the INEL are, however, revisiting these issues. Any programmatic changes regarding ICPP radioactive liquid and calcine waste management resulting from this effort will be considered and integrated as part of the on-going INEL EM Integration Project.

1. LEGAL DRIVERS AND AGREEMENTS

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 diminished 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 continued 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 (m³) of calcine waste are in inventory at the ICPP.

Several legal drivers and agreements exist which commit the Idaho National Engineering Laboratory (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 the DOE 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 Proposed Site Treatment Plan has been completed, and negotiations with the State of Idaho are underway to reach a Consent Order agreement by October, 1995.

Consistent with requirements of the December 22, 1993, District Court Order, a draft site-wide Environmental Impact Statement (EIS) has been issued, and the final EIS will be issued by April 30, 1995. The selection of technologies for the treatment of the radioactive liquid and calcine wastes will be made in conjunction with this EIS Record of Decision (ROD), due no later than June 1, 1995.

Additional environmental requirements exist (i.e., Resource Conservation and Recovery Act [RCRA] permitting, air permitting, etc.) which must eventually be accounted for in schedules and cost estimates. However, these requirements are not evaluation drivers and do not serve as discriminators in the evaluation process; thus, they are not evaluated as part of this document. This document discusses the process that is being employed to identify and assess alternatives for meeting all legal drivers and agreements involving the management of radioactive liquid and calcine waste, particularly the selection of a preferred treatment alternative in conjunction with the EIS ROD as required by the March 22, 1994, Modified Notice of Non-compliance (NON) Consent Order.

2. 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 Applied Systems Engineering Department at the INEL 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 Modeling, 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. EVALUATION PROCESS

3.1 Program Goal

Through a series of facilitated meetings, the need to provide viable radioactive liquid and calcine waste treatment options which could utilize both existing and new facilities and technologies was considered. 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, program personnel obtained assistance from other INEL organizations 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. Lockheed Idaho 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 waste and calcine, and both must be immobilized. Though the capability of a particular process to effectively treat both waste types is not required by regulation, preliminary analysis indicates that those combinations of technologies which can handle both waste types have an economic advantage over other options. For that reason, dual processing capability is being evaluated for all waste treatment alternatives.

- 3) Treatment alternatives must immobilize HAW¹ using vitrification. Per RCRA LDR [40 CFR 268.40], vitrification (using the technologies employed at the Savannah River Site) is the specified treatment standard for the "nonwastewater" toxic metal and corrosive characteristic of mixed radioactive high-level liquid wastes generated during the reprocessing of SNF. Since INEL technologies differ from those addressed by 40 CFR 268.40, vitrification of liquid high-level wastes and calcine (even though it is considered a "nonwastewater") will require an equivalency determination; otherwise, a variance from the treatment standard would have to be obtained for the resulting waste form. Treatment technologies other than vitrification will require an equivalency determination or variance as well.

¹ 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 (see item 4, below), per NRC, EPA, and DOE classifications. The RCRA regulatory analysis depends on such a determination.

Additionally, HAW carries RCRA-listed waste codes, and since vitrification does not meet the LDR treatment standards for some of these codes, the final HAW form will either have to be delisted, granted a variance from the treatment standard for these waste codes, or disposed in a RCRA approved disposal site.

- 4) Treatment alternatives for LAW must meet concentration-based LDR treatment standards for characteristic and listed waste codes, or treatment standard variances will have to be obtained. The final LAW form will also carry RCRA-listed waste codes with technology-based treatment standards, which will require that the waste be either delisted or granted a variance from these listed code treatment standards.
- 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 wastes.

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 ICPP HAW nor a final storage or disposal location for ICPP immobilized LAW. This requires that immobilized radioactive wastes be stored until final disposal sites are available.

3.3 Identify Alternatives

After the decision in April 1992 to 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 (Aluminum Nitrate Nonahydrate) or Silica Addition	Preparation of a high sodium solution for calcination by addition of ANN or activated silica to maintain the fluidized bed operation and avoid agglomeration.	Calcination of sodium-bearing radioactive liquid waste
Calcination	Denitration and conversion of a radioactive liquid waste to a granular solid form using a fluidized bed at 500°C.	Radioactive liquid waste treatment
Thermal Treatment	Concentration of liquid or conversion of liquid to solid using evaporation or a rotary kiln.	Radioactive liquid waste treatment
Dissolution	Conversion of a solid radioactive waste (i.e., calcine) to a liquid by chemical reaction with an acid.	Calcine treatment
Denitration	Use of chemical or thermal methods to significantly reduce the nitrate content of the waste.	Calcine treatment of HAW
Separations		
Halide Volatility	Conversion of an element to a halide gas which can then be preferentially separated by trapping the constituent gases at different temperatures.	Calcine treatment
Oxidation / Reduction	Conversion of elemental valences for optimized 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 defined 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 selective ion membranes and electrical current or voltage.	Recycles sodium and acid from LAW produced from either 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
Sodium Removal: Freeze Crystallization (FC) Sodium Extraction (NaEX)	FC: Using a temperature depression method, such as a refrigerant, FC separates out crystallized water and some of the saturated sodium nitrate (sodium nitrate currently limits the efficiency of the NWCF). NaEX: Process using counter-current aqueous and organic streams to selectively remove sodium from the aqueous solution using crown ethers.	Radioactive liquid waste treatment only, specifically the sodium nitrate
Ion Exchange (IX)	Process (utilizing absorption) which uses an organic resin or inorganic sorbent to preferentially remove ions in exchange for other ions pre-deposited on these surfaces.	To remove cesium (via IX) or other hazardous components from liquid waste streams

Table 1: Initial Candidate Technologies		
Alternatives	Description	Application
Off-Gas Treatment	Filtration or chemical process to remove hazardous pollutants and/or radioactive contaminants from the process off-gas.	Will be used in all processes as needed to control effluents
Precipitation (PPT) by neutralization	Process (utilizing pH changes and various flocculants and additives) which uses the solubility properties of certain components to segregate those that do not form a solid or stay in the solution.	Radioactive liquid and dissolved calcine waste treatment
Pyrochemical / Pyrometallurgical	High temperature processes which convert a solid to a vapor or metallic liquid form.	Calcine waste treatment
Selective Leaching	Selective dissolution of radioactive solids into liquid by chemical reaction. For example, the dissolution of cesium from calcine with water.	Calcine waste treatment
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 treatment; part of a Pyrochemistry methodology
Immobilization		
Canning	Sealing waste inside a metal container.	Final waste forms and potentially calcine
Grouting	Encapsulation or incorporation of waste into a solidified matrix of thermosetting materials, thermoplastics, or solidified hydrated oxides.	LAW immobilization
Glass	Incorporation of waste into a matrix of non-crystalline solidified liquid.	Both LAW and HAW immobilization
Glass-Ceramic	Incorporation of waste into a form which contains some glass, but which also contains a large proportion of crystalline matrix.	Both LAW and HAW immobilization

3.4 Develop Alternatives

Mass balance calculations (see Appendix B), resulting from literature studies and laboratory testing, 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, senior program personnel 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.

The technologies listed in Table 2, along with direct vitrification, provide twenty-seven potential technology combinations (each with their own immobilization and waste form options) that meet baseline requirements and support program goals.

Table 2: Technologies Presented on Decision Trees		
Technology	Technology Use	Applicable Decision Node(s)
Pre-treatment		
ANN or Silica Addition	Added directly to radioactive liquid waste or to the resulting HAW fraction from the FC or PPT process	3
Calcination	Conversion of sodium-bearing liquid plus additive to granular solid form	3
Dissolution	Used on all calcine wastes	4
Separations		
Freeze Crystallization (FC)	Used on sodium-bearing liquid waste	2
Precipitation (PPT) by neutralization	Used on both radioactive liquid and dissolved 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), actinides and strontium	2 & 4 for TRU; 7 for strontium
Electrohydrolysis	Used on the LAW fraction from PPT separation and, potentially, FC	2 & 4
Ion Exchange (IX)	Used to remove cesium and separate the LAW fraction generated from FC, PPT, or TRU removal methods	7
Immobilization		
Grouting	Immobilization method for LAW	6
Glass	Immobilization method for HAW or LAW	5 & 6
Glass-Ceramic	Immobilization method for HAW or LAW	5 & 6
Canning	All final HAW forms	Assumed for all HAW forms

NOTE: Detailed descriptions of each treatment and immobilization technology, including schematic diagrams and development issues, are outlined in Appendix A of this document.

3.4.1 Decision Tree of Treatment Alternatives

Potential combinations of treatment and immobilization technologies are arranged according to seven identified key process decisions, the first four of which are presented in Figure 1.

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

The first node allows selection of (1) 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 (2) during the second phase of the project, following radioactive liquid waste processing. 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 storage of concentrated HAW, would be required until a HAW Immobilization plant is operational.

The second decision node deals with the radioactive liquid waste processing. Here, there are four possibilities: (1) Freeze Crystallization, (2) Precipitation through Neutralization, (3) TRUEX-like radionuclide partitioning, and (4) No Na Separation, which includes either continued calcination or direct immobilization. Each of the three separations technologies produces 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 waste and calcine. Detailed descriptions of each processing technology appear in Appendix A of this document.

Decision node three involves options for continuing use of the existing NWCF or for shutting it down. 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 nonahydrate (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. Further studies are in place to identify more efficient calcination processes for sodium-bearing liquid waste. The NWCF is presently equipped for ANN calcination; however, if the decision is made to use silica, some other additive, or a new high-temperature calciner vessel instead, major modification would be required to the calciner prior to performing calcination campaigns. Regardless of which method 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 will not be required to process radioactive liquid waste after January 1, 1998 (see Section 1.0). 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. The number of normal ANN calciner campaigns is two for all cases except Options 12-14 (continued calcination), where five campaigns are assumed as a baseline.

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, Radionuclide Partitioning via TRUEX-like process, and Direct Immobilization of calcine into a HAW waste form (see Appendix A). Both the Precipitation and Radionuclide Partitioning processes require the calcine to be dissolved.

3.4.2 Decision Tree of Immobilization Technologies

Nodes 5, 6, and 7 (see Figure 2) represent integrated decisions regarding disposal form and waste classification options for each of the 27 radioactive waste processing alternatives shown in Figure 1.

Figure 2: Decision Tree (Nodes 5, 6, and 7) for Disposal Form and Waste Classification

Decision node five involves selecting a HAW immobilization technology; HAW immobilization processes available are Glass and Glass-ceramic. The glass process involves combining the HAW stream with appropriate glass forming additives (typically SiO_2 , B_2O_3 , and Na_2O) at high temperatures in a glass melter to produce a glass immobilized waste form (see Section A-2.2). There are three possible feeds to this process: (1) sodium-bearing waste, (2) calcine waste, or (3) the concentrated actinide and fission product stream from separation process(es). The glass melter would be operated at temperatures between 1050 and 1250°C, producing a molten glass product that would be poured into canisters, sealed, and temporarily stored pending final disposal. Similarly, the glass-ceramic process involves combining and thoroughly mixing the HAW stream with appropriate additives, sealing the mixture in stainless-steel canisters, and processing the canisters at a high temperature and under moderately high pressure (see Section A-2.3). A hot-isostatic press (HIP) is typically used to form the Glass-ceramic waste forms at temperatures between 1000 and 1200°C, and at pressures ranging from 15,000 to 20,000 psi.

LAW immobilization process selection between Glass, Glass-ceramic, normal Grout (Portland-type cement), and FUETAP (Formulated Under Elevated Temperature And Pressure) Grout, is made in decision node six. If no separations is performed, then LAW immobilization and LAW class are not necessary and are described in the tree as "None." Glass and glass-ceramic processes are analogous to those described above for HAW. Grouting or cementation technology refers to the process of encapsulating or stabilizing the LAW in a material which can be pumped into transportable containers where it is cured and solidified. FUETAP grout requires applying heat and pressure externally to accelerate the curing process. The key to controlling grout consistency is selecting the most appropriate mixing process and controlling the mixing of ingredients. The process of mixing the grout can be divided into three categories: batch mixing, in-line mixing, and in-container mixing (see Section A-2.1).

The final 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, or C). If a class A or B waste is selected, then strontium and cesium removal via SREX and IX, respectively, is required in addition to all separations technologies.

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. Additional variables include waste immobilization techniques for high and low level waste forms, interim storage, and calciner operations. A computer-based model was developed to assist in the evaluation and analysis of alternatives by identifying development activities needed to support technology evaluation, prioritizing development efforts by identifying essential information needed prior to selecting an optimum process, and establishing relationships between available data and process selection criteria. Each of the twenty-seven candidate processes was configured using a uniform basis for each cost element (see Appendices C, D, E, and F); this ensured an objective comparison of waste treatment alternatives by presenting each alternative in its most cost-effective configuration.

3.5.1 Technology Evaluation and Analysis Methodology (TEAM) Model

The computer-based Technology Evaluation and Analysis Methodology (TEAM) Model computes the present value (in 10/94 dollars) for life-cycle costs and cost components 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 to be important factors in the selection and implementation of waste treatment technologies. Consequently, the TEAM 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 among 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 TEAM 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 criterion (see Appendix E, Section E-7).

3.5.2 Strategy for Evaluation

To identify the most economical treatment option, the TEAM Model was used to evaluate the 27 alternative processes against a number of evaluation criteria (see Section 4.0), using base case parameters with user variation. Because the relative importance of evaluation criteria differ among individual stakeholders and decision makers, and since no one alternative is likely to satisfy all stakeholder concerns, 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, 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.

Over the past few months, the model was used in facilitated meetings with key decision makers at DOE-ID and HQ to discuss technological and programmatic changes that may increase the favorability of a given option and to get immediate feedback on the results of those changes. Additionally, the model was used by scientists and engineers to compare optimization scenarios of favorable options. This information proved useful in helping evaluators single out those alternatives with the greatest potential for meeting radioactive liquid and calcine waste processing demands at the ICPP. Data regarding options that performed favorably across a broad range of criteria are discussed in Section 5.0 of this report.

3.5.2.1 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. The cost outputs from the TEAM Model should be considered a relative cost analysis, since there is more confidence in the cost difference between options than the total absolute cost of a single option. More confidence in absolute costs can only be obtained through further development of both technology and cost data. To identify the parameters for which further investigation will be most valuable, a sensitivity analysis was performed using the TEAM Model to assess the range of parameter uncertainty and to determine if varying certain parameters had a significant impact on the ranking of options. First, the range of uncertainty was assessed for each parameter of interest, and the high and low ends of that range were defined. The model was then run 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.

The sensitivity analysis looked at the effects of uncertainty in the separation factors, densities, and weight percent loadings. The results showed that a small percentage (2-4%) of the total cost changed due to uncertainty surrounding these three parameters, with weight percent loadings having the greatest recognizable impact. Other parameters (e.g., disposal costs) were changed drastically, but had no measurable effect on the relative performance of each alternative.

3.6 Technical Peer Reviews

Four Technical Peer Reviews have been conducted over the past two years regarding technologies and processes being evaluated as part of the ICPP Radioactive Liquid and Calcine Waste Technologies Evaluation program. These reviews are listed below:

- ▶ Evaluation and Selection of Aqueous-Based Technology for Partitioning Radionuclides from ICPP Calcine
- ▶ ICPP Sodium Waste Alternative Technologies Peer Review
- ▶ Report of the Technical Peer Review of the Idaho Chemical Processing Plant High-Level Waste Treatment Program
- ▶ ICPP Radioactive Waste HLW Immobilization Treatment Technologies: NUMATEC Comments and Recommendations

With the exception of the NUMATEC report, all peer reviews were conducted in the earlier stages of the technologies development program (February 1993 through September 1994). Updated versions of both the Spent Fuel and Waste Management Technologies Development Program (SF&WMTDP) Plan and the ICPP Radioactive Liquid and Calcine Waste Technologies Draft Evaluation Report were issued in September and October of 1994, respectively, and address many of the comments and recommendations from the earlier peer reviews. Appendix G documents associated issues as well as addresses comments in the NUMATEC report, issued after publication of the aforementioned updates.

3.7 Stakeholder Involvement

The evaluation and selection of treatment and immobilization technologies for dispositioning ICPP radioactive liquid and calcine waste should be founded not only on technical considerations, but also on the incorporation of stakeholder values 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 identification of all parameters important to stakeholders and the relative importance of each parameter is a value choice rather than a purely technical decision.

In an effort to assess and incorporate stakeholder values into the evaluation and selection process, several discriminating attributes—shown to be of interest to both stakeholders and decision-makers—were identified through literature reviews and benchmarking of other DOE stakeholder efforts (see Section 5.3). These criteria, described in Section 4.0 of this report, were then presented to the INEL Public Participation Team to test the feasibility of the proposed stakeholder values assessment approach (see Appendix H) and to obtain a preliminary indication of the relative importance of each identified criterion. Results of the INEL Public Participation Team Values Assessment Workshop, held in November, 1994, are shown in Figure 3.

Figure 3: Values Assessment Workshop Results

As a result of this and other informal presentations, the following proposed stakeholder involvement activities were preliminarily approved by both the DOE-ID Communications Office and appropriate DOE-ID Programs Management in December, 1994, to further assist the DOE in evaluating and selecting waste treatment and immobilization technologies. Due, however, to uncertainties surrounding the EIS ROD, ongoing program integration activities at the INEL, and

current STP and FFCAct negotiations with the State of Idaho, it was decided by both DOE-ID and Lockheed Idaho programs personnel to postpone proposed stakeholder involvement efforts until following completion of those activities and issuance of an FFCAct agreement between the State of Idaho and the DOE.

4. EVALUATION DATA

Evaluations were performed for all twenty-seven waste treatment options according to the following evaluation and optimization criteria, identified by the INEL technical staff based on past experience with the DOE and on U.S. Government processes for selecting and funding new technology programs:

- ▶ Cost
 - Life-Cycle Costs
 - Cost-Time Profile
 - Peak Annual Cost
 - Average Annual Cost
 - Five-Year Costs
- ▶ High-level and Low-level Waste Volumes before and after Immobilization
- ▶ Health and Safety Concerns
- ▶ Possibility of Proliferation Through Process Reconfiguration
- ▶ Capability to Process Spent Fuel and Recover Fissile Uranium
- ▶ Low-level Waste Radioactivity
- ▶ Risk of Technology Failure
- ▶ Operation Start Date
- ▶ Operation Completion Date
- ▶ Number of Additional Calciner Campaigns Run Prior to Facility Startup

These criteria are sub-divided into three key categories, reflective of their utility in the evaluation and selection process, namely: (1) quantitative measures calculated by the computer model for each alternative, based on the assumptions of this report; (2) qualitative variables considered as part of the evaluation of the alternatives; and (3) timing issues associated with operational start and completion dates for implementing technologies to process radioactive liquid and calcine wastes.

As stated in section 3.5, alternatives were developed, evaluated, and compared in their most cost-effective configurations, according to the following default parameters:

- ▀ Phase I Title Design Starting in 2000;
- ▀ Phase II Title Design Starting in 2006;
- ▀ Phase I Operating Time of 6 years;
- ▀ Phase II Operating Time of 20 years;
- ▀ Calciner Operations - 2 campaigns except Options 12-14 which assume 5;
- ▀ High Level Liquid Waste Evaporator operation assumed for all options;
- ▀ New tank farm employed when needed for a given option;
- ▀ COGEMA Glass process available for title design in 1998, and cold-crucible and glass-ceramic technologies available for title design in 2001; and
- ▀ The new tank farm heelout schedule, as agreed to with the State of Idaho (January 24, 1995), is being used in order to meet NON-Consent requirements.

These conditions were selected primarily to allow for a consistent relative evaluation of all the options. Each parameter can be changed, however, to reflect possible variations in schedule and facility availability, to explore areas of technical uncertainty, and to optimize preferred waste treatment options.

4.1 Quantitative Evaluation Data

Quantitative evaluation data consist primarily of alternative cost and waste volume calculations, with cost data being sub-divided into the following 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 C). These components, discounted to the start of FY-95, are added together to give total life-cycle expenditures for each waste treatment option, as discussed in Section 4.1.1.

Data presented in sections 4.1.1 through 4.1.5 are relative values based on available information. The graphic representations of radioactive waste treatment options are a consistent evaluation comparison and should not be considered as the actual cost required to implement a given alternative.

4.1.1 Life-Cycle Costs

Life-cycle costs are measured in present value (see Appendix E). Figure 4 shows the twenty-seven processing options sorted according to the life-cycle costs, with the least expensive options on the left of the graph.

Figure 4: Life-Cycle Costs

The life-cycle costs shown here provide the decision-maker with an understanding of the overall relative cost for each option and for the range of life-cycle expenditures (\$2.1 billion to greater than \$9.6 billion) for all 27 options. The top third performers of this criterion are Options 10, 23, 13, 6, 2, 20, 11, 5, and 7.

4.1.2 Cost-Time Profile

The timing of expenditures is an important aspect of budgeting for the DOE due to the fact that many DOE programs are short on funds. If a program or process has large surges in funding (i.e., high peak annual costs), as shown in Figure 8, priorities within the DOE complex must change to meet increased funding needs; therefore, expenditures should be close to flat for the life time of a given program or process or the probability of receiving necessary funding is

greatly 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 at a later date.

Figure 5: Cost-Time Profile for Option 14

As shown, a large funding spike (peak annual cost) occurs when a glass ceramic plant is built during Phase II of the project, and again during HAW disposal.

The need of a flat profile is important to the entire INEL and encompasses more than just radioactive liquid and calcine wastes. At the INEL, program prioritization will be used to determine optimal phasing strategies and, thereby, reduce peak annual costs for needed projects. This could be performed in many ways, depending on INEL priorities as a whole. For example, instead of bringing a separations-grout facility on-line in Phase I and a vitrification facility on-line in Phase II, these could be reversed or even split into three phases, if deemed appropriate through EM Integration activities currently being performed at the INEL, to better accommodate INEL-wide EM waste management needs.

Figure 6 displays a comparative evaluation of all twenty seven options, according to the assumptions of this report, sorted by the peak annual cost for each option. As shown, those alternatives that employ a phased approach are technologically superior to those that build all necessary facilities at once.

Figure 6: Comparative Evaluation of Cost-Time Profiles

Peak Annual Costs range from \$112 million and \$927 million, with annual average costs ranging from \$78 and \$490 million. In the criterion of lowest peak annual cost, Options 10, 23, 6, 20, 2, 13, 17, 11, and 8 are in the top third. In the criterion of lowest average annual cost, Options 23, 10, 6, 2, 13, 20, 17, 26, and 11 rank in the top third.

4.1.3 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 a 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).

Figure 7: Five-Year vs. Life-Cycle Costs

This graph is displayed to show that it is possible to achieve low life-cycle costs as well as low five-year costs. These options appear in the lower left corner of the graph. The five year costs range from \$142 to \$255 million. Options in the top third, when ranked by low five year costs, are Options 27, 14, 15, 26, 23, 24, 13, 10, and 18.

4.1.4 Waste Quantities Before Immobilization

The total volume of waste requiring immobilization directly influences the volume of the final waste form, the size of the immobilization facilities, and ultimately the cost. Some of the options increase the volume of waste requiring immobilization more than others. The radioactive liquid waste can be calcined with the use of non-radioactive chemicals or segregated directly, and both waste types can be segregated into HAW and LAW by radionuclide partitioning technologies. These processes will add material requiring final immobilization. The waste quantities in Figure 8 display the dry weight equivalent (oxide form) with the water and other volatile components (such as nitric acid) removed; the data is sorted numerically by option. The data indicates that separations technologies associated with Options 2, 6, 10, 13, 17, 20, 23, and 26 result in the least amount of HAW requiring immobilization.

Figure 8: HAW and LAW Quantities Before Immobilization

4.1.5 Waste Volumes After Immobilization

Section 4.6 discussed the waste quantities before immobilization as an indication of the efficiency of the treatment process performed on the radioactive liquid and calcine waste. Each of these treated output streams (both HAW and LAW) are immobilized into a final form and placed into interim storage for final disposition. There are a number of immobilization techniques that can be applied, as was discussed in the Immobilization Decision Tree (Figure 2). The LAW facilities are less expensive to build and operate as the radioactivity level is decreased from Class C to B to A. The cost of those facilities decrease because of reduced shielding and remote maintenance needs. Thus, construction and operations of those facilities are less costly than if they were HAW or waste Class C facilities. Some facilities are more costly than others because of the number of unit of operations or the complexity of those operations (e.g., the high construction cost of glass-ceramic vs. the low construction cost of grout). All these factors were taken into consideration in the life-cycle cost, then the minimum life-cycle cost was used to select the immobilization option for each option. The corresponding volumes displayed in

Figure 9 are the result of optimization by life-cycle costs and do not reflect what the volumes might be if the options were optimized on another criteria such as volume and is the reason this data is shown in a non-sorted format.

Figure 9: HAW and LAW Volumes After Immobilization

Options resulting in the lowest volume of HAW requiring disposal after immobilization include: Options 2, 6, 10, 13, 17, 20, 23, and 26. For minimal LAW volumes following immobilization, Options 3, 4, 11, 14, 15, 18, 24, and 27 performed most favorably.

4.2 Qualitative Evaluation Data

Several of the criteria used to evaluate and optimize treatment and immobilization options are qualitative in nature, meaning that calculable numbers were not used for these criteria. Instead, the relative impact of each was identified as either low, medium, or high, depending on the qualitative judgement of technical experts involved with the various alternative processes. These criteria, described below, include: Health & Safety, Non- Proliferation Issues, Spent Nuclear Fuel Processing Capabilities, Low-Level Waste Radioactivity, and Technical Maturity.

4.2.1 Health & Safety

All identified alternatives require some type of new facilities, and current regulations mandate that those facilities be constructed and operated according to existing Health and Safety standards. In this way, all alternatives were seen as equal in regards to Health and Safety concerns. Additionally, strict environmental safeguards are expected for all new facilities; these environmental safeguards would only further equalize the alternatives one to another. Thus, this criterion was not seen as a technological discriminator between alternatives.

4.2.2 Non-Proliferation Issues

The Non-Proliferation Issues criterion addresses the ability of a given technological process to recover fissile uranium and plutonium for use in nuclear weapons productions; three potential qualitative impacts exist for this criterion. First, the alternative could allow for fissile material to be recycled directly back into the DOE stockpile for weapons use. Presently, none of the options allow for direct fissile material recovery.

Second, with proper reconfiguration, operational changes could be made to technological processes such that, after reconfiguration, fissile material could be recovered for military use. The alternatives that employ the radionuclide separations (i.e., TRUEX) chemistry are currently configured to place the long-lived isotopes, such as uranium and plutonium, into the High Activity Waste (HAW) glass for disposal in the repository. If politics changed such that enriched uranium could be used for other purposes, a reconfiguration could take place to allow for uranium and plutonium recovery, provided the timing of changes occurs early enough in the design phase.

Finally, the nature of a given alternative could make it impossible to recover fissile material, despite reconfiguration; this, according to stakeholders, is most acceptable under the Non-Proliferation criterion. All alternatives except those employing radionuclide partitioning (i.e., TRUEX) for radioactive liquid and calcine waste treatment fit this response.

Currently no plans exist for reconfiguring preferred alternatives to support proliferation; however, if necessary, the decision to reconfigure (as a functional requirement) could be made during the project design phase, thus leaving time to ensure more information is gathered on the potential reuse of DOE enriched uranium or on applicable disposal requirements.

4.2.3 SNF Processing Capabilities

SNF Processing Capability, in other words, is the ability to recover uranium and plutonium as a valuable resource material for use in power generation, is qualitatively opposite in nature to the Non-Proliferation Issues criterion just discussed. Three potential responses exist for this criterion as well: (1) direct uranium recovery is possible; (2) uranium recovery is possible only through process reconfiguration; and (3) uranium recovery is not possible, regardless of reconfiguration. As with Proliferation Issues, no identified alternatives are capable of direct recovery, and only those employing radionuclide partitioning technologies (i.e., TRUEX) can be reconfigured to do so. Once again, the decision to reconfigure could be made early in the project design phase.

Ultimately, the trade-off between Non-Proliferation Issues and SNF Processing Capabilities rests in whether recovered fissile material is targeted for use in the production of nuclear weapons or as resource material in power generation. This is a matter of qualitative choice, based on stakeholder and decision-maker values.

4.2.4 Low-Level Waste Radioactivity

Under the assumption that the low-level waste will more than likely remain in Idaho, the citizens of Idaho want the radioactivity of those waste streams to be as low as possible. One option associated with many of the alternatives is to reduce the radioactivity of the low-level waste stream through the removal of additional radionuclides, primarily cesium and strontium. This can be performed to achieve different radioactivity levels, categorized by NRC classifications for low-level commercial waste.

The capital and operational expenditures necessary to perform this additional separation are available as add-on items to all alternatives that employ some type of separation methodology. The economics of performing this type of separation is measured by selecting the classification of low-level waste, based on the minimum life-cycle dollars, for a given alternative.

4.2.5 Technical Maturity

Technical Maturity is dealt with in two ways. First of all, the maturity of a given technology is measured (on a low, mid, high scale) by how much time is required to develop that technology to the point where a facility could be designed for technology implementation. For example, the only direct immobilization method available during the 2011 Phase I time period, without resolution of difficult technology issues, is continued calcination (discussed in greater detail in Section 4.3.3). Additionally, due to the technology issues associated with direct vitrification of the calcine, several options in the bottom half of the decision tree in Figure 1 are unavailable for title design until 2006. On the other hand, Radionuclide Partitioning, Grouting, FC, and PPT technologies are technically mature enough to be considered for Phase I construction. The phased approach, as described in the top half of the decision tree, could begin Phase I title design as early as 2000 for any of the specified options. The number of years required for development,

and the associated development dollars, are added to the front of the project to ensure that time and money necessary to develop the technology are available prior to project initiation. This, ultimately, affects the implementation time for any given technology.

Secondly, Technical Maturity affects the quantitative output as a result of the contingency factor applied to the technology's implementation costs. This factor varies from 10%, for a project proven on similar material on a production scale, to 100%, for processes that are proven only in lab tests. The contingency factor is added to construction costs reported in the model for each applicable alternative.

4.3 Variable Inputs

Because priorities associated with proposed waste treatment and immobilization could change as a result of on-going INEL EM integration activities, it was essential to configure the TEAM model with various user-defined input to facilitate the development of optimal process phasing scenarios. The following variable inputs are described below: Operations Start Date, Operations Completion Date, and the number of calciner campaigns run prior to facility startup.

4.3.1 Operations Start Date

The Operations Start Date for Phase One processing was assumed at 2011, based on current data and programmatic assumptions. Variations in Operations Start Dates are used to identify what prioritization and project phasing scenarios are required to achieve relatively flat cost-time profiles, as discussed in Section 4.1.2.

4.3.2 Operations Completion Date

Operations Completion Dates are also variable so that analyses can be performed on the tradeoffs between building a larger facility and operating it for a shorter period of time versus building a smaller facility and operating it for a longer period of time. Figure 10 shows the relative size of the facility (in construction costs) varied according to the number of years required to process all radioactive liquid and calcine waste under the technologically preferred alternative.

As shown, the costs associated with operating a larger facility for a shorter period of time (10 years) versus those

Figure 10: Option 10 Facility Size per End Date

incurred by operating a smaller facility over a 30 year time frame are relatively similar. It appears, however, that building and operating a facility to treat and immobilize all radioactive liquid and calcine wastes in the 15 to 20 year time frame results in a significant savings in both construction and total life-cycle dollars.

4.3.3 Calciner Campaigns Run Prior to Facility Startup

In an effort to bring anticipated programmatic costs within DOE projected funding levels and still meet immediate HLLW management needs, the DOE and the State of Idaho are currently considering long-term operation of the calciner as a means of delaying the procurement of radioactive liquid and calcine waste treatment and immobilization processes until a later date. Evaluation results for Option 10 (see Figure 11, below) indicate that a certain number of calciner campaigns (1 or 2) are needed to reduce life-cycle costs and meeting Court Order milestones.

Figure 11: Option 10 Life-Cycle and Peak Annual Costs per Calciner Campaigns

If run for three campaigns or less, the calciner may be operated under Interim Status. Additionally, one or two campaigns will eliminate the need to use Calcined Solids Storage Facility (CSSF) #7, and no new CSSFs nor replacement of the calciner vessel will be required for any number less than five.

Campaigns of three or more, however, may result in the following:

- ▶ the for a RCRA Part B Permit in order to continue operations;
- ▶ an increase in the size of the immobilization facility, and associated processes, needed to treat and immobilize the resulting calcine inventory;
- ▶ an increase in the quantity of resulting LLW; and
- ▶ required replacement of the calciner vessel.

As shown in Figure 11, operation of the calciner beyond two or three campaigns significantly increases both life-cycle and peak annual costs.

5. EVALUATION RESULTS

Sections 5.1 through 5.3 present the result of the ICPP radioactive liquid and calcine waste technologies evaluation based on the quantitative and qualitative data presented in Section 4 of this document.

5.1 Quantitative Results

Quantitative results regarding cost and waste volume evaluations are presented here according to (1) treatment technologies and (2) immobilization technologies employed for each alternative.

5.1.1 Treatment Technologies

Table 3, shown below, subdivides the twenty-seven waste treatment options into three groups of nine, according to their performance per the identified criteria. Options are displayed in order of their performance to facilitate the identification of consistently top performing options. By evaluating the alternatives against the criteria and splitting them into thirds, it becomes apparent which options do not require further development.

Table 3: Summary of Criteria Performance

Criteria	Top Third	Middle Third	Bottom Third
Life-Cycle Costs	10, 23, 13, 6, 2, 20, 11, 5, 7	8, 14, 4, 17, 3, 15, 9, 26, 12	1, 19, 22, 16, 25, 27, 24, 18, 21
Cost Time Profile Peak	10, 23, 6, 20, 2, 13, 17, 11, 8	7, 5, 4, 3, 9, 15, 1, 26, 14	12, 19, 25, 22, 16, 18, 21, 27, 24
Cost-Time Profile Average Annual Cost	23, 10, 6, 2, 13, 20, 17, 26, 11	7, 8, 4, 3, 15, 5, 9, 14, 1	12, 19, 22, 25, 26, 21, 27, 18, 24
Five Year Costs	27, 14, 15, 26, 23, 24, 13, 10, 18	25, 19, 21, 11, 3, 4, 12, 5, 7	8, 17, 2, 22, 20, 6, 16, 1, 9
Minimal HAW Volume	6, 10, 23, 2, 13, 20, 17, 26, 9	5, 11, 7, 8, 1, 4, 3, 12, 15	14, 22, 19, 16, 25, 24, 21, 18, 27
Minimal LAW Volume	15, 14, 27, 11, 24, 4, 3, 18, 1	12, 19, 5, 9, 22, 7, 8, 21, 25	26, 17, 20, 6, 10, 23, 16, 2, 13

Using Table 3, option performance can be measured by observing the cumulative number of times an option appears in the top third. For purposes of evaluation, each time an option appeared in the top third for any of the six criteria presented, it received one point. There is a distinct break between those options that performed favorably, accumulating four points or more, and those that did not. Table 4 summarizes the accumulated points for each of the twenty-seven waste treatment options.

Table 4: Summary of Accumulated Option Points	
Option Numbers	Points Accumulated
None	6
10, 13, 23	5
2, 6, 11, 20	4
17, 26	3
14, 15, 18, 24	2
1, 3, 4, 5, 7, 8, 9, 27	1
12, 26, 29, 21, 22, 25	0

Option 10, with five points accumulated, employs a phased approach using Radionuclide Partitioning technology for both the radioactive liquid and calcine waste treatment phases. Option 23 closely follows Option 10, except that a HAW immobilization is built and used during Phase I along with Radionuclide Partitioning. Option 13 uses Direct Calcination on the maximum quantity of radioactive liquid waste that can be processed before Phase II and Radionuclide Partitioning technology on the calcine and any remaining liquid waste during Phase II.

The next grouping consists of Options 2, 6, 11, and 20. Option 2 uses the FC technology and the NWCF during the radioactive liquid waste treatment phase and Radionuclide Partitioning on the calcine wastes. Option 6 uses the PPT technology and the NWCF calciner on the radioactive liquid waste and Radionuclide Partitioning on the calcine wastes; Option 20 is nearly the same as Option 6, except that a HAW immobilization facility is built and used in Phase I in place of the Calciner following Precipitation of the radioactive liquid waste, and is followed by Radionuclide Partitioning on the calcine. Option 11 uses Radionuclide Partitioning technology on the radioactive liquid waste and Direct Immobilization on the calcine wastes.

Options receiving three points were 17 and 26. Option 17 is similar to Option 2 above, except that a HAW immobilization facility is operated in parallel to FC, the calciner is shut down, and Radionuclide Partitioning is used on the calcine wastes. Option 26, on the other hand, uses the Direct Immobilization treatment technology for radioactive liquid waste in Phase I and Radionuclide Partitioning for calcine wastes. The remainder of the options, those receiving two or less points, were not considered further in the evaluation.

Of the top three performers, Option 10 placed either first or second for four of the five criteria in which it was rated in the top third. For that reason, Option 10 was used as the baseline for comparison with other top performing alternatives .

Table 5 shows the results of a direct comparison, criteria by criteria, of the top performing options (those with four points or more) against Option 10 and gives either a "more favorable" or "less favorable" percentage for that option on each criteria. Options showing more favorable performance for a given criteria, when compared to Option 10, represent tradeoffs that may require further analysis.

Table 5: Direct Comparison of Options to Option 10

Option #, (Phase I technology, Phase II technology)	Baseline: Option 10, (TRUEX, TRUEX)	Option 13, (Direct Calcination, TRUEX)	Option 23 (TRUEX, TRUEX)	Option 2 (FC, TRUEX)	Option 6, (PPT, TRUEX)	Option 11, (TRUEX, Direct Immobilization)	Option 20, (PPT, TRUEX)
Criteria							
Total Life-Cycle Costs (in \$ millions) ¹	2,049	2,463 20% Less Favorable	2,094 2% Less Favorable	2,541 24% Less Favorable	2,467 20% Less Favorable	3,348 63% Less Favorable	2,706 32% Less Favorable
Fast-Time Profile Peak (in \$ millions) ¹	112	218 95% Less Favorable	142 27% Less Favorable	189 69% Less Favorable	179 60% Less Favorable	231 106% Less Favorable	187 67% Less Favorable
Fast-Time Profile Average (in \$ millions) ¹	78	96 23% Less Favorable	78 No Difference	95 22% Less Favorable	92 18% Less Favorable	137 76 % Less Favorable	98 26% Less Favorable
Five-Year Cost (in \$ millions) ¹	197	196 1% More Favorable	191 3% More Favorable	236 20% Less Favorable	245 24% Less Favorable	207 5% Less Favorable	239 21% Less Favorable
HAW Volume (in MT)	612	689 13% Less Favorable	633 2% Less Favorable	625 2% Less Favorable	562 8% More Favorable	3,737 511% Less Favorable	829 35% Less Favorable
LAW Volume (in MT)	9,534	10,963 15% Less Favorable	9,534 No Difference	10,027 5% Less Favorable	9,366 2% More Favorable	1,916 80% More Favorable	9,177 4% More Favorable

¹ Unescalated FY-95 (10/94) dollar values.

There are only six cases where other options had more favorable performance indicators than Option 10. These cases—HAW Volume for Options 6; LAW Volume for Options 6, 11, and 20; and Five-year Costs for Options 13 and 23—show, with one exception, a resulting difference of eight percent or less. Because the percentage of difference is relatively insignificant, these tradeoffs will not be investigated further. One criteria that is significantly more favorable is the LAW Volume for Option 11; however, this Option performed poorly under four of the remaining five criteria.

In light of these analyses, Option 10, which uses Radionuclide Partitioning via TRUEX as the processing technology, performed best in almost all the criteria. Additionally, the process is adequately mature (see Section 5.2) to support title design in the year 2000.

5.1.2 Immobilization Technologies

To help identify the differences between immobilization technologies, a comparative evaluation of the different methods available is shown in Table 6. All comparisons were performed using Option 10—the most cost-effective method—as the baseline, shown in the first row.

Table 6: Comparative Evaluation of Immobilization Technologies						
Option Description	Total Cost (in \$ millions)	Five-year Cost (in \$ millions)	HAW Volume (m ³)	LAW Volume (m ³)	Cost Profile Peak (in \$ millions)	Cost Profile Average (in \$ millions)
BASELINE: Option 10 with Glass-HAW and FUETAP Grout-LAW	2,049	197	612	9,534	112	78
Option 10 with Glass-Ceramic-HAW and FUETAP Grout-LAW	2,291 12% less favorable	207 5% less favorable	144 76% more favorable	9,534 No Difference	165 47% less favorable	85 9% less favorable
Option 10 with Glass- HAW and Portland Grout-LAW	2,114 3% less favorable	197 No Difference	612 No Difference	29,324 208% less favorable	111 1% more favorable	82 5% less favorable
Option 10 with Glass- HAW and Glass-LAW	5,400 164% less favorable	210 7% less favorable	612 No Difference	17,508 84% less favorable	463 313% less favorable	207 165% less favorable
Option 10 with Glass- HAW and Glass-Ceramic-LAW	2,477 21% less favorable	217 10% less favorable	612 No Difference	4,955 48% more favorable	162 45% less favorable	93 19% less favorable

In the first two rows of this evaluation, tradeoffs can be observed between HAW volume and costs. Total HAW volume can be reduced by 76% of the glass HAW volume by selecting Glass-Ceramic. This selection would, however, result in: (1) an increase in life-cycle costs by 12%—\$242 million in 10/94 dollars, (2) an increase of the cost time profile peak by 47%, and (3) increasing the average annual expenditure by 9%. Based on this technical evaluation and these tradeoffs, Glass appears to be the preferred HAW Immobilization Technology when associated with Radionuclide Partitioning technologies under Option 10.

The bottom three rows in Table 6 show the alternative methods for LAW Immobilization and their tradeoffs. The first of these three rows compares the FUETAP Grout method on the base case (top row) with a Portland-type Grout method. The evaluation results show little benefit (one criterion at 1%) to the Portland-type Grout method when compared to FUETAP, note the 208% increase in LAW volume. Completing development of the FUETAP Grouting technology in the near future (see Appendix A) will verify whether or not FUETAP is superior to Portland-

type Grout technology. Additionally, Glass does not appear favorable when compared to FUETAP for LAW immobilization. LAW Glass requires an increase in life-cycle cost by 164%—\$3,351 million in 10/94 dollars, 84% more LAW volume than FUETAP, and results in 313% larger funding spikes on the cost-time profile. Glass-Ceramic shows similar tradeoffs as it did in the HAW Immobilization discussion above. In the LAW case for Glass-Ceramic, the life-cycle cost difference by 21%—\$328 million in 10/94 dollars, the cost-time profile peak is increased by 45%, and the average cost increases by 19%; however, the LAW volume decreases by 48%. It is believed that stakeholder and decision maker values will not place the minimization of LAW volume so high in importance that the Glass or Glass-Ceramic methodology would be favored over the FUETAP Grout technology.

Additionally, processes that require a Glass immobilization facility in Phase I will employ the COGEMA Glass process. Both the stir-melter and Glass-Ceramic technology have technical issues that must be resolved prior to committing funds towards design and construction of these processes. The COGEMA process has low throughput that requires the size and cost of the facility to be substantially larger if the technology treatment option employs direct immobilization or precipitation on the calcine waste. Current HAW immobilization technology development favors phasing the HAW immobilization process or removing the fluoride components prior to immobilization. If the waste is segregated such that the fluoride containing components are placed in the LAW fraction, the same technological development issues remain and will require several years to resolve. If Glass or Glass-Ceramic were selected for Phase I LAW Immobilization, a project delay would result until remaining technological issues were resolved. This would likely delay a Phase I project long enough to require a new tank farm.

Due to the performance factors measured, technology maturity levels, and a preferred phased approach with LAW immobilization in Phase I and a HAW immobilization in Phase II, FUETAP Grout technology for LAW and Glass (Vitrification) for the HAW are the preferred technologies for the immobilization of radioactive liquid and calcine waste.

5.2 Qualitative Evaluation Results

Qualitative evaluations were performed on all twenty-seven Options, with alternatives being ranked as Highly Acceptable, Acceptable, and Unacceptable, based on the relative performance of each alternative according to the qualitative criteria described in Section 4.2 of this report. Alternatives were then awarded 2 points for each Highly Acceptable rating, 1 point for each Acceptable rating, and 0 points for each Non-Acceptable rating. Comparative result appear below in Table 7.

Table 7: Comparative Qualitative Evaluation Results

Option	Health and Safety	Non-Proliferation	SNF Processing	LLW Radioactivity	Technical Maturity	Cumm. Rating
1	⊕	⊕	⊖	⊙	⊕	7
2	⊕	⊙	⊙	⊕	⊕	8
3	⊕	⊕	⊖	⊕	⊙	7
4	⊕	⊕	⊖	⊕	⊖	6
5	⊕	⊕	⊖	⊕	⊕	8
6	⊕	⊙	⊙	⊕	⊕	8
7	⊕	⊕	⊖	⊕	⊙	7
8	⊕	⊕	⊖	⊕	⊖	6
9	⊕	⊙	⊙	⊕	⊕	8
10	⊕	⊙	⊙	⊕	⊕	8
11	⊕	⊙	⊙	⊕	⊙	7
12	⊕	⊕	⊖	⊕	⊕	8
13	⊕	⊙	⊙	⊕	⊕	8
14	⊕	⊕	⊖	N/A	⊙	5
15	⊕	⊕	⊖	N/A	⊖	4
16	⊕	⊕	⊖	⊕	⊕	8
17	⊕	⊙	⊙	⊕	⊕	8
18	⊕	⊕	⊖	⊕	⊖	6
19	⊕	⊕	⊙	⊕	⊙	7
20	⊕	⊙	⊙	⊕	⊕	8
21	⊕	⊕	⊖	⊕	⊖	6
22	⊕	⊙	⊙	⊕	⊕	8
23	⊕	⊙	⊖	⊕	⊕	8
24	⊕	⊙	⊖	⊕	⊙	7
25	⊕	⊕	⊖	⊕	⊖	6
26	⊕	⊙	⊙	⊕	⊖	6
27	⊕	⊕	⊖	N/A	⊖	4

⊕ Highly Acceptable (2 points)

⊙ Acceptable (1 point)

⊖ Unacceptable (0 points)

Options 2, 5, 6, 9, 10, 12, 13, 16, 17, 20, 22, and 23 ranked favorably, having received 8 points each, in regards to the Qualitative criteria described above. By comparing these results with the Quantitative analysis results shown in Table 4, we see that six of the Options (i.e., Options 10, 13, 23, 2, 6, and 20) ranked in the top third both quantitatively and qualitatively, Option 10 being the preferred alternative.

5.3 Comparison to Hanford's Waste Management Process

Upon completion of the technical evaluation it became apparent that the identified favorable option (Option 10) involved technologies that differed from those selected at the DOE Hanford site; Hanford has selected chemical washing of tank farm sludge and phased vitrification (glass) as the technologies to treat and immobilize both their high-level waste (HLW) and low-level waste (LLW) prior to disposal. These differences were investigated in an attempt to further validate the ICPP technologies evaluation. The investigation identified several reasons why different technologies were selected at the two sites, including: characterization of wastes, compatibility with separations technologies, compatibility with immobilization processes, waste composition, retrievability/handling, LLW Immobilization Facility costs, HLW immobilization costs, operating costs, and technology acceptability by other countries and in the United States. These differences are discussed below in greater detail.

- ▶ **Characterization of Waste:** In-depth characterization of the 17-20 waste streams contained in 177 Hanford tanks, some of which contain organic complexants and bismuth phosphates, has not been completed. ICPP waste, on the other hand, have been sufficiently characterized such that the reactivity of the various waste components during both separations and immobilization processes is clearly understood. Additionally, NRC LLW classification levels for Hanford wastes would be either Class B or C; ICPP LLW would be Class A, allowing for direct contact handling.
- ▶ **Compatibility with Separations Technologies:** Some of Hanford's tank farm sludges have only been dissolved to about 70% in laboratory tests. Additionally, Hanford wastes have been neutralized and would require considerable quantities of acid to convert them to a form compatible with similar separations technologies. ICPP waste is already acidic, and calcine can be sufficiently (99%) dissolved, thus allowing for more efficient separations to occur.
- ▶ **Compatibility with Immobilization Processes:** Hanford's LLW has a high sodium content (5-7 molar) which is difficult to immobilize into a grout waste form but easier to immobilize into glass, allowing higher wt% loading. ICPP separated LLW waste contains a considerable quantity of elements that are beneficial to grouting (yielding a high weight loading) and detrimental to glassification (yielding a low weight loading).
- ▶ **Technical Issues:** Hanford does not have high fluoride waste solutions. ICPP calcine wastes contain large quantities of fluoride which cause high corrosion in a glass melter, thus requiring frequent replacements. When separation processing is used, the fluoride goes to the LLW stream where the grouting process inactivates the corrosiveness of the fluoride.

- ▶ **Retrievability/Handling:** Hanford's proposed grout program was to place its grout (NRC Class B and C) in large irretrievable storage bins, resulting in permanent disposal of remote handled wastes at the Hanford site. ICPP proposes to place its grout (NRC Class A) in square steel drums that are easily stacked and moved, allowing for more efficient LLW grouting equipment maintenance and for close contact handling of waste containers.
- ▶ **LLW Immobilization Facility Costs (in 10/94 dollars):** A Class A LLW vitrification facility at the ICPP large enough to accommodate ICPP segregated waste would require a minimum of either three stir-melters or 12 COGEMA style melters at a facility cost of \$930 million using stir-melters and \$1.3 billion using COGEMA style melters. A corresponding grout plant achieving the same throughput would cost \$180 million, resulting in a cost difference of \$180 million to \$1.1 billion.
- ▶ **HLW Immobilization Costs (in 10/94 dollars):** A direct vitrification plant would require either 15 COGEMA melters or 4 stir-melters, at a facility cost of \$2.2 billion or \$360 million, respectively, to achieve the needed throughput. A glass plant for the HLW fraction from separations—Option 10's recommended Phase II—would require one COGEMA melter (1/4 stir-melter) at a facility cost of \$384 million. This represents a cost difference of \$546 million to \$1.8 billion.
- ▶ **Operating Costs (in 10/94 dollars):** LLW vitrification operational costs are \$28.5 million/year, as compared to LLW grout costs—Option 10's recommended Phase I—of \$10.8 million/year. This results in a cost difference of \$17.7 million/year. HLW vitrification operations cost with separations—Option 10's recommended Phase II—is \$18 million/year, as compared to \$127 million/year for direct vitrification (Hanford's selected technology). This is a cost difference of \$109 million/year.
- ▶ **Acceptability by other Countries and in the United States:** Hanford's Tri-Party Agreement between the State of Washington, the EPA, and DOE to use vitrification for LLW differs from the current world trend of using grout to stabilize radioactive LLW. Each waste stream is evaluated on its own merits to determine the most appropriate waste for final disposal. In most cases, grout is being used or is planned for use in many foreign countries (England, France, Japan) and in the United States (West Valley, Savannah River, Oak Ridge, and Rocky Flats) to stabilize radioactive LLW with an equivalent or larger quantity of radioactivity than ICPP wastes.

Despite differences in evaluation results, many of the values established by Washington stakeholders during the technology selection for Hanford wastes were identified as being applicable to the ICPP technology selection process. These values, taken from the Final Report of the Hanford Tank Waste Task Force published in September, 1993, include:

- ▶ **Timing:** "Get on with the cleanup' to achieve substantive progress in a timely manner." Actions taken should (1) move all major facets of the cleanup forward and in the proper sequence; (2) keep technical options that have realistic, cost-effective chances to

significantly improve waste management practices open; and (3) consider the ability to evaluate, expand upon, or change course based on technical and scientific advancement.

- ▶ **Project Management:** "Use a systems design approach that keeps endpoints in mind as intermediate decisions are made, [and] establish management practices that ensure accountability, efficiency, and allocation of funds to high priority items."
- ▶ **Technology Feasibility:** "Use the most practicable, timely, available technology, while leaving room for future innovation, [and] keep a folio of technological options and make strategic investments over time to support a limited number of promising options." These suggestions grew out of concern that the high cost and uncertainty of high-tech pretreatment and R&D would threaten funding for higher performance low-level waste form, vitrification, and cleanup.
- ▶ **Waste Forms and Storage:** "Put wastes in an environmentally-safe form, using retrievable waste forms when potential hazards from the waste may require future retrieval . . . , [and] let the ultimate best form for the waste drive decisions, not the size nor timing of a national repository." Additionally, stakeholders encouraged Hanford to "accept that interim storage, at least, of the waste . . . will occur for some time at Hanford [and to] select a waste form that will ensure safe interim storage . . ."
- ▶ **Transportation:** "Minimize transportation of radioactive and hazardous materials to and from the site to reduce the risks to the public and the environment . . . [and] assume treatment of Hanford's waste will occur on site." Paraphrased: it is not productive to transport untreated waste to or from the site.

As stated above, the conclusions of the ICPP radioactive liquid and calcine waste technologies evaluation (presented in Sections 4 and 5 of this report) are compatible with these values. A phased approach, such as is employed by Option 10, allows the most cost-effective alternative to be logically split into two phases, where the LLW grouting facility and high-priority radioactive liquid waste treatment occur during Phase I and the HLW vitrification facility and corresponding calcine treatment are delayed until Phase II. This approach allows ICPP to (1) move forward the fastest and (2) "get on with the cleanup" in a cost-effective, yet timely manner. Secondly, Option 10 provides the best technology implementation schedule to begin final processing for the well-characterized waste at the ICPP. Technologies employed by Option 10 have been successfully demonstrated on actual radioactive liquid and calcine wastes, although additional work remains to support a plant title design. Finally, all ICPP waste will be treated at its origin to minimize the risks associated with radioactive waste transportation. ICPP technology development management will continue to utilize a systems engineering approach to keep end points in mind and to focus development efforts on high-priority items to ensure accountability and efficiency in support of technologies evaluation and selection.

6. TECHNICAL RECOMMENDATION

Based on technical analysis data as of March, 1995, and on comparisons with waste treatment and immobilization technologies selected at Hanford, it is recommended that DOE consider Option 10 as the preferred alternative for the treatment and immobilization of radioactive liquid and calcine waste at the ICPP. Option 10 (see Figure 12) is a phased processing approach utilizing Radionuclide Partitioning for radioactive liquid and calcine waste treatment, FUETAP Grout for LAW immobilization during Phase I, and Glass (Vitrification) for HAW immobilization during Phase II. As stated below, development and optimization of Option 10 will continue in support of DOE objectives.

Figure 12: Option 10, Proposed Phased WIF

If implemented as proposed, Option 10 would be housed in the proposed Waste Immobilization Facility (WIF) and, as described above, would include a vitrification facility, a stabilizing grout facility, separation capability with acidic solutions, and a mercury separation/amalgamation process. Since these processes and facilities are essential to many of the mixed low-level and transuranic waste streams at the INEL and at other western sites, a pretreatment facility could be added on or near the proposed WIF to convert many of those waste streams into a form compatible for immobilization using one of the WIF processes. If properly planned for, the throughput capacity of WIF could be increased at the time of design and construction to accommodate the additional waste streams at a fraction of the cost required to add the throughput later on or to build a new facility. These plans will be included in the final INEL EM Integrated Program Plan for the treatment and disposal of INEL wastes and nuclear materials.

6.1 Path Forward

The following activities are planned to further support DOE in selecting and implementing optimum technologies for the treatment and immobilization of radioactive liquid and calcine wastes:

- ▶ Continue development of recommended technologies with additional scope for added waste streams from the INEL EM Integrated Plan.
- ▶ Begin pilot-plant testing to validate recommended technologies.
- ▶ Integrate the planning of needed new facilities and the use of existing facilities with the INEL EM Integration Plan.
- ▶ Support identification of technology timing needs to implement the INEL EM Integrated Plan.
- ▶ Support FFCA negotiations on the scheduling of recommended technologies to support INEL EM Integration Plan priorities and budget guidelines.
- ▶ Continue development of alternative decontamination techniques to ensure minimization of future liquid flows to the tank farm. The NON Consent Order to cease use of the tank farm cannot be met unless the WIF or an alternative facility (new tank farm) is built and waste flows to the existing tank farm are greatly reduced.
- ▶ Continued evaluation of LAW dispositioning options, including location of storage facility studies.
- ▶ Incorporate Technology Evaluation and Analysis Methodology (TEAM) Model data into the decision support model being developed for the INEL EM Integration Program.

Follow-on activities will support the requirement of the NON Consent Order; the planning of necessary facilities in accordance with the FFCAct negotiations; the day-to-day operations of the tank farm, the calciner, the Liquid Effluent Treatment and Disposal facility, and the Process Equipment Waste process; and the implementation of the INEL EM Integration Plan.

APPENDIX A: TECHNOLOGY DESCRIPTIONS

A-1 Treatment Technologies

A-1.1 Calcination

Calcination is a proven ICPP process that uses high temperatures to convert liquid waste into a granular solid, as shown in Figure A-1. Liquid wastes containing metal salts blended with additives and/or with other ICPP tank farm wastes are sprayed into a hot (500°C), air-fluidized bed of granular solids where volatile components are flashed off (resulting in off-gasses) and the metallic salts are converted to oxides. The calciner off-gas is passed through a cyclone, where a large portion of the entrained fine particles are settled out and combined with the larger solids, removed by the product take-off lines. Calciner off-gas is then treated by passing it through a quench tower, venturi scrubber and demister. The quench tower is used to cool the off-gas

Figure A-1: Calcination

which allows for the removal of moisture and solid particles. The resulting scrub solution is continually recirculated through the quench tower and venturi scrubber and is eventually recycled back to the calciner. The off-gas then passes through a heat exchanger, silica gel beds, demister, superheater, High-efficiency Particulate Air (HEPA) filters and is exhausted to the Atmospheric Protection System (APS), which exhausts to the main stack. This process can utilize radioactively contaminated organic solvents as fuel for the in-bed combustion system. Calcination greatly reduces the volume of radioactive liquid waste, usually by a factor of 3 to 10. Reducing the volume of radioactive liquid waste minimizes the amount of interim storage space required prior to final disposal. Additionally, risks to the environment can be significantly decreased by removing liquid wastes from the tank farm and putting them in a less corrosive, more immobile form (calcine). However, some types of liquid waste—radioactive sodium-bearing waste in particular—require that non-radioactive chemicals be added prior to calcination. Aluminum nitrate, calcium nitrate, and boric acid are typically blended with the tank farm waste to ensure, respectively, that (1) Na+K mol% of the calcine produced does not cause bed agglomeration; (2) fluorides, chlorides, sulfates and phosphates present in the waste are not volatilized during calcination; and (3) alpha alumina is not formed during calcination. The addition of these chemicals slows the treatment of the radioactive liquid waste and increases calcine waste volume. The ability to process sodium-bearing waste at higher sodium plus potassium waste loadings would decrease the amount of non-radioactive chemical addition and allow for a quicker processing of the tank farm waste. Pilot plant tests using a higher waste loading has been successful; however, full scale operation at the facility has not yet been achieved.

Flowsheets will need to be developed to process some of the waste streams that will be produced from the various proposed alternative radioactive liquid waste and/or calcine treatment technologies. Alternative technologies currently being developed for the treatment of radioactive liquid waste are Radionuclide Partitioning, Freeze Crystallization, Precipitation, and Electrohydrolysis, described below. These technologies will generate radioactive liquid mixed waste streams that may require calcination; flowsheet development will be required to ensure that the NWCF will be able to process resulting waste streams.

A-1.2 Calcine Dissolution

Acid dissolution of calcined material (see Figure A-2) is virtually the only method of efficiently converting the calcine to a suitable liquid feed for the partitioning processes (i.e., Radionuclide Partitioning, Precipitation, and Electrohydrolysis). The calcine dissolution process consists of dissolving the calcine with nitric acid in a heated vessel, the acidic solution continuously being stirred to increase the rate of dissolution. The resulting slurry is then directed to a settling tank where the bulk of suspended solids (i.e., metal cations and non-metal anions) settles to the bottom; these solids are periodically returned to the dissolver. The liquid exiting the settler passes, theoretically, through an additional fine solid/liquid separation system, and the output becomes the feed for aqueous partitioning processes. The necessity of removing non-settling solids from the "clear" liquid stream is still unknown; this issue will be determined by the choice of partitioning technologies. If, however, solids removal is necessary, either a centrifuge or a

Figure A-2: Calcine Dissolution

filter system will be required to perform the separation of the small particles, less than 10 μm . The specific shape of dissolution vessels that will allow safe operation with respect to nuclear criticality has yet to be determined and tested, as is the case with finding an acceptable method for solid/liquid mixing. The shape of the vessels could negatively impact the rate of dissolution and/or the rate of solid/liquid separation, and although an impeller may work well as a mixer, the use of impellers in a radioactive environment is undesirable because of maintenance concerns. Additionally, equipment for transporting settled solids from the settling tank back to the dissolver must still be defined. The major concerns here are that the transportation system may upset the settling process, resulting in inadequate solids removal, or that subsequent solids buildup will occur. Continued design and testing, as well as process chemistry verification, will be conducted to ensure that the calcine dissolution process will operate as desired.

A-1.3 Radionuclide Partitioning

A-1.3.1 Actinide Removal via Transuranic Extraction (TRUEX)

Actinide removal, as shown in Figure A-3, consists of a continuous counter-current solvent extraction process, in this case TRUEX, to separate actinides from the aqueous acidic feed stream. The process typically utilizes a chemical solvent—consisting of 0.2 M CMPO (octylphenyl-N,N-disobutylcarbamoylmethylphosphine oxide), and 1.4 M TBP (tributyl phosphate) in a branch chain hydrocarbon, Isopar-L—and includes (1) an extraction phase, where the actinides are partitioned into the organic solvent; (2) a scrub phase, where the organic solvent is washed with nitric acid to transfer some components not needing extraction back into the aqueous stream; (3) a strip phase, where partitioned actinides are transferred back to the aqueous stream; and (4) a solvent wash phase, where the stripped solvent is washed with sodium carbonate to remove degradation products and prepared for recycle back to the extraction phase. The use of centrifugal contactors during each phase of the process provides for more space efficiency and allows for an adequate and flexible through-put, assuming mercury is separated as part of the LLW stream.

Figure A-3: Actinide Removal via TRUEX

The TRUEX process has shown excellent alpha decontamination factors with experiments in single batch contacts on actual sodium-bearing waste and dissolved calcine wastes. It has also shown excellent recovery of the actinides from the TRUEX solvent. Little or no physical/chemical problems associated with interfacial crud, precipitation, or phase disengagement have been observed when tested on ICPP wastes.

There is some concern, however, that zirconium extraction and recovery with the actinides may increase the high-level waste (HLW) volume when zirconium calcines are processed, and that phosphate from the strip solution may decrease waste loading in the glass or glass-ceramic waste form. Development is continuing in the areas of (1) determining alternative strip solutions, (2) assessing zirconium behavior in overall process, (3) performing counter current tests for flowsheet verification, and (4) refining operating parameters to determine the effects of feed stream compositional changes. Additionally, studies will continue to further determine the number of partitioning stages required, solvent to aqueous flow ratios, and temperature effects.

A-1.3.2 Strontium Extraction (SREX)

The SREX process is a continuous counter-current solvent extraction method, similar to TRUEX, which utilizes variations of a crown ether (18-crown-6) to remove ^{90}Sr from sodium-bearing waste and dissolved calcine solutions. Under this process (see Figure A-4), developed extensively at Argonne National Laboratories, ^{90}Sr is extracted by 18-crown-6 in the presence of high acid concentrations, then stripped in the presence of dilute nitric acid. The extraction efficiency of the SREX solvent, however, is low compared to the TRUEX solvent. This requires that the SREX process use approximately twice the amount of extraction stages as the TRUEX process to achieve the required decontamination levels.

There are two variations of 18-crown-6 which may be used for ^{90}Sr removal: Dicyclohexano-18-crown-6, currently available as a high purity reagent in kilogram quantities; and 4',4', (5')-di-(t-butyl)dicyclohexo-18-crown-6, a variation of the first chemical and also available in kilogram quantities. However, these 18-crown-6 extractants have a small solubility in aqueous solutions and could potentially affect the final waste form. The potential effects of residual amounts of the extractant and other extracted hazardous components (i.e., lead, mercury, cadmium, and potassium) on final high-level waste forms still need to be evaluated.

The only other recognized solvent extraction alternative is a technology utilizing cobalt dicarbollide developed by Russian scientists. The SREX process has the distinct advantage of using a hydrocarbon diluent as opposed to nitrobenzene in the Russian process. Additionally, most ion exchange technologies lack the required selectivity for ^{90}Sr . A commercial ion exchange material which incorporates 18-crown-6 (Sr-SPEC) is currently available, however, only in highly-expensive, small-volume columns.

Figure A-4: Strontium Extraction (SREX)

A-1.3.3 Cesium Removal via Ion Exchange (IX)

From work accomplished to date, it appears that the most promising means of removing cesium from acidic solutions is IX, using ammonium molybdophosphate (AMP) with modified polyacrylonitrile (PAN) as an engineered support. In this process (see Figure A-5), liquid feed would be introduced to a column containing a fixed bed of AMP-PAN where sorptive mass transfer between cesium ions in the liquid and the active surface of the solid would occur. Once the bed is saturated with Cs, the resin would be removed and blended with other HAW and immobilized as HLW, and replaced with fresh resin. Experiments are in progress to elute the column to remove the Cs and regenerate for reuse. The spent resin, in any case, will require processing for final disposal as a LLW or HLW. If the AMP-PAN can be eluted and regenerated, the quantity of waste material will be significantly reduced.

Figure A-5: Cesium Removal via Ion Exchange (IX)

The principle advantage of AMP-PAN ion exchange process is the simplistic equipment required. Other advantages identified through laboratory testing via batch contacts include (1) high cesium selectivity and capacity, (2) rapid kinetics, and (3) chemical stability in highly acidic environments. Operational and design parameters, such as maximum flow rates, bed depths, temperatures, pressure drops, and usable capacities, for full-scale column operations are still under development. However, organic supports (polyacrylonitrile, polystyrene, and polyvinylpyridine) are not known to be as thermally or radioactively stable as inorganic supports. In addition, the fate of organics in production of a glass waste form is not well characterized and may be detrimental. If so, development work will be needed to identify suitable inorganic supports that will maintain high selectivity and good physical properties while being more desirable for the final glass form.

A-1.4 Freeze Crystallization (FC)

FC is a developing technology which separates liquids by freezing one or more components to a solid or crystalline phase. This is accomplished by removing heat and reducing the solution temperature below the freezing point of one or more of the solution components. Usually only one component in the solution crystallizes; that crystal is pure, a result of the natural rejections of substances foreign to the basic crystal structure. The purity is maintained by temperature control in the process crystallizer, which in turn limits the size of the resulting crystals.

Figure A-6: Freeze Crystallization

The process crystallizer is usually one of three types: (1) direct contact where the solution is injected with an immiscible refrigerant and its evaporation causes heat removal from the solution; (2) indirect contact where the heat is removed from a solution through a heat transfer surface in contact with an evaporating refrigerant; and (3) triple point where the solvent is the refrigerant.

Direct contact crystallization using liquid nitrogen was initially determined to be the most favorable for application to treatment of the sodium-bearing waste. Computer modeling has indicated that a large fraction of the water content, and up to 70% of the sodium, can be removed

from the liquid waste solution using this technology. The water will be removed as pure ice crystals, while other components, such as sodium nitrate, will become saturated in the remaining solution and removed from the radionuclide-contaminated solution as precipitate. For this process, four major components are required, as illustrated in Figure A-6: the crystallizer vessel, the salt growth vessel, the ice wash column, and the salt wash column. The crystallizer vessel is where liquid nitrogen is injected and ice formation occurs. The salt growth vessel provides sufficient residence time for the sodium nitrate crystal to grow. The ice wash column separates ice crystals from the concentrated solution and is washed with clean water. The salt wash column separates sodium nitrate salt from the concentrated solution and is washed with water saturated with sodium nitrate. Direct and indirect contact FC systems share some common development challenges, such as scale-up of the development process to a production scale facility, operating and maintaining the process remotely, and handling the resulting precipitated solids. Additionally, the direct contact method has presented challenges in preventing the refrigerant nozzle from freezing. While the indirect contact system has not encountered this freeze-up problem, corrosion and fouling of the heat transfer surface is a concern. Therefore, research and selection of materials is crucial.

FC is a well-proven industrial concept for non-radioactive applications, which achieves highly pure product streams, and does not involve chemical additives or generate secondary wastes. Additionally, a large fraction of the sodium are removed as the waste solution is simultaneously concentrated; partial sodium separation will significantly reduce the amount of diluent chemical, such as ANN, required for calcination, thus significantly reducing the amount of calcine generated. The sodium removal efficiency and product purity have not been determined for sodium-containing radioactive wastes. However, pilot plant testing is underway and preliminary test results are promising. The projected separation efficiency of 65% will require a second process to achieve the greater sodium removal; however, greater than 65% sodium removal may not be necessary to achieve the overall goal of removing waste from the tank farm. Completion of existing and on-going pilot plant tests are needed to determine the process efficiency as well as to clarify the process thermodynamics and precipitation rates.

A-1.5 Precipitation / Neutralization

In the wastewater treatment industry, by far the most widely used process for removal of heavy metals from solution is that of chemical precipitation. The most commonly used precipitation technique is hydroxide treatment due to its relative simplicity, low cost of precipitant, and ease of automatic pH control. In principle, as applied to sodium-bearing liquid waste, the solubilities of the various metal hydroxides are minimized for pH in the range of 7 to 11, thus causing precipitation of the hydroxides. A proposed sodium-bearing waste treatment process by hydroxide precipitation of the polyvalent cations and actinides is shown in Figure A-7.

Figure A-7: Precipitation by Neutralization

Hydroxide precipitation of heavy metals is an effective treatment technique in industry and is well suited for automatic control. For wastewater containing low concentrations of metals and trace contaminants, typical estimates of final concentration for most metals are less than 1 ppm. Removal of metals by hydroxide precipitation of mixed metal and actinide wastes may not be effective because the minimum solubilities for different metals occur at different pH values. The natural presence of complexing agents may also have an adverse effect on metal removal. Additionally, hydroxide sludge quantities may be substantial and are generally difficult to dewater due to the amorphous particle structure; chemical conditioners may, therefore, be required to improve liquid-solid separation. To minimize the high-level waste produced from hydroxide precipitation, and to minimize the metal residuals in supernate, for EH operation, at least two pH adjustments (pH 6-7, 12-14) may be required. The liquid supernate contains most of the alkali metals and less than 5% of the polyvalent metals; therefore, further separation of Sr and Cs from the supernate may be required to produce a Class B or Class A LLW.

Additionally, nearly all of the polyvalent cations can be rejected from sodium-bearing waste by neutralizing the excess acid with NaOH and raising the pH to a value range of 8-10. This results in a sludge containing the TRU, toxic metals, and a large fraction of the strontium along with the

inert polyvalent cationic precipitates. The majority of the sodium would remain in the LLW supernate, and the precipitate would be separated from the salt solutions by filtration or centrifugation. Sodium-bearing waste contains more than 17,000 ppm of aluminum and the aluminum hydroxide characteristically forms a gelatinous precipitate that is difficult to separate from the LLW supernate solution. Following filtration, the precipitate cakes can be directly vitrified, or used as a sodium additive for the glass-ceramic process after it has been thermally dried. The precipitate may require washing to remove residual sodium; subsequently, the precipitate can be redissolved and calcined in the ICPP calciner. Due to the large quantity of various polyvalent metals in the sodium-bearing waste, more than one pH treatment may be required to produce satisfactory insolubility for each of the metal ions and actinides present in the waste solution.

The optimum process conditions must be determined for different feed compositions. The ability to control the pH for high ionic strength solutions, especially for radioactive sodium-bearing waste solutions must be determined and a method of dewatering the gelatinous precipitate must be developed. Remote-operated filtration equipment to achieve maximum liquid-solid separation with minimum secondary waste generated must be selected and the effects of hydroxide precipitate aging must be determined.

A-1.6 Electrohydrolysis (EH)

EH involves the union of two broad technologies: electrolysis and membrane separation. It is characterized by the use of ion-selective membranes and an electric field orthogonal to the membranes. In general, an EH unit, or cell stack, consists of anion-selective, cation-selective, and bipolar membranes placed alternately between an anode and a cathode, as shown in Figure A-8. The electromotive force produced by the electric field causes ions produced in the solution to pass through the membranes. Anion-selective membranes will only allow anions and water molecules to pass. Cation-selective membranes, likewise, will only allow passage of cations and water molecules. Bipolar membranes, which are an anion-selective and a cation-selective membrane fused together, allow water molecules to pass between the two membranes. While inside the membrane, the influence of the electric field causes the water molecules to be split into hydronium ions (H_3O^+) and hydroxide ions (OH^-).

The following equilibrium reaction describes this water dissociation:

The hydronium and the hydroxide ions then pass through the cation-selective and anion-selective sides of the bipolar membrane, respectively. It is the action of the bipolar membrane that distinguishes EH from electrodialysis. Once in the bulk solution, the hydronium ions combine with the anions (A^-) in solution to form an acid by the following reaction:

Figure A-8: Electrohydrolysis

The hydroxide ions combine with the cations (C^+) in solution to form a base by the following reaction:

As a result, concentration occurs in the compartments where the weak acid and base are added while dilution occurs in the compartment where the waste is added. In the compartment adjacent to the anode, hydrogen ions combine to form hydrogen gas. Evolution of this gas is prevented by the introduction of an electrode rinse. Similarly, in the compartment adjacent to the cathode, oxygen gas is formed which is simultaneously removed by an electrode rinse.

EH has the ability to recycle acid and base back to plant processes for decontamination activities or back to the sodium-bearing waste precipitation processes. This reduces the volume of waste that must be ultimately treated for waste disposal. This process has not been demonstrated full-scale in a radioactive environment. Process feed streams must be relatively pure; membranes tend to foul when subjected to feeds with a number of different components.

Development requirements for EH are different depending on the process feed stream. A radioactive demonstration of the equipment is required. If the feed stream is a sodium nitrate solution, development activities will center on equipment since this application of EH has been proven in industry. However, if the feed stream is the supernate stream from precipitation by neutralization, some chemistry development is required due to the composition of the feed. Since precipitation does not remove all of the divalent cations, these must either be removed prior to introduction to the EH cell stack or special membranes that will not allow these cations to enter the base production cells must be used. If the divalent cations are allowed to enter the base production cells, they will combine with the hydroxide ions and form insoluble hydroxide compounds that will foul the membranes.

A-2 Immobilization Technologies

A-2.1 Grouting

Grouting technology refers to the process of encapsulating and/or stabilizing a waste material in a fluidal or molten material which can be pumped into a container where the material solidifies. Viable grouting options include, cements (Portland, gypsum, etc.), phosphate-bonded calcium aluminate, thermoplastic polymers (bitumen, sulfur-polymer cement, and polyethylene), and thermosetting polymers (vinyl-ester-styrene, polyester resins, and epoxy resins). Type I Portland cement was selected to stabilize the high sodium containing wastes at the ICPP. It appears that high-temperature calcination is required to reduce all of the nitrates in the wastes to an oxide form. The addition of silica or clay during thermal denitration may help form insoluble, leach resistant, sodium-alumina-silicates. It is expected that it will be possible to reach high waste loadings by implementing such waste conditioning measures. The key to controlling product consistency is selecting the most appropriate mixing process and carefully controlling the mixing of cement ingredients. Increased densification of the product may be achieved by curing cement-based grout forms under elevated temperature and pressure (FUETAP).

Processes for mixing the waste with cement can be divided into three categories: batch mixing, in-line mixing, and in-container mixing. Batch mixing, shown in Figure A-9, involves the addition of the waste, cement, and additives to a large mixing vessel. After achieving a homogeneous mixture, the grout is transferred to drums.

In-line mixing involves continuous mixing of the waste, cement, and additives with the mixture being continuously feed to the grout containers as illustrated in Figure A-10.

Figure A-9: Grout via Batch Mixing

Figure A-10: Grout via In-line Mixing

In-container mixing is achieved through either a tumbling action with the use of a mixing weight (inserted into the drum prior to capping) or by stirring via a planetary mixer, as shown in Figure A-11. Generally, the mixing weight is disposed with the waste while the stirring mechanism may either be disposed or reused.

Figure A-11: Grout via In-container Mixing

Grouting material and technology is well known, compatible with many waste types, available, and cost effective. Additionally, grout bonds or encapsulates the waste components in the cement matrix, resulting in low leachability for some radionuclides and good impact and compressive strength. Grouting produces a waste form with no free water, and allows rapid, controllable setting, without settling or segregation during curing.

Some waste forms affect the setting process or otherwise produce poor waste forms when grouted. Excessive heat may develop during the setting process with certain combinations of cement and waste. Swelling and cracking occur with some products when they are exposed to water during the grouting process. Dust problems may occur for some systems and potential maintenance problems may result from the premature cement setting process, especially in the

case of in-line mixers. Additionally, equipment for powder feeding is difficult to maintain in a radioactive environment.

A conceptual design for a grout pilot plant has been completed and includes the specifications for equipment to dry, denitrate, and calcine the waste. Improved in-line mixers and a double planetary mixer for in-container mixing are incorporated into the design. In-line and planetary mixers will be tested first, with other mixer types being tested as desired; the existing ICPP calciner pilot plant is being evaluated for this purpose. Alternatively, a wiped-film evaporator, followed by a kneader dryer or a rotary kiln, are also incorporated into the design. An evaluation of the mixing options will be made to select the most favorable option for the ICPP streams. Other parameters currently under investigation include the optimum water-to-cement ratio which is probably the most significant single parameter affecting the strength and chemical resistance of a hardened cement mix. Initial results showed that a 10% waste loading passed initial strength and leach resistance criteria at a water-to-cement ratio of about 0.5; current studies are achieving a greater than 25% weight loading under the same water-to-cement ratio.

A-2.2 Glass (Vitrification)

Vitrification involves combining a liquid or solid waste material with a glass-forming frit (typically SiO_2 , B_2O_3 , and Na_2O) at moderate-to-high temperatures (1050 to 1200°C) to produce a glass. The HAW vitrification process envisioned for the ICPP is shown in Figure A-12.

Figure A-12: Glass (Vitrification)

There are two possible feeds to the process: liquid and calcine. Liquid feed to the process would be either sodium waste or a solution containing the actinides and fission products resulting from a separations process; calcine would be retrieved from the bin sets and transported to a mixer where the calcine would be blended, sampled, and analyzed. For the case of liquid feed, the HLW liquid would be sampled and analyzed, and, based on the analytical results, a suitable frit composition and waste loading would be selected. The liquid would then be dried in a rotary calciner or blended directly with frit and introduced to the glass melter as a slurry. For calcine, a suitable frit and waste loading would be selected according to the results of the analysis. The frit and calcine would then be mixed together in the required proportions and fed to the glass melter. Typical calcine waste loadings in the glass vary from 25 to 33 wt% depending on the type of calcine to be vitrified.

The glass melter would typically be operated at a temperature between 1050 and 1200°C. Molten glass produced in the melter would be poured into canisters, sealed, and transported to an interim storage facility prior to final disposal. The melter off-gas consisting of hazardous (Hg and Cd) and radioactive (Cs, Tc, and Ru) materials would be treated in an off-gas treatment facility and recycled to the melter as needed prior to stack discharge.

A borosilicate glass process has been used in France by COGEMA to immobilize HLW slurries for a number of years. Vitrification processes are also being implemented at the West Valley and Savannah River DOE sites. Many features of this process could be directly applied to vitrification of ICPP liquid wastes and thereby reduce the amount of research required to implement the process. The wide spread use of vitrification technology could improve the acceptance of this treatment technology. Non-radioactive, pilot-scale tests of joule-heated ceramic glass melters completed at the ICPP on simulated waste have proved the initial feasibility of the calcine vitrification flowsheet.

The primary disadvantage of the vitrification process is associated with the waste volumes that are generated when calcine is directly vitrified. Suitable glass waste forms have been produced experimentally at calcine waste loadings of 25 to 33 wt%. At this loading, the volume of waste produced by the process increases by a factor of approximately 1.6 over the existing calcine. An additional problem with direct calcine vitrification is the corrosivity of several calcine and frit components such as CaF_2 , Na_2O , K_2O , and Li_2O . If a suitable material of construction for the melter is not selected, the corrosivity of the glass melt could significantly reduce melter life and increase the amount of secondary waste produced by a vitrification facility.

Much of the development work completed within the DOE complex and internationally has been completed with HLW slurries whereas the ICPP direct vitrification process must be capable of vitrifying calcine solid feed. Hence, much of the development and verification work required for the process is associated with solids handling, solids blending, sampling, and chemical analysis techniques.

Pneumatic retrieval and transport of the calcine has been proposed as a method to recover the calcine from the bin sets and deliver it to the vitrification process. Calcine transport has been

demonstrated at the ICPP and does not appear to present any unresolvable difficulties. However, a significant amount of equipment development is required to fully verify and accomplish calcine retrieval from the existing bin sets.

Calcine solids blending will require additional equipment and control development. As the frit composition and waste loading are a function of calcine composition; mixing, sampling, and chemical analysis, techniques and equipment will need to be developed. The blender size will be a function of the turn around time required for calcine analysis and the need to change the frit composition based on the composition of the calcine.

Several development issues are associated with the glass melter. Possible glass melter decisions include: (1) a joule-heated ceramic melter, (2) a stirred melter, and (3) an inductively-heated melter as presently used by COGEMA. Joule-heated ceramic melters have been studied for use at Savannah River, Hanford, and West Valley. A limited amount of development work on a joule-heated ceramic melter has been accomplished with simulated ICPP calcine. The melter was operated for 40 hours at which time the test was terminated and several modifications to the melter system were recommended. The principal issue identified during initial testing was the materials of construction used for the melter with respect to the corrosivity of the glass melt. Development of better fabrication techniques and melter materials was recommended.

A mechanically agitated or stirred melter has recently been recommended as a possible alternative to the joule-heated ceramic melter. The main issue associated with this melter technology is selection of the materials of construction. Materials presently being considered for melter construction include Inconel 690, carbon, and Haynes alloy 230. There are, however, some disadvantages associated with this technology; namely, the stirrer and the melter crucible are used as the electrodes and must be conductive, making them subject to accelerated corrosion rates. This will increase remote operations maintenance due to frequent changeout of the stirrer. Additional development issues include the effect of agitation on waste loading and the effects of waste formulation on operating temperatures, melt viscosities, and final product durability.

The inductively-heated COGEMA melter would be useable at the ICPP only if a separations process is implemented. The throughput of this melter type is low compared to the other two melter alternatives as inductive heating is not capable of transferring large amounts of energy to the glass melt. Development issues associated with the COGEMA melter would include demonstration of the technology on ICPP wastes, the effect of this melter type on waste loading and frit composition.

It is anticipated that the off-gas from the glass melter would be different from the off-gas produced at other existing vitrification facilities and on-site at the NWCF. As a result, modifications to existing off-gas treatment schemes are anticipated to be necessary before implementation at the ICPP.

A-2.3 Glass-Ceramic

The production of an acceptable glass-ceramic waste form would begin with the transport of calcine to the WIF. Newly generated calcine from the NWCF would be pneumatically transported directly to the WIF. Previously generated calcine stored on site would be retrieved and transported to the WIF. Production of a glass-ceramic waste form, as depicted in Figure A-13, begins with volatiles removal from the calcine. The calcine feed would be stabilized at 600° C to remove nitrates and water adsorbed to the calcine. A particle sizing step would be performed to reduce the particle size distribution span. This would decrease segregation tendencies induced by solid handling steps throughout the process. It also appears to improve waste form reaction kinetics during the densification step, which results in an increase in product durability and a decrease in the processing time.

Figure A-13: Glass-Ceramic

The varying composition of the calcines produced in the NWCF and the layered nature of calcine in the storage bins, would make it necessary to blend the calcine prior to processing. The calcine composition would be analyzed after blending and the analysis used to determine the additive composition. The frit and reactants would be sized similar to that of the calcine, and thoroughly mixed with the calcine.

The calcine-additive mixture would be loaded into a processing canister for densification. The equipment used to fill the canister must be designed to eliminate or minimize any dust or contaminant escape, and to fill the canister as completely as possible. Pre-compaction before densification might be necessary to obtain maximum final waste form volume efficiency. The filled canister would be evacuated, sealed, and decontaminated prior to densification. Evacuation is required because any remaining gas, such as air, would expand as the canister is heated, resulting in a non-durable porous product. Near-full, theoretically dense glass-ceramic waste forms are attainable by processing at high temperature and pressure. A HIP is currently used to produce the glass-ceramic in laboratory work.

The off-gas from all unit operations would consist of solids separation using cyclones, sintered metal filters, and HEPA filters. Off-gas cleanup systems would be required for the stabilization operation. The stabilizer off-gas system would be similar to the calciner off-gas system (see Section A-1.1). The HIP operation is carried out using argon gas. The gas would be monitored to ensure that no contamination had occurred during the HIP process, the gas would then be released or recycled.

Research has shown that a glass-ceramic waste form, with a calcine waste loading of about 70 wt%, and leaching properties comparable to a glass, can be achieved. It is estimated that the use of a glass-ceramic process and waste form could result in about 60% less immobilized waste volume as compared to the glass waste form and process.

Many of the operations required in the glass-ceramic process have been performed at the ICPP for several years. This includes pneumatic transport systems, fluidized bed systems which will be used in the stabilization, particle sizing, and blending operations, solids separations systems, and the off-gas clean up system for the stabilization operation.

The off-gas clean up system for the HIP process would be less complicated than the system used for the vitrification process. Both processes will be carried out at similar temperatures.

Waste Acceptance Preliminary Specifications (WAPS) have only been developed for a vitrified waste form. Draft specifications have been developed for a glass-ceramic waste form but, detailed reviews have not been performed by repository experts. In addition, further experimental testing of the glass-ceramic waste form is needed to help define those specifications. A glass-ceramic waste form has not been produced from radioactive calcine, and as such, waste form characterization is less mature than glass. The process is mechanically complex and will require in-depth verification and scale-up studies.

Currently, the physical and flow properties of the various types of calcine are not completely known, but would need to be determined to properly design the bulk solids handling and blending systems. A criteria for estimating the homogeneity of the calcine blend and the calcine-additive blend must be determined. Also, the sampling requirements and methods of the calcine blend and the calcine-additive blend must be established. This is a critical step in the glass-ceramic process. If the calcine is not homogeneous when sampled, the appropriate frit/additive cannot be selected. The calcine-additive blend must be homogeneous to obtain a durable and fully dense glass-ceramic waste form. The HIP must be modified for remote operations. This will require an extensive equipment development and verification effort. Product quality assurance criteria and physical measures need to be developed and verified to facilitate waste form acceptance.

APPENDIX B: MASS BALANCE CALCULATIONAL BASES

The assumptions contained in this appendix are conservatively based on best available data. On-going test results, however, generally exceed assumed values. As results are finalized, updated data regarding such elements as sodium removal efficiency, weight percent loadings, and grout densities will be incorporated into future evaluation efforts.

B-1 Feed Material

1. Mass balance calculations are based on feed compositions as shown in Tables B-1 and B-2 (personal correspondence from R. D. Boardman, "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 _{φ,i}	=	Apparent (partial) molar volume of component I (m ³ /mole)
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 B-1, to determine the net apparent molar volumes.

3. Nitrate values in Table B-1 are based on a charge balance and not the analytical analysis value (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 Sr⁹⁰, Y⁹⁰, Cs¹³⁷, Ba¹³⁷, and Pm¹⁴⁷ are from WINCO-1050, and the remaining isotopes are ratioed per IDO-10105.

Table B-1: Sodium Feed Composition

Component	Apparent Molar Volume m ³ /mole	Mass per m ³	
		gms	moles
Acid (H ⁺)	0	1577.5	1565
Hydroxide (OH ⁻)	-0.00000404	-	
Boron (B ³⁺)	0.00005575	194.6	18
Sodium (Na ⁺)	-0.00000121	43611.7	1897
Aluminum (Al ³⁺)	-0.0000422	17268.2	640
Potassium (K ⁺)	0.00000902	8015.9	205
Calcium (Ca ²⁺)	-0.00001785	2124.2	53
Chromium (Cr ³⁺)	-0.0000395	192.4	3.7
Manganese (Mn ²⁺)	-0.0000177	879	16
Iron (Fe ²⁺)	-0.0000247	1228.6	22
Nickel (Ni ²⁺)	-0.000024	93.9	1.6
Zirconium (Zr ⁴⁺)	0.000115.94	182.4	2
Molybdenum (Mo ⁶⁺)	-0.0000395	67.2	0.7
Cadmium (Cd ²⁺)	-0.00002	314.7	2.8
Lead (Pb ²⁺)	-0.0000155	290.1	1.4
Mercury (Hg ²⁺)	-0.0000193	220.6	1.1
Fluoride (F ⁻)	-0.00000116	1310.9	69
Chloride (Cl ⁻)	0.00001783	1028.1	29
Nitrate (NO ₃ ⁻)	0.000029	348933	5627.5
Phosphate (PO ₄ ³⁻)	0.0000291	1804.5	19
Sulphate (SO ₄ ²⁻)	0.00001398	4803.1	50
Undissolved Solids		2488	
Water (H ₂ O)		763249.3	42366.6
Density (kg/m ³)	-	1297.65	
H-3 (Tritium)	0	0.00000342	0.00000114
Strontium-90	-0.00001816	0.28	0.003
Yttrium-90*	0	-	-
Technetium-99	0.00002283	0.64	0.006
Iodine-129	0.00003622	10.59	0.08

Table B-1: Sodium Feed Composition

Component	Apparent Molar Volume m ³ /mole	Mass per m ³	
		gms	moles
Cesium-137	0.00002134	0.47	0.003
Barium-137*	0	-	-
Actinides	0.00001591	92.77	0.39

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

Note: Apparent Molar Volume values are not well predicted for electrolyte solutions and are a function of ionic charge, radius, and concentration. The values above have been extracted from the experimental values published in the literature. Negative values indicate an increase in density and positive values indicate a decrease in density, as observed experimentally.

Table B-2: Calcine Feed Composition

Component	Mass (Kg) per m ³	
	Aluminum	Zirconium 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
Phosphate (PO ₄)	--	1.581

Table B-2: Calcine Feed Composition		
Component	Mass (Kg) per m ³	
	Aluminum	Zirconium Mix
Sulphate (SO ₄)	13.201	4.656
Density (kg/m ³)	1,100.0	1,600.0
Radionuclides	Ci/m ³	
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	

B-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 in a letter to T. A. Todd, "Interim Report on Calcine Dissolution Studies, 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 CaF₂; fluoride is assumed to be present only as CaF₂. However, CaF₂, 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 CaF₂ 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, then it is possible that the amount of solids will be negligible.

B-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 (Ca^{+2}) will foul the membranes due to high concentrations of those cations (personal correspondence from R. D. Boardman to D. V. Croson, "Technical Review of Sodium-Bearing Waste Treatment Alternatives," 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 (+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 modeled. 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 m³ as 400 volumes are used; all other volumes are then ratioed accordingly.

B-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 (H₂O) stays in the LAW liquid stream and 5% with the HAW solid product. 100% solid/liquid separation is assumed.
3. Component removal % (See Table B-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 B-3: Precipitation Removal Percentage

<u>Component</u>	<u>Removal %</u>
Aluminum+3 (D)	90
Fluoride-1 (G)	0
Nitrate-1 (G)	0
Potassium+1 ©	0
Sodium+1 ©	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 ©	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) Personal correspondence from J. A. Nenni to D. V. Croson, "Sodium-Bearing Waste Treatment Program Scoping Study Results," 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.

B-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:

Anode Reaction

Cathode Reaction

The amount will be the NaOH required to do the neutralization in B-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 unsplit water remaining, 25 wt% leaves with the HNO_3 stream, 25 wt% leaves with the NaOH stream, and 50 wt% remains in the dilute waste stream.

B-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., August, 18, 1983).

4. Na removal of 64 wt% is assumed as NaNO_3 precipitate for freeze crystallization in each cycle (FAX transmission from FTC Acquisition Corp., August 2, 1983).
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.

B-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:

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

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 ($\text{Al}(\text{NO}_3)_3$)	2.2	1.3648
Boric Acid (H_3BO_3)	0.75	1.0143
Calcium Nitrate ($\text{Ca}(\text{NO}_3)_2$)	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).

B-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 can it 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 mass transfer coefficient that quantifies the amount of cesium sorbed when in equilibrium with the contacting solution. From the mass transfer coefficient and the capacity, one can estimate the cesium concentration where the material becomes saturated and bed breakthrough curves. 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. The assumed engineered sorbent form is ammonium molybdophosphate (AMP) on a polyacrylonitrile (PAN) support. Sorbent loading in the engineered form is 80 wt% for AMP. (Material supplied by Dr. Ferdinand Sebesta of the CZECH National Institute).
2. Break-through sorbent capacity for AMP is 9.3g Cs per kg of AMP. This is a conservative number based on tests performed at ICPP, but is prudent until further testing can be accomplished. (Faubel and Ali, 'Separation of Cesium from Acid ILW-PUREX Solutions by Sorption on Inorganic Ion Exchangers,' *Radiochimica Acta*, 40, 49-56, 1986)
3. At this point it is planned that spent sorbents will not be regenerated. They will be incorporated into a HAW glass or glass-ceramic. It is not presently known how the spent resin will behave during the immobilization process because of its organic composition, but the organic portion is expected to volatilize and be

carried with the off-gas. Testing is being performed to elute the adsorbed Cs and literature suggests that it will be feasible. If elution tests are successful, the spent resin must still be disposed of, but probably not as HAW. (Process knowledge and conversations with B. Staples.)

B-8 SREX: Strontium Extraction

1. The Strontium extraction (SREX) process utilizes 4',4'(5')-di-tertbutyldicyclohexo)-18-crown-6 as a Sr extractant in either 1-octanol or 1.2 M TBP/Isopar L.
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 amounts of K and Na are removed per process cycle in sodium-bearing wastes. Higher distribution coefficients are attained in dissolved calcine solutions which allow a decontamination factor of 10^6 (99.9999% removal) for Sr in one process cycle. However, a value of 99.7% removal per process cycle has been used for all calculations to provide a conservative result. (Recent experimental results presented in Application of SREX Solvent for Removal of ^{90}Sr from ICPP Liquid Wastes, D. J. Wood, T. J. Tranter, and T. A. Todd, draft 1994).

B-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 ^3H 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.

B-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 (personal correspondence from W. D. Bolon and L. O. Nelson 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 (personal correspondence from W. D. Bolon and L. O. Nelson to J. D. Herzog, "Estimated Immobilized Waste Volumes, Number of Canisters, and Metal Canister Mass Based on Current Waste Inventories", 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 ^3H in the feed are volatilized during denitration/calcination of the waste.

APPENDIX C: COSTS

Appendix C 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.

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

Where

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

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 C-1, but may be selected as user inputs in the model.

NOTE: When looking up values for cost variables in Table F-1 for HAW glass immobilization, use the Glass HAW Liquid row for options using TRUEX in Phase II, otherwise use the Glass HAW Liquid Solid row.

Table C-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 DCS start date	1997
YI_{con}	Phase I DCS 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 DCS start date, in years, equals DI_{ops} plus YI_{ops} minus YII_{con}	2004
YII_{con}	Phase II DCS 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

C-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 C-1.1
- C_{dc} = development cost for calciner, from Section C-1.1
- C_{dPII} = development cost for Phase II process, from Section C-1.1
- C_{dHAW} = development cost for HAW immobilization process, from Section C-1.1
- C_{dLAW} = development cost for LAW immobilization process, from Section C-1.1

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

C-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 process and are calculated by the following equation for C_{dPI} , C_{dC} , C_{dPIB} , C_{dHAW} , and C_{dLAW} .

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

Where

- FTE = the number of principle investigators (full time equivalent person years) required for development, from Table F-1
- F_{supp} = the ratio of support personnel to principle investigators needed to support technology development, from Table F-2
- LR_{dev} = the fully burdened annual labor rate for development personnel, from Table F-2
- F_{sm} = the factor of the labor budget expended for subcontract support and materials during technology development, from Table F-2
- t_d = development time, from Section C-1.1.1
- C_{test} = advanced testing costs, from Table F-1
- C_{WQD} = cost for waste qualification development work, from Section C-1.1.2

C-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 C-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 C-1
- YII_{dev} = the Phase II development years, from Table C-1

C-1.1.2 Waste Qualification Development

Waste qualification development costs (C_{WQD}) are calculated for C_{dHAW} by the following equation:

$$C_{WQD} = (2)(F_{supp})(LR_{dev})(1+F_{sm})(6)$$

Where

- F_{supp} = the ratio of support personnel to principle investigators needed to support technology development, from Table F-2
- LR_{dev} = the fully burdened annual labor rate for development personnel, from Table F-2
- F_{sm} = the factor of the labor budget expended for subcontract support and materials during technology development, from Table F-2

Waste qualification development costs (C_{WQD}) for C_{dPI} , C_{dC} , C_{dPII} , and C_{dLAW} is equal to zero.

C-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 C-2.1
- C_{dcsC} = design, construction, and start-up cost for calciner, from Section C-2.1
- C_{dcsPII} = design, construction, and start-up cost for Phase II process, from Section C-2.1
- C_{dcsHAW} = design, construction, and start-up cost for HAW immobilization process, from Section C-2.1
- C_{dcsLAW} = design, construction, and start-up cost for LAW immobilization process, from Section C-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 F-1 and need to be multiplied by F_{cp} (from Table F-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, otherwise the sodium transfer cost is added to Phase II C_{dcs} . Sodium transfer costs are the costs to add a transfer line from the tank farm to the new facility.
- (2) If calcination is chosen for Phase I, or $C_{p_{add}}$ is greater than 300,000 gallons, then surge capacity (new tank farm) costs are calculated by the following equation from new tank farm cost estimates for ICPP. This cost is added to the Phase I DCS costs.

$$C_{sc} = (310,000,000) \left(\frac{C_{p_{add}}}{2,000,000} \right)^{0.6}$$

Where

$C_{p_{add}}$ = the maximum value of surge capacity needed as calculated in Section D-3

NOTE: The resulting value is discounted as outlined in Section E-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 E-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 E-3.2.

- (9) Sodium-bearing waste pre-treatment costs are added to Phase II C_{dcs} costs if the HAW vitrification plant is delayed to Phase II and no separations in Phase I and II. This cost is added to Phase I C_{dcs} costs if Phase I vitrification plant and no separations in Phase I.
- (10) Utilities costs are added to Phase II DCS costs unless the Phase I process is the same as the Phase II process and there is a separation process in Phase I, OR the HAW vitrification plant is delayed to Phase II and there is no separation in Phase II.
- (11) Calciner vessel replacement.

C-2.1 General Design, Construction, and Startup Costs

The following equations is used to calculate C_{dcsPlb} , C_{dcsC} , C_{dcsPlb} , C_{dcsHAW} , and C_{dcsLAW} for either Phase I or II, except for Glass Ceramic (see Section C-2.3) and Glass (see Section C-2.4). Use the following equation if $T_h > T_b$.

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

Use the following equation if $T_h \leq T_b$.

$$C_{dcs} = (F_{cp}) (C_{const}) (F_{CH})$$

Where:

F_{cp}	=	the factor to adjust construction cost to design, construction, and start-up cost, Table F-2
C_{const}	=	the estimated construction costs for a facility capable of handling the baseline throughput, from Table F-1
T_h	=	the needed throughput, from Section C-2.2
T_b	=	baseline throughput used for estimating construction costs of processing equipment and facilities, from Table F-1
0.6	=	throughput rates are obtained by scaling according to the six tenths rule (0.6) [Williams, <u>Chem. Eng.</u> , 54(12) 1947, p. 124]
F_{CH}	=	a multiplier for grout and FUETAP grout that is equal to 1 if Class A, 1.45 if Class B, or 2.27 if Class C; otherwise it equals 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 C-2.1.1. Also, when calculating C_{dcsC} , $T_h = T_b$.

When calculating C_{dcsC} and the number of calciner campaigns is greater than 3, add \$5.88 million per year to C_{dcsC} for the years 2002 through 2006.

C-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 F-4
Na_{MT}	=	metric tons of sodium-bearing liquid waste, from Section D-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table F-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 F-4
Al_{sep}	=	the Aluminum calcine separation factor, from Table F-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 F-4
Zr_{sep}	=	the Zirconium waste separation factor, from Table F-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 D-2.1
$Zr_{calcine}$	=	metric tons of zirconium calcine currently in inventory, from Table F-2

C-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.

$$T_h = \frac{W_i}{(OPS_i)(36525)(24)(0.75)(0.6)}$$

Where

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

NOTE: The maximum of T_h for Phase I and Phase II should be used. The 0.5 on-line efficiency factor is omitted from the equation when calculating T_h for glass-ceramic.

C-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 C-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 D-1
1000	=	liters per cubic meter

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

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

Where

$Al_{calcine}$	=	the metric tons of Aluminum calcine, from Section D-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 F-2
 5,000 = the liters of nitric acid required to dissolve one metric ton of Zirconium calcine
 Na_{CO} = Liters of sodium bearing liquid waste carried over from Phase I.
 $Na_{CO} = (Na_{liq})(1000)$ if there is no processing in Phase I and ANN Calcine is chosen. Otherwise Na_{CO} equals zero.

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 D-1
 Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-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.

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

Where

Na_{MT} = the metric tons of sodium-bearing liquid waste from Section D-1, if using HAW evaporated storage OR there is no processing in Phase I and the vitrification plant is planned for Phase II OR silica calcine is being used. Otherwise Na_{MT} equals 0.
 Na_{Sep} = the sodium-bearing liquid waste separation factor from Phase I process (Table F-3). If there is no Phase I processing and the ANN calciner is being used then Na_{Sep} is based on the Phase II separation process.
 $Al_{calcine}$ = the metric tons of Aluminum calcine, from Section D-2.1
 Al_{sep} = the Aluminum calcine separation factor, from Table F-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 F-2
 Zr_{sep} = the Zirconium waste separation factor, from Table F-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 I calciner is calculated in liters by the following equation.

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

Where

- Na_{liq} = cubic meters of sodium-bearing liquid waste from Section D-1
- Na_{sep} = sodium-bearing liquid waste separation factor from Table F-3.
This will be the HAW separation factor.
- 1000 = conversion from cubic meters to liters

Since the calciner is in operation only during Phase I, there is no calcination W_i calculation for Phase II.

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

C-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 C-2.3.4
 N_{HIP} = the number of HIPs, based on throughput (T_h), from Section C-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)

C-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 C-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

C-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 0.44
If the waste classification is Class B, then F_{waste} equals 0.69
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%.

C-2.3.4 Glass-Ceramic Facility Scalable Cost

The Process Development Facility (PDF) feasibility study showed a throughput of 25 kg/hr for a Glass plant costing \$64 million. Of this \$64 million, \$4 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 (\$64,000,000 - \$4,000,000 = \$60,000,000). This cost was scaled to a Glass-Ceramic facility (GC_{HIP}) containing one HIP by the following equation.

$$GC_{HIP} = \left(\frac{T_{GC}}{25} \right)^{0.6} (scale)$$

Where

T_{GC}	=	Glass-Ceramic facility throughput in kg/hr, from Table F-2
25	=	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, <u>Chem. Eng.</u> , 54(12) 1947: p. 124]
scale	=	the scalable portion of the cost for a Glass-Ceramic facility, from Table F-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

C-2.3.5 Number of HIPs

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

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

Where

INTEGER	=	the integer function which truncates the resulting value into an integer
T_h	=	the needed throughput, from Section C-2.2
T_b	=	baseline throughput used for estimating construction costs of processing equipment and facilities, from Table F-1
WT_{AVG}	=	the weighted average weight percent loading, from Section C-2.1.1. The note in section C-2.1 indicates that T_b must be multiplied 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

C-2.4 C_{dcs} for Glass Immobilization

Glass immobilization costs are calculated differently depending on which method is used, the COGEMA melter or the cold crucible. Explanations of when each type of melter design is to be used are outlined below.

For HAW:

If the HAW vitrification plant is planned for Phase I then the COGEMA melter is used when TRUEX is used in Phase II OR if the HAW vitrification plant is planned for Phase I and the Phase I development duration (YI_{dev}) is less than the number of years needed to develop the stir melter technology (Y_{DSM}) OR if the HAW vitrification plant is planned for Phase II and ($YI_{dev} + YII_{dev}$) is less than the number of years needed to develop the cold crucible technology (Y_{DSM}). Otherwise the cold crucible is used.

For LAW:

The cold crucible is used for LAW unless YI_{dev} is less than Y_{DSM} if the LAW immobilization plant is built in Phase I OR ($YI_{dev} + YII_{dev}$) is less than Y_{DSM} if the LAW immobilization plant is built in Phase II, in which case the COGEMA melter is used.

The equation for calculating C_{dcs} for cold crucible glass is as follows.

$$C_{dcs} = [54,440,000 + (N_{melt} - 1)(C_{agm})] (F_{waste})(F_{cp})$$

Where

54,400,000	=	baseline cost for cold crucible plant
N_{melt}	=	number of melters, from Section C-2.4.1.
C_{agm}	=	cost of an additional glass melter, from Table F-2
F_{waste}	=	waste classification factor, from Section C-2.3.3
F_{cp}	=	the factor to adjust construction to design, construction, and startup cost, from Table F-2

C_{dcs} for COGEMA melter glass is calculated using the following equation and Table C-2 (shown below) based on the number of melters calculated from N_{melt} (Section C-2.4.1).

$$C_{dcs} = (COST)(F_{waste})(F_{cp})$$

Where

COST	=	cost of COGEMA glass melter, from Table C-2
F_{waste}	=	waste classification factor, from Section C-2.3.3
F_{cp}	=	the factor to adjust construction to design, construction, and startup cost, from Table F-2

Table C-2: COGEMA Glass Melter Cost (\$)	
Number of Melters (N_{melt})	COST
1	64,000,000
2	72,780,000
3	81,560,000
4	90,840,000
5	99,620,000
6	108,400,000
7	172,400,000
8	181,180,000
9	189,960,000
10	199,240,000
11	208,020,000
12	216,800,000
13	280,800,000
14	289,580,000
15	298,360,000
16	307,640,000
17	316,420,000
18	325,200,000
19	389,200,000
20	397,980,000
21	406,760,000
22	416,040,000
23	424,820,000
24	433,600,000
25	497,600,000

C-2.4.1 Number of Glass Melters

The number of glass melters (N_{melt}) is calculated by the following equation.

$$N_{melt} = \text{INTEGER} \left[\frac{T_h}{(T_b)(WT_{AVG})} \right] + 1$$

Where

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

C-3 Operating Cost

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

$$C_{Tops} = C_{opsPI} + C_{opsC} + C_{opsPII} + C_{opsLAW} + C_{opsHAW} + C_{OTHER}$$

Where

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

C-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.

$$C_{ops} = (C_{mats} + C_{labor}) OPS_t$$

Where

- C_{mats} = the annual cost of materials and supplies during operations, from Section C-3.1.1
 C_{labor} = annual labor costs to operate the facility, from Section C-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 C-1. For calciner operations OPS_t equals YI_{ops} plus two.

C-3.1.1 Material Cost

The cost of materials during operations (C_{mats}) is calculated by the following equation.

$$C_{mats} = (F_{matR})(F_{matB})\left(\frac{T_h}{T_b}\right)$$

Where

- F_{matR} = the ratio of materials expenses to baseline material cost for facility operations, from Table F-1
 F_{matB} = annual baseline process material cost factor, from Table F-2
 T_h = needed throughput, from Section C-2.2
 T_b = baseline throughput used for estimating construction costs and materials cost factors of processing equipment and facilities, from Table F-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 C-2.1.1.

C-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 F-1
 N_{ao} = the number of additional operators per shift is determined as noted below
 C_{oper} = annual cost per operator position, from Table F-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 C-2.1.1. Use the maximum of T_b for Phase I and Phase II.

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 F-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_{ao} when calculating operating costs for Phase II (C_{opsPII}).
- (5) If no processing in Phase I or Phase II then 8 extra operators are added to N_{ao} for Glass or Glass Ceramic.

C-3.2 HAW Operating Cost

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

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

Where

- C_{mats} = annual cost of materials and supplies during operations, from Section C-3.1.1
- C_{can} = cost of a one cubic meter canister, from Table F-2
- NC_Y = number of canisters of immobilized waste per year, from Section C-3.2.1 for Phase I and Section C-3.2.2 for Phase II
- C_{MPC} = cost for a multi-purpose canister, from Table F-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 F-2
- C_{labor} = annual labor costs to operate the facility, from Section C-3.1.2
- C_{maint} = annual maintenance expenses for a facility, from Section C-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 C-1

C-3.2.1 Phase I Canisters

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

$$NC_Y = \frac{[(Na_{MT})(Na_{sep})](1000)}{(F_{eff})(WT_{Na})(D_{HNa})(YI_{ops})(V_{CAN})} + \frac{C_{maint}}{C_{gm}}$$

Where

- Na_{MT} = metric tons of sodium-bearing liquid waste, from Section D-1
- Na_{sep} = sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor.
- 1000 = kilograms per metric tons
- F_{eff} = the canister filling efficiency factor, from Table F-2
- WT_{Na} = sodium-bearing liquid waste weight percent loading, from Table F-4
- D_{HNa} = the density of sodium-bearing liquid waste, from Table F-5
- YI_{ops} = the Phase I operating years, from Table C-1
- V_{CAN} = the canister volume, from Table F-2

- C_{maint} = annual maintenance expenses for a glass facility, from Section C-3.2.3
- C_{gm} = replacement cost for a glass melter from Table F-2

C-3.2.2 Phase II Canisters

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

$$NC_Y = \frac{(T_{si})}{(F_{\text{eff}})(YII_{\text{ops}})(V_{\text{CAN}})} + \frac{\left[\frac{(Na_{MT})(Na_{\text{sep}})}{(WT_{Na})(D_{HNa})} + \frac{(Al_{\text{calcine}})(Al_{\text{sep}})}{(WT_{Al})(D_{HAl})} + \frac{(Zr_{\text{calcine}})(Zr_{\text{sep}})}{(WT_{Zr})(D_{HZr})} \right](1000)}{(F_{\text{eff}})(YII_{\text{ops}})(V_{\text{CAN}})} + \frac{C_{\text{maint}}}{C_{\text{gm}}}$$

Where

- 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 D-2.2, otherwise T_{si} equals zero.
- D_{HZr} = the density of zirconium calcine HAW, from Table F-5
- Na_{MT} = metric tons of sodium-bearing liquid waste. If using HAW evaporated storage OR there is no processing in Phase I and ANN calcine is being used then calculated Na_{MT} as in Section D-1, otherwise Na_{MT} equals zero.
- Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor. If no processing in Phase I and ANN calcine then the Na_{sep} is based on the Phase II process.
- WT_{Na} = the sodium-bearing liquid waste weight percent loading, from Table F-4. If no processing in Phase I and ANN calcine then the WT_{Na} is based on the Phase II process.
- D_{HNa} = the density of sodium-bearing liquid HAW, from Table F-5. If no processing in Phase I and ANN calcine then the D_{HNa} is based on the Phase II process.
- Al_{calcine} = the metric tons of Aluminum calcine, from Section D-2.1
- Al_{sep} = the Aluminum calcine separation factor, from Table F-3. This will be the HAW separation factor.
- WT_{Al} = Aluminum calcine weight percent loading, from Table F-4
- D_{HAl} = the density of aluminum calcine HAW, from Table F-5
- Zr_{calcine} = the metric tons of Zirconium calcine, from Table F-2
- Zr_{sep} = the Zirconium waste separation factor, from Table F-3. This will be the HAW separation factor.

WT_{Zr}	=	Zirconium calcine weight percent loading, from Table F-4
D_{HZr}	=	the density of zirconium calcine HAW, from Table F-5
1000	=	kilograms per metric ton.
F_{eff}	=	the canister filling efficiency factor, from Table F-2
$Y_{II_{ops}}$	=	the Phase II operating years, from Table C-1
V_{CAN}	=	the canister volume, from Table F-2
C_{maint}	=	annual maintenance expenses for a glass facility, from Section C-3.2.3
C_{gm}	=	replacement cost for a glass melter from Table F-2

C-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. If the vitrification facility is planned for Phase II then the C_{maint} during Phase I is 0.

For Glass use the following equation.

$$C_{maint} = \frac{(N_{melt})(C_{gm})}{M_{freq}}$$

Where

N_{melt}	=	the number of melters, from Section C-2.4.1
C_{gm}	=	the cost of a glass melter, from Table F-2
C_{Mrep}	=	the cost for replacing a glass melter, from Table F-2
T_h	=	the needed throughput, from Section C-2.2
T_{Sb}	=	the Savannah River baseline throughput that matches the baseline melter replacement costs, from Table F-2
M_{freq}	=	maintenance frequency, from Table F-2

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 C-2.3.5
C_{HIP}	=	the cost of a HIP, from Table F-2
C_{Hrep}	=	the cost for replacing a HIP, from Table F-2
M_{freq}	=	maintenance frequency, from Table F-2

C-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 retrieval cost for a CSSF, from Section C-3.3.1
- C_{nTFops} = new tank farm operating cost, from Table F-2. If no new tank farm is needed, then C_{nTFops} equals zero.
- C_{TFops} = existing tank farm operating costs, from Table F-2
- C_{OWops} = other waste operating costs, from Table F-2
- C_{ECops} = cost of early calcination campaigns, from Section C-3.3.2

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

C-3.3.1 Retrieval 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 F-2.

If CSSF 7 and 8 are used then C_{RET} equals two times C_{Bops} , from Table F-2.

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

C-3.3.2 Early Calcination Operating Costs

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

$$C_{ECops} = [(F_{matR})(F_{matB}) + (N_o)(C_{oper})(Y_{endcal} - 1995 + Y_{SD})]$$

Where

- F_{matR} = the ratio of materials expenses to baseline material costs for facility operations, from Table F-1
- F_{matB} = the annual baseline process material cost factor, from Table F-2
- N_o = number of operators per shift, from Table F-1

C_{oper}	=	annual cost per operator, from Table F-2
Y_{endcal}	=	year early calcination ends, from Section D-5
1995	=	start date for early calcination operations
Y_{SD}	=	three years for shutdown if shutdown of calciner is chosen, otherwise, $Y_{SD} = 1$

C-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 C-4.1, C-4.2, and C-4.3
Y_{Lstor}	=	the number of operating years of the LAW storage facility, from Section C-4.4
CS_L	=	the interim storage capital cost for LAW, from Section C-4.5, C-4.6, and C-4.7
OS_H	=	the annual interim storage operating cost for HAW, from Section C-4.8
Y_{Hstor}	=	number of operating years of the HAW storage facility, from Section C-4.9
CS_H	=	the interim storage capital cost for HAW, from Section C-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.

C-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-WTE-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 C-4.1.1

C-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 C-4.1.1.1
 V_{IILAW} = the total volume of LAW produced, in cubic meters, during Phase II, from Section C-4.1.1.2
 YI_{ops} = years duration of Phase I operations, from Table C-1
 YII_{ops} = years duration of Phase II operations, from Table C-1
 YS_{LCap} = number of years of storage capacity for LAW, from Table F-2

C-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.

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

Where

Na_{MT} = the metric tons of sodium-bearing liquid waste, from Section D-1
 Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-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 F-4
 D_{LNa} = the density of sodium-bearing liquid LAW, from Table F-5

C-4.1.1.2 Total Phase II LAW Volume Produced

The total volume of immobilized LAW (m³) produced during Phase II (V_{II LAW}) operations is calculated using the following equation.

$$V_{II LAW} = \frac{(Zr_{calcine})(Zr_{sep})(1000)}{(WT_{Zr})(D_{LZr})} + \frac{(Al_{calcine})(Al_{sep})(1000)}{(WT_{Al})(D_{LAl})} + \frac{(Na_{MT})(Na_{sep})(1000)}{(WT_{Na})(D_{LNa})}$$

Where

- Zr_{calcine} = the metric tons of Zirconium calcine, from Table F-2
- Zr_{sep} = the Zirconium calcine separation factor, from Table F-3. This will be the LAW separation factor.
- 1000 = kilograms per metric ton
- WT_{Zr} = the weight loading for Zirconium calcine, from Table F-4
- D_{LZr} = the density of Zirconium calcine LAW, from Table F-5
- D_{LAl} = the density of Aluminum calcine LAW, from Table F-5
- Al_{calcine} = the metric tons of Aluminum calcine, from Section D-2.1
- Al_{sep} = the Aluminum calcine separation factor, from Table F-3. This will be the HAW separation factor.
- WT_{Al} = the weight loading for Aluminum calcine, from Table F-4
- Na_{MT} = the metric tons of sodium-bearing liquid waste, from Section D-1. If no separations in Phase I and ANN Calcine then Na_{MT} is calculated as in Section D-1. Otherwise Na_{MT} equals zero.
- Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-3. This will be the LAW separation factor based on the Phase II process.
- 1000 = kilograms per metric ton
- WT_{Na} = the weight loading for sodium-bearing liquid waste, from Table F-4 based on the Phase II process.
- D_{LNa} = the density of sodium-bearing liquid LAW, from Table F-5 based on the Phase II process.

C-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/m³ for Class B and \$10,000/m³ for Class A (a 2:1 ratio). Based on this ratio Class B annual storage operating costs are calculated as follows.

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

C-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/m³ for Class C and \$10,000/m³ 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 C-4.1.1

C-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 C-1

DI_{ops} = Phase I operation start date, from Table C-1

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

$$\begin{aligned} DII_{ops} &= \text{Phase II operation start date, from Table C-1} \\ DI_{ops} &= \text{Phase I operation start date, from Table C-1} \\ YS_{LCap} &= \text{years of LAW storage capacity, from Table F-2} \end{aligned}$$

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

$$Y_{Lstor} = 0$$

C-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-WTE-10443). They are calculated using the following equation.

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

Where

$$V_{Lstor} = \text{the LAW volume produced in cubic meters, from Section C-4.1.1}$$

C-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/m³ for Class B and \$10,000/m³ for Class A (a 2:1 ratio). Based on this ratio CS_{LB} is calculated as follows.

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

C-4.7 Interim Storage Capital Cost for Class C

Interim storage capital costs for Class C waste (CS_{LC}), is based on the feasibility study estimates. CS_{LC} is calculated by the following equation.

$$CS_{LC} = 10,772(V_{Lstor}) + 34,291,000$$

Where

$$V_{Lstor} = \text{the LAW volume produced in cubic meters, from Section C-4.1.1}$$

C-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 C-4.8.1

C-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.

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

Where

V_{IHAW} = the volume of HAW produced, in cubic meters, during Phase I, from Section C-4.8.1.1
 V_{IIHAW} = the volume of HAW produced, in cubic meters, during Phase II, from Section C-4.8.1.2
 YI_{ops} = years duration of Phase I operations, from Table C-1
 YII_{ops} = years duration of Phase II operations, from Table C-1
 YS_{Hcap} = number of years of storage capacity for HAW, from Table F-2
 V_{CAN} = volume of HAW canister from Table F-2
 F_{eff} = canister filling efficiency, from Table F-2

C-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. If the HAW vitrification plant is planned for Phase II, then V_{IHAW} equals zero.

$$V_{IHAW} = \frac{(Na_{MT})(Na_{Sep})(1000)}{(WT_{Na})(D_{HNa})} + \frac{C_{maint}}{C_{gm}} (F_{eff})(YI_{ops})$$

Where

Na_{MT}	=	the metric tons of sodium-bearing liquid waste, from Section D-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table F-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 F-4
D_{HNa}	=	the density of sodium-bearing liquid HAW, from Table F-5
C_{maint}	=	annual maintenance expenses for a glass facility, from Section C-3.2.3
C_{gm}	=	replacement cost for a glass melter from Table F-2
F_{eff}	=	canister filling efficiency factor, from Table F-2
YI_{ops}	=	Phase I operating duration from Table C-1

C-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.

$$V_{IIHAW} = \frac{(Zr_{calcine})(Zr_{Sep})(1000)}{(WT_{Zr})(D_{HZr})} + \frac{(Al_{calcine})(Al_{Sep})(1000)}{(WT_{Al})(D_{HAL})} + T_{si} + \frac{(Na_{MT})(Na_{Sep})(1000)}{(WT_{Na})(D_{HNa})} + \frac{C_{maint}}{C_{gm}} (F_{eff})(YII_{ops})$$

Where

$Zr_{calcine}$	=	the metric tons of Zirconium calcine, from Table F-2
Zr_{sep}	=	the Zirconium calcine separation factor, from Table F-3. This will be the HAW separation factor.

1000	=	kilograms per metric ton
WT_{Zr}	=	the weight loading for Zirconium calcine, from Table F-4
D_{HZr}	=	the density of zirconium calcine HAW, from Table F-5
$Al_{calcine}$	=	the metric tons of Aluminum calcine, from Section D-2.1
Al_{sep}	=	the Aluminum calcine separation factor, from Table F-3. This will be the HAW separation factor.
WT_{Al}	=	the weight loading for Aluminum calcine, from Table F-4
D_{HAl}	=	the density of aluminum calcine HAW, from Table F-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 D-2.2, otherwise T_{si} equals zero.
Na_{MT}	=	if the HAW vitrification facility is planned for Phase II and the selected technology for Phase I is TRUEX OR no separations in Phase I and ANN Calcine then Na_{MT} is calculated as in Section D-1. Otherwise Na_{MT} equals zero
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor. If no processing in Phase I and ANN Calcine then the Na_{sep} is based on the Phase II process.
WT_{Na}	=	the sodium-bearing liquid waste weight percent loading, from Table F-4. If no processing in Phase I and ANN Calcine then the Na_{sep} is based on the Phase II process.
D_{HNa}	=	the density of sodium-bearing liquid HAW, from Table F-5. If no processing in Phase I and ANN Calcine then the Na_{sep} is based on the Phase II process.
C_{maint}	=	annual maintenance expenses for a glass facility, from Section C-3.2.3
C_{gm}	=	replacement cost for a glass melter from Table F-2
F_{eff}	=	canister filling efficiency factor, from Table F-2
YII_{ops}	=	Phase II operating duration from Table C-1

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

If the HAW vitrification plant is built in Phase II then

$$Y_{Hstor} = Y_{II_{ops}}$$

Where

$Y_{II_{ops}}$ = Phase II operating duration, in years, from Table C-1

C-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 (personal correspondence from W. D. Bolon, "Estimated Immobilized HLW and Sodium-bearing Waste Volumes Based on Current Waste Inventories"). CS_H is based on feasibility study estimates and is calculated by the following equation.

$$CS_H = [10,772(CAN_{Hstor}) + 34,291,000] (N_{fac})$$

Where

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

C-4.10.1 Number of HAW Storage Facilities

N_{fac} is determined by the following equation.

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

Where

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

C-5 Disposal Costs

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

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

Where

WASTE	=	total amount of radioactive waste to be immobilized (m ³), from Section C-5.1
DUR	=	the duration of disposal in years, from Section C-5.1
C_{waste}	=	cost of waste disposal per m ³ , from Table F-6
SD	=	the start date of disposal, from Section C-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 F-6

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 C-4.8.1.1
V_{IIHAW}	=	the volume of HAW produced, in cubic meters, during Phase II, from Section C-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

C-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:

$$\begin{aligned} SD &= DI_{LDisp}, \text{ from Section E-5.5} \\ DUR &= YI_{LDisp}, \text{ from Section E-5.5} \\ WASTE &= V_{ILAW}, \text{ from Section C-4.1.1.1} \end{aligned}$$

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

$$\begin{aligned} SD &= DII_{LDisp}, \text{ from Section E-5.5} \\ DUR &= YII_{LDisp}, \text{ from Section E-5.5} \\ WASTE &= V_{IIAW}, \text{ from Section C-4.1.1.2} \end{aligned}$$

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 C-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

$$\begin{aligned} SD &= DI_{HDisp}, \text{ from Section E-4.5} \\ DUR &= YI_{HDisp}, \text{ from Section E-4.5} \\ WASTE &= (NC_{YI})(YI_{ops}) \text{ divided by 3, from Section C-3.2.1} \end{aligned}$$

For Phase II HAW disposal cost

$$\begin{aligned} \text{SD} &= \text{DII}_{\text{HDisp}}, \text{ from Section E-4.5} \\ \text{DUR} &= \text{YII}_{\text{HDisp}}, \text{ from Section E-4.5} \\ \text{WASTE} &= (\text{NC}_{\text{YII}})(\text{YII}_{\text{ops}}) \text{ divided by 3, from Section C-3.2.2} \end{aligned}$$

C-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.

$$C_{\text{Tdd}} = (0.50)(C_{\text{dcsPI}} + C_{\text{dcsC}} + C_{\text{dcsPII}}) + (0.33)(C_{\text{dcsHAW}}) + (0.20)(C_{\text{dcsLAW}})$$

Where

$$\begin{aligned} C_{\text{dcsPI}} &= \text{the design, construction, and startup costs for Phase I from Section C-2} \\ C_{\text{dcsC}} &= \text{the design, construction, and startup costs for calciner from Section C-2} \\ C_{\text{dcsPII}} &= \text{the design, construction, and startup costs for Phase II from Section C-2} \\ C_{\text{dcsHAW}} &= \text{the design, construction, and startup costs for HAW immobilization from Section C-2} \\ C_{\text{dcsLAW}} &= \text{the design, construction, and startup costs for LAW immobilization from Section C-2} \end{aligned}$$

APPENDIX D: RADIOACTIVE WASTE VOLUMES

D-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 D-1.1 for the year DI_{ops} minus one
V_{Igen}	=	volume of waste generated between startup of Phase I and startup of Phase II, from Section D-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

D-1.1 Current Tank Farm Volumes

Tank Farm volumes (V_{TF} , in gallons) for a specified year of a selected option are calculated using the following equation, where V_{TF} is a moving total. If V_{TF} becomes negative value, then V_{TF} equals zero.

$$V_{TF} = INV_{TF} - V_{pcal} + V_{add} - V_{PHI} - V_{PHII}$$

Where

INV_{TF}	=	the Tank Farm volume, in gallons, from the previous year starting with the value from Table F-2
V_{pcal}	=	volume processed by the calciner, from Section D-1.1.2
V_{PHI}	=	the volume processed during Phase I, from Section D-1.1.3

V_{PHI} = the volume processed during Phase II, from Section D-1.1.4
 V_{add} = waste volume added, from Section D-1.1.1

D-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.

$$V_{add} = V_{WNa} + V_{WH+} + V_{addc} + V_{FL} + V_{TA}$$

Where

V_{WNa} = Sodium waste volume, from Table F-7
 V_{WH+} = acid volume, from Table F-7
 V_{addc} = solution generated as a result of calciner operations from Section D-1.1.1.1
 V_{FL} = volume of waste generated by the filter leach process, from Section D-1.1.1.2
 V_{TA} = the volume of waste, in gallons, generated from the calciner turnaround

D-1.1.1.1 Annual Solution Generated

Annual solution generated (V_{addc} in gallons) is calculated by the following equation. V_{addc} becomes zero after the last campaign is completed.

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

Where

C_{dep} = gallons per month deep recycle returned to calciner, from Table F-2
 T_{cm} = calciner operating months during a given calendar year, from Table F-7
 N_{bd} = number of calciner bed dissolution per campaign, from Table F-2
 T_{camp} = number of months the calciner campaign occurs, from Table F-2
 V_{bed} = the gallons per bed dissolution, from Table F-2

D-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.

$$V_{FL} = (N_{EF})(131) + (N_{NF})(23)$$

Where

N_{EF}	=	the number of existing filters (as of 1993) processed during the year being calculated as defined below
N_{NF}	=	the number of new filters processed for a specific year as defined below
131	=	the number of gallons required to dissolve an existing filter
23	=	the number of gallons required to dissolve a new filter

The starting inventory of existing filters (INV_{EF}) is 207. INV_{EF} is a running inventory equaling the previous years inventory minus the number of filters processed (N_{EF}) for the current year. The starting inventory of new filters (INV_{NF}) is 33. INV_{NF} is a running inventory equaling the previous years inventory minus the number of filters processed (N_{NF}) for the current year plus the number of filters generated in the current year (N_{FGEN}). N_{FGEN} is calculated by the following equation for all years except for 1998.

$$N_{FGEN} = 14 + 6(T_{CM})$$

N_{FGEN} is calculated for 1998 by the following equation.

$$N_{FGEN} = 118 + 6(T_{CM})$$

Where T_{CM} is the number of months the calciner operates in the current year (from Table F-7). Note that T_{CM} equals zero for campaign numbers higher than the number of campaigns chosen by the user (N_{camp}).

N_{NF} for each year, except 1994 and 1995, is calculated by the following:

If $INV_{NF} \geq 75$ then N_{NF} equals 75
Else N_{NF} equals INV_{NF}

Note: N_{NF} equals 16 for 1994 and 50 for 1995.

N_{EF} for each year is calculated by the following:

If $INV_{NF} \geq 75$ then N_{EF} equals 0
 Else if $(75 - INV_{NF}) \geq INV_{EF}$ then N_{EF} equals INV_{EF}
 Else N_{EF} equals $75 - INV_{NF}$

Where INV_{EF} is the previous year's INV_{EF} .

D-1.1.1.3 Turnaround Volume

Turnaround volume (V_{TA}) is the volume of liquid waste generated from calciner turnaround and is determined as follows.

In 1994 V_{TA} equals 78,750 gallons, thereafter V_{TA} equals 0, except during a turnaround, which are calculated as follows.

$V_{TA} = 30,000$ gallons in the last year of each campaign (i.e. for campaign 1 V_{TA} equals 30,000 in 1998, see Table F-7 for campaign schedule).

and

$V_{TA} = 15,000$ gallons in the year after the last campaign and in the year after every third campaign (i.e. for 5 campaigns V_{TA} equals 15,000 in 2004 and 2011).

D-1.1.2 Volume Processed by Calciner

The volume processed by the calciner (V_{pcal} in gallons) for a specified year of a selected option is calculated by the following equations.

During the first campaign

$$V_{pcal} = (R_1)(T_{cm})(30.4)(24)$$

During the second and following campaigns

$$V_{pcal} = (R_2)(T_{cm})(30.4)(24)$$

Where

$R_1 =$ net processing rate for the first calciner campaign in gallons per hour, from Section D-1.1.2.1

T_{cm}	=	number of months a calciner campaign is run, from Table F-7
30.4	=	days per month
24	=	hours per day
R_2	=	net processing rate for any calcine campaigns following the first, from Section D-1.1.2.2

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

D-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})

$$R_{B1} = \frac{(G_r)(0.75) - (G_r)(0.75)(0.20)}{B1_r}$$

Where

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

Blend rate 2 (R_{B2})

$$R_{B2} = \frac{(G_r)(0.75) - (G_r)(0.75)(0.20)}{B2_r}$$

Where

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

Blend rate 3 (R_{B3})

$$R_{B3} = \frac{(G_r)(0.75) - (G_r)(0.75)(0.20)}{B3_r}$$

Where

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

D-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 F-2
 B_r = the blend ratio of WM189 to WM183, from Table F-2
 V_{183} = the volume of waste currently in WM183 tank, from Table F-2

Gallons of blend 2 processed (P_{B2})

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

Where

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

Gallons of blend 3 processed (P_{B3})

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

Where

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

D-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.

$$R_2 = \frac{(G_r)(0.75) - (G_r)(0.75)(0.20)}{B3_r}$$

Where

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

D-1.1.3 Phase I Volume Processed

Volume processed by Phase I, V_{PHI} , equals 0 except when operating during Phase I (Phase I operations occur from DI_{ops} to $DI_{ops} + YI_{ops}$). If the vitrification facility is planned for Phase I and there is no separations during Phase I then V_{PHI} is calculated by the following equation.

$$V_{PHI} = [(T_h)(365.25)(24)(0.75)(0.5)] \left(\frac{0.26418}{0.1192} \right)$$

Note: The 0.5 factor is omitted when calculating V_{PHI} for Glass Ceramic.

If the vitrification facility is not planned for Phase I and there is separations during Phase I then V_{PHI} is calculated by the following equation.

$$V_{PHI} = [(T_h)(365.25)(24)(0.75)(0.5)] (0.26418)$$

D-1.1.4 Phase II Volume Processed

Volume processed by Phase II, V_{PHII} , equals 0 except when operating during Phase II (Phase II operations occur from DII_{ops} to $DII_{ops} + YII_{ops}$). If no separations occur during Phase II then:

$$V_{PHII} = [(T_h)(365.25)(24)(0.75)(0.5)] \left(\frac{0.26418}{0.1192} \right)$$

Note: The 0.5 factor is omitted when calculating V_{PHII} for Glass Ceramic.

Else, if separations occur during Phase II then:

$$V_{PHII} = [(T_h)(365.25)(24)(0.75)(0.5)](0.26418)$$

D-1.2 Volume of Radioactive Wastes Generated

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

$$V_{Igen} = \sum_{DI_{ops}}^{DII_{ops}} [V_{WNa} + V_{WH+} + V_{FL}]$$

Where

DII_{ops}	=	Phase II operation start date, from Table C-1
DI_{ops}	=	Phase I operation start date, from Table C-1
V_{WNa}	=	Sodium waste volume, from Table F-7
V_{WH+}	=	acid volume, from Table F-7
V_{FL}	=	volume of waste generated by the filter leach process, from Section D-1.1.1.2

D-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 D-2.1) and second is the inventory generated from Silica calcine (Section D-2.2).

D-2.1 Total Aluminum Calcine Generated

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

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

Where

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

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

D-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 D-1.1.2.1.2
- C_{B1} = number of liters of calcine generated for each liter of waste processed during campaign 1, from Table F-2
- P_{B2} = gallons of blend 2 processed, from section D-1.1.2.1.2
- C_{B2} = number of liters of calcine generated for each liter of waste processed during campaign 2, from Table F-2
- P_{B3} = gallons of blend 3 processed, from section D-1.1.2.1.2
- C_{B3} = number of liters of calcine generated for each liter of waste processed during campaign 3, from Table F-2
- T_{camp} = number of months a calciner campaign is run, from Table F-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 D-1.1.2.1
- 1000 = liters per cubic meter

D-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 F-2
T_{camp}	=	number of months a calciner campaign is run, from Table F-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 D-1.1.2.2
1000	=	liters per cubic meter

D-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 D-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor.
M_{ac}	=	Aluminum calcine multiplier, from Table F-2. M_{ac} equals zero if ANN calciner is not used to solidify the HAW from Phase I.

D-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.

$$T_{si} = \frac{\max [(Si_{calcine} - M_{MTform}) , 0] (1000)}{(WT_{si})(2440)} + \frac{(Na_{MT})(Na_{Sep})(1000)}{(WT_{si})(2440)}$$

Where

- $Si_{calcine}$ = amount of silica from silica calcine, from Section D-2.2.3
- M_{MTform} = metric tons of waste form to be silica calcined, from Section D-2.2.1
- 1000 = kilograms per metric ton
- WT_{si} = the weight loading from silica calcine, from Table F-4
- 2440 = the density of silica HAW, from Table F-5
- Na_{MT} = the metric tons of sodium-bearing liquid waste, from Section D-1. If no separations in Phase I and ANN Calcine then Na_{MT} is calculated as in Section D-1. Otherwise Na_{MT} equals zero.
- Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor.

D-2.2.1 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.

$$M_{MTform} = \left[\frac{(Na_{MT})(Na_{Sep})}{WT_{Na}} + \frac{(Al_{calcine})(Al_{sep})}{WT_{Al}} + \frac{(Zr_{calcine})(Zr_{sep})}{WT_{Zr}} \right] WT_s$$

Where

- Na_{MT} = metric tons of sodium-bearing liquid waste, from Section D-1
- Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor.
- WT_{Na} = the sodium-bearing liquid waste weight percent loading, from Table F-4
- $Al_{calcine}$ = metric tons of aluminum calcine, from Section D-2.1

Al_{sep}	=	the Aluminum calcine separation factor, from Table F-3. This will be the HAW separation factor.
WT_{Al}	=	the weight loading of aluminum calcine, from Table F-4
$Zr_{calcine}$	=	amount of zirconium calcine in metric tons, from Table F-2
Zr_{sep}	=	the Zirconium waste separation factor, from Table F-3. This will be the HAW separation factor.
WT_{Zr}	=	the weight loading for zirconium calcine, from Table F-4
WT_{Si}	=	the weight loading for silica calcine, from Table F-4

D-2.2.2 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 F-2
Na_{MT}	=	metric tons of sodium-bearing liquid waste, from Section D-1
Na_{sep}	=	the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor.

D-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) or 300,000 gallons, which is calculated by the following equation.

$$Cp_{na} = (V_{TF})(1.25) - Cp_{TF}$$

Where

V_{TF}	=	the current Tank Farm volume, from Table D-1.1
1.25	=	25% contingency from new tank farm cost estimates
Cp_{TF}	=	the current Tank Farm capacity, from Section D-3.1

If complying with the court order and $Cp_{add} > 300,000$, then TF_Y equals 2000, otherwise, TF_Y equals DI_{ops} , unless the HAW vitrification plant is planned for Phase II and there is no Phase I separations, then TF_Y equals the year Cp_{na} becomes positive.

D-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 F-7
285,000	=	current ICPP single tank capacity, gal/tank
Cp_{st}	=	the additional available capacity of the selected technology, from Section D-3.1.1

D-3.1.1 Available Capacity from Selected Technology

The available capacity of the selected technology (Cp_s) 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_{ops}). If new technology is not built during Phase I, then no surge capacity will be added.

D-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} (calculated every year throughout the life-cycle of a selected option) to 1594 metric tons. If Al_{new} is greater than or equal to 1594 metric tons during any given year, then CSSF 7 is going to be used. If Al_{new} is greater than or equal to 3556 metric tons during any given year, then CSSF 8 will be built and used. If CSSF 8 is used, the year it is needed ($B8_y$) is the year Al_{new} exceeds 3556 metric tons.

D-5 Year Early Calcination Ends

The year early calcination ends is determined from Table F-7. 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 F-7. The year corresponding to the last occurrence of the desired campaign number is Y_{endcal} . For 2 campaigns, for example, Y_{endcal} would equal 2000.

D-6 Amount of LAW to be Immobilized

The amount of LAW before immobilization (LAW_{immob} , in metric tons) is calculated by the following equation:

$$LAW_{immob} = (Zr_{calcine})(Zr_{sep}) + (Al_{calcine})(Al_{sep}) + (Na_{MT})(Na_{sep})$$

Where:

- $Zr_{calcine}$ = metric tons of zirconium calcine from Table F-2
- Zr_{sep} = the Zirconium waste separation factor, from Table F-3. This will be the HAW separation factor.
- $Al_{calcine}$ = metrics tons of aluminum calcine from Section D-2.1
- Al_{sep} = the Aluminum calcine separation factor, from Table F-3. This will be the HAW separation factor.
- Na_{MT} = metrics tons of sodium waste from Section D-1
- Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor. If no processing in Phase I and ANN calcine then the Na_{sep} is based on the Phase II process.
- Na_{MT} = metric tons of sodium-bearing liquid waste, from Section D-1

D-7 Amount of HAW to be Immobilized

The amount of HAW before immobilization (HAW_{immob} , in metric tons) is calculated by the following:

If the option chosen uses the silica calciner for the calciner options then use the following equation.

$$HAW_{immob} = (Zr_{calcine})(Zr_{sep}) + (Al_{calcine})(Al_{sep}) + (Na_{MT})(Na_{sep})(M_{sc})$$

Otherwise the following equation is used:

$$HAW_{immob} = (Zr_{calcine})(Zr_{sep}) + (Al_{calcine})(Al_{sep}) + (Na_{MT})(Na_{sep})$$

Where:

- $Zr_{calcine}$ = metric tons of zirconium calcine from Table F-2
- Zr_{sep} = the Zirconium waste separation factor, from Table F-3. This will be the HAW separation factor.
- $Al_{calcine}$ = metrics tons of aluminum calcine from Section D-2.1
- Al_{sep} = the Aluminum calcine separation factor, from Table F-3. This will be the HAW separation factor.
- Na_{MT} = if the HAW vitrification facility is planned for Phase II and the selected technology for Phase I is TRUEX OR no separations in Phase I and ANN Calcine then Na_{MT} is calculated as in Section D-1. Otherwise Na_{MT} equals zero
- Na_{sep} = the sodium-bearing liquid waste separation factor, from Table F-3. This will be the HAW separation factor. If no processing in Phase I and ANN Calcine then the Na_{sep} is based on the Phase II process.
- M_{sc} = silica calcine multiplier from Table F-2

APPENDIX E: 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 E-1 provides the basis for present value calculations; the remainder of Appendix E 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 (1994 dollars) comparisons of candidate radioactive waste treatment processes.

E-1 Present Value Discounting

E-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

E-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 E-1 shows a summary of these timing variables as defined in Table C-1.

Figure E-1: Summary of Timing Variables

E-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 (Section E-1). This same method is used to calculate time discounting for the Calciner (Section E-3) and for HAW and LAW Immobilization (Sections E-4 and E-5).

E-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 C-1, and can be calculated by dividing development costs (C_d) from Section C-1.1, by years of development (YI_{dev}) for Phase I.

E-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 C-1. Half of the cost (C_{dcs}) from Section C-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.

E-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 C-1, and can be calculated by dividing operating costs (C_{ops}) from Section C-3.1, by years of operation (YI_{ops}) for Phase I.

E-2.4 Phase II (Calcine Processing) Development Costs

The Phase II development costs (C_d) from Section C-1.1, are spread out evenly over Phase I (YI_{dev}) and/or Phase II (YII_{dev}) development time periods, per Table C-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.

OR

E-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 C-1. Half of the DCS costs (C_{dcs}) from Section C-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.

E-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 C-1, and can be calculated by dividing operating costs (C_{ops}) from Section C-3.1, by the operations years (YII_{ops}) for Phase II.

E-3 Calciner Time Discounting

E-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 C-1, and can be calculated by dividing development costs (C_d) from Section C-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.

E-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 C, Table C-1. Half of the costs (C_{dcs}) from Section C-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_{dc} 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 $C_{p_{add}}$ is greater than 300,000 gallons then C_{sc} is determined by the equation in section C-2, Note (2).

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

$$Start\ Date = (TF_Y + 1) - BT_Y$$

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 F-2

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

$$StartDate = B8_Y - BC_Y$$

Where

- $B8_Y$ = the year CSSF 8 is needed, from Section C-4
 BC_Y = the number of years to build a CSSF, from Table F-2

- 3) Also, if CSSF 8 is used, then the calcine retrieval costs are divided evenly over the number of years of calcine retrieval construction (Y_{sCon}). The date upon which costs begin to incur is determined as follows.

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

Where

- DII_{ops} = the date Phase II operations start, from Table C-1
 YII_{ops} = the years of duration of Phase II operations, from Table C-1
 CR_Y = the number of years of calcine retrieval, from Table F-2
 Y_{sCon} = years of interim storage construction, from Table F-2

- 4) If CSSF 7 is used, then the calcine retrieval costs are divided evenly over the number of years of calcine retrieval construction (Y_{sCon}). The date upon which costs begin to incur is determined as follows.

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

Where

- DII_{ops} = the date Phase II operations start, from Table C-1
 YII_{ops} = the years of duration of Phase II operations, from Table C-1
 CR_Y = the number of years of calcine retrieval, from Table F-2
 Y_{sCon} = years of interim storage construction, from Table F-2

E-3.3 Calciner Operating Costs

The Phase I operating costs are spread evenly over the $YI_{ops} + 2$ time period starting in the DI_{ops} year, per Table C-1, and can be calculated by dividing operating costs (C_{ops}) from Section C-3.1, by the calciner operations years (YI_{ops}). The extra two years are for shutdown and cleanup.

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.

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

Where

- DII_{ons} = date Phase II operations start, from Table C-1
 YII_{ons} = years of duration of Phase II operations, from Table C-1
 CR_Y = number of years of calcine retrieval, from Table F-2

- 2) If CSSF 8 is used, then the CSSF retrieval operating cost (C_{Bops}) is incurred yearly over the number of years of calcine retrieval (CR_Y). The date upon which C_{Bops} begin to incur is determined as follows.

$$Start\ Date = DII_{ops} + YII_{ops} - CR_Y$$

Where

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

- 3) If the additional surge capacity needed (C_{padd}) is greater than 300,000 gallons, then new tank farm operating costs (C_{nTFops}), from Table F-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 (DII_{ops}) 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 C-1
 YII_{ops} = years of duration of Phase II operations, from Table C-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 F-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 F-2

- 5) Other waste operating costs (C_{OWops}), from Table F-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 (DII_{ops}) 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.

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

Where

- 1995 = start date for incurred costs
 DII_{ops} = Phase II operations start date, from Table C-1
 YII_{ops} = years of duration of Phase II operations, from Table C-1

- 6) Early calcination operating costs (C_{ECops} , from Section C-3.3.2) are incurred over the number of years difference between 1995 and the end of early calcination (Y_{endcal}), per the following equation.

$$\text{Number of Years} = Y_{endcal} - 1995 + Y_{SD}$$

Where

- Y_{endcal} = end of early calcine campaigns, from Section C-5
 1995 = start date of early calcination operations
 Y_{SD} = three years for safe shutdown if shutdown of calciner is chosen, otherwise, $Y_{SD} = 1$

E-4 HAW Immobilization Time Discounting

E-4.1 HAW Immobilization Development Costs

The HAW immobilization development costs (C_d) from Section C-1.1, are spread out evenly over Phase I (YI_{dev}) and/or Phase II (YII_{dev}) development time periods, per Table C-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.

E-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.

OR

E-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.

AND/OR

E-4.4 HAW Immobilization Interim Storage Costs

E-4.4.1 HAW Interim Storage Capital Costs

The HAW interim storage capital costs (CS_H / N_{fac}) for the first storage facility, from Section C-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

$$\text{Start Date} = DI_{ops} - Y_{sCon}$$

Where

$$\begin{aligned} DI_{ops} &= \text{start date for Phase I operations, from Table C-1} \\ Y_{sCon} &= \text{years of interim storage construction, from Table F-2} \end{aligned}$$

If a vitrification plant is planned for Phase II, then

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

Where

$$\begin{aligned} DII_{ops} &= \text{start date for Phase II operations, from Table C-1} \\ Y_{sCon} &= \text{years of interim storage construction, from Table F-2} \end{aligned}$$

The second and third storage facilities are discounted over the same number of years with different start dates. The start date for the second storage facility is as follows.

$$\text{Start Date} = DII_{ops} + YS_{HCap} - Y_{sCon}$$

Where

$$\begin{aligned} DII_{ops} &= \text{start date for Phase II operations, from Table C-1} \\ YS_{HCap} &= \text{years of HAW storage capacity, from Table F-2} \\ Y_{sCon} &= \text{years of interim storage construction, from Table F-2} \end{aligned}$$

The start date for the third storage facility is as follows.

$$\text{Start Date} = DII_{ops} + (2) YS_{HCap} - Y_{sCon}$$

Where

$$\begin{aligned} DII_{ops} &= \text{start date for Phase II operations, from Table C-1} \\ YS_{HCap} &= \text{years of HAW storage capacity, from Table F-2} \\ Y_{sCon} &= \text{years of interim storage construction, from Table F-2} \end{aligned}$$

The start date for the fourth storage facility is as follows.

$$\text{Start Date} = DI_{ops} + (3) YS_{HCap} - Y_{sCon}$$

Where

$$\begin{aligned} DI_{ops} &= \text{start date for Phase II operations, from Table C-1} \\ YS_{HCap} &= \text{years of HAW storage capacity, from Table F-2} \\ Y_{sCon} &= \text{years of interim storage construction, from Table F-2} \end{aligned}$$

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

E-4.4.2 HAW Interim Storage Operating Costs

The yearly HAW storage operating costs (OS_H) from Section C-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.

$$\text{Number of Years} = Y_{Hstor}$$

Where

$$Y_{Hstor} = \text{the years of HAW storage from Section C-4.9}$$

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

E-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.

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

Where

- $V_{I\text{HAW}}$ = the volume of HAW produced, in cubic meters, during Phase I, from Section C-4.8.1.1
- F_{eff} = canister filling efficiency, from Table F-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 F-6
- Y_c = current year for which disposal cost is being calculated
- F_{incr} = annual increase factor, from Table F-6

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 C-1 to the years of storage capacity for HAW (YS_{HCap}) from Table F-2 as follows.

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

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.

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

Where

- DI_{ops} = start date for Phase I operations, from Table C-1
- YI_{ops} = years of Phase I operations, from Table C-1
- DI_{HDisp} = date when HAW disposal costs begin, from Section E-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 ($DI_{\text{HDisp}} = Y_{\text{rep}}$, from Table F-2). The minimum YI_{HDisp} is 2.

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

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

Where

V_{IIHAW}	=	the volume of HAW produced, in cubic meters, during Phase I, from Section C-4.8.1.2
F_{eff}	=	canister filling efficiency, from Table F-2
Y_{IIHDisp}	=	number of years of Phase I HAW disposal as defined below
C_{waste}	=	cost of waste disposal per m^3 , from Table F-6
Y_c	=	current year for which disposal cost is being calculated
F_{incr}	=	annual increase factor, from Table F-6

The date upon which HAW disposal costs begin to incur (D_{IIHDisp}) is determined by adding the start date of Phase II operations (D_{IIops}) from Table C-1 to the years of storage capacity for HAW (Y_{SHCap}) from Table F-2 as follows.

$$D_{\text{IIHDisp}} = D_{\text{IIops}} + Y_{\text{SHCap}}$$

The number of years over which disposal costs are incurred (Y_{IIHDisp}), in the event of a Phase II vitrification plant, is by subtracting Y_{SHCap} from the years of Phase II operations (Y_{IIops}) as follows.

$$Y_{\text{IIHDisp}} = D_{\text{IIops}} + Y_{\text{IIops}} - D_{\text{IIHDisp}}$$

Where

D_{IIops}	=	start date for Phase II operations, from Table C-1
Y_{IIops}	=	years of Phase II operations, from Table C-1
D_{IIHDisp}	=	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 ($D_{\text{IIHDisp}} = Y_{\text{rep}}$, from Table F-2). The minimum Y_{IIHDisp} is 2.

E-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.

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

Where

$$\begin{aligned} YII_{ops} &= \text{number of years of Phase II operations, from Table C-1} \\ YS_{HCap} &= \text{years of HAW storage capacity, from Table F-2} \end{aligned}$$

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

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

Where

$$\begin{aligned} DII_{ops} &= \text{Start Date of Phase II operations, from Table C-1} \\ YS_{HCap} &= \text{years of HAW storage capacity, from Table F-2} \end{aligned}$$

E-5 LAW Immobilization Time Discounting

E-5.1 LAW Immobilization Development Costs

LAW immobilization development costs (C_d) from Section C-1.1, are spread out evenly over Phase I (YI_{dev}) and/or Phase II (YII_{dev}) development time periods, per Table C-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.

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

LAW immobilization design, construction, and startup costs, per Section C-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.

E-5.3 LAW Immobilization Operating Costs

LAW immobilization operating costs (C_{ops}), per Section C-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.

E-5.4 LAW Immobilization Interim Storage Costs

E-5.4.1 LAW Interim Storage Capital Costs

The LAW interim storage capital costs (CS_L) from Sections C-4.5, C-4.6, and C-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

$$\begin{aligned} DI_{ops} &= \text{start date for Phase I operations, from Table C-1} \\ Y_{sCon} &= \text{number of interim storage construction years, from Table F-2} \end{aligned}$$

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

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

Where

$$\begin{aligned} DII_{ops} &= \text{start date for Phase II operations, from Table C-1} \\ Y_{sCon} &= \text{number of interim storage construction years, from Table F-2} \end{aligned}$$

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

E-5.4.2 LAW Interim Storage Operating Costs

The yearly LAW interim storage operating costs (OS_L) from Sections C-4.1, C-4.2, and C-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}). If a separations process is used during Phase II only, then OS_L costs begin to incur on the Phase II start date (DII_{ops}).

$$\text{Number of Years} = Y_{Lstor}$$

Where

$$Y_{Lstor} = \text{Years of LAW storage from Section C-4.4}$$

E-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 by the following equation.

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

Where

V_{ILAW}	=	the total volume of LAW produced, in cubic meters, during Phase I, from Section C-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 F-6
Y_c	=	current year for which disposal cost is being calculated
F_{incr}	=	annual increase factor, from Table F-6

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 C-1 to the years of storage capacity for LAW (YS_{LCap}) from Table F-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 C-1
 DI_{ops} = start date for Phase I operations, from Table C-1

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

$$YearlyDisposal\ Cost = \frac{(V_{II\ LAW})}{(YII_{LDisp})} (C_{waste}) [1 + (Y_c - 1995)(F_{incr})]$$

Where

$V_{II\ LAW}$ = the total volume of LAW produced, in cubic meters, during Phase II, from Section C-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 F-6
 Y_c = current year for which disposal cost is being calculated
 F_{incr} = annual increase factor, from Table F-6

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 C-1 to the years of storage capacity for LAW (YS_{LCap}) from Table F-2 as follows.

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

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 C-1
 YS_{LCap} = years of storage capacity for LAW, from Table F-2

E-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.

$$\text{StartDate} = DII_{ops} + YII_{ops}$$

Where

$$\begin{aligned} DII_{ops} &= \text{start date of Phase II operations, from Table C-1} \\ YII_{ops} &= \text{years of Phase II operations, from Table C-1} \end{aligned}$$

E-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.

E-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 (Section E-4.1); the discounted design, construction, and startup costs (Section E-4.2); the discounted operating costs (Section E-4.3); the discounted storage costs (Section E-4.4); and the discounted disposal costs (Section E-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. HAW glass-ceramic is not allowed as a choice if the development time (either YI_{dev} or $YI_{dev} + YII_{dev}$) is less than the years needed to develop glass-ceramic technology (Y_{DGC} , from Table F-2); glass-ceramic needs about 7 more years of development.

E-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 (Section E-1.1, 2.1); the discounted design, construction, and startup cost (Section E-1.2, 2.2); and the discounted operating costs (Section E-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 (Section E-5.1); the discounted design, construction, and startup costs (Section E-5.2); the discounted operating costs (Section E-5.3); the discounted storage costs (Section E-5.4); and the discounted disposal cost (Section E-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 F: VARIABLES FROM EQUATIONS

Table F-1: Process Unit Cost Factors

<i>Process Unit</i>	<i>Baseline Throughput (T_N)</i>	<i>Advanced Testing Costs ($\\$, C_{test}$)</i>	<i>Persons Needed (FTE)</i>	<i>Construction Costs ($\\$, C_{const}$)</i>	<i>Material Cost Factor (F_{matR})</i>	<i>Number of Operators/ Shift (N_o)</i>	<i>(F_{COND})</i>
Separations Options							
TRUEX Class A	700 L/hr	850,000	5	67,000,000	3	14	0.5
TRUEX Class B	700 L/hr	850,000	5	64,000,000	3	13	0.5
TRUEX Class C	700 L/hr	500,000	1.5	59,000,000	1	9	0.5
Precipitation Class A	700 L/hr	1,000,000	7.5	70,000,000	6	14	0.5
Precipitation Class B	700 L/hr	1,000,000	7.5	67,000,000	6	13	0.5
Precipitation Class C	700 L/hr	750,000	4	62,000,000	4	8	0.5
Freeze Crystallization Class A	700 L/hr	1,350,000	6	67,000,000	4	13	0.5
Freeze Crystallization Class B	700 L/hr	1,000,000	2.5	64,000,000	2	9	0.5
Calciner Options							
ANN Calcine	76 L/hr	200,000	1.5	0	1	11	0.05
Silica Calcine	510 L/hr	500,000	2.5	6,000,000	1	11	0.5

Table F-1: Process Unit Cost Factors

<i>Process Unit</i>	<i>Baseline Throughput (T_b)</i>	<i>Advanced Testing Costs ($\\$, C_{test}$)</i>	<i>Persons Needed (FTE)</i>	<i>Construction Costs ($\\$, C_{const}$)</i>	<i>Material Cost Factor (F_{mat})</i>	<i>Number of Operators/ Shift (N_s)</i>	<i>(F_{cont})</i>
HAW Evaporator Storage	150,000 gal	750,000	1.5	3,900,000	1	0	0.1
Shutdown	0	0	0	0	0	0	0
Immobilization Options							
Glass HAW Liquid (COGEMA)	25 Kg/hr	9,000,000	3.5	64,000,000	2	8	0.2
Glass HAW Liquid Solid (Cold Crucible)	80 Kg/hr	7,000,000	4.5	54,440,000	2	9	0.5
Glass-Ceramic HAW	57 Kg/hr	10,000,000	5	n/a	2	14	1.0
Glass LAW (COGEMA)	25 Kg/hr	9,000,000	3.5	n/a	2	8	0.2
Glass LAW (Cold Crucible)	80 Kg/hr	7,000,000	4.5	n/a	2	8	0.5
Grout LAW (A)	628 Kg/hr	500,000	2.5	30,000,000	2	10	0.1
Grout LAW (>A)	628 Kg/hr	750,000	3.5	33,000,000	2	10	0.1
Grout LAW (FUETAP A)	628 Kg/hr	500,000	2.5	32,000,000	2	12	0.2
Grout LAW (FUETAP >A)	628 Kg/hr	750,000	3.5	35,000,000	2	12	0.2
Glass-Ceramic LAW	49 Kg/hr	5,000,000	5	n/a	2	14	0.5

Table F-1: Process Unit Cost Factors

<i>Process Unit</i>	<i>Baseline Throughput (T_b)</i>	<i>Advanced Testing Costs (\$C_{test})</i>	<i>Persons Needed (FTE)</i>	<i>Construction Costs (\$C_{const})</i>	<i>Material Cost Factor (F_{matR})</i>	<i>Number of Operators/Shift (N_s)</i>	<i>(F_{cond})</i>
Glass-Ceramic LAW (>A)	49 Kg/hr	7,000,000	5	n/a	2	14	1.0
Sodium Add-ons Phase I							
Sodium Transfer	n/a	n/a	n/a	2,500,000	n/a	1	
Utilities	n/a	n/a	n/a	15,000,000	n/a	0	
SBW Pretreatment	n/a	n/a	n/a	48,000,000	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	9,000,000	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 F-2: Equation Constants		
<i>Symbol</i>	<i>Value</i>	<i>Basis</i>
Al_{INV}	560	cubic meters of aluminum calcine in inventory currently
$B1_{cr}$	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).
$B2_{cr}$	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).
BC_v	4	the number of years to build CSSF
BT_v	6	the number of years to build a 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_{Bons}	1,643,200	Operations cost, per year, for each CSSF retrieval.
C_{can}	3800	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 F-2: Equation Constants

<i>Symbol</i>	<i>Value</i>	<i>Basis</i>
C_{gm}	8,780,000	Cost for additional glass melter, from feasibility study estimates.
C_{gm}	\$190,000	Cost for replacement of a glass melter, from feasibility study estimates.
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_{nTFops}	\$2,460,000	yearly operating costs for new tank farm.
C_{oper}	\$1,012,960	Annual cost per operator, per the following calculation. $C_{oper} = (50)(10,400) + (3)(79)(2080)$: Labor costs per person (\$50/hr for hourly and \$79/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 5 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}	\$8,190,000/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 F-1. This adjustment is consistent with the WINCO cost estimating basis for determining total project costs.
C_{TFops}	\$2,460,000	yearly operating costs for existing tank farm.
C_{VR}	\$29,400,00	cost for calciner vessel replacement.
F_{cp}	6	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 F-2: Equation Constants

<i>Symbol</i>	<i>Value</i>	<i>Basis</i>
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	180 gal/hr	Gross calciner feed rate
INV_{TF}	1,237,996	current Tank Farm inventory after evaporation by HLLWE in gallons
LR_{dev}	\$164,320	$LR_{dev} = (\$79/hr)(2080 \text{ hr/yr})$: Labor rate per person (\$79/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, 0	The Phase I aluminum calcine multiplier for precipitation, freeze crystallization, and no separations respectively
M_{freq}	0.5 / 0.167 / 10	Number of years between melter or HIP change-out: 0.5 years for COGEMA Glass, 0.167 years for Stir melter Glass, and ten 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).

Table F-2: Equation Constants

<i>Symbol</i>	<i>Value</i>	<i>Basis</i>
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 ($N_r = \text{gross feed rate} * 0.75 - (\text{gross feed rate} * 0.75) * 0.015$)
scale	\$ 60,000,000	scalable portion of a glass-ceramic facility, from feasibility study estimates
Si_{calcine}	5166.4	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
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}	12,000	gallons per bed dissolution
V_{CAN}	0.445 m ³ /can	volume of HAW canister
Y_{sCon}	3	The years needed to construct a storage facility or CSSF retrieval unit.
Y_{DSM}	7	Years to develop the Stir melter technology for ICPP wastes
Y_{DGC}	7	The number of years needed to develop glass-ceramic technology
Y_{SHCap}	7	This is the default value for years of storage for HAW.
Y_{SLCap}	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}	5200	Metric tons of Zirconium calcine in current inventories.

Table F-3: Fractions ⁵		
Fractions of HAW After Sodium Separation (Na _{sep}) ⁴		
Freeze Crystallization ¹	0.67	
Precipitation ¹	0.25	
TRUEX ²	0.054	
NONE ³	1	
Fractions of LAW After Sodium Separation (Na _{sep}) ⁴		
Freeze Crystallization ¹	0.33	
Precipitation ¹	0.74	
TRUEX ²	0.96	
NONE ³	0	
Fractions of HAW Separated From Calcine Process		
	Aluminum Calcine (Al _{sep})	Zirconium Calcine (Zr _{sep})
Precipitation ¹	0.854	0.624
TRUEX ²	0.023	0.04
NONE ³	1	1
Fractions of LAW Separated From Calcine Process		
	Aluminum Calcine (Al _{sep})	Zirconium Calcine (Zr _{sep})
Precipitation ¹	0.141	0.378
TRUEX ²	1.2	1.05
NONE ³	0	0

- 1 - Flowsheets for Sodium-Bearing Waste Processing Alternatives (personal correspondence from K. M. Wendt)
- 2 - TRUEX Flowsheets for Sodium-Bearing Waste and Calcine Technology Selection Process (personal correspondence from J. D. Law)
- 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 (personal correspondence from R. J. Rivard)
- 5 - Validation of flowsheets used for sodium-bearing liquid waste and calcine technology selection process (personal correspondence from J. D. Law and A. L. Olsen).

Table F-4: 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	0.20	N/A	N/A	N/A
		Glass-Ceramic	0.4	N/A	N/A	N/A
		Grout	0.081	N/A	N/A	N/A
		Grout (FUETAP)	0.15	N/A	N/A	N/A
	HAW	Glass	0.3	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	0.095	0.4	0.2	N/A
		Grout (FUETAP)	0.18	0.6	0.50	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	0.20	0.2	N/A
		Glass-Ceramic	0.4	0.65	0.65	N/A
		Grout	0.10	0.4	0.2	N/A
		Grout (FUETAP)	0.19	0.6	0.5	N/A
	HAW	Glass	0.25	0.20	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 (personal correspondence from J. A. Nenni)

Table F-5: Densities (kg/m ³)					
		FC	PPT	TRUEX	No Separations
LAW	D_{LNa}	Phase I Process			
	Glass	2320	2400	2400	N/A
	Glass-Ceramic	2310	2500	2470	N/A
	Grout	1400	1400	1400	N/A
	Grout (FUETAP)	2000	2000	2000	N/A
	D_{LAI}	Phase II Process			
	Glass	N/A	2510	2510	N/A
	Glass-Ceramic	N/A	2720	3110	N/A
	Grout	N/A	1400	1400	N/A
	Grout (FUETAP)	N/A	2000	2000	N/A
	D_{LZr}	Phase II Process			
	Glass	N/A	2490	2520	N/A
	Glass-Ceramic	N/A	2650	2860	N/A
	Grout	N/A	1400	1400	N/A
	Grout (FUETAP)	N/A	2000	2000	N/A
HAW	D_{HNa}	Phase I Process			
	Glass	2520	2480	2790	2500
	Glass-Ceramic	2730	2590	4040	2530
	D_{HAI}	Phase II Process			
	Glass	N/A	2600	2520	2210
	Glass-Ceramic	N/A	2930	3110	2890
	D_{HZr}	Phase II Process			
	Glass	N/A	2590	2470	2550
	Glass-Ceramic	N/A	3030	3090	3110

Glass and Glass-ceramic waste formulations (personal correspondence from K. Vinjamuri)

Table F-6: Disposal Costs

Waste Class	Cost of Waste (C_{waste} , \$/m ³)	Annual Increase Factor (F_{inc}) ³
Class A ¹	10,000	0
Class B ¹	20,000	0
Class C ¹	110,000	0
HAW Glass ²	500,000/15' Slot	0
HAW Glass-Ceramic ²	500,000/15' Slot	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 F-7: Waste Volumes

Year	Sodium Waste Volume (V_{wNa}), in gallons	Sodium Waste Reduction Factor (R_{rNa})	Acid Volume (V_{wH+}), in gallons	Acid Reduction Factor (R_{rH+})	Campaign Number	Calciner Schedule (T_{cm})	Number of Available Tanks (N_{tks})
1994	33762.5	1.91	22200	1.17	0	0	10
1995	28212.5	3.45	9500	1.21	0	0	10
1996	23825	3.67	13650	1.14	1	4	10
1997	25191.5	3.58	73950	1.60	1	12	10
1998	24008	3.66	14450	1.28	1	2	10
1999	23600	3.69	4000	1	2	10	10
2000	23600	3.69	4000	1	2	8	9
2001	29600	3.34	4000	1	3	4	9
2002	29600	3.34	4000	1	3	12	8
2003	29283.5	3.36	4000	1	3	2	8
2004	27783.5	7.41	11500	1	4	0	8
2005	25783.5	7.62	19000	1	4	0	7
2006	23283.5	7.91	19000	1	4	10	7

Table F-7: Waste Volumes

Year	Sodium Waste Volume (V_{wNa}), in gallons	Sodium Waste Reduction Factor (R_{rNa})	Acid Volume (V_{wHCl}), in gallons	Acid Reduction Factor (R_{rHCl})	Campaign Number	Calciner Schedule (T_{ca})	Number of Available Tanks (N_{at})
2007	23283.5	7.91	19000	1	4	8	6
2008	23283.5	7.91	19000	1	5	4	10
2009	23283.5	7.91	19000	1	5	12	6
2010	29666.667	7.92	19000	1	5	2	6
2011	29666.667	7.92	19000	1	6	10	6
2012	29666.667	7.92	4000	1	6	8	6
2013	29666.667	7.92	4000	1	7	0	6
2014	29666.667	7.92	4000	1	7	0	6
2015	29666.667	3.72	4000	1	7	4	0
2016	29066.667	3.72	4000	1	7	12	0
2017	29066.667	3.72	4000	1	7	2	0
2018	29066.667	3.72	4000	1	8	10	0
2019	29066.667	3.72	4000	1	8	8	0
2020	20600	3.72	4000	1	9	4	0
2021	20600	3.72	4000	1	9	12	0
2022	20600	3.72	4000	1	9	2	0
2023	20600	3.72	4000	1	N/A	0	0
2024	20600	3.72	4000	1	N/A	0	0
2025	20600	3.72	4000	1	N/A	0	0
2026	20600	3.72	4000	1	N/A	0	0
2027	20600	3.72	4000	1	N/A	0	0
2028	20600	3.72	4000	1	N/A	0	0
2029	20600	3.72	4000	1	N/A	0	0
2030	20600	3.72	4000	1	N/A	0	0

APPENDIX G: TECHNICAL REVIEW COMMENTS AND RESOLUTIONS

G-1: Evaluation and Selection of Aqueous-Based Technology for Partitioning Radionuclides from ICPP Calcine

A panel of nuclear separations experts was assembled on the Idaho State University campus in Pocatello, Idaho, from February 16 through 19, 1993, to assist Westinghouse Idaho Nuclear Company scientists and engineers in selecting, evaluating, and ranking candidate aqueous-based processes and technologies for potential use in partitioning selected radionuclides from nitric acid solutions of retrieved ICPP calcine. The panel of experts included:

- ▶ Dr. Clark D. Carlson—Research Scientist, Battelle Pacific Northwest Laboratory
- ▶ Dr. Larry Burchfield—Oak Ridge Analytical Services, Inc.
- ▶ Arlin Olsen—Advisory Engineer, Westinghouse Idaho Nuclear Company
- ▶ Wally Schultz—Independent Consultant, Retired from Westinghouse Hanford Company
- ▶ John L. Swanson—Staff Scientist, Battelle Pacific Northwest Laboratory
- ▶ Dr. Major C. Thompson—Advisory Engineer, Savannah River Site

Comments and recommendations of the Evaluation and Selection of Aqueous-based Technology for Partitioning Radionuclides from ICPP Calcine are shown, with resolutions, in Table G-1.1.

Table G-1.1: Evaluation and Selection of Aqueous-Based Technology	
Comments and Recommendations	Resolutions
Characterization of ICPP Calcine	
Additional and more detailed characterization data is needed [for ICPP calcine] . . . to develop and demonstrate integrated process flowsheets for producing a low-level waste meeting NRC Class A waste specifications. A program to sample and analyze all the various types of calcine needs to be developed and implemented.	A program to completely characterize the existing calcine will be completed in mid 1995. This is based on calciner feed sample analysis. The cost of sampling bin sets is much too high.
Dissolution of ICPP Calcine	
Systematic studies with all the different types of ICPP calcine should be performed to establish optimum conditions for both water leaching and acid dissolution of the water-based calcine.	Several studies have been performed at the ICPP to determine optimum conditions for water leaching and calcine dissolution. Fission product leach rates have been determined for both aluminum and zirconium type calcines. Optimum leach conditions being: (1) large water volume to calcine wt. ratios, (2) elevated temperatures, and (3) aggressive mixing. Much work has also been done with regard to calcine dissolution. Admittedly, zirconium calcine dissolution is better characterized than the aluminum calcine; however, early work performed on aluminum calcine indicates that the optimum dissolution parameters are similar to those for zirconium.

Appropriate statistically-designed screening tests should be performed to establish those [calcine] leaching variables of greatest importance.	Complete. As previously mentioned, conditions necessary for optimum leaching and dissolution have been performed.
In later, more comprehensive tests, water leachates should be analyzed to determine the amounts of all important solubilized components, both radioactive and nonradioactive.	Complete. A letter report was written summarizing the results of leach tests.
Stability of ICPP Calcine	
An experimental program should be designed and implemented to investigate and establish the stability towards solids formation of dissolver solutions prepared from various types of ICPP calcine . . . It may be necessary or desirable to analyze precipitated solids to establish their content of radionuclides and inert components.	A preliminary calcine feed stability study using dissolved pilot plant calcine solutions has been completed. The results are documented in <u>Experimental Results: Pilot Plant Calcine Dissolution and Liquid Feed Stability</u> , Lockheed Idaho Report, February 1995, currently in press. The foundation established by this work will be extended in subsequent laboratory and process scale-up work using both pilot plant and actual calcines.
Evaluation and Ranking of Candidate Separations Processes and Technology	
A liquid-liquid extraction process utilizing a bifunctional reagent such as CMPO (TRUEX process) or DHDECMP is the most promising technology for separation of actinides elements from acidified ICPP calcine. . . . Of course, close attention must be given to careful use of masking agents such as oxalic acid to minimize extraction of contaminants such as Zr(IV) and Fe(III).	For the DHDECMP solvent extraction system, the Zr and Fe distributions during extraction contacts are low enough the masking reagents added to the feed are not required or beneficial and a suitable scrub is sufficient to remove these components from the organic phase. In the case of TRUEX, the use of classical masking/scrubbing reagents such as oxalate or ketomalonnate result in the formation of unwanted precipitates during batch scale contacts. A suitable masking and scrubbing reagent has been identified and extensively studied in batch scale contacts. This reagent will subsequently be tested during countercurrent pilot plant tests in the near future.
. . . extraction chromatographic procedures . . . may have some advantages for removal of TRU elements from acidified ICPP calcine. Some experimental work to investigate application of extraction chromatography appears warranted.	A preliminary study was performed using TRU.Spec extraction chromatography columns and simulated wastes. The results are documented in WIN-374, July 1994.
The SREX process . . . is currently the favored technology for removal of ⁹⁰ Sr from dissolved calcine.	Flowsheet development has been performed on simulated and actual dissolved calcines. Distributions for Sr are ~10 times better than in sodium-bearing waste. It is expected that SREX would be highly effective for treatment of calcines (results in preparation for publication).
With further development, certain inorganic sorbents, e.g., CST, may prove useful for selective and efficient removal of ⁹⁰ Sr from acidic waste solutions. Similarly, extraction chromatographic materials such as the EICrom Industries product SR.Spec may eventually be found, after much more testing to be useful for plant-scale removal of ⁹⁰ Sr from acidic media. The panel recommends that . . . scientists/engineers closely track progress of further development and testing of CST, SR.Spec, and cobalt dicarbollide materials and processes.	SR.Spec extraction chromatography has been tested on simulated wastes. WIN-374, July 1994 documents these results. CST's have been tested on actual and simulated wastes for Cs removal, but are not effective at removing Sr under acidic conditions—a report is pending. Cobalt Dicarbollide has been tested on actual wastes (report WINCO-1230, September 1994) and will be tested on simulated wastes later this year in centrifugal contactors.

From available published data, it appears preferable to remove ^{99}Tc during extraction of TRU elements and/or ^{90}Sr .	The behavior of Tc in extraction, scrubbing, stripping, and wash contacts has been evaluated with both the TRUEX and DHDECMP solvent extraction systems. The preliminary results indicate Tc can be partially removed from the aqueous feed with either of these processes. Removal of Tc by the SREX process has not yet been evaluated at the ICPP; however, literature indicates Tc is partially extracted in the SREX process.
... both acid-side and alkaline-side processes for removal of ^{137}Cs from solutions of ICPP calcine should be considered and investigated. Thus, further evaluations may show that it is both economically and technically desirable to make acidified calcine solutions, after prior removal of TRU elements, ^{90}Sr , ^{99}Tc , and ^{129}I , alkaline and remove ^{137}Cs from the alkaline supernant liquid.	Alkaline-side cesium removal is carefully being monitored; however, all of the experimentation at the ICPP has focused on acid-side removal. Alkaline-side techniques will be tested if deemed necessary in the future.
The Panel favors uses of well-established ion exchange, either organic or inorganic sorbents, process technology for removal of ^{137}Cs .	There are not any well established ion exchange technologies for acid-side solutions that have proven extremely effective for cesium removal. The majority of the work for cesium removal has been for alkaline solutions. Current focus has been on AMP and CST for acid-side Cs removal.
The Panel recommends that both types of organic ion exchangers [Phenolic-based and resorcinol-based] be examined in bench-scale tests with actual dissolved ICPP calcine.	Phenolic and resorcinol based resin are not highly stable in acidic solutions. Organic resins are not very stable in radioactive environments. These resins will be maintained as backup technologies for Cs removal on the alkaline side.
The Panel also recommends that progress in various world-wide laboratories toward development and demonstration of solvent extraction processes employing either crown ethers or cobalt dicarbollide be closely monitored.	Solvent extraction processes for cesium removal are being monitored. Some techniques have been tested at the ICPP, and Crown ether and cobalt dicarbollide studies are being continued.
Volitization of ^{129}I during dissolution of the ICPP calcine would ... be the most effective method for accomplishing needed removal of ^{129}I .	Volatilization studies using ^{131}I and ^{137}Cs have been performed on the calcine itself with very poor iodine and cesium decontamination factors being achieved. The behavior of iodine during calcine dissolution has not been determined. Tests are planned using simulated calcine with ^{131}I baked into the calcine particles to evaluate iodine volatility during calcine dissolution.
Iodine precipitations should not be evaluated until its chemistry in the solvent extraction process has been determined.	Concur.
The Panel recommends the bench-scale studies of both the volitization and solvent extraction approaches to removal of ^{129}I be pursued. Such studies should also address technology for final disposal of radioiodine trapped from dissolver off gas or in spent solvent washes.	Concur. Such tests are planned.
Laboratory Testing Recommendations	
The Panel recommends that ... researchers not only locate and review the references listed in Section 7.0 [of the peer review report], but other reports and articles mentioned in those key references.	Completed. The separations group are familiar with the references in Section 7 of the peer review and many of the articles referenced therein.

<p>The Panel also recommends that . . . management consider negotiating one to three week temporary assignments of some of their researchers to work with highly experienced separations specialists at the Argonne National Laboratory and, possibly, other DOE sites.</p>	<p>Completed. Although it is not cost effective to assign researchers temporarily to ANL, constant communication is maintained between ANL researchers, such as E. P. Horwitz, G. F. Vandegrift, and R. A. Leonard, regarding work being performed by researchers at both Laboratories. Furthermore, contracts are currently in place with the separation experts at ANL (and others, including W. W. Schulz) to provide independent review of process development and data generated.</p>
<p align="center">Characterization of Process Reagents</p>	
<p>To assure suitable data quality and that the desired radionuclide removal can be obtained, it is essential to determine reagent purity and relevant properties . . . Particular attention needs to be paid to the purity and other properties of solvent and diluents to be used in development and testing of liquid-liquid extraction processes.</p>	<p>Such procedures are currently in place. For example, the TRUEX solvent is subjected to QC procedures that are documented in <u>CMPO Purity Tests In The TRUEX Solvent Using Americium-241</u>, Report WIN-355, October 1993. Such QC measures are currently being established for the DHDECMP solvent being tested. The Quality Control Laboratory at the ICPP is used in solvent preparation for most of the reagents used in the solvent extraction work.</p>
<p align="center">Solvent Extraction Test Procedures</p>	
<p>On a bench-scale, the required [solvent extraction] testing should include, initially, batch contacts and, later, continuous counter-current runs with laboratory-scale contactors. The goal of such tests should be to obtain all the requisite information for design and operation of a pilot plant-scale solvent extraction system for determination of an optimized flowsheet.</p>	<p>Currently being done. Properties of the important radionuclides are evaluated in batch contacts to determine extraction, scrubbing, stripping and washing behavior anticipated in counter-current flowsheet tests. This information is used to develop counter-current tests in the centrifugal contactor mock-up, the results of which are used to develop full scale solvent extraction flowsheets. A hot mockup is currently being installed in cells to test continuous flowsheets on real wastes.</p>
<p>Appropriate references , e.g. Treybal (1963), Lowe, Baird, and Hanson (1991), etc. should be consulted for guidance on the features of the experimental data needed to successfully develop a competent liquid-liquid extraction system.</p>	<p>These references are being used to develop laboratory batch contact experiments and in the counter-current flowsheet tests.</p>
<p>Batch contacts should be performed to develop and test conditions for the scrubbing and stripping portions of the extraction flowsheet as well as the extraction portion.</p>	<p>All portions of the flowsheet are being examined in the batch scale laboratory contacts.</p>
<p>Knowledge of the aqueous phase acidity after contact is necessary for proper [solvent extraction] evaluation results . . . Distribution ratios of all components including HNO₃ should be determined in each batch scrub contact.</p>	<p>Not only is the equilibrium aqueous phase acidity determined after the batch contacts, but the organic phase acidity is also measured. This information is used to determine nitric acid distribution coefficients for the various contacts.</p>
<p>. . . it is necessary to establish conditions for stripping (back extraction) of radionuclides from scrubbed organic phases.</p>	<p>Conditions for the stripping of radionuclides from the scrubbed organic are evaluated during the bench scale tests.</p>
<p>Initial countercurrent tests should be performed with simulated acid feeds to minimize the volume of actual acidified ICPP calcine.</p>	<p>Simulated feeds are utilized in process development activities. The simulants are spiked with the respective radionuclide(s) and the extraction, scrub, strip and wash behavior evaluated. Ultimately the tests must be extended to actual radioactive wastes to verify the results with simulants. Some tests with actual wastes have been completed and the results are typically in excellent agreement with results using simulants.</p>

Ion Exchange/Extraction Chromatographic Test Procedures	
[During ion exchange/extraction chromatographic tests] appropriate radiometric and other analytical measurements should be made to determine behavior of components of interest.	Radiometric and other analytical measurements are made for both the feed solutions and the post-contact solutions.
Precipitation/Coprecipitation Process Test Procedures	
The most important property to measure in each precipitation [coprecipitation process] experiment is the completeness of precipitation of the candidate radionuclide (or radionuclides)	Precipitation processes require many additional unit operations to partition Cs, Sr, and TRU's and has been shown to be much less effective than solvent extraction. No further work is planned in this area.

G-2: ICPP Sodium Waste Alternative Technologies Peer Review

A peer review of ICPP Sodium Waste Alternative Technologies was conducted at the Shilo Inn in Idaho Falls, Idaho, on September 27 and 28, 1993, to meet the following objectives: (1) provide a critique and evaluation on four different sodium waste treatment and disposal options; (2) rank various options in order of preference, as well as justify the criteria used to rank the options; (3) recommend alternatives option(s) or variations on the options presented; and (4) collectively decide in and rank in order of importance various criteria that need to be employed in order to evaluate between options. Peer review committee members include:

- ▶ Dr. Jimmy Bell—Chairman, Oak Ridge National Laboratory
- ▶ Dr. Major C. Thompson—Savannah River Site
- ▶ Dr. Jerry Straalsund—Battelle, Pacific Northwest Laboratories
- ▶ Dr. Tom Carlson—University of Idaho (U of I) Department of Chemical Engineering
- ▶ Monte Crippen—Westinghouse Hanford Company

Additional review members present include:

- Arlin Olsen—Advisory Engineer, Westinghouse Idaho Nuclear Company
- ▶ Judy Burton—NWCF Operations Manager, Westinghouse Idaho Nuclear Company
- ▶ Karen Plessas—Program Management, DOE-ID
- ▶ Steve Ayers—DOE-HQ EM-30 Programs, Washington, D.C.

Comments and recommendation of the ICPP Sodium Waste Alternative Technologies Peer Review are shown, with resolutions, in Table G-2.1.

Table G-2.1: ICPP Sodium Waste Alternative Technologies Peer Review

Comments and Recommendations	Resolutions
A consensus was reached on the three preferable options for continued development: (1) precipitation; (2) freeze crystallization; and (3) TRUEX.	Based on this consensus, Precipitation, Freeze Crystallization, and Radionuclide Partitioning (TRUEX) were identified in a November 15, 1993, letter to the State of Idaho as viable technologies for the treatment of sodium-bearing liquid waste and calcine. FY-94 and 95 work continued to focus on FC and TRUEX. Additionally, a full-fledged precipitation study was initiated and completed in early FY-95.
Recommendations: TRUEX work plans	
The development of the TRUEX process for treating the total calcine waste is supported by a different program, and does not warrant support by the sodium waste programming. However, the two efforts have some overlap and can mutually contribute their technologies.	The separations sub-unit, lead by T. A. Todd, incorporated sodium waste studies into their TRUEX studies. They had already initiated TRUEX studies with calcine, and completed Na studies in late 1994.
The ion exchange studies [from the sodium waste and 'other' program] may be combined for the "most for the buck."	The work on ion exchange between the Na and calcine groups is ongoing. Personnel from each program are currently communicating to provide synergy to the work in progress.
The TRUEX shake-out tests can benefit from following the precipitation shake-out studies . . . The precipitates can be dissolved directly into a smaller volume of 1 M HNO ₃ for the TRUEX shake-out studies.	TRUEX shake-out tests were not needed, based on precipitation study results.
Recommendations: Freeze Crystallization	
[Freeze Crystallization] work should continue its present course with the "cold" pilot plant development. However, it is very important to do some small scale "hot" studies.	Cold pilot plant work was completed; however, negative results of cold pilot plant testing did not justify hot testing. FC was, therefore, abandoned as an option in early FY-95.
Particular questions relative to occlusion of radionuclides can be addressed to assure that the "cold" pilot plant development is on course and to support the future "hot" pilot plant tests.	Radionuclide occlusion in the ice crystals is of concern if FC is ever revisited as an option. At this time, FC development has been terminated based on results from the TEAM model. This is an appropriate decision.
The amount of decontaminated sodium nitrate must be determined to better calculate the amount of ANN that must be added before proceeding this waste to the calciner.	This was done, but is only applicable to FC. As stated above, FC is currently no a practical option.
Recommendations: Precipitation	
[Formic acid addition for nitric acid destruction, neutralization to pH 10, a solid-liquid separation, and calcination] technologies are well developed and can be tested in engineering scale equipment directly succeeding cold tests.	Cold tests were completed according to these parameters. However, engineering-scale tests were not warranted based on the results from earlier test and from the TEAM model.
. . . small bench-scale tests should begin to determine process parameters like the best pH to produce a good precipitate, and whether or not small amounts of flocculating agents are needed.	Bench-scale tests were initiated and completed for precipitation. These tests determined the best pH and identify necessary flocculent agents.

The crown ether option included a data point that is so outstanding that the program should continue this work to assure that this option was not eliminated too soon.	Continued work with crown ethers showed that this application (for Na) was not scientifically achievable.
General Recommendations	
It is recommended that effort be directed toward improving definition of the functional requirements associated with the interfaces between the Na waste processing and the other elements of the Idaho waste management system.	Functional requirements were clearly defined by the Systems Analysis effort in 1994.
... a number of interface issues could have major impact on the relative viability of the processing options. Examples are the heavy metal and radionuclide limits for low level waste [o]ptions and associated criteria for highly radioactive waste. Another interface issue is compatibility with calcine processing plans. Given the technical similarities of the Na waste and calcine waste problems, it is likely that an integrated solution for these two problems will be required.	Both LLW and HLW PAs and WACs were completed in 1994 to define key radionuclide limits. An integrated solution for calcine and NA was found in 1994 (refer to the Phase I/II WIF recommendation from the TEAM model).
... the committee recommends that lawyers be included as a part of the team working on the waste processing option. Many of the decisions are not technically based, but are legal in nature and require interpretation by someone in the legal profession.	Lawyers specializing in Environmental Law were consulted numerous time during 1994 and 1995.
... the scientists and engineers need to read and become knowledgeable about the laws and regulations affecting their technical work.	Key technical staff became cognizant of applicable requirements and regulations.

G-3: Report of the Technical Peer Review of the Idaho Chemical Processing Plant High-Level Waste Treatment Program

A peer review of the Idaho Chemical Processing Plant's High-Level Waste Treatment Program was held in Idaho Falls on July 13 and 14, 1994, to assess the degree to which the High-Level Waste Treatment Program is meeting the regulatory, programmatic, and technological requirements that are necessary to safely and efficiently immobilize the sodium-bearing liquid wastes, calcine, and high-level liquid wastes at the ICPP. Peer review committee members include:

- ▶ Dr. Jeffery L. Turek—Chairman, H&R Technical Associates
- ▶ Dr. Jimmy T. Bell—Oak Ridge National Laboratory
- ▶ Dr. Thomas E. Carlson—University of Idaho (U of I) Department of Chemical Engineering
- ▶ Bruce A. Higley—Westinghouse Hanford Company
- ▶ Thomas F. Kocialski—West Valley Demonstration Project
- ▶ Dr. M. John Plodinec—Westinghouse Savannah River Company

Comments and recommendation of the Technical Peer Review of the Idaho Chemical Processing Plant High-Level Waste Treatment Program are shown, with resolutions, in Table G-3.1.

Table G-3.1: Technical Peer Review of the ICPP High-Level Waste Treatment Program

Comments and Recommendations	Resolution
Identifying Assumptions	
A universal and consistent set of assumptions covering the HLW Treatment Program was not evident and, as a result, different program activities may use inconsistent assumptions or fail to take advantage of a universally accepted set of assumptions.	A unified list of programmatic, project, and process assumptions has been developed, and all assumptions were reviewed in an effort to ensure consistency.
Identifying Criteria	
What appears to be missing is a strong consensus by management as to what criteria will be used to make the required strategic decisions.	Criteria to be used in the technology selection process were reviewed and updated as needed.
Deferring High-Level Waste Form Selection	
The decision on whether to separate the HLW into separate components (i.e., a HLW stream and LLW stream) and the decision on the appropriate LLW form should be made as soon as possible.	Concur.
Technical risk factors are not represented in the TEAM Model and should be represented.	Technical risk factors were further developed and are now represented in the TEAM Model.
The input parameters currently used in the TEAM Model are skewed against glass and these parameters should not be used to make the waste form decision.	All input parameters used in the TEAM Model have been reviewed and adjusted as needed to that ensure the highest level of confidence in the values used is maintained.
While the performance assessment work was well conceived and well-executed, this work did not support the HLW form selection process except by determining that there is no need for a more durable waste form.	The determination that a more durable waste form is not needed was an integral part of the HLW form selection process.
A key in the decision on the HLW form should be incorporation of the WAPS into the decision framework.	Waste form assumptions are being compared to the requirements in the WAPS.
Increasing Organizational Interaction	
Additional interaction and input from Operations staff and management is recommended to support cost analyses and feasibility studies.	Personnel with over 55 years of operating experience have evaluated the operating requirements for the facilities proposed in the TEAM model. The experience involved operations, technical shift engineering, and operations systems engineering. The personnel broke down the proposed facilities into single operations pieces to evaluate comparable costs. Personnel also studied the operating samples required and their frequency, and the number of operators required for each unit operation were defined. The length of time each operator will spend at each unit process was defined as well as how many relief operators will be required.

Deferring Calcine Immobilization

With the possible exception of the first bin set, the calcine, as currently stored, should be acceptable from an environmental, safety, and health (i.e., risk) perspective for the design life of the bin sets. Therefore, a decision on the transformation of the calcine into a different waste form could be deferred until a repository is operational and the specific WAC are known.

A decision on transformation of calcine could be deferred until the WAC criteria are known. Lockheed Idaho is currently modeling integrated INEL waste treatment and the date for calcine treatment will be one of the results of this study. The current version of the Site Treatment Plan defers calcine treatment until 2035.

Validity of Assumptions

A unified list of programmatic, project, and process assumptions is needed. Consistency among assumptions is necessary.

A unified list of programmatic, project, and process assumptions has been developed, and all assumptions were reviewed in an effort to ensure consistency.

All organizations involved in operating the INEL and ICPP need to agree upon the interpretation of the program goal and objectives.

All organizations involved in the operation of ICPP were involved and agreed upon the interpretation of the program goal and objectives. It would be an impractical task to include all organizations at the INEL in this decision.

Alternate Interpretations

The sodium-bearing liquid wastes could be calcined or otherwise processed and the HLLW, which do not contain sodium, could be calcined.

Alternative programs involving many direct calcination scenarios for sodium waste are being investigated to further cut costs.

The cost study should address shipment of the TRUEX generated HLW fraction to a vitrification facility at another DOE site for treatment.

A feasibility and cost study was performed to evaluate shipping HAW to Hanford (A. L. Olsen to J. H. Valentine "SBW Treatment Study", WBP-8-95, ALO-3-95, February 20, 1995). This study showed that although the cost was reasonable, the institutional barriers (i.e., Licensing, permits, stakeholders concerns) could probably not be overcome.

Uncertainty of Results and Consequences if Wrong

A sensitivity study of the TEAM Model results is required before decisions based on the model can be made

A sensitivity study of the TEAM Model was completed and is included in the final report.

The TEAM Model needs to be accessible to reviewers and must be defensible. In particular, the results from use of the model need to be presented more cogently.

The final report includes a section which discusses the results of technical evaluations completed with the use of the TEAM Model. Additionally, the completed model has been made available to decision makers to assist them in further assessing the impact of values held by different stakeholder groups.

The results of the TEAM Model appear to contradict the recent decision with respect to tank waste at the Hanford Site. An explanation of the cost differences and any compensating issues is needed

Upon completion of the initial technical evaluation it became apparent that the identified favorable option (Option 10) involved technologies that differed from those selected at the DOE Hanford site. A section was added to the final report that discusses this in detail (see Section 5.3)

Appropriateness and Limitations of Methodology and Procedures

The TEAM Model evaluation showed limited interaction with other organizations such as operations and maintenance organizations. This apparent limited involvement has resulted in the use of four rather than five operator work crews and in failure to adequately address the requirements for training facilities (i.e., mock-ups and simulators).

Extensive integration occurred between all organizations determined to have a significant impact on the outcome of technology selection. It was determined that some requirements (i.e., training, mock-ups, lab support) would remain unchanged for any technology selected and therefore were not discriminating factors for the selection of a final technology.

Risks (e.g., health risks to workers and the public, technical risks) are not adequately modeled.	Risks being modeled were evaluated and additional risk factors developed and included in the final model.
The WIF Feasibility Studies were based on a glass-vitrification facility design. Some feasibility analyses would appear to be appropriate for other types of immobilization technologies which are being evaluated.	During the feasibility studies, several types of immobilization processes were reviewed to determine if they were appropriated for use on the various types of wastes being produced by the processing. Glass and glass-ceramic were investigated for high-level waste immobilization as well as grout. Glass, glass-ceramic, and grouts were investigated for immobilization of low-level wastes. The study also used two main processing themes, one where the actinides were separated out of the waste and one where the waste was encapsulated into a single form. The single waste form plant study had progressed to the point where glass-vitrification had been deemed the most cost-effective of the HLW immobilization processes being evaluated; that process was reported to the assessment team. The glass-ceramic immobilization had been evaluated to the point where the costs were determined to be about twice the glass plant's; hence, it was dropped from consideration. Also, grout was investigated for possible immobilization of HLW, but was dropped from further consideration when the actinides of the wastes at ICPP could not be shown to stay encapsulated in the grout for the required 10,000 year performance period.
An integrated hot-testing facility (1/100–1/1000 scale) needs to be developed preferably to precede pilot-plant testing.	Prepare schedule and cost estimates for an integrated hot-testing facility.
The only decision discriminators that panel members could identify were costs and waste volumes. Other discriminators (e.g., technical risk, robustness, and stakeholders' acceptance) must either be compiled from other sources or developed.	Other discriminators were developed and included in the final report.
The interaction of the proposed processes with analytical support laboratories should be considered in greater detail than was presented in the review material.	As part of the operational requirements review of the proposed immobilization facilities, each system operation was evaluated for type and quantity of samples required. The sampling techniques were reviewed and transport requirements to the test lab were also investigated. The number, type, and analysis requirements for all the samples were compiled and interactive meetings with the analytical lab personnel were held to ensure that the sampling required should be performed with existing facilities and analysis hardware. The meetings identified how the samples could be run using the existing hot analytical facilities without additional space or analysis hardware.
Pilot-plant testing was not covered in detail in the review material.	A list of objectives and a schedule for pilot-plant testing were prepared.
A method for evaluating technology alternatives was demonstrated based on cost, cost time profiles, and waste volumes. The need to include other evaluation factors was stated, but no clear methodology for obtaining and using these other factors was demonstrated.	The need to include other factors was evaluated and additional factors were added and used in the final evaluation (Section 4).

Adequacy of Applications

A team should be sent to Hanford to study the lessons learned from the renegotiations of Hanford's TriParty Agreement. This study will help to identify issues of public and state concern.

The lessons learned from the Hanford experience have been obtained and studied by ICPP personnel. The lessons learned have been included in waste management planning for the ICPP.

Accuracy of Calculations

Given the input data, the calculations appear reasonable. However, owing to the importance of the TEAM Model in programmatic decisions, the model should be given an in-depth independent technical review or validation.

The TEAM Model was given an in-depth independent technical review by representatives from NUMATEC, a Cogema, Inc./SGN Company (January 1995).

Validity of Conclusions

Adequate information appears to exist to support the ROD (i.e., to separate waste components or not to separate waste components). However, the panel was not given enough information to determine if enough data will be available with which to make a HLW form decision by June 1995.

A schedule was prepared for vitrification hot tests to ensure this data would be available for the June 1995 decision.

Adequacy of Requirements and Criteria

The actual criteria with which to make a decision were not presented.

The criteria are now presented in detail in the report.

A partial listing of criteria or outcomes is presented as assumptions in WINCO-1176. A complete list of all mandatory criteria should be assembled to insure that the evaluation candidates truly meet the minimum requirements.

A complete list of all mandatory criteria has been assembled but is far too lengthy to include in the report.

Review Findings on Waste Technology Evaluation Report

Table B-1 indicates a rather lengthy phase II operating campaign (30 years) for a small volume of waste. A sensitivity analysis should be performed to determine the economic minimum campaign needed for waste treatment.

The second phase operating period was determined by the operating life of the plant versus a throughput evaluation. Several operating periods were evaluated to determine which waste type operating period drove the facility capacity. The 30 year period provided the best utilization of a facility by using up its design life versus constructing more capability to process the volume in a short time. Two high level waste streams are being processed in the second phases. The first is a very small volume, about 50,000 gallons, and the HLW immobilization can process that quantity of waste in about a hundred days. The second HLW volume will be about 5500 cubic meters which will take 30 years to immobilize for final disposal. In the proposed scenario, the operating cost and facility costs are about equal. The larger you make the facility the less the operating costs; however, the facility costs go high causing a cost tradeoff. One object of facility costs for DOE has been to construct minimal cost facilities to keep up-front cost as low as possible.

<p>In Section B-2.1, Scaling of Capital Cost Estimates, a scaling factor of 0.6 has been assumed for estimation of facility construction cost. A better estimate can usually be obtained by using industry specific scaling factors.</p>	<p>The use of the 0.6 scaling factor was reduced to a minimum.</p>
<p>The calculation in Section B-2.1.1, Calculation of Weighted Average Weight Percent Loading (WT_{AVG}), assumes that each waste type is campaigned separately through the process. This assumption may not realistically represent the process strategy.</p>	<p>This interpretation of the equation appears to be in error. The equation actually assumes the various calcines are mixed in ratios equal to this relative inventory. Since the calcines are mixed to some extent in most of the bins, this assumption is probably adequate for estimating the cost of the processing plant.</p>
<p>As presented in Section B-2.2, Needed Throughput, the process efficiency and on-line efficiency seem rather conservative.</p>	<p>The process efficiency and on-line efficiency do indeed appear conservative. However, they are based on actual operating experience gained with major ICPP systems similar to WIF, such as the NWCF.</p>
<p>The operating costs given in Section B-3, Operating Costs, do not appear to include allowances for staff other than the direct process operators.</p>	<p>The operating costs for personnel include the operations required specific personnel for five operating shifts. The costs also include a 5 to 1 ratio of support personnel to direct operators. The two types of personnel are costed at different rates, namely, the actual operator and support personnel costs for current ICPP operators.</p>
<p>The construction costs for the various major unit processes vary from \$50 to \$100 million and are much lower than the costs estimated for new waste treatment facilities at Hanford.</p>	<p>The unit process costs were determined from over two years of feasibility studies to determine the operating requirements and the costs of buildings and hardware necessary to perform the specific process. The model was updated to include the detailed cost estimates from the completed feasibility studies that generated costs for 27 various waste processing throughput options. Without knowing the process, throughput, or final waste forms of the Hanford Facility, we cannot comment on the comparison of ICPP vs. Hanford costs.</p>
<p>Some of the assumptions used in the cost study are global assumptions. These assumptions include the 0.6 scaling factor for capital costs and the 18 percent of total cost of design, construction, and startup factor for decontamination and decommissioning.</p>	<p>The model has been updated with facility cost estimates from two years of feasibility studies that generated 27 cost estimates for processing at various rates using various processes; this was done as a refinement to the model over the past 8 months. The use of the 0.6 scaling factor was reduced to a minimum. The 18 percent of total costs for D&D was determined by compiling cost numbers from the last major ICPP D&D activities. All Costs incurred to D&D the facilities and dispose of the wastes generated were included in the cost rollups. The facility costs were then compared to the D&D costs to get a know factor for D&D costs of new facilities.</p>

G-4: ICPP Radioactive Waste HLW Immobilization Treatment Technologies: NUMATEC Comments and Recommendations

Under Lockheed Idaho subcontract n° C95-175006, an extended review of ICPP Radioactive Waste HLW Immobilization Treatment Technologies was conducted by representatives from NUMATEC, a Cogema, Inc./SGN Company. This review, published January 1995, identified several programmatic and technological improvements necessary to safely and efficiently immobilize the sodium-bearing liquid wastes, calcine, and high-level liquid wastes at the ICPP. Principle review committee members include:

▶ Patrick Cantin	▶ Charles Madic
▶ Anne-Marie Chabert	▶ Jean-Paul Moulin
▶ Jean-François Dozol	▶ Gérard Naud
▶ Jean Duhamet	▶ William Pottier
▶ Anne Gresle	▶ Christine Thenáud
▶ Luc de Lamartinie	▶ Benoît Wagner

ICPP Radioactive Waste HLW Immobilization Treatment Technologies: NUMATEC Comments and Recommendations are divided into five sections: (1) Separations processes, (2) HLW immobilization, (3) LLW immobilization, (4) TEAM - Cost evaluation methodology and results, and (5) Recommendations. Specific NUMATEC comments and recommendations are shown below, with applicable resolutions, in Table G-4.1.

Table G-4.1: NUMATEC Comments and Recommendations	
Comments and Recommendations	Resolutions
Section 1.6—Separations Processes	
Lanthanides (Ce, Pm, Eu) are modeled in the GTM but do not appear in TEAM Model. They can contribute to saturation of the solvent and should be considered (pg. 9)	Lanthanide extraction is understood, however, no measurable effects have been observed in simulant or hot tests on actinide distributions. Consequently, the rare earths do not seriously impact TRUEX solvent loading, and they will follow the actinides in the process. The TEAM model could easily be modified to incorporate the (insignificant) effects of lanthanide extraction.
Due to the effect of phosphate on glass volume, alternative stripping reagents other than HEDPA should be investigated (pg. 13)	Alternate strip reagents have been evaluated, including dilute HNO_3 (0.01 M), Na_2CO_3 (0.05 - 0.25 M), $\text{H}_2\text{C}_2\text{O}_4$, $(\text{NH}_4)_2\text{C}_2\text{O}_4$, tetrahydrofuran tetracarboxylic acid (THFTCA), & NH_4F . None of the tested reagents provide gross actinide stripping with the same effectiveness as HEDPA. For stripping reagents other than HEDPA, multiple stripping sections would be required to effectively back extract the actinides. The concentration of HEDPA has not been optimized and it is likely that it could be reduced by an order of magnitude, therefore minimizing the effects on glass volume.
TRUEX flowsheet should be tested on alpha microplant with actinides and technetium (pg. 13)	TRUEX flowsheet has been tested with 5.5 cm contactors using simulated waste and Am surrogate (Nd). An alpha microplant will not be built since a hot microplant will be utilized. (see next item)
TRUEX flowsheet should be tested on microplant with real waste solutions (pg. 13)	Planned for FY-96.

Degredation products of the TRUEX solvent due to radiolysis and hydrolysis should be investigated (pg. 14)	Much work has been done on this subject by ANL
Liquid/Liquid contacting equipment types should be evaluated (pg. 14)	Mixer settlers and pulse columns were evaluated but centrifugal contactors were selected
The hydraulics of the liquid/liquid contactor selected should be tested with inactive solutions with fresh and degraded solvent (pg. 14)	This work is in progress with an anticipated completion date of 9/30/96. TRUEX solvent properties and Am stripping are closely monitored during testing
SREX extractant discrepancies should be further examined (pg. 6)	Solvent discrepancies are not found from the supplier of the better crown. This supplier performs a D_{Sr} test on every batch of crown before shipment. The other supplier has a history of poor quality control.
The influence of temperature on the extraction equilibria for the SREX process should be investigated (pg. 8)	Literature reports indicate that elevated temperature suppresses Sr extraction. Temperature will be examined further for other extractible with an anticipated completion date of 9/30/95.
The extraction of nitric acid in the SREX process should be investigated (pg. 10)	This work is near completion (9/30/95) but has not been published.
The verification of extractability of saline nitrates appears necessary to confirm the interpretations of the test results (pg. 10)	This work is in progress for Sr, K, Na, La. Anticipated completion date: 7/30/95.
Degredation products of the SREX solvent due to radiolysis and hydrolysis should be investigated (pg. 13)	This work has been reported by ANL. Further work will be performed with an anticipated completion date of 9/30/95. * Horwitz et al. Solvent Extraction and Ion Exchange 9(1), 1-25, (1991)
It would be useful to supplement the extraction data of nitric acid and extractable cations (K, Ca, ZrO, Na) by first measuring their distribution coefficients separately (pg. 13)	This work is in progress with an anticipated completion date of 4/30/95.
It would be advantageous to elaborate a detailed flowsheet of the SREX process from the distribution coefficients measured experimentally (pg. 13)	This has been done and flowsheet tests in 5.5 cm contactors are in progress.
A preliminary analysis of the transfer kinetics of the extractable elements between the aqueous and organic phases would be useful (pg. 13)	This work has been performed with Sr. The other extractible are under progress with an anticipated completion date of 9/30/95.
Need to pay close attention to choice of a solvent (pg. 14)	Solvent comparisons completed. TBP / Isopar L viewed as preferred solvent.
Need to pay close attention to the extraction and scrub of extractable cations (pg. 14)	This concern is under investigation in lab experiments and in contactor tests. Anticipated completion date: 4/30/95.
Ammonium from AMP and nitric acid from the SREX process could be a potential safety problem. (pg. 7)	Ammonium nitrate has to be in dry form to be explosive - must have an ignition source. Octanol is no longer being used so these associated problems have been removed.
The vitrification of AMP could significantly increase quantity of glass produced (pg. 7)	This analysis has been completed. Mo and P(from AMP) are not significant drivers in waste volume.

Both AMP elution tests and "endurance" tests are required to evaluate the feasibility of Cs removal (pg. 8)	Elution and endurance tests have been performed. Cesium can be removed. These tests are being continued for verification of data.
The durability of PAN as a support for the AMP under gamma irradiation should be studied (pg. 9)	This analysis is scheduled to be performed by Sebesta et al in Czech. Or by contract with Sandia. Anticipated completion date: 9/30/95.
The influence of titanium from CST's on glass volume should be studied (pg. 10)	More information on CST with ICPP waste stream is required before a thorough evaluation of titanium impact on HLW glass volume can be performed. However, it is expected (based on AMP-PAN evaluation), that the CST sorbent will have a small impact on the glass volume regardless of the titanium glass loading.
NUMATEC's(CEA) is developing a sliding bed column process for Cs and Sr removal using zeolites. Lockheed Idaho should consider this (pg. 10)	Zeolites sorb ^{137}Cs from weakly acidic solutions but breakdown in stronger acid solutions. Sliding bed column technology may be developed in the future but no plans have been made.
Calixarene's should be considered for Cs removal by solvent extraction (pg. 12)	Could be considered for long term use. Were initially not tested due to relative infancy of technology and based on expert review of Cs removal technologies
The contribution of salt-free reagents such as oxalic acid, tartaric acid, citric acid, and hydrogen peroxide to improve selectivity and to decrease extraction of Zr, Mo, and Fe in the TRUEX process should be investigated (pg. 11)	Iron is not excessively extracted and can be effectively scrubbed from the TRUEX solvent. Molybdenum is a minor contributor in the waste. Numerous Zr masking agents have been tested including H_2O_2 , oxalic acid, citric acid, keto malonic acid, diethylene triamine pentacetic acid, none of which were effective at suppressing Zr extraction. We have identified an excellent Zr masking and scrubbing reagent. Using this solution, Zr can be eliminated from the actinide containing HLW fraction.
Some salt-free reagents could be used to strip the actinides from the TRUEX solvent without the use of phosphorus (pg. 11)	Alternate strip reagents have been evaluated, including dilute HNO_3 (0.01 M), Na_2CO_3 (0.05 - 0.25 M), $\text{H}_2\text{C}_2\text{O}_4$, $(\text{NH}_4)_2\text{C}_2\text{O}_4$, tetrahydrofuran tetracarboxylic acid (THFTCA), & NH_4F . None of the tested reagents provide gross actinide stripping with the same effectiveness as HEDPA. For stripping reagents other than HEDPA, multiple stripping sections would be required to effectively back extract the actinides. The concentration of HEDPA has not been optimized and it is likely that it could be reduced by an order of magnitude, therefore minimizing the effects on glass volume.
Hydrazine-carbonate could be used to strip radionuclides from the solvent treatment system in the TRUEX process (pg. 11).	The use of hydrazine compounds is not acceptable
CEA uses solvents containing only C, H, O, and N such as the DIAMEX process. The use of this process at ICPP should be investigated. (pg 14-15)	Researchers at ICPP are not very familiar with the DIAMEX process, however, other US experts reviewing our program did not feel the DIAMEX process was as technically mature as other actinide removal technologies using CMP or CMPO solvents. Due to limited resources and time restraints efforts have focused on these two processes.

Solubility of TRUEX solvent needs to be addressed for potential accidents (pg. 16).	TRUEX solubility has been extensively addressed by Argonne and by other researchers. Due to the similarity of TRUEX and PUREX solvents, PUREX studies are somewhat relevant.
Solvent degradation effects on TRUEX process performance should be determined (pg. 17-18).	Solvent degradation has been extensively studied at ANL and by other researchers. Solvent cleanup is a mandatory part of the TRUEX flowsheet to prevent adverse effects of solvent degradation products.
The major issue with the evap/prec process will be to handle the solids which crystallize in the evaporator, before the transfer to the crystallization vessel. For this part, as well as the washing and solid/liquid separation parts, no experience exists in a radioactive environment (pg. 8).	<p>Solids handling, along with washing and solids/liquid separation, are not seen as major problems with the evap/prec process. Continuous centrifuges are commercially available for solids/liquid separation. These can be fabricated to directly drop the initially separated solids into the wash solution vessel. This vessel would be equipped with a mixer, and the slurry would be transferred (pumped) to a second similar centrifuge, which would separate the "clean" solids from the wash solution. The solids from the second centrifuge would drop into a different mixed vessel, where it would redissolve in water to form the sodium nitrate solution product. This solution would be transferred to a hold tank for eventual LLW immobilization treatment.</p> <p>Although experience in radioactive environments for this process, as a whole, likely does not exist, direct radioactive environment experience for a majority of the individual process components (evaporator, centrifuges, etc.) does exist.</p>
NaNO ₃ stream from evaporative crystallization process will still need to be treated as LLW and would not be favorably immobilized as grout (pg. 10)	At SRP high NaNO ₃ wastes have been successfully grouted at about 10% NaNO ₃ . Similar results are available from Hanford that suggest loadings of 12% sodium and 18% nitrate. Preliminary grout waste forms have been produced in the laboratory at ICPP with 30 wt % loadings (dry waste to dry cement) that meet compressive strength and TCLP criteria.
The treatment of existing SBW should be included in a general evaluation of the future effluents and their treatments. (pg. 11)	The ongoing systems model effort is continually looking at experimental data and evaluating effluents and their treatments and the effects on waste forms.

<p>The identification of possible uses of the nitric acid and sodium hydroxide from the EH process should be performed (pg. 11).</p>	<p>This has been done. A summary of possible uses is given below.</p> <p><u>NITRIC ACID*</u></p> <ol style="list-style-type: none"> 1) Scrub solution for future NWCF campaigns 2) Decon solution for Decon Facility Filter Leach activities - 6 M to 2 M 3) Facility in-cell "first-cut" decon activities - 601, 603, NWCF, WCF 4) Regeneration of Ion exchange beds for CPP-603 water treatment processes 5) RWMC - decon processes? 6) WG/WH tank nitric acid heels 7) Dissolution of precipitates 8) Future dissolution of Rover ash recovered during decon <p>* The Nitric acid can be concentrated in the LET&D acid fractionator, to meet potential user's needs.</p> <p><u>SODIUM HYDROXIDE</u></p> <ol style="list-style-type: none"> 1) Decon solution for facility "first-cut" decon activities 2) Use as a precipitating agent
<p>Full-scale implementation of the evaporation-crystallization option should be evaluated as it employs operations that are new to the nuclear industry (pg. 5).</p>	<p>Solids handling, along with washing and solids/liquid separation, are not seen as major problems with the evap/prec process. Continuous centrifuges are commercially available for solids/liquid separation. These can be fabricated to directly drop the initially separated solids into the wash solution vessel. This vessel would be equipped with a mixer, and the slurry would be transferred (pumped) to a second similar centrifuge, which would separate the "clean" solids from the wash solution. The solids from the second centrifuge would drop into a different mixed vessel, where it would redissolve in water to form the sodium nitrate solution product. This solution would be transferred to a hold tank for eventual LLW immobilization treatment.</p> <p>Although experience in radioactive environments for this process, as a whole, likely does not exist, direct radioactive environment experience for a majority of the individual process components (evaporator, centrifuges, etc.) does exist.</p>
<p>Section 2.0—HLW Immobilization (Glass, Glass Ceramic)</p>	
<p>Begin glass formulation studies to determine temperature and residence times for Al calcine and SBW vitrification.</p>	<p>Al calcine data available, SBW formulation development in progress.</p>
<p>Evaluate the benefit of mixing different calcines.</p>	<p>Some data will be available from hot tests. Devise mixing experiment to fully evaluate the problem.</p>
<p>Determine the range of composition and process parameters necessary for production.</p>	<p>Some data available from pre-treatment flow sheets. Use statistical design of experiments to characterize pilot-scale process.</p>

Assess waste loadings using separations waste streams.	Complete initial waste form development for separations waste streams.
Integrate separations and waste form development.	Establish a program of joint monthly progress meetings between the separations and waste form development groups to stimulate the exchange of information and ideas, and focus development efforts.
Initiate studies required for waste acceptance (qualification).	Prepare Preliminary Waste Form Compliance Plan (PWCP).
Initiate studies required for process qualification.	Prepare PWCP.
Provide pre-conceptual design information on process control and quality assurance requirements.	Prepare PWCP.
Initiate cold full- (or near full-) scale pilot testing early in development process.	Construct pilot-scale testing facilities.
Section 3.0—Low-Level Waste	
Provide justification for not investigating bitumen stabilization for low-level (also polyester and epoxy).	Grout work in this arena is being followed by Brookhaven and other researchers outside the INEL, but is too costly to develop at the INEL at this time.
Resolve . . . questions concerned with packing of low-level waste. What are LITCO's? What are NUMATEC's?	LITCO's concern involves subsurface vs. above surface and off-site vs. on-site packing of low-level waste. Additionally, drum size has not been resolved.
Why has SPC been discarded as a choice by LITCO? Development testing is still planned especially for debris waste. A developed technology for debris waste may be applicable for LLW.	If applicable and if Systems Analyses show a cost effectiveness, SPC testing results from debris treatment may be leveraged toward LLW.
Continue to follow Brookhaven to address PE concerns noted by NUMATEC.	An attempt to contract Brookhaven has been postponed.
Address acid attack in cement matrix after lime treatment.	This will be investigated if warranted.
Clarify NUMATEC definition of rate (7 to 28%) vs. weight loading. Resolve NUMATEC request to identify a volumetric grout rate.	Conversion factors between European and US are known which compare a . . .
In terms of compressive strength, clarify the NRC conditions.	NRC conditions are similar to current DOE orders.
Obtain radionuclide leach rates and compression data for natural setting/28 day cure conditions.	This will be done in future hot testing, if funding is provided.
For denitrated residue that resulted in a viscous grout, was a fluidizing agent used?	
Define need to investigate methods to decrease porosity and utilize ion exchange to produce non-leaching grout. Also, maybe the formation of insoluble calcium/cesium ferrocyanide.	These methods are currently being investigated.

Pursue opportunities to utilize existing NUMATEC grout test facilities and pilot plants . . . Fully investigate NUMATEC's unique mixing designs.	The contract between LITCO and NUMATEC is being significantly altered to the point that this opportunity may not exist.
Section 4.0—Cost Estimate and Methodology Results	
. . . the lack of transparency concerning 'contingencies' . . . could boost costs by a factor of 2 (or even more!) The document does not allude to any contingencies, except perhaps on the particular point of DCS costs: direct construction costs are multiplied by a factor F_{cp} . . . but in the document describing TEAM methodology . . . the factor F_{cp} is not described and is considered identical irrespective of the process concerned . . . so doesn't it take into account contingencies? (pg. 7)	'Contingencies' were identified and incorporated in the final TEAM Model cost equations.
The explanations of which process are involved for each individual option are very general; it is necessary to clearly indicate which process are set and how they are linked together . . . it is difficult to see the exact alternatives in Figure 2 to which [the 12 technologies listed in Table 2] correspond, culminating in the 27 cases used to make the complete estimate. (pg. 8)	Immobilization and waste form options shown in Figure 2 apply to <u>all</u> 27 waste treatment option shown in Figure 1; Figure 2 is merely an extension of Figure 1. Wording in the introductory paragraph for Figure 2 has been altered to make this more clear.
References of each process . . . would allow to identify main R&D topics to perform. For each option, it would also be interesting to summarize available basic data . . . and hypothesis . . . (pg. 9)	This level of detail was beyond the scope of this document.
. . . its not only important to highlight the capacities required for each option or for each group of options, but also to indicate the quantities of waste generated . . . a block flow diagram or flow sheet for each option would be welcome . . . (pg. 9)	This level of detail was beyond the scope of this document.
A breakdown into different buildings . . . for the functions considered in each option would help to pinpoint and compare the construction costs. (pg. 9)	This level of detail was beyond the scope of this document.
This document . . . has very little to say about the [cost studies] results obtained. Figures 4 to 12, and Tables 5 and 6 undoubtedly present certain result, but only in general terms . . . it is difficult to determine precise values from the Figures . . . A better comparison of the different alternatives could be obtained by detailing the results: option by option . . . , process function by process function . . . , item by item . . . in summary tables. (pg. 9-10)	This level of detail was beyond the scope of this document.
It is important to distinguish the following development costs: process development, waste qualification, pilot plant cost (pg. 12).	Process development, waste qualification, and pilot-plant costs were distinguished and included in the final report.
If the treatment considered leads to the production of a final waste, it is important to distinguish clearly a cost corresponding to [final waste] classification (pg. 13).	Costs associated with the production of a final waste have been distinguished.

[Development time] must be considered at the time required (and just necessary) to complete development, and not as the time available. In fact, the combination (number of principal investigators/development time) must be set for each process, with a constraint which is the available time (pg. 13).	This adjustment has been incorporated in the TEAM Model.
... is PII development considered to begin in 1995 or 1998? (pg. 14)	Phase II development begins in 1995.
Owing to industrial experience . . . , it is considered that development [for the COGEMA melter] will only be to investigate the behavior of the chemicals in the process [i.e., 1 year]. (pg. 15)	Development for the COGEMA melter has been adjusted to one year.
Waste qualification is considered identical for all [cold crucible] vitrification processes {i.e., 6 years with 2 FTEs}. (pg. 16)	All cold crucible waste qualification has been set at six years with 2 FTEs.
Since [the cold crucible] process (with out calcination) is cheaper than the COGEMA melter, pilot-plant cost can be estimated at . . . 7 M\$. (pg. 16)	Pilot-plant costs for the cold crucible process have been set at \$7,000,000.
[DCS costs] are calculated by the principle of multiplying a direct equipment cost by a factor F_{ep} . . . we do not consider this principle fully satisfactory . . . at all events, it appears advisable to break down the factor F_{ep} into different sub-factors [i.e., title design, field facilities, construction management, tax, insurance, escalation, contingency]. (pg. 19)	This factor has been broken down into sub-factors.
We agree with the idea of the radioactive waste classification factor. However, the values used appear to be somewhat high. (pg. 20)	Values being used were reevaluated and the appropriate adjustments made.
One of [the process and on-line efficiency] parameters (we do not which, because we find the precise definition of each of them to be somewhat elusive) must vary according to the selected process. (pg. 21)	This factor was identified and increased.
The explanations about just when each type of melter design is to be used are not very clear. Moreover, the conclusion "Otherwise the stir melter is used" [see Section C-2.4] is certainly not appropriate if low capacity is required in Phase II. (pg. 23)	The use of stir melter was replaced with cold crucible.
... we assume that [costs for the COGEMA melter] are very different from one country to another, from one operator to another, and from one location to another . . . [costs] must therefore be determined individually for the specific case of the ICPP. (pg. 26)	Costs were determined for the ICPP specifically.
[US canister] characteristics . . . communicated to us by Hanford . . . are not the same as those considered in the document (Figure F-2): canister volume, 1 m ³ ; waste glass volume, 0.85 m ³ . (pg. 27)	Our analysis was based on the use of five foot canister.

According to our experience, the mere fact that a unit normally operating at elevated temperatures must be remote-demountable multiplies its process by a factor of 4 (not counting dismantling equipment, working station, additional hot cell space, etc.). (pg. 30)	The Glass-ceramic costs used for this analysis are conservatively high further adjustment of those costs are not necessary to account for this.
The combination of pressure and temperature will entail a more complicated mechanical design, hence not difficult remote-dismantling. The factor of 3.3 (page 154, Table F-2) therefore seems low, especially since it does not appear to have included the workstations . . . (pg. 30)	The Glass-ceramic costs used for this analysis are conservatively high further adjustment of those costs are not necessary to account for this.
A large number of factors will vary the DCS of an installation. It is therefore important to consider the contingencies in order to calculate the most representative possible cost of the installation. (pg. 31)	DCS costs used in the TEAM Model were revisited and contingencies evaluated. These results were incorporated into the final model.
. . . in the calculation of the operating cost for Phase I, calciner, Phase II and LLW immobilization, it seems maintenance expenses have not been taken into account. (pg. 34)	The maintenance costs were taken into account for our analysis.
The canister volume used in the calculations is 1 m ³ , which is different from the US canister. (pg. 34)	This canister volume was changed to the five foot canister.
. . . the first sentence in the explanations [Section C-3.1.1] is wrong and does not correspond to the formula used. (pg. 36)	The first sentence was changed to correspond to the formula used.
. . . concerning the parameter C_{oper} [Section C-3.1.2], it should not be called 'Annual cost per operator,' but rather (considering the ways in which it is calculated) 'Annual cost per operator position.' (pg. 36)	This parameter is now called annual cost per operator, as suggested.
Concerning the way C_{oper} is calculated: all hourly employees are not paid 43 \$/h [i.e., shift manager, . . .]; all the exempt employees are not paid 60 \$/h [i.e., secretary, . . .]. (pg. 36)	All pay rates are expressed as an INEL average.
. . . contingencies on the operating costs of a facility are primarily due to the variations in maintenance costs, consumables, spare parts, waste volume, radiological state of the installation, etc. (pg. 38)	Comment incorporated.
Interim storage has been treated as an item, in the same way as development costs or DCS costs. We feel that it would be better to consider interim storage as a process function (and buildings to be built), depending on each option and itself being the subject of: development costs (even if zero in principle), design, construction and startup costs, operating costs, decontamination and decommissioning costs. (pg. 40)	This level of detail is beyond the scope of this document.
The formula [C-4.8.1] should theoretically include the volume of a canister V_{CAN} . (pg. 40)	Canister volume was added to this equation.

<p>The cost of geological disposal, expressed per m³ of waste, must . . . be calculated taking account of the following parameters:</p> <ul style="list-style-type: none"> - site evaluation (laboratories), - site operations (engineering, site preparation, surface installation, shafts and descenderies, underground installations) - site utilization - waste transport (casks, transport) <p>(pg. 45)</p>	<p>The analysis already includes this.</p>
<p>For a reprocessing plant, the total decommissioning cost (Level 1, 2, and 3) is about 50% of the DCS cost. (pg. 48)</p>	<p>The total decommissioning cost was adjusted to 50% of the DCS cost.</p>
<p>For the specific case of a vitrification facility, we have evaluated the Level 2 decommissioning cost [as] 33% of the DCS cost. (pg. 48)</p>	<p>Decommissioning cost for a vitrification facility were adjusted to 33% of the DCS cost.</p>
<p>The figure of 18% of construction costs for the first five years used in the TEAM model seems low for the HL facilities, which in fact account for the major share for the total cost. Different F_{ad} factors should be distinguished for the activity levels of the facilities concerned:</p> <ul style="list-style-type: none"> - 5% for inactive or very low-level facilities (interim storage), - 15 to 20% for LL facilities (LLW grouting), - 30 to 35% for HL facilities (HLW vitrification). <p>(pg. 49)</p>	<p>Comment incorporated.</p>
<p>Section 5.0—Recommendations</p>	
<p>NUMATEC identified some major technical uncertainties attached to option 10 . . . [and] believes that these uncertainties could be solved with an appropriate R&D program (including alternative processes evaluation) to be performed in the short term . . . (5.1, pg. 3)</p>	<p>This issue is currently being addressed as part of the INEL EM Integration Program.</p>
<p>. . . based on current design and performances of option 10's evaporation processes, the decontamination and «groutability» criteria are complied with but . . . the glass volume reduction factor still needs to be enhanced. Should this enhancement not be achieved, the superiority of option 10 on direct vitrification would probably be compromised . . . calculations show that the glass volume is currently being artificially increased by: the use of chemical reagents . . . [and] the large amount of zirconium which is extracted together with the actinides in the TRUEX process . . . by suppressing or decreasing these two main effects, together with some other secondary improvements [see Section 2.2 of the NUMATEC report], the total volume of glass could be lowered to less than 1/10th of the glass waste volume generated by direct vitrification. (5.1, pg. 4)</p>	<p>Recommendations regarding glass volumes and the associated glass volume reduction factor have been noted. Studies to further reduce glass volumes generated by direct vitrification may be performed in the future, if deemed necessary.</p>

<p>A big part of the required glass waste volume reduction can be obtained by the replacement of HEDPA by a salt-free reagent . . . A further reduction could possibly be obtained through the use of two salt-free processes . . . : the DIAMEX process for actinides and lanthanides separation and the extraction by calixarenes for cesium separation. (5.1, pg. 5)</p>	<p>These options are being pursued for possible incorporation.</p>
<p>NUMATEC recommends to maintain as a back up option the direct vitrification associated with pretreatment of the SBW by «Evaporation-Precipitation» prior to their calcination. «Evaporation-Precipitation» has been tested very recently at the ICPP and has not been incorporated into Lockheed Idaho's 27 options . . . NUMATEC believes that it is a promising process and . . . could be part of a 28th option [option 4, with «Evaporation-Precipitation» replacing Freeze Crystallization]. (5.1, pg. 5)</p>	<p>This process is currently being investigated, along with other potential options, as part of the INEL EM Integration project. If shown effective, it will be incorporated into the analysis model, and calculations will be run again.</p>
<p>An important R&D program will be needed in ICPP's R&D facilities [to address the following issues:]</p> <ul style="list-style-type: none"> the possibility to replace the HEDPA by a salt-free reagent in the TRUEX process, the possibility to reduce the amount of zirconium extracted in the TRUEX process, the possibility to reduce the impact of the AMP on the vitrification (by eluting it or replacing it), [and] the resulting glass waste volume reduction within appropriate glass compositions. (5.2, pg. 2) 	<p>All R&D activities at the INEL are currently being reviewed for incorporation into the waste treatment and immobilization effort and the INEL EM Integration Program. It is anticipated that these activities will result in significant programmatic changes that will enhance R&D productivity and reduce redundancy.</p>
<p>Concerning the vitrification, the type of glass composition to be used is still to be determined for most wastes . . . Glass formulation studies for both the option 10 and the direct vitrification case, need to be conducted simultaneously with separation studies . . . for a time and cost effective process development, NUMATEC recommends cold pilot vitrification tests to be performed at an early stage of the glass formulation studied. (5.2, pg. 3)</p>	<p>Agreed. The possibility of conducting simultaneous studies is currently under review.</p>
<p>. . . NUMATEC insists on the importance of an integrated and flexible management of the upcoming R&D work . . . the following items are important:</p> <ul style="list-style-type: none"> a precise definition of the objectives and specifications of each part of process being studied . . . , continuous mutual information between the different R&D groups, through both written reports and meetings, [and] for a time and cost effective advantage of the program, . . . maintain similar degrees of development in the different parts of process studied. (5.2, pg. 3) 	<p>All R&D activities at the INEL are currently being reviewed for incorporation into the waste treatment and immobilization effort and the INEL EM Integration Program. It is anticipated that significant R&D changes will result from these on-going activities.</p>

<p>... more accurate estimation of process ... the basis of the process performances taken into account in the TEAM program should be clearly presented in the INEL 94/0119 Report, with indications on the level of uncertainty attached to them. (5.3, pg. 2)</p>	<p>It was not the intent of this report to describe each particular process in detail, but rather to focus on evaluation results and present data regarding preferred treatment and immobilization alternatives. Key uncertainties have been noted in Section 3.5.2.1, and process descriptions appear in Appendix A, both of this report.</p>
<p>... take better into account the differences in level of confidence of both process and cost estimations for technologies which have very different levels of maturity ... this is particularly the case for R&D cost estimations. (5.3, pg. 2)</p>	<p>Comment incorporated.</p>
<p>... integrate the evaluation of ICPP's HLW management options in a more general evaluation of INEL's future activities. For example, the benefit (and cost) of sodium separation from the SBW can be vary much influenced by the possibility to recycle nitric acid and sodium hydroxide slightly contaminated on the site. (5.2, pg. 2)</p>	<p>Efforts to integrate all EM programs at the INEL are currently underway. Data obtained as part of the ICPP Radioactive Liquid and Calcine Waste Technologies Evaluation are being considered and incorporated into those activities.</p>

APPENDIX H: PUBLIC PARTICIPATION IMPLEMENTATION PLAN FOR THE ICPP RADIOACTIVE LIQUID AND CALCINE WASTE TECHNOLOGY EVALUATION PROGRAM

H-1: Vision

The Systems Analysis Unit of Lockheed Idaho High-level Waste Engineering and Project Management Department has developed and evaluated numerous waste treatment and immobilization options according to their technological performance and is currently preparing to make a final recommendation of preferred technologies to the DOE. A key concern, however, in recommending technological alternatives for dispositioning ICPP radioactive liquid and calcine waste is incorporating stakeholder values into the evaluation and recommendation process, due to the fact that the selection of technological alternatives should be based both on technological considerations and the incorporation of public needs and values. The basic premise is that technical experts can rank the performance of each alternative against given parameters; however, identification of all parameters important to stakeholders and the relative importance of each parameter is a value choice rather than a technical decision.

H-2: Background

After the decision in April 1992 to discontinue reprocessing DOE-owned spent nuclear fuel (SNF), an initiative was undertaken to identify and develop technologies for dispositioning INEL radioactive wastes. Through mid-1993, extensive laboratory testing and detailed 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 were identified and combined into processing systems capable of handling radioactive liquid and calcine wastes at the ICPP.

Mass balance calculations based on literature studies and laboratory testing were made for processing systems compatible with ICPP radioactive liquid and calcine wastes. Mass balances were then used to evaluate candidate technologies relative to ICPP radioactive waste streams and to develop estimates of cost, schedule, throughputs, and waste volumes. Additionally, a panel of 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 processes were eliminated from further consideration. This resulted in 27 viable technological alternatives for processing radioactive liquid and calcine wastes at ICPP. Evaluations were then performed for all 27 waste treatment options and for 26 additional high- and low-level waste immobilization options according to the following discriminating attributes, identified through literature reviews and benchmarking of other DOE stakeholder efforts: (1) Costs, (2) Waste Volumes, (3) Schedules, (4) Low-level Waste Classifications, (5) Proliferation/Reprocessing Capability, and (6) Technical Maturity. It is now our intent to interface with various interest groups in an effort to inform them of the ICPP radioactive liquid and calcine waste technologies evaluation program, verify the completeness of

our list of attributes, and establish the relative importance of each attribute according to stakeholder value (see "Attachment H-A: Stakeholder Involvement Strategic Planning").

NOTE: A detailed description of the technology options evaluation process and results is available in the ICPP Radioactive Liquid and Calcine Waste Technologies Evaluation Final Report and Recommendation, April 1995.

H-3: Requirements / Drivers

The need for the technology selection decision stems from existing legal drivers and agreements, including:

- ▶ RCRA Land Disposal Restrictions (LDR)
 - Waste forms must meet EPA requirements
 - Wastes after 5/8/92 must meet LDR standards
- ▶ Modified Notice Of Noncompliance (NON) Consent Order (March 22, 1994)
 - Cease use of pillar and panel tanks by 2009
 - Cease use of monolithic tanks by 2015
 - Operate New Waste Calcine Facility (NWCF) every three years
- ▶ December 22, 1993, Court Order (DOE/Navy/Idaho Agreement)
 - Calcine all non-sodium HLW by 1/1/98
 - Calcine some sodium waste by 1/1/98
 - Select sodium and calcine processing technologies by 6/95
 - Begin new tanks, if needed, by 1996; complete within 4 years
- ▶ Federal Facilities Compliance Act (FFCA Act)
 - Reach agreement with the State of Idaho on the site treatment plan

H-4: Objectives

Our objective is to determine stakeholder values related to the radioactive liquid and calcine waste treatment program and include those values in the technologies recommendation to DOE. Specifically, we plan to obtain the following information:

- ▶ Degree of public agreement or disagreement with established measurable attributes;
- ▶ Identification of additional measurable attributes not yet considered;
- ▶ Rank ordering of attribute importance; and
- ▶ Identification of technology preferences, based on stakeholder values.

H-5: Primary Audience

DOE and the State of Idaho are actively interested stakeholders. Other interested stakeholders may include the Site Specific Advisory Board, local governments, Chambers of Commerce from local cities, INEL employees, the INEL Oversight Committee, Shoshone-Bannock Native Americans, the Oil Chemical and Atomic Workers (OCAW) labor union, environmentally concerned citizens, and the general public.

H-6: Strategy

The following stakeholder involvement activities were preliminarily approved (see Attachment H-B) by both the DOE-ID Communications Office and appropriate DOE-ID Programs Management to support the DOE in selecting the preferred technological alternative for treating and immobilizing radioactive liquid and calcine wastes at the ICPP:

- ▶ Identify select interest groups using the DOE-ID Stakeholder database.
- ▶ Issue letters of invitation to identified interest groups regarding participation in stakeholder values assessment activities.
- ▶ Make informative presentations to interested groups regarding work done thus far on technology evaluation and recommendation and conduct values assessment workshops on discriminating attributes using the *OptionFinder* system and the Technology Evaluation and Analysis Methodology (TEAM) computer simulation model.
- ▶ Compile and verify, by direct feedback to the stakeholder, stakeholder input and our report findings to the Site-Specific Advisory Board at either the February or March, 1995, meeting, if requested.
- ▶ Incorporate stakeholder input into the final evaluation report and recommendation of preferred treatment technologies.

Informative presentations and stakeholder values assessments conducted with interested groups will take approximately 1½ to 2 hours—depending on the time required to address questions and discuss related issues—and will follow the proposed agenda outlined below.

H-6.1: Proposed Agenda for Stakeholder Values Assessment Workshops

(1) Discuss Meeting Agenda and Purpose of Presentation (2-10 minutes):

"Obtain input on the relative importance of various discriminating attributes in order to present stakeholder information for DOE consideration during technology and waste management strategy selection."

(2) Discuss Program Background (3-10 minutes):

- ICPP Spent Fuel Processing History
- Current state of ICPP tank farm and calcine storage bins

(3) Discuss Program Drivers (3 minutes):

- Legal agreements and Court Orders
- Environmental regulations specifying acceptable waste forms

(4) Discuss Technology Requirements (2 minutes):

(5) Discuss Evaluation Process (5-15 minutes):

- Identified potential technologies
- Developed 27 technology options—discuss if necessary
- Developed discriminating attributes to judge technology performance

(6) Discuss Discriminating Attributes in detail (20 minutes):

- Describe attributes and established ranges
- Add additional attributes, if necessary
- Identify relative trade-offs between attributes
- Assess understanding and clarify, if necessary

(7) Rank Discriminating Attributes using *OptionFinder* System (35 minutes):

- Individual ranking of discriminating attributes—using handout
- Demonstrate OptionFinder system
- Assess group importance of each discriminating attribute
- Conduct pair-wise comparison of discriminating attributes

(8) Display and Discuss Results (20 minutes):

- Enter final group ranking into the *TEAM: Rank-It* computer model
- Display selected treatment and immobilization option—per group ranking
- Discuss selected process and show process costs, waste volumes, etc.

H-7: Products / Deliverables

The following deliverables are anticipated from the Public Participation effort.

- A prioritized list(s) of stakeholder-identified/approved discriminating criteria.

- An inferred prioritized list(s) of stakeholder values.
- A ranked listing of stakeholder preferred technology options.
- General stakeholder comments, critiques, and feelings about the issues and processes associated with liquid and calcine wastes.

H-8: Schedule

In order to achieve our stakeholder objectives, we anticipate implementing stakeholder involvement activities as follows.

Activities	Deliverable Date
Workshops with interested stakeholders	To Be Determined (TBD)
Present decision making model to SSAB	TBD
Provide feedback and complete documentation of results	TBD
Issue final report	TBD

H-9: Roles / Responsibilities

The following stakeholder involvement activities will be undertaken by the parties indicated:

Roles	Responsible Parties
Planning	Applied Systems Engineering
Implementation Plan Development	Applied Systems Engineering
Implementation Plan Approval	LITCO Public Affairs, DOE-ID Communications
Public Presentations	Applied Systems Engineering
Incorporation of Results	Applied Systems Engineering
Results Summary and Documentation	Applied Systems Engineering

Attachment H-A: Stakeholder Involvement Strategic Planning

1. What is the decision statement?

We are undertaking a process to provide DOE with information and recommendations to help them decide amongst available technical alternatives for dispositioning ICPP radioactive liquid and calcined solid waste.

2. What is the impetus for this decision?

The impetus for the technology selection decision stems from existing legal drivers and agreements (see Requirements / Drivers above).

3. What is the decision making process?

- ▶ Define Problem and Program Goal
- ▶ Determine Functional Requirements
- ▶ Determine Alternatives
- ▶ Develop and Evaluate Alternatives
- ▶ Optimize Alternatives
- ▶ Select Alternative

4. Where are we in the decision making process?

We have identified alternatives that meet the functional requirements and have developed and evaluated such alternatives. We are at the point of assessing stakeholder values and recommending preferred alternatives to the DOE.

5. Who are the decision makers?

LITCO will make recommendations. DOE, with consideration of stakeholder input, will make the final selection.

6. Does this project need stakeholder involvement?

Yes. The topic of waste management is already controversial. In addition, while it appears that the decisions are primarily technical, such decisions have social and political ramifications and must meet the needs of the public; the criteria for making a decision can be weighted differently to reflect different stakeholder interests.

7. Who should be consulted in decisions about stakeholder involvement?

- ▶ Lockheed Idaho Systems Analysis Unit
- ▶ DOE-ID

8. Are there any constraints or special circumstances that make it more difficult or problematic to undertake effective stakeholder participation?

- ▶ We are late in getting stakeholder input from a large portion of stakeholders. An optimum stakeholder plan includes stakeholder involvement at each stage of the decision making process. While we want to address the concerns of evaluative criteria and alternative recommendation, some stakeholders may be concerned about issues regarding the program goal and established functional requirements.
- ▶ Time constraints. Doing public involvement right away would be beneficial because the recommendation to DOE will be submitted in March, 1995.
- ▶ There are many INEL projects occurring concurrently which are seeking public involvement. Interested public may get saturated with requests for involvement. Therefore, we may not get a large response. Nevertheless, the public should be involved as much as possible.

9. Where do we go from here?

We need official approval from our DOE-ID counterpart and the DOE-ID Communications Office.

10. What is the level of controversy? What level of public involvement should be planned?

The selection of an alternative for treatment and disposition of radioactive liquid and calcine waste will probably not be as controversial as some of the larger decisions included in the EIS. Thus, a national, regional, or massive public involvement campaign is not warranted. However, the economic, health/safety, legal, and philosophical issues will likely elicit local stakeholder interest.

United States Government

Department of Energy

Idaho Operations Office

memorandum

DATE: December 6, 1994

SUBJECT: Stakeholder Involvement Activities for the ICPP Radioactive Liquid and Calcine Waste Technologies Evaluation Program (OPE-AM-94-358)

TO: R. D. Jones, Coordinator
SSAB, DOE-ID, MS 1101

As you are aware, the Department of Energy is committed to developing, demonstrating, and implementing technologies for the safe, efficient, and environmentally sound treatment and interim storage of radioactive liquid and calcine wastes currently in storage at the Idaho Chemical Processing Plant, in accordance with the U.S. District Court Order of December 22, 1993, and the Modified Notice of Noncompliance Consent Order, dated March 22, 1994. Specifically, the DOE must take the following actions:

- "... 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 pretreatment 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."
- "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."

To aid the DOE in meeting these milestones, the Systems Analysis Unit of Lockheed Idaho's High-level Waste Engineering and Project Management Department has developed and evaluated numerous waste treatment and immobilization options according to their technological performance, and is preparing to make a final recommendation of preferred technologies to the DOE in March of 1995.

The recommendation of treatment and immobilization technologies for dispositioning ICPP radioactive liquid and calcine waste is based both on technological considerations and public perception. The basic premise is that technical experts can rank the performance of various alternatives against given parameters; however, the identification of all parameters important to stakeholders and the relative importance of each parameter is a value choice rather than a purely technical decision.

The technologies evaluation program has identified, through literature reviews and benchmarking of other DOE stakeholder efforts, several discriminating criteria (see Attachment 1) shown to be of interest to both stakeholders and decision-makers. It is now our intent to interface with various interest groups to establish the relative importance of those criteria. The following stakeholder activities have been approved by both the DOE-ID Communications Office and appropriate DOE-ID Programs Management to meet the March, 1995, milestone of making a final technology recommendation:

- Target select interest groups (i.e., local governments, Chambers of Commerce from local cities, INEL employees, Shoshone-Bannock Tribal members, the Oil Chemical and Atomic Workers (OCAW) labor union, environmentally concerned citizens, and the general public) using the DOE-ID Stakeholder database.
- Issue letters of invitation to identified interest groups regarding participation in stakeholder values assessment activities.
- Make informative presentations to select interest groups regarding work done thus far on technology evaluation and recommendation and conduct values assessments on discriminating criteria using the "Option Finder" system and the Technology Evaluation and Analysis Methodology (TEAM) computer simulation model. A typical stakeholder value assessment presentation agenda is shown in Attachment 2.
- Compile stakeholder input and report findings to the Site-Specific Advisory Board at either the February or March, 1995, meeting.
- Incorporate stakeholder input into the final evaluation report and recommendation of preferred treatment technologies, to be issued in March, 1995.

We feel it important to keep the SSAB abreast of these efforts and ask that you share this information with your colleagues at the SSAB meeting to be held on December 6 and 7, 1994. Additionally, we request a spot on the February agenda to present the decision making model to the Board.

If you have any questions regarding either the technologies evaluation or the stakeholder values assessment process, feel free to contact S. A. Brennan (DOE-ID) (208) 526-3993 or R. Klingler, Systems Analysis Unit Supervisor, at (208) 526-0183.

M. G. Bonkoski, Manager
Spent Fuel Program

Attachment

CC: G. C. Bowman, DOE-ID
M. M. McKnight, DOE-ID
R. Haines, DOE-ID
R. W. Russell, DOE-ID
S. Brennan, DOE-ID
C. L. Nash, DOE-ID
J. B. Malmo, DOE-ID
R. Guley, LITCO
J. H. Valentine, LITCO
R. D. Klingler, LITCO
D. A. Knecht, LITCO
K. Simpson, LITCO
M. R. Smith, LITCO

Attachment 1: Discriminating Attributes

Objective:

Decide which combined technology is most desirable for immobilizing ICPP wastes

Attachment 2: Proposed Stakeholder Presentation Agenda
(Approximate Time: 1 hour 30 minutes)

- 1) Discuss Meeting Agenda and Purpose of Presentation (2 minutes):

"Obtain input on the relative importance of various discriminating attributes in order to present stakeholder information for DOE consideration during technology and waste management strategy selection."
- 2) Discuss Program Background (3 minutes):
 - ICPP Spent Fuel Processing History
 - Current state of ICPP tank farm and calcine storage bins
- 3) Discuss Program Drivers (3 minutes):
 - Legal agreements and Court Orders
 - Environmental regulations specifying acceptable waste forms
- 4) Discuss Technology Requirements (2 minutes):
- 5) Discuss Evaluation Process (5 minutes):
 - Identified potential technologies
 - Developed 27 technology options-discuss if necessary
 - Developed discriminating attributes to judge technology performance
- 6) Discuss Discriminating Criteria in detail (20 minutes):
 - Describe criteria and established ranges
 - Identify relative trade-offs between criteria
 - Assess understanding and clarify, if necessary
- 7) Rank Discriminating Attributes using "OptionFinder" System (35 minutes):
 - Individual ranking of discriminating attributes-using handout
 - Demonstrate OptionFinder system
 - Assess group importance of each discriminating attribute
 - Conduct Pair-wise comparison of discriminating attributes
- 8) Display and Discuss Results (20 minutes):
 - Enter final group ranking into the "TEAM: Rank-It" computer model
 - Display selected treatment and immobilization option—per group ranking
 - Discuss selected process and show process costs, waste volumes, etc.