DOE/EM-0493

Technical Alternatives to Reduce Risk in the Hanford Tank Waste Remediation System Phase I Privatization Project

U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology
Tanks Focus Area

September 1999

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Revision: Final

Authors:

Harry D. Harmon, Team Leader

John L. Swanson

James H. Lee

Lawrence L. Tavlarides

M. John Plodinec

Major C. Thompson

John H. Roeker

E. Thomas Weber

Wallace W. Schulz

Frank E. Woolley

Executive Summary

The Department of Energy's (DOE) Office of River Protection (ORP) has begun a key phase of its program to immobilize and dispose of the high-level tank waste at the Hanford Site (Hanford). In August 1998, DOE entered into a 24-month contract (Phase I, Part B-1) with a team led by BNFL Inc. (BNFL), a United States subsidiary of British Nuclear Fuels plc, for the preliminary design of facilities to pretreat and immobilize Hanford's high-level tank waste.

In early 1999, the DOE Acting Deputy Assistant Secretaries of Waste Management and Science and Technology for Environmental Management (EM) requested the Tanks Focus Area (TFA) to identify technical improvements and alternative processes for the Hanford's high-level waste (HLW) program to ensure success of the current privatization strategy for HLW treatment (DOE 1999). In response to this request, the TFA convened a team of national experts (Team) in the appropriate technical areas. Team members consisted of:

Harry D. Harmon	John L. Swanson
James H. Lee	Larry L. Tavlarides
M. John Plodinec	Major C. Thompson
John H. Roecker	E. Thomas Weber
Wally W. Schulz	Frank E. Woolley

The Team was requested to evaluate technical risks and to identify technical alternatives for the high-risk portions of the current Hanford baseline. In this study, technical risk was defined as the probability that a unit operation would not perform as intended, multiplied by the consequences (cost and schedule impacts) to the project. The Team was also asked to recommend preferred technical alternatives and a prioritized list of any new work required to implement the preferred alternatives. Based on their review, the Team reached the following conclusions:

1. The Phase I project is based upon fundamentally sound waste treatment strategies and principles.

2. BNFL and the Project Hanford Management Contract (PHMC) personnel did an excellent job of identifying technical and programmatic risks and developing plans to resolve them.

3. At this early stage of the project, a number of technical risks still exist. From the information reviewed, it appears likely that all of these risks will be satisfactorily addressed as development work and design efforts progress. Therefore, Phase I, Part B, as currently defined, has a very good chance of succeeding.

4. Of the technical risks identified by the Team, two are rated high:

   - Sr-90/TRU element removal process – immature technology.

- Sulfate removal technologies – a system-wide issue whose resolution will likely require a combination of approaches.

5. The vitrification effort, involving BNFL, GTS Duratek, and Catholic University, is a sound, well-integrated program.

The functions covered by this independent alternatives review include waste characterization, retrieval, staging, transfer, pretreatment (i.e., sludge washing, solid/liquid separation, and radionuclide removal), immobilization, and product certification. Tank waste storage, and immobilized waste products storage and disposal are specifically excluded from this alternatives review. The scope of the review emphasizes Phase I activities and associated waste end states, and considers technology alternatives that could be implemented beyond Phase I.

The Team gathered information from document reviews, presentations, and responses to written questions from DOE, BNFL, and PHMC. The team members then identified technical issues and technology development needs for each unit operation in the currently proposed baseline flowsheet. Technical issues were evaluated based on whether they present a low, moderate, or high risk to the overall success of the project.

Based on the number of technical issues identified and their risk evaluation, the Team then assigned an overall technical risk to each unit operation. A detailed discussion of technology development needs to mitigate the risks for each unit operation is provided in this report. Also in this report, alternative technologies are prioritized using the criteria developed by the Team (see Table 4.4.1), and recommended technology development activities are defined for the highly ranked improvements and alternatives.

Recommendations on the overall technology development program, listed in priority order, are as follows:

- complete all baseline technology development tasks
- develop additional sulfate removal processes
- develop strontium-90/transuranic element (Sr/TRU) removal processes
- execute the in-tank mixer pump tests as soon as possible
- evaluate flammable gas release during mixer pump operation
- provide adequate analytical facilities
- test melters thoroughly
- develop alternative cesium-137 (Cs) removal processes
- provide a bench scale integrated, radioactive processing facility
- deploy a large (9-liter) waste sampler
- perform a similar review at the end of the Phase I, Part B-1 contract.

Completion of the additional development work described in this report for baseline verification, improvements to the baseline, and alternative processes, will further guarantee the success of this critical

project. Adequate resources must be provided to ensure timely completion of these key development activities.

Acknowledgments

The Review Team is deeply indebted to many individuals for their valued assistance throughout our review. We especially acknowledge the following individuals:

Mr. Tom Brouns (TFA). In his capacity as TFA Technical Team Manager, Mr. Brouns was directly responsible for assembling and organizing our Review Team. We thank him for his efforts on our behalf.

Ms. Lynne Roeder-Smith (TFA). As Communications Specialist for the TFA Technical Team, her skills and patience in preparing and editing the many drafts of our report were outstanding.

Ms. Bonnie Williams (TFA). Her careful attention to detail in arranging for conference rooms, working lunches, hotel accommodations and many other tasks is much appreciated.

Dr. Neil Brown (DOE-ORP). We benefited greatly from his many insightful comments and responses to our questions on the BNFL privatization contract and the proposed technological approach.

PHMC Personnel. Their presentations and reports were not only timely and well-done, but invaluable in evaluating the status of the waste retrieval and transfer technology.

BNFL Personnel. We sincerely thank Mr. Andy Elsden, Mr. Mike Johnson, and their colleagues, for taking time from their busy schedule to provide up-to-date information on proposed flowsheets and ongoing and future technology development programs.

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Acronyms and Abbreviations

BNFL	BNFL, Inc. (the U.S. subsidiary to British Nuclear Fuels Limited, plc, of the United Kingdom)
CST	crystalline silicotitanate
DOE	Department of Energy
DOE-HQ	Department of Energy - Headquarters
DST	double-shell tank
DWPF	Defense Waste Processing Facility
EM	Office of Environmental Management
EM-50	Office of Science and Technology
EM-30	Office of Waste Management
ESP	Environmental Simulation Program
HLW	high-level waste
IHLW	immobilized high-level waste
ILAW	immobilized low activity waste
LAW	low activity waste
LLW	low-level waste
ORNL	Oak Ridge National Laboratory
ORP	Office of River Protection
PHMC	Project Hanford Management Contract
QA	Quality Assurance
QC	Quality Control
RAM	Reliability, Availability, and Maintainability
SBS	Submerged Bed Scrubber
SRS	Savannah River Site
SRTC	Savannah River Technology Center
SST	single-shell tank
TFA	Tanks Focus Area
TSD	treatment, storage and disposal
TRU	transuranic elements
TWRS	Tank Waste Remediation System
TWRS-P	Tank Waste Remediation System Privatization
VSL	Vitreous State Laboratory (Catholic University)
WAPS	Waste Acceptance Product Specifications
WASRD	Waste Acceptance System Requirements Document
WESP	Wet Electrostatic Precipitator
WFDS	Waste Feed Delivery System
WVDP	West Valley Demonstration Project

1.0 Introduction

Approximately 54 million gallons of high-level radioactive waste are stored in 177 large underground tanks at the Hanford Site. This waste, derived from plutonium production for the nation's nuclear defense program, has been accumulating at Hanford since 1944. With many of the tanks approaching or past their design life, the DOE, regulatory agencies, and stakeholders all view cleanup of Hanford's tank waste as one of their top priorities. In 1992, DOE established the Tank Waste Remediation System (TWRS) program to integrate the tank waste storage, pretreatment, and immobilization activities into an environmentally sound and cost-effective program. In late 1999, a congressional mandate directed the DOE to establish the Office of River Protection (ORP) for managing all aspects of the TWRS program (DOE 1999).

1.1 Brief Summary of Office of River Protection Phase I Program

Beginning in 1994, DOE embarked on a strategy to procure the services of private companies to pretreat and immobilize these tank wastes. In the privatization approach, contractors are paid only upon delivery of an acceptable immobilized waste product to DOE. The privatization approach, as envisioned by DOE at that time, was to consist of a phased implementation program consisting of two distinct phases. Phase I was to be a small scale demonstration facility large enough to process 6% to 13% of the waste, followed by a Phase II facility to process the remainder of the wastes. Phase I was further subdivided into two parts; Part A for a conceptual design study, and Part B for final design, construction and waste processing.

Subsequently, in September 1996, DOE signed two 20-month Phase I, Part A contracts, one with BNFL, Inc. (BNFL), a United States subsidiary of British Nuclear Fuels plc, and a second with Lockheed Martin Advanced Environmental Systems (LMAES) (DOE 1998). The purpose of Part A was to establish the technical, operational, regulatory, business, and financial elements required by private contractors for providing tank waste pretreatment and immobilization services on a fixed-unit-price basis.

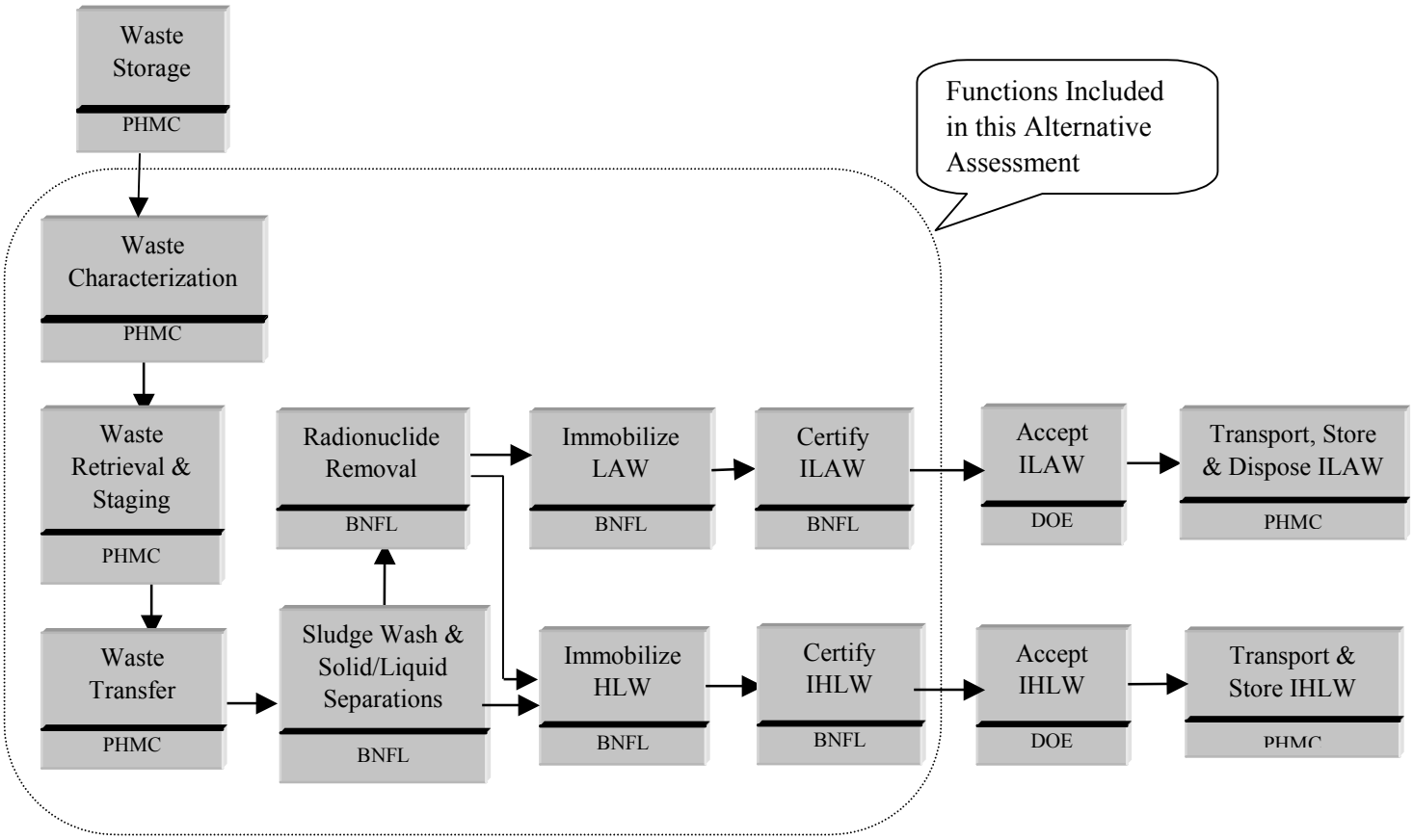
The two private contractors submitted their Phase I, Part A deliverables on January 26, 1998. DOE evaluated these deliverables and performed an authorization-to-proceed review. Based on this evaluation and review, DOE determined that only one of the contractors' (BNFL's) approaches was viable (DOE 1998).

Also, DOE's contracting strategy has continued to evolve with time in order to adjust to the realities of the vendor and financial markets, to incorporate lessons learned from other projects, and to consider feedback from stakeholders. Thus on August 24, 1998, DOE entered into a 24-month contract with BNFL for Phase I, Part B-1 to 1) optimize the LAW and HLW waste pretreatment and immobilization system, mitigate risk, and reduce contingencies in the waste pretreatment and immobilization system as defined by BNFL in its Part A deliverables; 2) revise the technical, operational, regulatory, and financial elements of the waste pretreatment and immobilization.

1.2 Division of Work Scope and Responsibilities

The major functions of work scope and organizational responsibilities are presented in Figure 1.2.1. The PHMC has responsibility for performing the work scope associated with waste storage, characterization, retrieval, staging and transfer to the privatization contractor (BNFL), and receipt, storage, and onsite disposal of immobilized low activity waste (ILAW), and receipt and interim onsite storage of immobilized HLW (IHLW) until its disposal offsite. The work scope assigned to BNFL consists of: 1) sludge washing to remove deleterious chemicals; 2) separations of solids from the liquid stream; 3) removal of radionuclides from the liquid stream to ensure that the immobilized LAW product will meet performance and regulatory requirements; and 4) immobilization (i.e., vitrification) of both the LAW and HLW. The DOE will perform acceptance verification and testing, as determined necessary, prior to receipt and transfer of the immobilized waste products to the PHMC.

Figure 1.2.1
Hanford Tank Waste Storage, Treatment, and Immobilization Functions and Division of Responsibilities



1.3 Assessment Team Charter

DOE-EM requested the TFA to conduct an independent assessment and provide recommendations on technical improvements and alternatives to the Hanford HLW program that might improve the current processing baseline, or be useful in the event that the current privatization strategy is unsuccessful. This request was made and formalized in a series of letters between DOE–Headquarters (HQ) and the DOE Richland Operations Office (see Appendix A).

The functions covered by this independent alternatives review are shown in Figure 1.2.1 and include waste characterization, retrieval, staging, transfer, pretreatment (i.e., sludge washing, solid/liquid separation, and radionuclide removal), immobilization, and product certification. Tank waste storage, and immobilized waste products storage and disposal, have been specifically excluded from this alternatives review. The scope of the review emphasizes Phase I activities and associated waste end states, but considers technology alternatives that could be implemented beyond Phase I. The Phase I waste end states are defined as follows:

- Tanks – removal of sufficient quantities of waste to meet privatization contractual feed delivery requirements, and provide tank space for future waste receipt and storage.

- Immobilized HLW – standard borosilicate glass canisters that are accepted by DOE as meeting contractor requirements and for interim storage in a passively cooled on-site facility. Specific contractual product requirements are contained in TWRS privatization Contract No. DE-AC06-RL13308 – Mod. No. A006.

- Disposed LAW – an immobilized waste form containing most of the chemicals in the tanks and a very limited amount of radionuclides. The waste is to be placed in on-site disposal facilities that meet long-term performance and regulatory requirements as demonstrated by a performance assessment. Specific contractual product requirements are contained in TWRS privatization Contract No. DE-AC06-RL13308 – Mod. No. A006.

- Secondary gaseous, liquid and solid waste – end state requirements for secondary waste streams are controlled by applicable environmental regulations and Hanford disposal facility waste acceptance criteria. Specific contractual requirements are contained in TWRS privatization Contract No. DE-AC06-RL13308 – Mod. No. A006.

In response to the DOE-HQ request, the TFA convened a team of national experts in the appropriate technical areas. The Team was requested to identify and evaluate the technical alternatives for the high-risk portions of the current Hanford baseline, and to recommend preferred technical alternatives and a prioritized list of any new work required to implement the preferred alternatives.

The Team was requested specifically to complete the following activities:

- Identify alternative technical approaches to address high-risk components of the technical program for Hanford HLW treatment. Include alternative approaches currently used internationally and in the

commercial sector, and under development through EM-50 and the TFA. Evaluate the current technical baseline from two perspectives: 1) baseline risk reduction; and 2) complete technical alternatives to the baseline. Baseline risk reduction alternatives are those that can be added or inserted into the baseline process, should the baseline or other alternatives fail. Complete technical alternatives would replace the existing technical baseline. Technical alternatives will include those that can be implemented in the short-term and those that could be implemented in the future, following additional development.

- Evaluate identified technical alternatives for their potential to reduce technical risk relative to current baseline technologies. Rank alternatives according to the maturity of the technology using evaluation criteria selected by the Team. The alternatives must be effective and consistent with the PHMC and BNFL schedules. Consider the potential for reduction in uncertainty and/or actual life-cycle costs, including final disposal costs. Do not conduct a life-cycle cost evaluation, but identify where alternatives can have an impact on life-cycle costs. Preferred alternatives should have likely risk reductions in the waste pretreatment and immobilization processes.

- Identify technical work needed to implement recommended alternatives, including current work. Prioritize that work based on highest potential impact and potential for success.

- Communicate results of the alternative assessment through a formal report and briefing to EM-30 and EM-50. The formal report will include:

  -- a description of each process step in the PHMC and BNFL technical baseline
  -- a description of the preferred technical improvements and alternatives for the identified high-risk portions of the baseline, and justification for the preferred alternatives
  -- for each preferred alternative, identification of technical work that is currently covered in TFA or ORP programs, and what additional work would be needed to implement the preferred alternatives within the existing schedules or as a long-range alternative
  -- a recommended prioritization of any new or additional work to implement the preferred alternatives
  -- a description of the assessment methodology
  -- resumes of the evaluation team.

The Team was requested to provide an interim status report by June 21, 1999, describing the technical risks identified and the criteria selected for assessment of alternatives. The draft final report documenting the alternatives assessment, preferred alternatives, and recommended path forward to implement preferred alternatives will be issued by July 30, 1999. Briefings for EM-30 and EM-50 at DOE-HQ will be scheduled in September 1999, prior to release of the final report.

1.4 References

DOE 1998 USDOE, Report to Congress-Treatment and Immobilization of Hanford Radioactive Tank Waste, July 1998.

DOE 1998a USDOE, Richland Operations News Release, *DOE and BNFL Inc. Sign Contract for Hanford Tank Waste Treatment, Environment and Local Community to Benefit,* August 24, 1998.

DOE 1999 USDOE, Integrated Management Plan for the Hanford Tank Waste Remediation System, January 1999.

2.0 Summary

The Team assessed the stage of development and technical risks of the Phase I TWRS Privatization (TWRS-P) program. We defined technical risk in this study as the probability that a unit operation would not perform as intended, multiplied by the consequences (cost and schedule impacts) to the project. The assessment was conducted at a very early stage in the project, when ongoing development work and design issues are leading to several changes in the PHMC and BNFL plans and flowsheets. Considerable additional development work is planned by the participants to mature the technologies that have been selected. The Team attempted to understand the development programs and the results obtained to date. Because the project is a "work in progress," our assessment represents a "snapshot in time," reflecting limitations due to the evolving program and incomplete information. Thus, we based our study primarily on current (as of mid-July 1999) plans and flowsheet information.[(a)]

2.1 Conclusions

1. The Team judges that the Phase I project is based upon fundamentally sound waste treatment strategies and principles.

2. BNFL and the PHMC did an excellent job of identifying technical and programmatic risks and developing plans to resolve them.

3. At this early stage of the project, the Team judges that a number of technical risks still exist. From the information reviewed, it appears likely that all of these risks will be satisfactorily addressed as development work and design efforts progress. Therefore, the Team believes that Phase I, Part B, as currently defined, has a very good chance of succeeding.

4. Of the technical risks identified by the Team, two are rated high:

   - Sr-90/TRU element removal process – immature technology.
   - Sulfate removal technologies – a system-wide issue whose resolution will likely require a combination of approaches.

5. The vitrification effort, involving BNFL, GTS Duratek, and Catholic University, is a sound, well-integrated program.

(a) This report benefited from two significant actions following issuance of the interim report: 1) vitrification subteam members visited the pilot-scale LAW melter facility in Columbia, Maryland, and 2) comments by DOE on the interim report provided valuable information. Both actions provided details that were not apparent earlier in the review process.

2.2 Recommendations

The following recommendations are listed in priority order:

1. **Support baseline tasks as essential to project success:** Full funding for baseline technology development is essential to the success of this project. Thus, the Team strongly recommends completion of all baseline technology development activities (including the new recommendations in this study, as well as those already planned by BNFL and the PHMC).

2. **Develop additional sulfate removal processes:** Removal of sulfate is a significant system-wide issue, with major implications on ILAW volume, melter offgas, treatment of recycle streams and melter safety. Present plans are to remove some of the sulfate during pretreatment using an ion exchange process and to incorporate the remaining sulfate in LAW glass. Present vitrification studies seek to increase sulfate solubility in the glass. Some blending of waste is also being considered. The Team recommends pretreatment studies that focus on precipitation of sulfate by evaporation and/or addition of calcium (Ca) or Sr. Vitrification studies should examine decomposition of sulfates in the melters with removal in the offgas system. The sulfate must be removed from any scrubber solutions which are recycled back into the process.

3. **Develop Sr/TRU element removal processes:** Priority should be placed on additional testing of the recently revised baseline process ($SrCO_3$ precipitation/isotopic dilution and MnO_2 carrier precipitation) for Sr/TRU element removal, which is required for selected wastes that contain high concentrations of organic complexants. Other alternatives and improvements, such as the use of oxidants other than permanganate and sorbents other than MnO_2, should also be studied to provide backup contingencies, and to improve understanding of the chemistry involved.

4. **Execute in-tank mixer pump test (project W-151) in FY00:** Completion of the project W-151 tests and evaluation of the resulting data are deemed essential to the design and successful operation of the PHMC baseline system to deliver required volumes of candidate waste sludge to BNFL.

5. **Evaluate flammable gas release during mixer pump operation:** The PHMC should carefully review Russian and Savannah River Site (SRS) experiences and mitigation approaches to minimizing combustible gas releases during operation of mixer pumps.

6. **Provide adequate analytical facilities:** The stability of melter operations, and the quality of the immobilized product, will depend on the ability of the melter feed system to deliver a uniform feed of the expected composition. Success of all process operations will depend on the availability of adequate analytical facilities. Design of such facilities cannot proceed until sampling and analysis requirements are identified, and methods and equipment are specified.

7. **Test melters thoroughly:** Full-scale testing with simulants is essential to sound design and reliable melter operation. BNFL's LAW melter pilot program should be continued through and beyond Phase I, Part B-1. Full-scale testing with simulants is also recommended. Failed melters should be routinely examined as a basis for continuous improvement of melter design.

8. **Develop a process for Cs removal using crystalline silicotitanate (CST) sorbent:** Non-elutable CST ion exchange process technology development studies should be conducted to provide a viable backup alternative, should the baseline technology not meet design specifications.

9. **Provide a bench-scale, integrated radioactive processing facility:** BNFL should have a test facility for processing actual waste samples whenever a major batch change occurs and to troubleshoot chemical problems arising during plant operation. The value of this capability has been demonstrated at SRS.

10. **Deploy existing 9-liter sampler:** The PHMC should deploy the existing large sampler (~9 L) on one of the five PHMC waste feed tanks to demonstrate the capability to provide large samples for BNFL development efforts.

11. **Review progress:** The status of technology development and technical risks should be reviewed again at the end of the Phase I, Part B-1 contract.

2.3 Summary of Development Status, Technical Risks, and Risk Mitigation

The Team evaluated the major unit operations or functions in the PHMC and BNFL flowsheets (see Figure 1.2.1). The DOE-EM technology development gate terminology was used to describe the various stages of technology development (Table 2.3.1). First, we evaluated the stage of development for the unit operations in the overall nuclear industry. We also applied these stages *based on the specific application of each technology to Hanford tank wastes*. In a number of cases, this led to assignment of a lower stage of development for some technologies (for example, mixer pumps for retrieval) used successfully elsewhere, but that have not been applied or demonstrated at Hanford.

Throughout this review, the Team stresses the need for technology development using actual Hanford liquid and solid wastes to be treated during Phase I. The reason for this emphasis is that the chemical and physical properties of nuclear wastes vary greatly depending on the chemicals added during processing and subsequent tank farm storage operations. The result is that the wastes can vary significantly from tank to tank, even at the same site. The wastes to be treated during Phase I were mostly generated during plutonium/uranium extraction (PUREX) process operations and should be similar to wastes at SRS and the West Valley Demonstration Project (WVDP), especially for the solids. This similarity in sludge composition and properties led to the selection of the same HLW melter. Differences do exist as shown in the liquid wastes where some of the Hanford waste contains high concentrations of organic complexants from early processing of waste to remove Cs and Sr. The complexants require additional pretreatment to remove TRU elements and Sr-90 prior to vitrification and affect the removal of technetium-99 (Tc) from the waste. Other wastes at Hanford contain much higher sulfate concentrations than are present in wastes at other DOE sites. The high sulfate concentration can affect vitrification of the LAW. Hanford wastes also generally contain higher concentrations of potassium (K) than wastes at other sites; this severely impacts the efficiency of some Cs-137 removal technologies.

Waste treatment technologies from other countries are less applicable because most foreign wastes are maintained as acid solutions, which are vitrified without pretreatment. The Russians use a phosphate glass for IHLW, rather than the borosilicate glass selected for U.S. wastes. Technology development needs specific for Hanford waste increase beyond Phase I because Hanford operated three different plutonium (Pu) recovery processes, reprocessed some of these wastes, and did extensive mixing of different waste types. Vitrification of Hanford's unique LAW requires extensive development.

The stage of development, technical risks, and risk mitigation actions for the various unit operations are summarized in Tables 2.3.2, 2.3.3, and 2.3.4. High-risk unit operations include Sr/TRU removal, and sulfate removal (a recent addition to the flowsheet). In Section 6.0, additional baseline development work for reducing risk is described. In other areas, development of alternatives is strongly recommended because the risk of failure is judged to be moderate, even after currently planned additional development work. Adequate resources must be provided to ensure timely completion of these key development activities.

Table 2.3.1
DOE-EM Stages of Development

Stage	Title	Activities
1	Basic Research	Build knowledge, develop theories, lab experiments, proof of principle
2	Applied Research	Laboratory experiments, linked to needs, define materials requirements and design concepts, define cost requirements
3	Exploratory Development	Show technical feasibility, laboratory-scale prototyping, estimate costs
4	Advanced Development	Proof of design, full-scale laboratory tests, preliminary field test, develop technical specifications
5	Engineering Development	Full-scale design, prototype and pilot-scale test, reliability testing
6	Demonstration	Full-scale operations with actual waste, prove economic viability
7	Deployment	Proven technology, in service treating actual waste cost-effectively

Table 2.3.2
Summary Evaluation for Waste Retrieval Unit Operations

Unit Operation	Stage of Development for Unit Operations		Overall Risk[a]	Impact of Failure of Current Baseline Technology	Risk Mitigation Actions Currently Being Taken	Adequacy of Risk Mitigation Actions	Recommended Additional Mitigation Actions for Phase I
	Nuclear Industry	Hanford					
Retrieval-Liquid	Deployment	Deployment	Low	Delay in delivery of waste feed to BNFL, $2.5M/day cost penalty to DOE	None	N/A	None
Retrieval-Solids	Deployment	Engineering Development	Moderate	Delay in delivery of waste feed to BNFL, $2.5M/day cost penalty to DOE	Mixer tests (project W-151) being conducted on tank AZ-101. See Table 6.2.1.1 for details	Action necessary, but not sufficient	- Review Russian experience - Perform state-of-the-art RAM - Review TFA technologies for application - Evaluate W-151 test results to extrapolate mixer pump performance to other tanks
Waste Transfer	Deployment	Demonstration	Moderate	Delay in delivery of waste feed to BNFL, $2.5M/day cost penalty to DOE	Several, see Table 6.2.2.1	Adequate, but additional work desirable	- Develop line unplugging technology - Update ESP model regularly
Feed Staging	Deployment	Demonstration	Low	Delays and changes in feed delivery	Contingency plans being developed. See Table 6.2.3.1	Adequate	None
Characterization	Deployment	Deployment	Low	Disagreements on feed characteristics	Extensive sampling program underway. See Table 6.2.4.1	Adequate	Ensure that requirements from BNFL and PA experts are included
Testing Samples	Deployment	Advanced Development	Low	Inability to test key process steps at bench scale	Large (3-10 liter) not currently in baseline plan. See Table 6.2.5.1	Inadequate	Accelerate demonstration of existing 9 liter sampler

(a) Risk is the product of the probability of an event occurring (i.e., unit operation process failure) multiplied by the consequence of the event. See Section 4.1.

Table 2.3.3
Summary Evaluation for Pretreatment Unit Operations

Unit Operation	Stage of Development for Unit Operations		Overall Risk[a]	Impact of Failure of Current Baseline Technology	Risk Mitigation Actions Currently Being Taken	Adequacy of Risk Mitigation Actions	Recommended Additional Mitigation Actions for Phase I
	Nuclear Industry	Hanford					
Waste Feed Receipt	Deployment	Demonstration	Low	May complicate solid-liquid separation	Lab scale tests for solids formation or exothermic reactions, determine immobilization path for solids. See Table 6.3.1.1	Adequate	None
Waste Feed Evaporation	Deployment	Deployment	Low	Frequent outages to remove pluggage	Lab scale evaporation of mixed stream to determine solids formation. See Table 6.3.1.1.	Adequate	None
Solid/Liquid Separation	Deployment	Engineering Development	Moderate	Reduced plant operating efficiency resulting in extended schedule and higher operating costs	Lab scale tests w/ actual waste, pilot scale tests w/ simulants. See Table 6.3.2.1.	Adequate	None
Sr/TRU Removal	Deployment	Basic Research	High	Inadequate decontamination of LAW, unacceptable ILAW product	Tests with permanganate addition approach underway. See Table 6.3.3.1.	Possbily inadequate due to immature technology	Study alternative TRU element sorbents and partial oxidation of complexants.
Cesium Removal	Deployment	Advanced Development	Moderate	Inadequate decontamination of LAW, unacceptable ILAW product	Study resin material properties and characteristics. See Table 6.3.4.1	Adequate	Ensure system compatibility with CST sorbent
Technetium Removal	Exploratory Development	Exploratory Development	Moderate	Inadequate decontamination of LAW, unacceptable ILAW product	Study resin material properties and characteristics, develop real time Tc monitor. See Table 6.3.5.1	Adequate	Consider alternative elutable resins
Sulfate Removal	Basic Research	Basic Research	High	Lower ILAW waste loading resulting in a higher volume, higher costs	Several studies underway. See Table 6.3.6.1.	Not clear that a successful pretreatment process is achievable	- Investigate crystalization/precipatation - Investigate waste feed blending
Water Washing of Sludge	Deployment	Engineering Development	Low	Lower IHLW glass quality and increased IHLW volume	None	Adequate, but additional monitoring capability desirable	Develop monitor to measure solution concentration/ionic strength
Caustic Leaching of Sludge	Deployment	Engineering Development	Low	Increased IHLW volume	Testing leaching and solution stability. See Table 6.3.8.1.	Adequate	Investigate sequential caustic & acidic leaching

(a) Risk is the product of the probability of an event occurring (i.e.; unit operation process failure) multiplied by the consequence of the event. See Section 4.1.

Table 2.3.4
Summary Evaluation for Immobilization Unit Operations

Unit Operation	Stage of Development for Unit Operations		Overall Risk[a]	Impact of Failure of Current Baseline Technology	Risk Mitigation Actions Currently Being Taken	Adequacy of Risk Mitigation Actions	Recommended Additional Mitigation Actions for Phase I
	Nuclear Industry	Hanford					
LAW Feed Preparation	Engineering Development	Engineering Development	Low	Melter operation instabilities leading to schedule delays	Numerous, see Table 6.4.1.1	Adequate, but additional actions desirable	Incorporate evaporation capability into feed blending tanks
LAW Vitrification	Engineering Development	Engineering Development	Moderate	Sulfate accumulation could damage melter and cause schedule delays. Resolution may require increased glass volume	Numerous, see Table 6.4.2.1	Adequate, but additional actions desirable	- decompose excess sulfate in melter - extend pilot scale melter operation through end of Part B-1 and beyond
ILAW Product Certifi-cation	Engineering Development	Engineering Development	Low	Schedule delays potentially leading to added costs	Develop detailed product certification acceptance strategy. See Table 6.4.3.1	Adequate, if timely	None identified
LAW Offgas	Engineering Development	Engineering Development	Moderate	Increased waste volumes leading to added costs. Component failures resulting in increased downtime	Separation of sulfates unresolved. See Table 6.4.4.1	Actions necessary, but insufficient.	Numerous actions identified in Table 6.4.4.1
HLW Feed Preparation	Deployment	Engineering Development	Low	Melter operation instabilities leading to schedule delays	Numerous, see Table 6.4.1.1	Adequate	Incorporate evaporation capability into feed blending tanks
HLW Vitrification	Deployment	Engineering Development	Moderate	Premature melter failure and solids accumulation	Numerous, see Table 6.4.6.1	Adequate	Full-scale melter testing with simulants.
IHLW Product Certifi-cation	Deployment	Engineering Development	Low	Schedule delays potentially leading to added costs	Develop detailed product certification acceptance strategy. See Table 6.4.7.1	Adequate, if timely	Consider solid blasting for canister decontamination
HLW Offgas	Deployment	Engineering Development	Low	Component failures resulting in increased downtime	Numerous, see Table 6.4.8.1	Actions necessary, but insufficient	Numerous actions identified in Table 6.4.8.1

(a) Risk is the product of the probability of an event occurring (i.e.; unit operation process failure) multiplied by the consequence of the event. See Section 4.1.

3.0 Description of TWRS-P Phase I Work Scope

This section (and Appendix B) presents a more detailed work scope description of the project participants (DOE, PHMC, and BNFL) and provides a summary process description and flowsheet for the TWRS-P Phase I waste processing activities. This process summary description, except as modified by verbal presentations and discussions, represents the PHMC's Case 1 in the *Tank Waste Remediation System Operation and Utilization Plan* (HNF 1999), and BNFL's process description presented in its *Preliminary TWRS-P Facility Dangerous Waste Permit Application* (BNFL 1999). The PHMC's work scope consists of storing and characterizing current and newly generated waste, retrieving and blending retrieved waste to meet contractual feed requirements, delivering feed to BNFL, receiving back from BNFL pretreated LAW,[(a)] entrained solids[(a)], and IHLW for interim storage, and receiving back ILAW for disposal. DOE's work scope includes formal acceptance of the ILAW and IHLW prior to transfer by BNFL back to the PHMC. Figure 1.2.1 depicts these major processing functions in a block flow diagram, as well as indicating organizational responsibilities.

The process description and flowsheet presented in this section and Appendix B represents the Team's understanding of the project baseline as of July 1999. The Team fully recognizes that the baseline flowsheet is continually evolving and our information may not be completely accurate at the time this report is read.

3.1 PHMC's Process Description

Phase I pretreatment processing functions previously planned to be performed by the PHMC were transferred to BNFL as a result of the contract agreement between DOE and BNFL in August 1998. Phase I processing to be performed by the PHMC now includes the following:

- Sluicing and/or mixer pump retrieval of sludge from five double-shell tanks (DSTs) - including carrier liquid that also becomes LAW feed, adjustment of HLW slurry properties (as necessary for specification compliance or to facilitate transfers), blending (as needed), and staging of feed batches to BNFL

- Retrieval of LAW supernate with simultaneous adjustment of properties (as needed), dissolution of salt slurry followed by retrieval of the solution, and staging of feed batches to BNFL

- Interim storage of pretreated selected liquid returned from BNFL[(a)]

- Interim storage of entrained solids returned from BNFL[(a)]

(a) BNFL may perform interim storage of entrained solids and pretreated LAW instead of returning these streams to PHMC.

A detailed description of PHMC feed delivery activities is presented in Appendix B.

3.2 BNFL's Process Description

The BNFL process will treat and store HLW and LAW from the PHMC DST system. Treatment processes are designed to pretreat these wastes to make them suitable for vitrification, immobilize the waste constituents in a glass matrix by vitrification, and treat the offgas to a level protective of human health and the environment. The BNFL pretreatment process will separate the wastes into LAW and HLW feed fractions suitable for vitrification. Two systems will be used in the vitrification process; one will produce ILAW and the other will produce IHLW. The BNFL process will use unique melter systems that are specially designed to immobilize each separate waste stream.

The ILAW and IHLW generated will be sealed in containers and placed in interim storage facilities. Secondary waste streams (radioactive and dangerous solid waste, nonradioactive and non-dangerous liquid effluents, and radioactive and dangerous liquid effluents) will be characterized and transferred to permitted facilities. Gaseous effluents generated from waste pretreatment will be treated, monitored, and discharged to the environment through a stack. Melter offgas will be treated to comply with risk-based performance standards, monitored, and discharged to the environment. One melter stack discharges treated LAW offgas; another melter stack discharges treated HLW offgas.

In BNFL's flowsheet, two processes proceed in parallel. The LAW path treats waste feed Envelope A, B, and C waste streams, while the HLW path treats waste feed Envelope D waste streams. Waste feed envelope definitions are provided in *TWRS Privatization Contract No. DE-AC06-96RL3308—Mod. No. A006*. The HLW process also incorporates intermediate products from pretreatment of the LAW feed, including Sr-90 and TRU precipitate, Cs-137 ion-exchange eluate, Tc-99 ion-exchange eluate, and entrained solids. Figure 3.2.1 presents a simplified process flow diagram of the BNFL processes.

A detailed description of the BNFL process is contained in Appendix B.

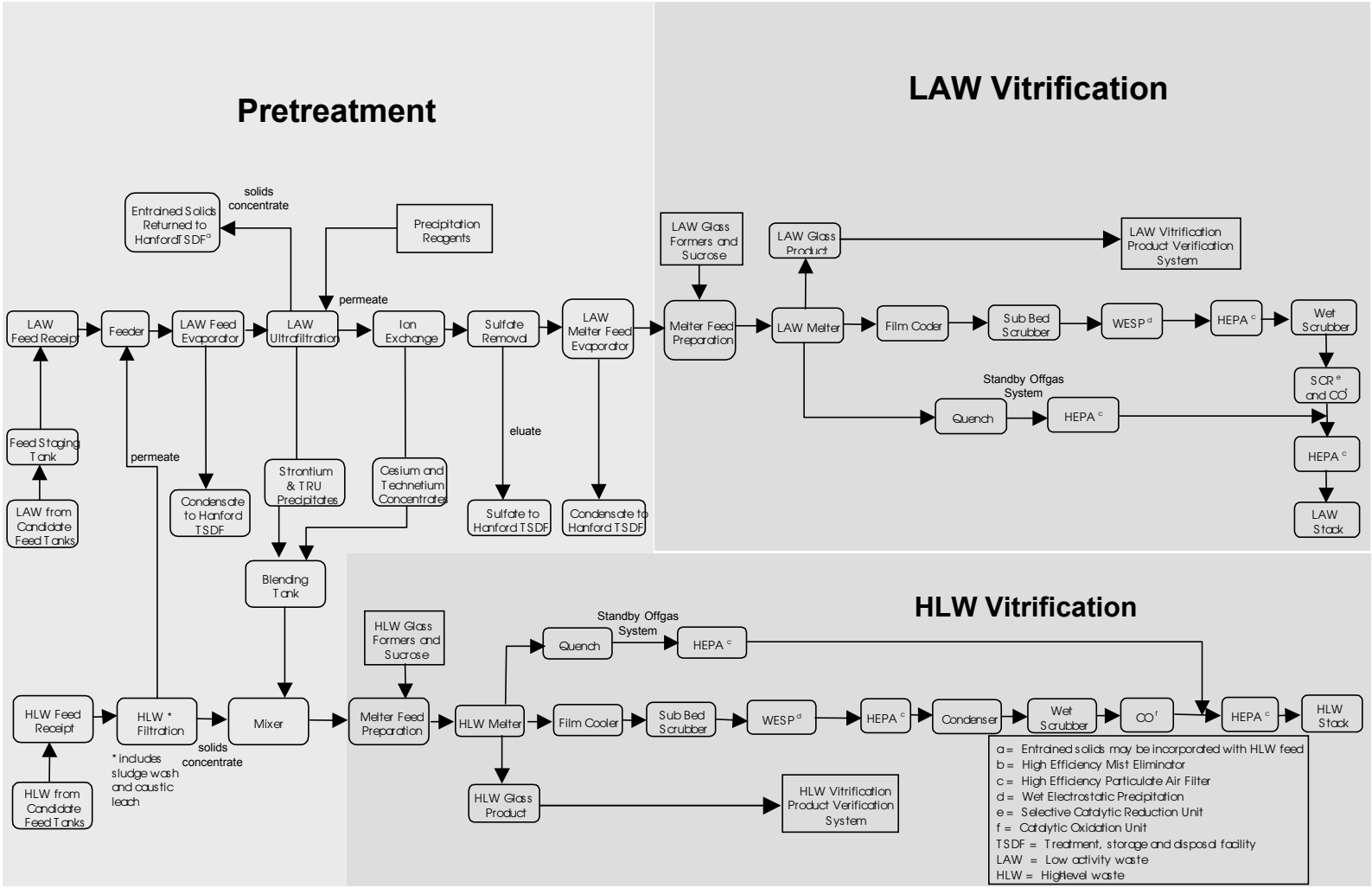
3.3 References

BNFL 1999 BNFL, Inc., *Preliminary TWRS-P Facility Dangerous Waste Permit Application,* BNFL-5193-RCRA-01, Rev. 0C, May 7, 1999.

HNF 1999 Kirkbride, R. A., et al., *Tank Waste Remediation System Operation and Utilization Plan*, HNF-SD-WM-SP-012, Rev. 1, Vol. I and II, May 4, 1999.

(a) BNFL may perform interim storage of entrained solids and pretreated LAW instead of returning these streams to PHMC.

Figure 3.2.1 Simplified Process Flow Diagram for the BNFL Facility



4.0 Description of the Assessment Methodology

4.1 Assessment Approach

The Team approached the assessment by working through the following stages:

- Study and clarification of the Team's charter
- Information gathering on planned PHMC and BNFL activities (including projects, operations, and technology development)
- Interpretation and clarification of the information provided
- Division of work activities into major flowsheet unit operations (see Table 4.1.1)
- Evaluation of current baseline flowsheet unit operations status
- Identification of technical issues that currently or could exist for each unit operation
- Evaluation of the risk presented by each technical issue
- Identification of technology development needed to resolve the technical issues
- Evaluation of baseline technology improvements and alternative technologies that could be developed as backup to the baseline
- Prioritization of baseline improvements and alternative technologies
- Development of recommended technology development workscope required to mature the alternative technologies.

To gain the required information, DOE-ORP (with support from BNFL) and PHMC staff gave technical presentations to the Team, and an initial set of key documents (documents reviewed by the Team are shown in Appendix C) were provided at the first meeting on May 11-12, 1999. The Team then prepared a detailed set of questions and requested additional documentation based on their review of the initial information. In the second meeting on June 2-4, 1999, additional presentations were made and answers to the Team's questions were provided by DOE-ORP, BNFL, and PHMC. The Team also requested additional documents. Three additional meetings were held in which the activities described below were performed, and the report was drafted.

Team members consolidated the results of their individual identification of technical issues and technology development needs for each unit operation (see Table 4.1.1) in the currently proposed baseline

Table 4.1.1
Division of PHMC and BNFL Work Activities into Unit Operations[a]

Work Area	Unit Operations
Waste Retrieval and Transfer (PHMC)	Retrieval Transfer Feed Staging Feed Characterization Testing Samples
Pretreatment (BNFL)	Feed Receipt and Evaporation Solid-Liquid Separation Sr/TRU Removal Cs Removal Tc Removal Sulfate Removal Water Washing of Sludge Caustic Leaching of Sludge
Immobilization and Product Certification (BNFL)	LAW Feed Preparation LAW Vitrification ILAW Product Certification LAW Off-gas HLW Feed Preparation HLW Vitrification IHLW Product Certification HLW Off-gas
(a) The term "unit operation" denotes major process functions or activities that form the overall flowsheet.	

flowsheet. Technical issues were evaluated based on whether they could present a low, moderate, or high risk to the overall success of the project. Risk is the product of probability of an event occurring multiplied by the consequences of the event. In this study, we defined probability as the probability that a unit operation will fail (not perform as intended) *even if the currently planned development program is implemented*. We have used **Low, Moderate**, and **High** to describe the probability as defined below:

- **Low** **<10% probability**
- **Moderate** **10-50% probability**
- **High** **>50% probability**

The primary consequences of concern in this assessment are significant cost and/or schedule impacts to the Phase I project. Thus, any technical issue that could significantly impact cost and schedule would present a high risk to the project if the probability of failure of the applicable unit operation due to this issue was judged to be **Moderate** or **High**.

Based on the number of technical issues identified and their risk evaluation, the Team then assigned an overall technical risk to each unit operation. Full Team discussion sessions were used to ensure that a common basis for risk evaluation was used. (The qualitative risk evaluations were done to identify the high risk areas of the project, not to calculate an overall project risk). A preliminary discussion of technology development needs for each unit operation was included in the interim status report (June 1999). A detailed discussion of these needs is provided in this report. Also in this report, alternative technologies are prioritized using the criteria described in Section 4.4, and the recommended technology development activities are defined for the highly ranked improvements and alternatives in Section 6.0.

4.2 Identification of Team Members and Team Organization

Individuals with expertise in waste storage, retrieval, waste characterization, waste chemistry, radionuclide separations processes, and waste vitrification processes, as well as process engineering and integration were required to conduct the assessment. Team members were to be independent of current ORP, PHMC, and BNFL activities. It was considered critical that the Team have direct experience and understanding of the challenges associated with Hanford's radioactive wastes, as well as broad knowledge of waste management experience across the DOE complex, including the WVDP and SRS. It was considered highly desirable to utilize experts from TFA's Technical Advisory Group, particularly including members who participated in DOE-EM's recent independent review of the SRS cesium processing/salt disposition alternatives study. Also, the National Research Council recently documented their recommendations on an end state methodology for identifying alternative approaches and technology needs for environmental management, using the Hanford tanks as an example. Thus, members of the National Research Council committee could serve as either Team members or as consultants to the Team.

With the above criteria in mind, ten Team members were selected. The Team members' current affiliation, experience, and areas of expertise are summarized in Appendix D, Table D.1, and complete resumes are also provided in Appendix D. To facilitate the review and make best use of the members' expertise, the group was organized into four subteams:

<u>Process and Systems Integration</u>

- Harry D. Harmon
- John H. Roecker

<u>Waste Retrieval and Transfer</u>

- Wallace W. Schulz
- James H. Lee
- John H. Roecker

Pretreatment

- John L. Swanson
- Lawrence L. Tavlarides
- Major C. Thompson

Immobilization

- M. John Plodinec
- E. Thomas Weber
- Frank E. Woolley

Subteam members had specific responsibilities for identifying technical risks and alternatives for their areas of expertise, but all Team members were equally responsible for providing a balanced overall assessment of the technologies selected for use in the project.

4.3 Outside Resources Used

As described above, DOE-ORP, BNFL, and PHMC staff were extremely helpful in providing information the Team needed to understand the planned activities. Several TFA Technical Integration Managers (Dr. William Holtzscheiter, Dr. Phillip McGinnis, Dr. Tom Thomas, and Mr. Peter Gibbons) provided informative presentations on alternative technologies currently under development. Also, Dr. John Garrick, chairman of the National Research Council Committee on Technologies for Cleanup of High-Level Waste in Tanks in the DOE Weapons Complex (Committee), and Mr. Alan Croff, a Committee member from Oak Ridge National Laboratory, made a presentation on their Committee's report entitled "An End State Methodology For Identifying Technology Needs For Environmental Management, With an Example from the Hanford Site Tanks" (NRC 1999). In addition, members of the Immobilization subteam visited the pilot melter facility at the GTS Duratek location in Columbia, Maryland, to assess the development status of the private contractor's melter systems and glass composition program.

4.4 Criteria Selected for Alternatives Evaluation

The Team's charter includes identification of the criteria used for alternatives evaluation. The Team studied criteria used in the past for: 1) BNFL's initial process selection; 2) evaluation of HLW melter alternatives; and 3) evaluation of cesium removal alternatives at SRS, as well as suggestions by DOE personnel supporting our assessment. The Team found that all of these sets of criteria had several common attributes appropriate to this study. However, the Team determined that for this study, two screening criteria would be used to allow for down-selecting from the large number of possible alternative technologies: 1) alternatives should be technically capable of meeting project objectives, and 2) alternatives should operate with minimal safety and environmental risk. After satisfying the screening criteria, alternatives were evaluated with respect to maturity, ability to integrate with existing processes, potential for life cycle cost reduction, and ability to maintain current schedule. These criteria and the alternative scoring method are summarized in Table 4.4.1.

Table 4.4.1
Evaluation Criteria for Alternatives Assessment

SCREENING	**SCORING**
Ability to meet technical performance requirements (includes operability and reliability)	YES/NO
Ability to minimize safety and environmental risks	YES/NO
EVALUATION	**SCORING**
Maturity of Technology	
Basic or Applied Research	Low
Exploratory, Advanced, or Engineering Development	Medium
Demonstration or Deployment	High
Ability to Integrate (i.e., effect on other process steps in flowsheet)	
Significant negative impact on other process steps	Low
Modest negative impact on other process steps	Medium
Little or no impact on other process steps	High
Potential for Life Cycle Cost Reduction[(a)]	
<1% cost reduction	Low
1-10% cost reduction	Medium
>10% cost reduction	High
Ability to Maintain Current Schedule	
Extended development program, major redesign, and/or significant change to facility footprint	Low
Modest development program, some redesign, and/or minimal change to facility footprint	Medium
Minimal development program, minimal redesign, and no change to facility footprint	High
(a) Assuming life-cycle costs of ~ $10 billion for Phase I, and ~$30 billion beyond Phase I.	

4.5 References

NRC 1999 National Research Council, "An End State Methodology for Identifying Technology Needs for Environmental management, with an Example from the Hanford Site Tanks," National Academy Press, Washington, D.C., 1999.

5.0 Identification of Technical Risks

Based on the information gathering stage of this study, the Team was able to evaluate the PHMC and BNFL flowsheet and the stage of development of each unit operation. The Team applied their knowledge of these unit operations and prior experience with similar processes to define technical risks (issues, concerns, potential problems, etc.) for each unit operation. These technical risks are tabulated and evaluated as to whether they present a Low, Moderate, or High risk to the project. Our use of the term "risk" in this context is described in Section 4.1.

5.1 Waste Retrieval and Transfer Operations

Successful Phase I waste pretreatment and immobilization at Hanford ultimately depends on timely delivery of specified amounts and types of stable and suitably-characterized wastes to BNFL. The DOE has assigned responsibility for retrieval and delivery of the requisite Phase I tank waste to the PHMC. The PHMC has already completed and issued various reports which provide detailed information concerning the sequence and other plans for retrieving liquid and solid wastes from chosen DSTs and SSTs (Kirkbride et al., 1999; Honeyman, 1998; Wojtasek, 1997).

Tank waste to be retrieved and delivered to BNFL in the Phase I privatization contract is either currently stored in or being transferred to the DSTs. The PHMC plans to install mixer pumps and transfer pumps in each of the candidate DSTs for retrieval and delivery of the tank contents to BNFL. Present PHMC plans include installation and operation of two 300 horsepower mixer pumps in each DST to obtain a well-mixed slurry of waste liquid and solids. Subsequently, slurries will be pumped, via buried, double-contained transfer lines, to one of two feed staging tanks for eventual transfer to the BNFL feed receiver tank. The Team evaluated PHMC retrieval risks based on the ability to provide acceptable feed to BNFL; heel removal and tank cleaning are not part of the Phase I scope and were not considered in this review.

The PHMC plans to use the DOE complex standard technology for retrieval and transfer activities. Mixer and transfer pumps are currently in use at SRS to retrieve wastes for pretreatment and/or vitrification. At the WVDP, such equipment was used very successfully to retrieve 1960s-generated waste. In addition, a mixer pump was installed in DST SY-101[(a)] at Hanford in 1993 and has operated quite successfully.

The Team is confident that the PHMC can and will retrieve and deliver all contractually specified tank wastes in a timely and satisfactory manner. However, several years must pass before the first wastes are retrieved from the Hanford DSTs. The waste retrieval approach planned by the PHMC involves a

(a) Tanks at Hanford are identified by the number 241-xx-xxx. As "241" is common to all HLW tanks in this report, the initial number (241) is hereafter omitted.

number of technical risks[a] which must be addressed. A list of the identified waste retrieval risks is provided in Table 5.1.1. These risks are grouped under the following headings: retrieval, transfer, staging, and characterization.

The Team identified two major technical risks associated with PHMC-planned waste retrieval and transfer activities: 1) possible inability of the planned Waste Feed Delivery System (WFDS), including mixer and transfer pumps to provide the scheduled amounts of waste to BNFL without utilizing contingency tanks; and 2) frequent plugging of buried waste transfer lines, either by settling of solids already in the candidate tanks or by intractable solids and/or gels formed during waste retrieval, dilution, and transfer operations. The concern that the WFDS could fail arises from the lack of experience with the

Table 5.1.1
Waste Retrieval, Transfer, Staging and Characterization Technical Risks

Technical Issue	Risk Rating
RETRIEVAL	
1. Two 300 horsepower mixer pumps may not provide adequate capability for retrieval of required waste volumes.	**H**
2. Waste retrieval operations may release excessive amounts of flammable gas.	**M**
3. Overall WFDS may not be sufficiently reliable.	**M**
TRANSFER	
1. Existing solids in retrieved wastes may settle and plug transfer lines.	**M**
2. Intractable solids and or gels may form during waste transfer operations.	**M**
3. The time to unplug a line or build a shunt around a plugged line is an issue.	**M**
4. Valve designs and systems could contribute to line plugging.	**L**
5. Upgrades in transfer line elevation may enhance plugging.	**L**
FEED STAGING	
1. Depth and extent of contingency if waste cannot be retrieved in the order presently specified is an issue.	**L**
FEED CHARACTERIZATION	
1. Sampling of wastes in large tanks may not be statistically valid.	**L**
2. Apparent lack of agreement between PHMC and BNFL about waste characterization data and protocols.	**L**
3. Failure to analyze waste transfers for important minor radionuclides could eventually be a significant shortcoming and major problem.	**L**
TESTING SAMPLES	
1. Failure to obtain adequate actual waste sample volumes could compromise testing of key process steps.	**L**

(a) Jordan (1998), in assessing the readiness to proceed of the TWRS Retrieval and Disposal Mission, listed 32 critical risks. Only three (Mixing and Retrieval System, Plugged Transfer Lines, and Waste Feed Out-of Specification) were technical risks. This Team identifies the same technical risks (see Table 5.1.1).

planned approach specific to Hanford. Whenever nuclear waste slurries are to be pumped fairly long distances through buried lines, significant concern exists that solids in the waste will settle and plug the line, thereby greatly compromising waste transfer activities and schedules.

Historical successes in tank farm operations at the Hanford Site and recent tank mixing operations are encouraging. The Team recognizes that site pipeline transfer procedures are very specific as to the permissible concentration of solids allowed. However, because there is no experience with retrieval-transfer operations planned specifically for the Privatization Phase IB activities, there is a possibility that the WFDS could fail.

SRS and the Russians have considerable experience transferring wastes, including sludge wastes, over considerable distances without line plugging. At SRS, sludge containing 19 wt% solids is transferred on an approximate bi-weekly basis to DWPF at distances up to a kilometer. To prevent and mitigate plugging risks, lines are flushed after transfer, and the line low point has a pump station.

An added concern in waste retrieval and transfer activities at Hanford is that difficult-to-manage solids and/or gels will form when wastes are diluted, blended, or physically moved, increasing the potential for these solids or gels to settle out and plug transfer lines. Evidence that such intractable solids and gels do form under certain conditions in Hanford tanks has been obtained in bench-scale tests conducted in the last few years. Finally, as noted in Table 5.1.1, the Team believes there are also technical risks involved with present PHMC plans to characterize and stage wastes to be delivered to BNFL. We consider these latter risks to be of lower importance than those associated with transfer line plugging and possible WFDS failure.

In addition to waste retrieval and transfer technical risks, Section 6.2, Table 6.2.1.1 identifies technologies whose development will likely resolve and mitigate the technical risks (technology development needs relate to both baseline performance and improvements to the baseline.) The single most important technology development need is to complete the original intent of project W-151.

Project W-151 involves the installation of two mixer pumps in Tank AZ-101 and a plan to test these pumps for their performance in the mobilization of the tank's sludge wastes. A well-designed test of these two mixer pumps can provide data and much needed operational experience to guide future installation, operations, and performance in candidate source tanks for waste feed to BNFL. The Team considers project W-151 test necessary, but not sufficient to the reduction of risks associated with the PHMC WFDS to BNFL. A thorough analysis of project W-151 test results must be combined with other mixer pump mobilization results in order to understand the applicability of the project W-151 test results to the prediction of retrieval risk for the PHMC WFDS. Tank AZ-101 sludge is sufficiently different from the sludge in Tanks AZ-102, AY-102, C-106, C-104, and C-102 that this correlation step is crucial for reducing risk in the PHMC WFDS.

Serious technical concerns that plugging of transfer lines by either solids already in candidate tanks or by newly-formed solids and/or gels require serious attention on multiple fronts. Installation of redundant transfer lines is recommended. All valves and lines should be designed and constructed to minimize places where solids could settle and plug lines. The Environmental Simulation Program (ESP) Model

(Eager, 1998) database should be updated regularly, and the ESP Model should be used extensively to simulate all waste retrieval, transfer, and other possible activities (blending, dilution, etc.). The ESP model is adequate for this purpose, although other models may be needed as the PHMC and BNFL move forward in Phase IB. More importantly, bench-scale tests with actual tank wastes should be performed to simulate all retrieval activities and to confirm ESP Model predictions. On-going work sponsored by the TFA to develop and test new technology for unplugging radioactive waste transfer lines should be closely monitored by the PHMC.

The Team judges that the technical issues involved with waste retrieval and transfer are **Moderate**. Technical risks associated with feed staging, characterization, and testing samples are considered **Low**.

5.2 Pretreatment

5.2.1 BNFL Waste Feed Receipt and Evaporation

BNFL receives LAW and HLW waste feeds from PHMC into separate feed receipt tanks for subsequent processing. The initial HLW waste feed slurries, as well as washes and caustic leaches of the HLW sludge, are ultrafiltered to the desired solids concentration with all permeates sent to the LAW waste feed receipt tank. The LAW waste feed tank receives waste solutions directly from the PHMC as well as HLW permeates and various recycled liquids from vitrification offgas scrubbers. Solutions from the LAW waste feed receipt tank are fed to an evaporator system to adjust the concentration prior to subsequent processing.

Mixing of the various solutions could result in solids formation. BNFL mitigation plans include investigation of mixing different feed envelopes with each other, as well as mixing sludge washes, caustic leaches, and recycle liquids with each feed envelope. Evaporation of alkaline wastes has been done successfully for many years at Hanford, Oak Ridge Reservation and SRS, and should require little development, except in the area of evaporator line pluggage.

Table 5.2.1 lists the technical issues associated with waste feed receipt and evaporation. One concern is the formation of solids during mixing of various liquids in the receipt tank. Radionuclides in the solutions could be co-precipitated, requiring that the newly formed solids be sent through the HLW vitrification process. Precipitation can also lead to formation of fine solids, which could plug the ultrafilter, resulting in low permeate rates. Plugging of evaporator lines with aluminosilicate or other solids during evaporation is a common problem during waste evaporation at SRS. The technical risk of these operations is **Low.**

Table 5.2.1
BNFL Waste Feed Receipt and Evaporation Technical Risks

Technical Issues	Risk Rating
Waste Feed Receipt	
1. Precipitation of solids with enough radioactivity to produce either HLW or TRU solids.	**L**
2. Formation of fine solids which plug the ultrafilter media and reduce filtration rate.	**L**
Waste Feed Evaporator	
1. Plugging of lines by aluminosilicates or other solids.	**L**

5.2.2 Solid-Liquid Separations

Current BNFL plans call for ultrafiltration systems to separate solids from liquids in the LAW and HLW feed streams, with a dedicated system for each stream (see Appendix B). The solids slurry is concentrated to the desired level.

BNFL selected the ultrafiltration solids removal technology over other alternatives including deep bed filter, centrifuge, precoat filter and sedimentation. In general, ultrafiltration is fully developed in commercial operations with proven remote maintenance and operations methods. It has also been demonstrated on full-scale HLW systems at SRS. BNFL uses ultrafiltration on low-level radioactive waste streams at Sellafield in the United Kingdom.

Despite the solid/liquid separation process maturity with other wastes, a development program is in progress to assess and overcome difficulties in filtration of the various Hanford waste envelope feeds. These studies use waste simulants with various pretreatments and the single-element Cells Unit Filter, and real wastes including Sr-90/TRU element precipitation scoping tests. A variety of filter inserts are being examined, and the impact of the pretreatment chemistry and slurry properties on filtration fluxes is being studied. Parameters which affect cleanup of filter units are being studied, and a pilot-scale ultrafiltration unit is also operational. The $SrCO_3$ and $Fe(OH)_3$ precipitation step produces a slurry that cannot be filtered, leading to the evaluation of other Sr-90/TRU element precipitation chemistries, particularly those involving permanganate addition. This process may develop filterable precipitates and achieve the desired decontamination factor (DF). Both hot and cold ultrafiltration tests of these precipitation processes are continuing.

Table 5.2.2 lists the technical issues of concern identified by the Team. These include the ability to: 1) achieve filtration rates which meet the design specifications, and 2) remove fine Sr-90- and TRU-element-containing colloids to meet ILAW specifications. The level of secondary waste generated by this process (due to the frequency of filter cleaning and replacement) must be within acceptable limits. The technical risk of this operation is **Moderate.**

Table 5.2.2
Solid/Liquid Separations Technical Risks

Technical Issues	Risk Rating
1. Low filtration rates, resulting from fine or gelatinous solids in highly viscous solutions, can reduce plant throughput rates.	**M**
2. Frequency of filter cleaning or replacement can reduce plant throughput rates and increase secondary waste volumes.	**M**
3. Inefficient filtration of Sr-90- or TRU-element-containing colloids could impact ability to meet DF requirements.	**M**

5.2.3 Sr/TRU Removal

Sr-90 and TRU elements are planned to be removed from Envelope C feed by a precipitation process, followed by ultrafiltration, to meet the ILAW specifications. The precipitation step can occur either before or after the feed is pretreated by evaporation and possibly for entrained solids removal. Current planning involves addition of permanganate ions, Ca or Sr ions, and sodium hydroxide (NaOH). After washing, the solids are transferred to the HLW vitrification system. The permeate stream is sent to the ion exchange processing units.

The Sr-90 removal process of isotopic exchange/carrier precipitation was selected because it was as good or better than adsorption processes. TRU element separation by ferric hydroxide precipitation was initially selected as this process was highly rated over solvent extraction and activated carbon adsorption. Difficulties in filtration of the ferric hydroxide precipitate and inconsistent DF values caused a recent change to the permanganate addition (manganese dioxide precipitation) process.

To achieve decontamination of Sr-90/TRU elements, an appropriate precipitation process is intimately linked to the ultrafiltration step for removing the finely divided solids. Therefore, a variety of chemistries are being screened to select a system which achieves the desired DF and produces a filterable product. These screening results are based on bench-scale tests with both real and simulated wastes.

Key technical issues associated with Sr-90/TRU element removal are specified in Table 5.2.3. Poor filtration rates with resultant TRU-element-containing solids present a major concern. Subsequent washing of resultant solids to minimize Na in HLW glass could dissolve the Sr-90 precipitate. The chemistry and reagent proportions have not been defined to obtain an adequate TRU element decontamination factor (DF). Post-precipitation leading to ion exchange column plugging is another concern. Although promising results have been obtained with the permanganate system (Ca or Sr and $NaMnO_4$), consistent and reliable decontamination and filtration have not been established. The technical risk of this operation is **High**.

Table 5.2.3
Sr/TRU Removal Technical Risks

Technical Issues	Risk Rating
1. Poor filtration rates with resultant TRU-element-containing solids.	**H**
2. The nature and quantity of material required to achieve needed TRU element removal are yet to be defined.	**M**
3. Uncertainty in ability to obtain adequate TRU element DF for all wastes containing organic complexants.	**M**
4. Nonradioactive Sr added could precipitate as sulfate and carry sulfate to HLW glass melter.	**L**
5. Washing of resultant solids (to minimize Na to HLW glass) could dissolve Sr precipitate.	**H**

5.2.4 Radioactive Cesium Removal

Radioactive Cs must be removed from LAW feed to comply with ILAW specifications. BNFL has chosen to use ion exchange with a regenerable resin for cesium removal (see Appendix B). Two methods were considered for cesium ion exchange: regenerable and once through. Both rated high in their 1996 evaluation compared to the other separation methods considered: solvent extraction, ferrocyanide precipitation, and crystallization. The apparent advantage of regenerable ion exchange over once-through ion exchange was that the latter process may not meet the requirements for minimization of IHLW quantity and may present solids handling and drying difficulties.

The technology development program underway involves studies on two elutable ion exchange resins - SuperLig®[(a)] 644 (SL644) and SuperLig® 632 (SL632) - using Envelope A and C simulants and actual waste solutions. A series of bench-scale experiments using consecutive adsorption and stripping cycles with SL644 showed acceptable achievement of column volumes before breakthrough. The resin shows substantial swelling (100%) during caustic pretreatment, which could cause hydraulic problems; additional tests are planned. Studies with SL632 have been suspended due to unsatisfactory stability of the resin. A pilot-scale ion exchange unit is operational for large scale simulant testing. Modeling of this ion exchange process has been initiated. BNFL is working with the resin supplier to scale-up and produce production quantities of resin which meet specifications.

Table 5.2.4 lists the technical issues associated with radioactive Cs removal operations using the selected baseline resin. One concern is the manufacturer's ability to consistently produce commercial quantities of qualified resin. Technical problems of shrinkage and expansion, and the mechanical integrity of SL644 resin, could impact column efficiencies and hydraulics. The technical maturity of these relatively new resins is low; continued development work is needed to determine the resin's reliability and performance capabilities to meet design specifications. The technical risk of this operation is **Moderate**.

(a) SuperLig® - registered trademark of IBC Advanced Technologies, Inc.

Table 5.2.4
Cesium Removal Technical Risks

Technical Issues	Risk Rating
1. Uncertain source of commercial quantities of qualified resin.	**M**
2. Shrinkage and expansion of resin may have excessive impacts on column efficiencies and hydraulics (loading, unloading, pressure drop, etc).	**M**
3. Sorption of TRUs could impact ability to dispose of resin as LLW.	**L**
4. Mechanical integrity of resin and possible impacts on column operations are unknown.	**M**
5. Column mass transfer kinetics and the definition of the mass transfer zone is needed to define column design.	**L**
6. Technical maturity of candidate resins is low.	**M**
7. The number of loading and elution cycles before resin disposal is required is unknown.	**L**
8. Hydrogen generation rates from loaded column could be a safety concern.	**L**

5.2.5 Technetium Removal

The fraction of Tc-99 present as pertechnetate in LAW feed must be removed to meet low-level waste performance requirements. BNFL has chosen to use ion exchange with a regenerable resin for Tc removal (see Appendix B). Regenerable ion exchange for Tc removal was selected after comparison with once through ion exchange, activated carbon adsorption and precipitation with sodium sulfide. Regenerable ion exchange was rated as equal to or better than the other technologies in all the evaluation criteria used by BNFL.

Technology development program studies with SuperLig® 639 resin are underway at the laboratory scale with both real wastes and with simulated waste containing rhenium (Re). The results show a rapid breakthrough of Re during column studies. This is likely linked to the length of time needed to reach equilibrium, as shown in batch equilibrium distribution coefficient (Kd) experiments. Elution studies show large volumes of solutions are needed. Pilot scale tests are underway with simulants. BNFL is working with the resin supplier to scale-up and produce production quantities of resin which meet specifications.

Table 5.2.5 lists the technical issues related to Tc-99 removal. The technical maturity of this relatively new resin is low; continued development work is needed to determine its reliability and performance capability with real wastes. The relatively low density of the resin (floats in the column) can cause channelling, and increases the potential for early breakthrough problems. Also, column hydraulics may be unfavorable if mechanical integrity problems for the resin exist. The technical risk for this operation is **Moderate**.

Table 5.2.5
Technetium Removal Technical Risks

Technical Issues	Risk Rating
1. Uncertain source of commercial quantities of qualified resin.	**M**
2. Mechanical integrity of resin and possible impacts on column operation are unknown.	**M**
3. Column mass transfer kinetics and the definition of the mass transfer zone is needed to define column design.	**L**
4. Technical maturity of candidate resin is low.	**M**
5. The number of loading and elution cycles before resin disposal is required is unknown.	**L**
6. Method for monitoring column breakthrough is unknown.	**M**

5.2.6 Sulfate Removal

Sulfate removal is required for some LAW feeds in order to: 1) avoid a separate phase in the LAW melters, which can cause a number of undesirable effects in melter operation; or 2) avoid making an excessive quantity of ILAW. A regenerable ion exchange process has been proposed by BNFL; development of a suitable ion exchange resin is ongoing. The system for sulfate removal is described in Appendix B.

Sulfate removal studies with SuperLig® 655 (SL655) are ongoing. These studies include actual waste contacts to determine equilibrium distribution coefficients. Laboratory scale column studies and pilot scale column studies have not been specified, although we expect they will be conducted if the SL655 resin shows favorable Kd's. The BNFL program currently includes investigation of alternatives (to regenerable ion exchange) for sulfate removal. This work represents one part of the parallel path approach to resolving the sulfate issue.

Table 5.2.6 lists the technical issues of sulfate removal operations. The resin has not been used in commercial scale operations and is still in the development stage. The resin capacity for sulfate is very low, with breakthrough in about one column volume. The technical risk for this operation is **High**.

Table 5.2.6
Sulfate Removal Technical Risks

Technical Issues	Risk Rating
1. Suitable ion exchange resin has yet to be developed.	**H**
2. Uncertain source of commercial quantities of qualified resin.	**H**

5.2.7 Water Washing of Sludge

Water washing of Envelope D sludge is an HLW pretreatment unit operation. It is used to lower the concentration of water soluble salts in the sludge liquid, so that such salts do not impact the volume of IHLW produced. The washing of sludge is similar to the ultrafiltration concentration cycle. Water is added to the HLW ultrafiltration feed vessel and mixed with the concentrated sludge, and subsequent concentration by filtration is repeated. The HLW feed composition and the extent of waste concentration determines the number of water washes necessary.

BNFL selected this method of operation because it can be executed with the same vessels and ultrafiltration units used for the concentration step. Additional technology development is planned.

Table 5.2.7 lists the technical issues associated with this unit operation. The technology is straight forward in application. The primary concern is adequate washing to remove excess soluble materials to minimize the IHLW volume. Ionic strength should be maintained high enough that solids peptization does not occur; peptized solids could reduce the effectiveness of solid/liquid separation. The technical risk of this operation is **Low**.

Table 5.2.7
Water Washing of Sludge Technical Risks

Technical Issues	Risk Rating
1. Assure good mixing of wash liquid and sludge solids.	**L**
2. Determination of when degree of washing is sufficient to meet the goal for subsequent processing.	**L**
3. Potential peptization of solids due to excessive washing.	**L**

5.2.8 Caustic Leaching of Sludge

Caustic leaching of Envelope D sludge is an HLW pretreatment operation. Caustic leaching will be used in the flowsheet when partial dissolution of solids containing aluminum (Al), phosphate (P), and chromium (Cr) is desired to minimize the impact of these materials on the IHLW volume. The process for caustic leaching is described in Appendix B. Minimal benefit of caustic leaching is expected during Phase I operation, but substantial benefit is expected (and necessary) with the variety of sludges to be processed beyond Phase I.

BNFL selected this operation (as opposed to the alternative of acidic dissolution of sludges coupled with acid-side separation processing to remove important radionuclides) because they concluded that acid dissolution is more expensive, harder to operate, and less reliable than caustic leaching. Caustic leaching of sludge can be executed with the same vessels and ultrafiltration units used for the concentration cycle. Additional technology development activities with real waste are planned.

Table 5.2.8 lists the technical issues associated with caustic leaching of sludge. The primary issue is to establish the leach time, temperature, etc., to maximize dissolution of target materials. Solids formation/precipitation when leach solutions are cooled and/or diluted with other solutions, and the potential impact on subsequent radionuclide removal processing, present added concerns. The technical risk of this operation is **Low**.

Table 5.2.8
Caustic Leaching of Sludge Technical Risks

Technical Issues	Risk Rating
1. Optimum conditions for leaching target components need to be defined.	**L**
2. Scale-up and equipment factors in the process must be demonstrated.	**L**
3. Solids formation/precipitation could occur when the leach solutions are cooled and/or diluted with other solutions.	**M**

5.3 Immobilization and Product Certification

5.3.1 LAW Feed Preparation

The purpose of the LAW feed preparation step is to provide LAW feed for vitrification. After removal of TRU elements, Sr-90, Cs-137, Tc-99 and sulfate from the soluble portion of the tank waste, the remaining LAW is blended with glass-forming chemicals and sucrose (for redox control in the melter). The product from this step must be capable of reliably producing an acceptable LAW glass product. The technology employed is based on adaptation of that used at WVDP, where glass formers and waste are blended to prepare the HLW feed for vitrification. This process has worked well in that environment.

In general, the chosen technologies are reasonably mature and have been deployed elsewhere. However, the adaptation of these technologies to the Hanford tank environment is at an early stage. Large scale blending of concentrated solutions and glass forming materials is not common in the glass industry or existing HLW vitrification plants. Because the capacity of the LAW melter is much higher than any existing waste vitrification system, the scale of LAW feed preparation will exceed any prior experience. However, there is no question that with sufficient testing, these technologies can be successfully adapted.

Definition of the product/process control and sampling strategy is also at an early stage. It is important that the sampling and analytical needs for product acceptability and process control be established early in the program to minimize project cost and schedule risk. For both WVDP and the DWPF, sampling and analysis requirements associated with process control and product acceptance were not recognized when the facilities were being designed. As a result, the analytical facilities in particular limit the throughput for these facilities. For example, at both SRS and WVDP, the product acceptance/process control strategy required extensive characterization of the uniformity of feed within

feed blend tanks. Without a clearly defined strategy, significant risk exists that costly delays will be encountered prior to startup while requisite data is collected, and that melter (and perhaps feed system) stability problems will be encountered during operations due to the lack of uniformity of melter feed. A product/process control strategy should include detailed requirements for: 1) batch formulation rules (models), including recycle streams; 2) sampling and analyses; and 3) characterizing and ensuring feed blend uniformity. The latter will require a rather extensive development program, and it appears that significant attention is already being given to this activity. Establishing a uniform melter feed also involves accommodating recycle streams (e.g., from melter offgas treatment) and reductant additions (e.g., sucrose). These additions may affect flow properties and potential for segregation of the feed blend.

Table 5.3.1
LAW Feed Preparation Technical Risks

Technical Issue	Risk Rating
1. Sampling and analyses methods are not yet defined.	**L**
2. Recovery from off-specification feed is not yet defined.	**M**
3. Feed variability and heels management strategy needs greater definition.	**L**
4. Impact of recycle streams on feed is unclear.	**L**

Because of the extensive development activities being performed and planned by BNFL, the technical risk is **Low**.

5.3.2 LAW Vitrification

The LAW melter system converts blended waste slurry and glass formers into molten glass. The molten glass is poured into canisters where it cools to form a durable glass waste form. BNFL selected the low-temperature (1150ºC) ceramic-lined joule-heated melter because it has fewer technical risks compared to the various melter concepts available, and because similar melters have been operated successfully with HLW at WVDP, SRS, and Mol, Belgium. The LAW melter has many features in common with the HLW melter, reducing development time and cost for both. The LAW melter is based on a well-established concept. It will be challenging to achieve the desired scale-up, which is four times the glass production capacity of the DWPF HLW melter. Most potential problems appear to have been identified and are being addressed, and each component of the melter system appears adequate. An extensive program of pilot testing of the LAW melter is underway on a full-scale prototype of one section of the three-section production melter design.

The most important unresolved technical issue results from the uncertainty that sufficient sulfate can be removed in pretreatment. If the level of sulfur in the melter feed exceeds the solubility in the molten glass, a molten salt layer (primarily sulfates and chlorides) forms between the cold cap and the molten bath. This layer rapidly attacks the refractories, bubblers, and thermocouples near the melt surface. A molten salt layer could also be a safety hazard, since contact with the slurry feed could result in very rapid steam generation and liquid splattering. To avoid formation of a molten salt layer, it is necessary to

include additional reductants (e.g., charcoal) in the feed, and control the cold cap thickness to obtain decomposition of sulfate to SO_2 that escapes with the offgas. The strongly reducing condition required for decomposition of sulfates causes some metals to volatilize (e.g., Cs, Cd) or to precipitate (e.g., Pb), so it would be difficult to find a set of conditions to avoid all these problems simultaneously. Table 5.3.2 lists other key technical issues with this operation.

Table 5.3.2
LAW Vitrification Technical Risks

Technical Issues	Risk Rating
1. Molten salt layer (mainly sulfates and chlorides) may form on the melt surface.	M
2. The extent of pilot melter testing may be insufficient to ensure reliability.	L
3. Program to develop cold cap and redox control method is incomplete.	L
4. Approach to handle tank-to-tank and envelope-to-envelope waste feed variability is not yet completely defined.	L
5. Discharge riser and trough may be troublesome components and need to be characterized through long-term testing.	L

Strong glass composition research and large-scale melter testing programs are underway at GTS Duratek and Catholic University's Vitreous State Laboratory (VSL). These are well planned and integrated programs and should be continued throughout the next few years to ensure reliable operations. Large-scale testing is necessary because of the complexity of the phenomena occurring in melters, which makes it impossible to reliably predict failure modes and lifetimes of components without extended full-scale tests. Limited testing on the initial pour spout design at DWPF was an important contributor to the pouring problem at that facility. More extensive testing would likely have revealed the problem and led to its solution prior to radioactive operations.

Because of the risk that adequate sulfate removal in pretreatment may be unsuccessful, and because work on its removal is still at the research stage, the technical risk is **Moderate**.

5.3.3 ILAW Product Certification

BNFL will be required to certify that their immobilized waste form product meets the applicable product specifications. A compliance strategy for meeting product specifications is being revised, in part to accommodate recent changes in the designated size and shape of the storage container.

It appears that the process by which DOE will accept the LAW product provided by BNFL is still under negotiation. A strategy has been defined which has the intent of assuring that the ILAW product is consistent with assumptions used in the disposal Performance Assessment. Because the glass leach criteria in the contractual product specification does not directly reflect assumptions in the Performance Assessment, the potential exists for additional constraints (as yet undefined) on BNFL's glass formulations from this process. Other technical risks are summarized in Table 5.3.3.

A key technical need is for BNFL to develop an integrated compliance strategy, then begin testing of key components (such as canister filling) immediately. Another key issue is determination of the effects of recycled materials on glass formulation. If the glass formulation must be modified to accommodate recycled material, it is not clear how this will be accomplished. A working concept of a process/product control strategy will help provide solutions to these issues.

Based on the program being pursued by BNFL to ensure acceptability of the glass and waste form product, the risk is **Low**. However, an inadequate strategy could have large impacts on project schedule and cost, including costly redesign of the analytical facilities, or changes to the process equipment designs. An inadequate strategy would result if BNFL underestimates the degree of rigor required for product qualification and certification, or if the strategy is not developed until after significant facility design has occurred and costly facility changes are required for implementation.

Table 5.3.3
ILAW Product Certification Technical Risks

Technical Issue	Risk Rating
1. Strategy for ensuring product acceptability is unresolved.	**L**
2. The ability to uniformly fill the canister is not established.	**L**
3. Inclusion of recycle streams in batches may require composition modification.	**L**

5.3.4 LAW Offgas

The LAW offgas system removes contaminants from the LAW vitrification system effluents so that contamination of the human environment, both within and outside the plant, is avoided. The design of this system has recently been changed. Individual system components currently included in the design represent mature technologies, and each has been used in nuclear facilities. Essentially the same system concepts have been selected for both LAW and HLW offgas treatment, potentially reducing development time and cost. Therefore, the technical issues for the two systems are similar. Tests are underway at GTS Duratek and VSL to determine the composition of the LAW offgas streams – the starting point for design of the systems.

The principal technical issue for LAW offgas relates to the removal of volatile elements that have limited solubility in the molten glass, especially sulfur (S), chlorine (Cl) and possibly fluorine (F). Any excess of these elements in the melter feed (over the maximum amount that will dissolve in the molten glass) must be removed from the offgas system. Otherwise, their recycle to the melter could result in the formation of a molten salt layer in the melter. A method for removing S, Cl, and F from the offgas stream, and for separating them from radioactive offgas components (e.g., Cs) that can be recycled to the melter is not yet defined. Other technical risks are summarized in Table 5.3.4.

Scale-up and design modifications of the two major components of the primary offgas system (the Submerged Bed Scrubber [SBS] and the Wet Electrostatic Precipitator [WESP]), require further development. It is not clear when this is planned. Testing for corrosion, pluggage and catalyst poisoning is planned in the pilot melter at GTS Duratek. Full-scale integrated testing is needed to ensure

compatibility of components and system operability. Control and troubleshooting of this system are expected to be challenging.

Primarily because of the sulfate removal issue, the technical risk is **Moderate**.

Table 5.3.4
LAW Offgas Technical Risks

Technical Issue	Risk Rating
1. Methods by which sulfur, chlorine and fluorine will be separated from radionuclides and removed for disposal are not yet defined.	**M**
2. Scaleup of the SBS and WESP has not been demonstrated.[(a)]	**L**
3. Corrosion of offgas system components may be increased by acidic gases of sulfur, chlorine and fluorine.[(a)]	**L**
4. There is a possibility of pluggages due to salts.[(a)]	**L**
(a) These risks are common to both LAW and HLW offgas systems.	

5.3.5 HLW Feed Preparation

The HLW feed preparation step provides HLW feed for vitrification. This step blends the TRU elements, Sr-90, Cs-137, and Tc-99 (removed from the soluble portion of the tank waste) with the insoluble HLW fraction of the tank waste, and with glass-forming chemicals and sucrose (for redox control in the melter). Except for the differences in feed composition and the scale of operation, HLW feed preparation is the same as that for LAW. The discussion in section 5.3.1 applies also to HLW, as does Table 5.3.1.

Because of the extensive development activities being performed and planned by BNFL, the technical risk is **Low**.

5.3.6 HLW Vitrification

The HLW melter system converts blended waste slurry and glass formers into molten glass. The glass is poured into canisters where it cools to form a durable glass waste form. BNFL selected the low-temperature (1150ºC) ceramic-lined joule-heated melter because it has fewer technical risks compared to the various melter concepts available, and because similar melters have been operated successfully with HLW at WVDP, SRS, and Mol, Belgium. The HLW melter has many features in common with the LAW melter, reducing development time and cost for both. The HLW melter is based on a well thought-out concept. Most potential problems have been identified and are being addressed, and each individual component of the melter system appears adequate. Laboratory tests are planned in a 1/3-scale melter that lacks certain key features of the production concept.

The main technical concern is the possibility of forming noble metal and spinel solid precipitates in the melter that could block discharge risers, reduce the melting rate, and eventually perturb current distribution so severely as to shut down the melter. This is a challenging problem that has not yet been completely solved elsewhere, and is difficult to study with simulated wastes. Molten silver deposits on the melter bottom are an additional concern, since they could penetrate joints in the refractory and cause short circuiting to the shell. A development program to address the metals issue has not been designed beyond small (1/30-scale) laboratory tests. No tests are planned in either a full- or reduced-scale melter that incorporates the intended combination of sump, bubblers and delivery system to remove suspended solid noble metal deposits. Information received by the Team did not demonstrate a strategy to handle the molten silver that is expected with some of the waste feeds. More large-scale testing will be needed. Because of the complexity of interactions within melters, it is not possible to reliably predict failure modes and lifetimes of components without extended full-scale tests. Table 5.3.6 lists other key technical issues with this operation; they are essentially the same as with LAW.

Even though the metals issues are very serious, VSL has the necessary expertise and most of the necessary facilities. Thus, the overall technical risk is **Moderate**.

Table 5.3.5
HLW Vitrification Technical Risks

Technical Issues	Risk Rating
1. Noble metal and spinel sludges may accumulate in bottom of melter.	**M**
2. Molten silver may collect on the melter bottom, penetrate joints and short-circuit the melter.	**M**
3. The extent of pilot melter testing may be insufficient to ensure reliability.	**M**
4. Program to develop cold cap and redox control method is incomplete.	**L**
5. Tank-to-tank variability, and plausible feed sequences need to be considered in melter testing.	**L**
6. Discharge riser and trough may be troublesome components and need to be characterized through long-term testing.	**L**

5.3.7 IHLW Product Certification

A compliance strategy for certification by BNFL that the IHLW product meets applicable specifications is currently being revised. The Team anticipates that a strategy similar to that used at WVDP for compliance with vitrified HLW product specifications will be adopted. The contract product specifications are derived from the high-level waste repository requirements for waste acceptance (Office of Civilian Radioactive Waste Management [OCRWM]'s "Waste Acceptance System Requirements Document" [WASRD]). If past practice is followed, the detailed BNFL/ORP compliance strategy will ultimately be subjected to independent peer review, including representation from OCRWM. Such a

process could impose some risks, due to the complexity of the BNFL/ORP contractual relationship and interfaces between governmental institutions.

One major feature of the waste form product different from both WVDP and DWPF is the canister size. Until key qualification tests and analyses are completed for the larger canister specified by ORP, there is risk that changes may be required which could have significant cost impacts.

A key technical need is for BNFL to develop the compliance strategy, then begin immediately testing the key components, such as canister filling and integrated production steps (feed blending and melting). An inappropriate strategy could result in large impacts on project schedule and cost. At both SRS and WVDP, frequent skirmishes occurred over the qualification program, in part because it was developed long after facility design (and at SRS, after construction) was completed. A functioning qualification program based on a well-conceived strategy will provide valuable insights into the impacts of process changes.

Because the strategy is expected to mirror that at WVDP, the risk is **Low**.

Table 5.3.6
IHLW Product Certification Technical Risks

Technical Issues	Risk Rating
1. Strategy for ensuring product acceptability is not fully demonstrated.	**L**

5.3.8 HLW Offgas

The HLW offgas system removes contaminants from the HLW vitrification system effluents. Essentially the same system concepts have been selected for both LAW and HLW offgas treatment, potentially reducing development time and cost. The technical risks are generally the same for both systems, so the discussion of Section 5.3.4 applies also to HLW offgas treatment.

The principal technical issue specific to HLW offgas is the removal of mercury (Hg), while S, Cl, and F are not expected to be problems. The HLW feed envelope D lists an upper bound of 0.1g Hg per 100g waste oxides. Control of Hg releases will be requested for permitting. Also, mercury can induce corrosion of offgas system components, as discovered during development of the DWPF process. A method for removing Hg from the offgas stream, and for separating it from radioactive offgas components (e.g., Cs) that can be recycled to the melter is not yet defined. Table 5.3.8 lists other key technical issues with this operation.

Because the levels of S and Cl are expected to be lower in HLW, the degree of risk is **Low**.

Table 5.3.7
HLW Offgas Technical Risks

Technical Issue	Risk Rating
1. Method by which mercury will be separated from radionuclides and removed from the system in not yet defined.	M
2. Corrosion of offgas system components, especially due to mercury and halides.[(a)]	L
3. There is a possibility of pluggages due to salts.[(a)]	L
4. SCR catalyst for NO_x removal may be attacked by offgas components such as Hg.	L
(a) These risks are common to both LAW and HLW offgas systems.	

5.4 References

Eager, K.M. 1998. "Evaluation of the Environmental Simulation Program (ESP) as a Computer Simulator of Nuclear Waste Processing," HNF-3257, Fluor Daniel Hanford, Richland, Washington.

Honeyman, J. O. 1998. "Management Assessment of Tank Waste Remediation System Contractor Readiness to Proceed with Phase IB Privatization," HNF-2021, Rev. 1, Lockheed Martin Hanford Co., Richland, Washington.

Jordan, K. N. 1998. "Tank Waste Remediation System Retrieval and Disposal Mission Readiness-to-Proceed Memorandum," HNF-2019, Rev. 1, Lockheed Martin Hanford Co., Richland, Washington.

Kirkbride, R. A., et al. 1999. "Tank Waste Remediation System Operation and Utilization Plan," HNF-SD-WM-SP-012, Rev. 1, Numatec Hanford Corp., Richland, Washington.

Wojtasek, R. D. 1997. "Readiness-to-Proceed Plan for M&I Contractor Workscope in Support of TWRS Phase IB Privatization," HNF-1241, prepared by Lockheed Martin Hanford Corporation for Fluor Daniel Hanford, Inc., Richland, Washington.

6.0 Technology Development Program Requirements

In this section, technology development needs are identified for each unit operation and the needs are categorized as baseline, improvements, and alternatives. These terms are defined in this report as follows:

- Baseline – required to ensure that the baseline meets requirements and performs as intended (example: Cs-137 removal is conducted by elutable ion exchange using SuperLig® 644).

- Improvement – enhancement or incremental improvement in the baseline approach (example: using a different elutable ion exchange resin for Cs-137 removal).

- Alternative – completely different approach to performing the function or unit operation (example: Cs-137 removal is conducted by non-elutable ion exchange using CST).

Improvements and alternatives were evaluated using the criteria described in Section 4.1. Highly ranked improvements and alternatives were identified both for the high risk unit operations of the Phase I flowsheet and for application beyond Phase I. These highly ranked improvements and alternatives are discussed below. Subsequent sections describe the technology development needs and the ranking of improvements and alternatives for each unit operation.

6.1 Highly Ranked Improvements and Alternatives

The highly ranked improvements and alternatives were selected from the tables in Sections 6.2, 6.3, and 6.4. In Table 6.1.1, improvements and alternatives that could be incorporated into the Phase I project are listed in priority order. The prioritization shown in Table 6.1.1 is based on the technical risk of the subject unit operation and its overall impact on project success. For example, sulfate removal is given highest priority because of the high technical risk and system-wide significance of this issue. Although the Team rated the risk of Cs removal as moderate, we included the CST sorbent in Table 6.1.1 because we believe that a viable backup alternative must be available for this critical process step. Aggressive development programs will be required to implement these improvements and alternatives in Phase I. Technology Development Task Sheets (presented in Appendix E) outline the technology development activities required for implementation in Phase I with an estimate of the duration of each task and the total development time.

Table 6.1.2 presents a prioritized list of the highly-ranked technologies that would be best implemented beyond Phase I. We recommend these for evaluation beyond Phase I because either 1) the technology is not sufficiently mature for incorporation into ongoing design, or 2) the degree of difficulty of integrating the process into the Phase I BNFL plant, or 3) the primary benefit of the technology does not pertain to waste feeds identified for Phase I. The Technology Development Task Sheets for each technology recommended for investigation for potential use beyond Phase I are also presented in Appendix E.

Table 6.1.1
Highly Ranked Improvements and Alternatives for Phase I

Priority	Improvement / Alternative	Basis	Total Development Time
1	Sulfate accommodation in LAW - Pretreatment - Vitrification - Offgas	Technical risk of sulfate removal is high; sulfate impact must be addressed as a system-wide issue. See Section 6.3.6, 6.4.2, and 6.4.4.	2 – 3 years
2	Partial oxidation and other sorbents for Sr-90/TRU elements removal	Technical risk of Sr-90/TRU element removal is high due to recent flowsheet changes. See Section 6.3.3.	2 – 5 years
3	Enhancements to mixing in sludge retrieval operations.	Success of the PHMC feed delivery system is critical to success of the project. See Section 6.2.1.	2 – 2.5 years
4	Crystalline silicotitanate (CST) non-elutable sorbent for Cs-137 removal	Technical risk of Cs-137 removal is moderate and a backup technology for this critical step is needed. See Section 6.3.4.	1 – 2 years
5	Sequential caustic and acid leach	Life-cycle costs reduction from reduction in IHLW volume. See Section 6.3.8.	1 – 2 years

Life-cycle cost reduction is the primary driver for alternative technologies to be implemented beyond Phase I. Given the same end states, the primary ways to create significant life cycle cost savings are 1) reducing the volume of immobilized HLW (by increasing waste loading or by removing non-radioactive components like chromium that can control waste loading), and 2) increasing the capacity of the unit operations so that the mission can be completed sooner. The "Beyond Phase I" alternatives in Table 6.1.2 are a by-product of our examination of alternative technologies for the Phase I BNFL flowsheet and prescribed end states. Thus, they represent a narrowly-defined range of possible alternatives. For other possible end states, a follow on study could identify different technology development needs.

Table 6.1.2
Highly Ranked Technologies for Application Beyond Phase I

Priority	Technology	Basis for Priority	Total Development Time
1	Enhanced Cr leaching	Life-cycle costs reduction from reduction in IHLW volume	2 – 4 years
2	Higher temperature HLW melting	Reduced IHLW volume by higher waste loading	3 – 4 years
3	Combined Cs-137 and Tc-99 solvent extraction	Cost reduction from combining two unit operations	2 – 4 years
4	Chemically assisted sludge heel removal	Reduced cost and time for final retrieval	2 – 4 years
5	Acidic dissolution and separation	Life-cycle cost reduction from reduction in IHLW volume	6 – 8 years
6	Cold crucible melter	Reduced IHLW volume by higher waste loading	5 – 6 years

6.2 Waste Retrieval and Transfer Operations

6.2.1 Retrieval

The baseline technology for mobilization and retrieval of waste in the designated feed supply tanks consists of 300 hp long shaft mixer pumps (2 per tank) and an in-tank transfer pump. The mixer pumps will mobilize the waste in the five designated feed tanks and mix it to maintain solid suspension. The mixer pumps have a functional requirement for retrieval which is thought to provide enough mixing and mobilization to retrieve 90% of the waste in each of the designated feed tanks. Pumps of this capability will supply ample volume of feed to BNFL using only five tanks and retrieve enough waste so that these feed tanks can be used for subsequent operations. The transfer pump must be able to deliver waste at acceptable velocities with proper slurry properties. The baseline retrieval technology is based on extensive SRS experience and the Westinghouse Hanford Company-PNNL test series started about 10 years ago. These test series developed understandings and figures of merit for mixer pump performance in mobilizing a variety of expected waste conditions. Modeling using the TEMPEST computer code also predicts the viability of using two, 300 hp mixer pumps for mobilizing 90% of the expected wastes in the feed tanks. Further, a full-scale mixer pump test is planned as project W-151. This test will:

- demonstrate safe operations of both tanks and pumps
- provide data to estimate mobilization and cleansing effectiveness of two mixer pumps
- provide data to quantify the three-dimensional distribution of the mobilized solids and subsequent settling rates after turnoff of mixer pumps.

For the Retrieval Unit Operation, we assumed that the baseline approach (two 300 hp mixer pumps and one transfer pump) would be effective for mobilizing and mixing a substantial portion of the waste contained in the five designated feed tanks. However, the inability to predict how much waste in each tank is mobilized and retrieved has both schedule and cost impacts. Insufficient waste delivered from the designated tanks with the baseline retrieval system could result in: 1) the use of additional waste feed tanks with an infrastructure cost of $30M per tank (for capital and installation costs for two mixer pumps and transfer pumps), or 2) costly modification of the five feed tanks to deploy a third mixer pump per tank. Thus, the Team considered technology improvements to the baseline mobilization capability that could supplement the two mixer pumps per tank without extensive additional capital and installation costs. This section presents improvements in retrieval unit operations that could allow the baseline equipment to achieve enough mobilization and mixing to meet waste feed delivery requirements to BNFL using only the designated tanks. Due to the focus of this review group on Phase I activities, retrieval and mixing technologies associated with operations in SSTs beyond Phase I were not considered here.

Full execution of project W-151 is fundamental to the success of the PHMC WFDS. Without the data from this test, fully analyzed to extrapolate its applicability to the several feed baseline and contingency tanks, there is high potential for failure of the WFDS. However, project W-151 itself does not guarantee success of the mobilization and mixing systems. The test is necessary, but not sufficient for success in

Table 6.2.1.1
Technology Development Needs for Waste Mobilization and Mixing

Baseline

1. Execute PHMC Project W-151 to confirm mixer pump mobilization and retrieval performance.
2. Confirm the performance of the baseline transfer pump performance at appropriate waste transfer conditions.
3. Perform a detailed analysis of the results of Project W-151 in order to extrapolate the mobilization results on Tank AZ-101 to the other required feed tanks.
4. Design and execute tests and measurements on the flammable gas release rate in the waste of the feed tanks when 300 HP mixer pumps are used to mobilize this waste.
5. Review Russian and SRS experience and approaches to minimizing and mitigating combustible gas production during waste mobilization.
6. Conduct a detailed, state-of-the-art analysis of the overall PHMC Waste Feed Delivery System with tools capable of not only providing conventional RAM analysis, but also predictive maintenance capability.

Improvements

1. Evaluate the capability of the following retrieval technologies to supplement the baseline long-shaft mixer pumps so as to increase volume of waste retrieval from feed and contingency tanks.

   -- Fluidic Pulse Jets (AEA Technology)

   -- Pulsating Monitor (ARES, Inc.)

   -- Pulsed Air Mixer (Pulsair, Inc.)

   -- Borehole Miner (Pacific Northwest National Laboratory)

   -- Light Duty Utility Arm (LDUA) + Confined Sluicing End Effector (CSEE) (Pacific Northwest National Laboratory)

   -- Past practice sluicing

   -- FLYGT mixers (FLYGT)

Alternatives

1. Chemical retrieval of waste heel.

meeting the BNFL feed needs. A detailed analysis of project W-151 data is necessary to predict the performance of the baseline retrieval system on the other feed tanks.

The improvements rated in Table 6.2.1.2 represent an abundant, existing technology base to choose from for this application. Significant long-term investment by EM-50 (TFA) and EM-30 sites have enabled these choices. These technologies can supplement the mobilization and mixing of the baseline mixer pumps, if needed, at greatly reduced cost and time, in lieu of using additional feed tanks or adding a third 300 hp pump. Beyond Phase I, these technologies offer mobilization and mixing technologies that can replace long-shaft mixer pumps and greatly reduce the retrieval cost for the remaining Hanford tanks. These technologies (except chemical retrieval) are ready for deployment at Hanford.

All of these technologies do not perform equally well in mobilization and mixing of wastes. In addition to the ratings of Table 6.2.1.2, these technologies are grouped based on their performance capability.

Table 6.2.1.2
Evaluation of Improvements and Alternatives for Waste Mobilization and Mixing

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements – Mobilization and Mixing						
1. Pulse Jet	H	L	H	L	M	M
2. Pulsating Monitor	H	M	H	L	M	M
3. Past Practice Sluicing	H	H	M	L	L	M
4. Borehole Miner	H	L	M	L	M	M
5. LDUA + CSEE	H	M	L	L	L	L
6. Pulsed Air Mixer	H	M	H	L	M	H
7. FLYGT Mixers	H	L	H	L	M	H
Alternatives						
1. Chemical Retrieval	L	L	L	L	M	M

-- Group I: Pulsating Monitor; Pulse Jet; Borehole Miner; Past Practice Sluicing. The performance capabilities and integration issues associated with these approaches are well understood. Past Practice Sluicing has been used at Oak Ridge National Laboratory (ORNL) and Hanford, but this retrieval method creates very dilute waste streams and cannot mobilize all sludges. The Pulsating Monitor is capable of higher jet pressures and velocities than the Pulse Jet. Both have been demonstrated to be effective retrieval technologies. All these technologies integrate into the tanks easier than long-shaft mixer pumps.

-- Group II (in preference order): LDUA + CSEE; Chemical Retrieval. The LDUA + CSEE approach has been used effectively at ORNL. This technology combination is suitable for final tank cleanout, but is complex and expensive for Phase I activities. Chemical retrieval is a research effort that can be demonstrated on neutralized PUREX process waste at Krasnoyarsk-26.

-- Group III (in preference order): Pulsed Air Mixer; FLYGT mixers. Both have been demonstrated to be effective mixing technologies (Pulsed Air at ORNL; FLYGT at SRS). Integration of these mixers into a tank is understood and straight forward.

The Russians, in their review of the PHMC WFDS (ARES98-004, Waste Feed System Critical Review, SNL Contract BD-2720, January 1999), concluded that substantial amounts of combustible gases (100-150 m^3 from either Tank AN-105 or AN-104) could be released during mixer pump retrieval

operations. This release may be intensified if the mixer pump operator inadvertently turns on both 300 hp pumps at the same time at full power. The Russians predict that in this case, an explosion of the combustible gases is *very likely*. The Russian review recommends a two-phase method for degassing these feed tanks during mobilization and mixing operations to minimize the chance of such an explosion. We recommend that the PHMC consult with the Russian experts to make the most of their extensive experience and help ensure safe retrieval.

Finally, under baseline recommendations, we recommend the PHMC conduct a detailed analysis of the WFDS reliability. Penalties for feed system failure are so large ($2.5M/day) and the down times for unreliable equipment so long (due to the effect of radiological hazards on repair times) that a sophisticated, state-of-the-art analysis is needed as a basis to design a feed delivery system that will provide acceptable availability.

The Russians, in their critical review, state that "The (PHMC) Reliability, Availability, and Maintainability (RAM) document only describes relatively minor causes of possible time delays during implementation of the Waste Feed Delivery Program. However, failures and delays in the implementation of the program, resulting from other off-normal events that have not been described in the RAM document may cause more severe consequences (ARES 98-004, p 39)."

Conventional RAM analysis is necessary, but is not sufficient for system operations with such large consequences for failure. The PHMC also needs to couple the reliability modeling and prediction capability with sensor technology to develop a truly "predictive maintenance" system. Historical failure data needs to be combined with real-time sensor data from critical equipment to provide an accurate, up-to-date status of the WFDS. This will allow early detection of impending failures in advance of the actual failure, giving the system operator time to prevent system failure. The cost of implementing this Predictive Maintenance System will probably be much less than the one-day penalty for loss of feed, and result in a markedly improved overall system availability.

A detailed, systems level study of the reliability and availability of this Waste Feed Delivery System is needed that is much more sophisticated than the rather conventional RAM analysis performed to date. The PHMC should use reliability modeling software that serves as a design for a reliability tool. Key will be the development of fault trees and root cause analyses. Other key analysis needs are:

- sensitivity and uncertainty analyses
- optimal reliability allocation
- field failure data analysis
- trade-off and cost-benefit analysis
- maintenance cost analysis
- cost minimization
- space optimization.

6.2.2 Transfer

The baseline technology for underground transfer of waste slurries from candidate tanks to a feed staging tank involves installation and operation of a submerged transfer pump in each candidate tank (Table 6.2.2.1). Successful experience at various DOE sites attests to the correct selection of the baseline transfer technology for the Phase I privatization contract. There is presently no viable alternative to the use of transfer pumps and buried lines to remove waste slurries from Hanford DSTs.

Table 6.2.2.1
Technology Development Needs for Waste Transfer

Baseline

1. Conduct modeling (ESP Model) of all projected waste retrieval and transfer operations.
2. Conduct appropriate experiments with actual waste from all candidate tanks to determine waste parameters for transfer without plugging of lines.
3. Define procedures for rapidly and safely installing by passes (shunts) around plugged lines.
4. Install redundant transfer lines to minimize installation costs and costly interruptions of waste feed delivery to BNFL.
5. Establish waste transfer line specifications and practices (for example: transfer lines that withstand overpressures to allow removal of line plugs; minimize sharp turns and elevation changes in transfer lines; use low hydraulic resistance valving; employ redundant valving; evaluate short transfer line runs to optimize ability to find and bypass plugs; and regularly flush transfer lines to remove residual solids.)

Improvements

1. Ensure that the ESP Model continues to incorporate the latest system chemical equilibrium data relating to formation of solids and gels.
2. Develop and validate methods for rapidly unplugging buried lines.

Alternatives

N/A

In Section 5.1, the Team identified that the major technical risks and concerns with the baseline technology are not with transfer pumps and their operation, but with the very real possibility that buried underground transfer lines could become plugged and inoperable. Such lines may be plugged by settling of solids already in the candidate tanks, by newly-formed solids and/or gels, or by a combination thereof. Some improvements to the baseline transfer technology for preventing and dealing with plugged transfer lines are included in Table 6.2.2.1.

An evaluation of the most important improvements to the baseline transfer technology listed in Table 6.2.2.1 is given in Table 6.2.2.2. A straightforward way to accommodate line plugging is to install redundant transfer lines between appropriate tanks. It appears that the PHMC already plans to install such redundant lines; if not, the Team recommends they do so. The Team also understands that the PHMC intends to use the ESP Model to model all planned waste retrieval and transfer operations. The ESP Model is a powerful tool for predicting the formation of objectionable solids and gels. To be most effective, the ESP Model database needs to be regularly updated with relevant system equilibrium data as these data emerge from ongoing programs.

TFA-sponsored technology development programs are in progress at several laboratories and Florida International University (FIU) to study and develop workable procedures for unplugging buried radioactive waste transfer lines. PHMC engineers, of course, know of these technology development efforts; they should continue to monitor these programs and be prepared to incorporate any feasible unplugging methodology in their overall waste retrieval and transfer operations.

Table 6.2.2.2
Evaluation of Improvements and Alternatives for Waste Transfer

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Update ESP Model regularly	H	H	H	L	L	H
2. Develop and validate methods for unplugging transfer lines	L	L	M	L	M	H
Alternatives						
N/A						

6.2.3 Feed Staging

A well planned strategy for retrieval of waste from candidate Phase I tanks must be in place at the startup of waste retrieval operations. The PHMC has prepared and documented (Kirkbride et al. 1999) such a baseline feed staging plan.

Beyond the baseline staging plan, we deem it essential to formulate and document contingency feed tanks (Table 6.2.3.1). This action is necessary to be able to plan for unexpected difficulties and delays which may be encountered in retrieving wastes from one or more tanks in the original baseline retrieval sequence. We understand that appropriate discussions are underway which might allow, if necessary, modification of the Phase IB privatization contract to permit retrieval of wastes from tanks other than those specified in the present contract. Successful completion of such discussions could result in a beneficial impact upon the Phase IB feed delivery schedule.

Table 6.2.3.1
Technology Development Needs for Feed Staging

Baseline

1. Develop and document comprehensive contingency plans for waste retrieval and transfer operations to be used if the baseline tank staging order suffers either minor or major interruptions and delays.

Improvement

N/A

Alternatives

N/A

6.2.4 Feed Characterization

For the Phase I privatization contract, the PHMC is required to provide BNFL with specified amounts of four different waste types , or "envelopes." To accomplish this objective, the PHMC must:

- properly specify the tanks from which to retrieve waste, and
- characterize the retrieved wastes to verify that their composition and selected physical properties are within contract specifications.

The baseline characterization technology (Table 6.2.4.1) is to take grab samples (bottle-on-a-string) from candidate DSTs, including feed staging tanks, and analyze them for a limited number of analytes and physical properties. Technical risks identified for the baseline technology (see Section 5.1) include: 1) major uncertainties that statistically representative waste samples are taken and analyzed; 2) concerns that the suite of specific analytes to be determined does not include all those of importance to BNFL operations; and, 3) concerns that the amount of several potentially-significant long-lived minor radionuclides (e.g., Se-79, etc.) in feeds supplied to BNFL are not routinely analyzed.

Table 6.2.4.1 lists one alternative to the baseline technology. Table 6.2.4.2 evaluates the fluidic sampler alternative. The fluidic sampler (AEA Technology) includes a reverse flow diverter pump with a specially designed sampling tee installed in the discharge piping that delivers a sample of the liquid to a sampler container. The TFA is presently sponsoring technology development efforts to design, construct, and install fluidic sampler devices in tanks at both Hanford and SRS to obtain representative analytical-size samples from both static and well-mixed tanks. Related technology development work is also in progress to develop sensor and monitoring instrumentation for use in conjunction with fluidic sampling systems to determine when tank waste mixing and particle concentration have reached a steady-state condition. These technologies have shown great promise of success; the Team recommends that ORP and PHMC should seriously pursue implementation of fluidic sampler devices.

Table 6.2.4.1
Technology Development Needs for Feed Characterization

Baseline

1. Conduct extended discussions among the PHMC, ORP, and BNFL to establish the physical properties and concentrations of major analytes the PHMC will specify in each batch of feed delivered to BNFL.
2. Conduct in-depth discussions with Performance Assessment experts from the PHMC, ORP, and BNFL to establish the minor long-lived radionuclides the PHMC should analyze.

Improvements

N/A

Alternative

1. Design and deploy fluidic samplers in designated feed staging tanks to obtain representative samples from well-mixed tanks

Table 6.2.4.2
Evaluation of Improvements and Alternatives for Feed Characterization

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
N/A						
Alternatives						
1. Fluidic Samplers	H	L	H	L	L	M

6.2.5 Liquid Sampling

Large (3-10 liter) samples of liquid (with associated solids) waste from candidate feed tanks are needed to support scheduled development and testing of the baseline BNFL pretreatment and immobilization processes. The inability to obtain these large samples could jeopardize the validation of key BNFL processes and result in greater risk to plant operational startup. The acquisition of greater than liter size amounts of liquid or slurry wastes from Hanford (or SRS) DSTs has been a very difficult task. Based on these challenges, we found a very limited technology base to support this need. These needs are presented in Table 6.2.5.1.

Table 6.2.5.2 provides an evaluation of some alternative technologies for taking large liquid samples from candidate Phase I DSTs. Very likely, the most reliable and efficient way to obtain greater than liter-size samples of wastes from DSTs is to use the 9-liter sampler, specially designed by personnel at SRS. This sampler, now on the Hanford Site, has never been used because of funding difficulties which precluded completion of required on-site safety and other procedures. Because of its specific design features, the 9-liter sampler appears to be particularly suited for acquiring the large volumes of actual waste required to complete development and testing of the technology BNFL expects to deploy. The Team strongly recommends that the DOE vigorously pursue final testing and deployment of the 9-liter sampler in a Hanford DST feed tank.

A second alternative is to build, install, and operate a modification of the present AEA Technology fluidic sampler. We believe the present TFA program on fluidic samplers should be rescoped to include consideration of equipment design modifications needed to take greater than liter-size samples from well-mixed DSTs at Hanford. The time required to design, install, and test a liter-size fluidic sampler at Hanford is a concern with this alternative.

Table 6.2.5.1
Technology Development Needs for Liquid Sampling

Baseline

1. Established baseline technology for acquiring greater than liter-size samples of waste slurries from Hanford DSTs does not exist.

Improvements

N/A

Alternatives

1. Use specially-designed 9-liter sample sampler (now on site) to take required greater than liter-size samples from Hanford DSTs for scheduled BNFL tests with actual waste.
2. Install and use appropriately-modified fluidic sampler equipment to take liter-size samples of waste.
3. Adapt procedures and equipment successfully used at SRS to acquire large samples of waste from Hanford DSTs.

Personnel at SRS have successfully taken large (25 liters) samples of wastes from underground tanks at that site. Their experience, if not already embodied in the design of the 9-liter sampler discussed earlier, may provide another alternative for designing equipment which can be used to take greater than liter-size samples from Hanford DSTs.

Table 6.2.5.2
Evaluation of Improvements and Alternatives for Liquid Sampling Baseline

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
N/A						
Alternatives						
1. Deploy specially-designed 9-liter sampler presently on site	H	L	M	M	L	H
2. Design, build, and install modified fluidic large-volume samplers in selected Hanford DSTs	M	L	M	M	L	L
3. Design, utilizing offsite experi-ence, build, and deploy a new large-volume sampling device	H	L	L	L	M	L

The schedule for deploying the 9-liter sampler at Hanford is likely more commensurate with the BNFL schedule than are deployment times for the other alternatives listed in Table 6.2.5.2. A suitably designed fluidic sampler may be the optimum device for obtaining representative large volume samples from Hanford DSTs, but the development and deployment schedule for such a device may not fall in the BNFL schedule window.

6.3 Pretreatment

6.3.1 BNFL Feed Receipt and Evaporation

The technology development needs for BNFL feed receipt and evaporation are listed in Table 6.3.1.1. There are few technology development needs for this part of pretreatment processing. The most important needs under the baseline flowsheet include tests to ensure that highly exothermic reactions do not occur and solids do not form during mixing of the various solutions in the LAW feed receipt tank. Any solids that form must be characterized to determine if they will require vitrification with the HLW, possibly increasing IHLW volume. This work is already planned by BNFL. Although evaporation is a well-known process in waste management throughout the DOE complex, one problem that does occur during evaporation of waste solutions is formation of aluminosilicate solids, which crystallize in instrument and other lines. Severe plugging can result in shut down of the evaporator to remove solids. Combining caustic leach solutions containing dissolved silica with LAW solutions containing aluminum could increase the frequency of such plugging. Fewer problems are expected during Phase I than beyond Phase I, because Phase I sludges will require little caustic leaching compared to later sludges.

Table 6.3.1.1
BNFL Feed Receipt and Evaporation Technology Development Needs

Baseline
1. Laboratory scale tests of mixing different liquids in LAW receipt tank using simulants and actual waste solutions to determine potential for solids formation or exothermic reactions.
2. If solids are formed, evaluate radioisotope content to determine disposal route.
3. Laboratory scale evaporation of mixed streams to determine potential for solids formation.
Improvements
N/A
Alternatives
N/A

No improvements or alternatives to the baseline technologies are identified for this portion of the flowsheet.

6.3.2 Solid/Liquid Separation

The technology development needs important to solid/liquid separation are listed in Table 6.3.2.1. There are few technology development needs for this part of pretreatment processing. Laboratory scale

tests with some Hanford waste solutions were conducted in the past with TFA funding. The BNFL research and development program includes laboratory tests with actual wastes and simulant tests at pilot scale. Methods for removing solids from plugged filter media should be included in the BNFL test program.

One possible improvement to the baseline is listed in Table 6.3.2.2. This improvement is mainly for use during treatment of Envelope C solutions where colloidal particles containing Sr-90 and TRU elements may be present. The presence of colloids could lead to incomplete removal of these radionuclides during ultrafiltration. Methods for measurement of colloids could allow treatment of solutions to cause aggregation into larger particles prior to ultrafiltration, resulting in better removal of the radionuclides.

Table 6.3.2.2 shows two alternatives, which are most likely to be required with the TRU element precipitate only. Recent studies by BNFL show that the ferric hydroxide carrier precipitate does not filter well with crossflow ultrafiltration. The gelatinous nature of the hydroxide allows compression on the filter surface, reducing porosity and, consequently, filtration rates. Deep bed filtration, with a material which is part of the glass formulation, may work better than ultrafiltration. Deep bed filtration with sand is used by BNFL at Sellafield to clarify low-level liquid waste solutions prior to removal of Cs-137 by ion exchange. Centrifugation was effective for removing ferric hydroxide from the test solutions during initial studies by BNFL and could be used for plant operations. Centrifugation has been used for MnO_2 removal at both Hanford (REDOX plant) and SRS. Substitution of permanganate addition for iron addition, to give MnO_2 precipitate, should allow TRU element removal by ultrafiltration.

Table 6.3.2.1
Solid/Liquid Separation Technology Development Needs

Baseline

1. Lab and radioactive bench-scale demonstrations with actual waste mixtures.
2. Tests to determine the best method for removing solids from filter.

Improvements

1. Use of precoat material in ultrafiltration.
2. Develop methods for detection and quantification of colloids containing TRU elements or Sr-90.

Alternatives

1. Deep bed filtration, especially for TRU element precipitate.
2. Centrifugation, especially for TRU element precipitate.

Table 6.3.2.2
Evaluation of Improvements and Alternatives for Solid/Liquid Separation

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Colloid measurement	M	M	H	L	L	H
Alternatives						
1. Centrifugation of TRU element precipitate	H	H	M	L	L	M
2. Deep bed filtration of TRU element precipitate	H	M	M	L	L	M

6.3.3 Sr-90/TRU Element Removal

Strontium-90 and TRU elements are present in some of the tank waste solutions in higher-than-usual concentrations because of the presence of organic complexants. In order to meet the ILAW specifications, these radionuclides must be removed from the liquid. The baseline process for these few tank waste solutions involves ultrafiltration following the addition of chemicals to "load" or oxidize the complexants and remove the Sr-90 by isotopic exchange/carrier precipitation and the TRU elements by carrier precipitation. Extreme difficulties encountered in ultrafiltration of the initially-selected TRU element carrier precipitant (ferric hydroxide) resulted in selection of an alternative approach. This revised baseline approach involves the addition of permanganate, which not only results in the formation of a more easily-separated carrier precipitate (manganese dioxide), but also apparently destroys some of the organic complexants responsible for keeping materials in solution.

The technology development areas of importance here are given in Table 6.3.3.1. The baseline activities are centered on the permanganate addition approach. Laboratory scale precipitation and ultrafiltration studies, as well as the bench-scale demonstration, should emphasize work with real wastes to be processed, because of the extreme difficulty of preparing good simulants of those wastes. The currently planned $SrCO_3$ precipitate may partially redissolve when solids are washed to dilute the concentration of salts in the liquid associated with the solids; the impact of this redissolution on the process DF must be determined.

The current baseline approach of permanganate addition is very promising, and should be pursed vigorously; we believe that BNFL is doing this. However, because of the immature and poorly understood nature of this technology, it is recommended that BNFL also pursue investigation of some possible improvements and alternatives.

Table 6.3.3.1
Sr-90/TRU Element Removal Technology Development Needs

Baseline
1. Laboratory scale optimization studies of the permanganate (plus Sr) addition approach, emphasizing DF, precipitate filterability, and redissolution on washing.
2. Radioactive bench-scale verification tests.
Improvements
1. Materials other than permanganate for partial oxidation of organic complexants.
Alternatives
1. Use strong TRU element sorbents to remove TRU elements from untreated complexant solutions.
2. Use TRU element sorbents to remove TRU elements from complexant solutions that have undergone partial oxidation.
3. Use chelating polymer with reverse osmosis filtration for TRU element removal.
4. Complete oxidation of organic complexants, to give Sr-90 and TRU element precipitation.

Investigation of materials other than permanganate for partial oxidation of organic complexants might provide improvements over the baseline approach, and perhaps more importantly, might provide insight into the mechanism by which the permanganate approach is effective. An alternative approach to the baseline is to remove TRU elements from the complexant solutions using sorption processes; such sorbents must be strong enough to overcome the action of the complexants. A very strong TRU element sorbent might remove the TRU elements from untreated complexant solutions. A less-strong TRU element sorbent (e.g., sodium titanate, as is used at SRS) might suffice, following partial oxidation of some organic complexants. The use of chelating polymers with reverse osmosis filtration for TRU element removal is somewhat similar to the use of sorbents; the required strength of the polymer would depend on whether the organic complexants have been partially oxidized. The alternative approach of complete destruction of organic complexants was investigated quite extensively several years ago, but not from the standpoints of DF and solids filterability.

The Team's evaluation of these potential improvements and alternatives are summarized in Table 6.3.3.2.

Table 6.3.3.2
Evaluation of Improvements and Alternatives for Sr-90/TRU Element Removal

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reduction		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Partial oxidation; oxidants other than permanganate	L	L	H	L	L	H
Alternatives						
1. Strong TRU element sorbents	L	L	M	L	L	M
2. Strong TRU element sorbent after partial oxidation	M	L	H	L	L	H
3. Chelating polymer with reverse osmosis	L	L	M	L	L	L
4. Complete oxidation of complexants	M	M	L	L	L	L

6.3.4 Cesium Removal

Cesium-137 present in tank waste solutions must be removed from LAW feed for the ILAW to comply with the Nuclear Regulatory Commission's incidental waste classification requirements. The baseline unit operation to accomplish this separation is elutable ion exchange. The resin currently favored is SL644.

The technology development areas of importance here are given in Table 6.3.4.1. Baseline activities should focus on understanding and remediation of the shrinkage and swelling behavior of the resin. Tests should be conducted to determine if there are any problems with mechanical stability of the resin. These physical properties impact operational issues of column hydraulics and resin transport. The mass transfer characteristics of the resin should be well defined through pilot studies with simulants to permit appropriate column design and operation. Column cycle studies should be performed with real wastes to demonstrate that design specifications can be achieved and to evaluate the life cycle costs. The extent of radiolytic hydrogen generation should be determined under process conditions. Column designs, verified by experiments, should be implemented to mitigate possible safety problems during operation and loss of column efficiency due to fluid channeling or resin pore blockage. Thermal effects on K_ds should be determined over worst case scenarios of temperature excursions to determine whether reduced column loading and earlier breakthrough of cesium would prevent attainment of optimum column performance. The potential impact of chemical and radiolytic instabilities on resin performance characteristics and subsequent process steps (e.g., Tc removal) should be determined. The BNFL technology development program appears to include most of these activities.

A technology improvement would be to consider alternative elutable resins, should any exist with characteristics superior to SL644. The Team's evaluation of this improvement and the three alternatives are shown in Table 6.3.4.2.

Table 6.3.4.1
Cs-137 Removal Technology Development Needs

Baseline

1. The shrinkage and swelling problem of the resins must be understood and remediated if possible.
2. The mechanical integrity of the resin must be determined.
3. Mass transfer characteristics of the resin must be well defined through pilot studies with simulants to permit appropriate column design and column operation.
4. Column cycle studies must be performed with real wastes.
5. Design studies must be made to mitigate the problems due to H_2 generation, safety, and loss of column efficiency due to channeling or resin pore blockage (new task).
6. Thermal effects on K_ds must be determined over worst case scenarios of temperature excursions.
7. The potential impact of chemical and radiolytic instabilities on resin efficiency and subsequent process steps (e.g., Tc-99 removal) should be determined.

Improvements

1. Alternative elutable resins should be considered.

Alternatives

1. CST non-elutable ion exchange.
2. Combined Cs-137 and Tc-99 solvent extraction.
3. Solvent extraction of Cs-137 with calixarene-crown ether extractant.

The highest ranked alternative for Cs-137 removal employs non-elutable CST as the ion exchange material; this is the backup of choice selected by BNFL. This material appeared to perform very well in an earlier TFA funded program with real Hanford waste, and has been used to successfully treat tens of thousands of gallons of waste at the Oak Ridge Reservation. The down-select process in progress at the SRS to select a cesium separation process for waste supernate solutions includes a major technology development program on CST ion exchange. Studies include: 1) evaluation of mechanical properties and transport characteristics of CST; 2) H_2 generation studies and the impact on safety issues and column efficiency due to channeling and sorbent pore blockage; 3) elevated temperature effects on lowering K_ds and deleterious chemical changes of the CST; and 4) Cs breakthrough experiments with real wastes. Substantial progress has been made on column modeling for performance and operation analysis.

Further technology development needs for application of this alternative at Hanford would include:

- laboratory scale breakthrough studies with a wide variety of real wastes

- pilot scale studies with simulated wastes to determine column design issues (temperature control, confirm expected mass transfer performance, transfer of solids into and out of the columns)

- chemical stability studies of CST with real wastes

- determine maximum titanium oxide loading for acceptable glass to minimize IHLW volume.

Two alternative approaches described for Cs-137 removal involve solvent extraction operations instead of the baseline process of ion exchange. The area of Cs-137 removal by solvent extraction is one in which great progress has been made in recent years. Progress on Cs-137 removal alone (without Tc-99) was especially significant during 1998. At that time, work funded under EM-50's Efficient Separations and Processing Crosscut Program and Environmental Management Science Program was expanded by SRS funding, resulting in solvent extraction as a close contender to ion exchange in the down-selection process for the two approaches to be carried forward for possible application at SRS.

Table 6.3.4.2
Evaluation of Improvements and Alternatives for Cs-137 Removal

	Maturity of Technology		**Ability to Integrate**	**Life Cycle Cost Reductions**		**Maintain Schedule**
	Nuclear Industry	**Hanford**		**Phase I**	**Beyond Phase I**	
Improvements						
1. Alternative elutable resin	H	M	H	L	L	H
Alternatives						
1. CST non-elutable sorbent	H	M	M	L	L	H
2. Combined Cs-137 and Tc-99 solvent extraction	L	L	M	M	M	L
3. Cs solvent extraction	M	L	M	L	L	L

Development work on this alkaline-side Cs-137 solvent extraction process has continued, and some of the problems that existed at the time of the SRS down-selection process have since been resolved. Development of Cs plus Tc-99 co-extraction has been curtailed by the emphasis on the Cs-137-only approach for application at SRS, but co-extraction and stripping of these two elements has been demonstrated in batch tests on water washes of Hanford sludge.

The removal of Tc-99 at the same time as Cs-137 appears to offer a substantial benefit in overall process simplicity. The Team recommends work on co-extraction of Cs-137 and Tc-99.

The technology development needs for the solvent extraction approach involve study of:

- batch tests with a wider variety of real wastes
- continuous countercurrent testing of flowsheets, first with simulants, then with real wastes
- chemical and radiolytic stability of the solvent - methods of solvent clean-up
- extended operation with real waste and full recycle of solvent.

Both of these alternatives should have a high priority for funding. Execution of the CST non-elutable ion exchange technology development studies would permit a smooth transition to this alternative and minimize schedule delays. The combined Cs-137 and Tc-99 solvent extraction technology development studies would continue the development of this promising alternative and provide a strategic backup approach for the removal of Cs-137 and Tc-99.

The tetraphenylboron (TPB) cesium removal process under evaluation in the SRS down-select study was not considered to be a suitable alternative. TPB did not meet the Team's screening criteria for minimization of safety and environmental risks. Also, the high potassium levels in Hanford waste would require substantially more TPB due to co-precipitation of KTPB with CsTPB, and would have an adverse impact on IHLW volume and life cycle costs.

6.3.5 Technetium Removal

Technetium-99 present as pertechnetate in tank waste solutions must be removed from LAW feed so that the ILAW complies with performance requirements. The baseline unit operation to accomplish this separation is elutable ion exchange. The resin currently favored is SL639.

The technology development areas of importance here are given in Table 6.3.5.1. The mechanical integrity of the resin should be determined, as this physical property impacts the operational issues of column hydraulics and resin transport. The potential impact of chemical instabilities on resin performance characteristics should be determined. Mass transfer characteristics of the resin should be well defined through pilot studies with simulants to permit appropriate column design and operation. Column cycle studies should be performed with real wastes to demonstrate that design specifications can be achieved and to evaluate life cycle costs. Development of an on-line Tc-99 monitor should be pursued to permit effective control and operation of the columns. The BNFL program includes most of the baseline technology development areas.

A technology development improvement would be to consider alternative elutable resins with comparable or superior characteristics to SL639. The use of a liquid fluidized bed contactor or continuous stirred tank slurry contactor may be more effective than column operation if the kinetics of adsorption are too slow.

The Team's evaluation of the improvements and three alternatives are shown in Table 6.3.5.2.

Table 6.3.5.1
Tc-99 Removal Technology Development Needs

Baseline

1. The mechanical and chemical integrity of the resin should be determined.
2. Mass transfer characteristics of resin should be well defined through appropriate studies with simulated supernates to permit appropriate column design and column operation.
3. Column cycle studies should be performed with real wastes.
4. Develop a real time Tc-99 monitor for column operation

Improvements

1. Other elutable resins should be considered.
2. Investigate the use of liquid fluidized bed or continuous stirred tank contactor instead of column.

Alternatives

1. Solvent extraction in combination with Cs-137 extraction.
2. A precipitation process based on sulfide as a reducing agent to form Tc_2S_7.
3. Electrochemical reduction (beyond Phase I).
4. Aqueous biphasic extraction (beyond Phase I).

Table 6.3.5.2
Evaluation of Improvements and Alternatives for Technetium Removal

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Alternative elutable resin	M	M	H	L	L	H
2. Fluidized bed / continuous stirred tank contactor	M	L	M	L	L	M
Alternatives						
1. Combined Cs-137 and Tc-99 solvent extraction	L	L	H	M	M	L
2. Sulfide precipitation	L	L	M	L	L	M
3. Electrochemical reduction	L	L	M[(a)]	L	L	L
4. Aqueous biphasic extraction	L	L	L[(a)]	L	L	L

(a) For Beyond Phase I alternatives, this rating refers to the ability to retrofit Phase I plant with this alternative for beyond phase I work.

The alternative to remove Tc-99 by sulfide precipitation was demonstrated using sodium sulfide at Savannah River Technology Center in 1984 to give 95% yield at pH 6-7. Also, a fourfold reduction in Tc-99 concentration was observed with a composite from several tanks at Hanford in 1994. These results indicate promising potential for this removal technology; sufficient merit exists to explore this alternative as a backup to ion exchange.

Technology development needs for application of this alternative include:

- scoping studies with representative real waste to determine optimal range of sodium sulfide: Tc-99 ratios at expected pH and temperatures on decontamination factors

- bench-scale studies with simulants to determine contact times needed for adequate precipitation and DFs

- pilot-scale studies with simulants to determine suitable contractor geometry and mixing requirements, demonstrate contact times for adequate DFs, and demonstrate precipitate separations, using ultrafiltration (or other suitable solids-removal)

- bench-scale studies with real wastes to demonstrate attainment of DFs and solids separation with ultrafiltration.

The alternative approach of removing Tc-99 by solvent extraction along with Cs-137 was discussed in the previous section. Technology development needs for this approach were also listed there and will not be repeated here.

6.3.6 Sulfate Removal

Sulfate must be removed from some of the waste feeds in Phase I to minimize the volume of ILAW. Although the required DF is low (about 2), the ion exchange process chosen as the baseline technology has a high risk of failing to meet the DF in a cost effective manner. The technology development needs considered to be mandatory for sulfate removal in pretreatment are listed in Table 6.3.6.1. Methods of addressing problems with sulfate are largely unknown for the entire system at this time. Although BNFL would prefer to remove sulfate during pretreatment, sulfate removal during vitrification and development of methods to achieve higher sulfate limits in the glass are also being studied. The present baseline pretreatment process for sulfate removal is by ion exchange with a resin that is still under development. Thus, the work is in the early stages of basic research. Resins tested thus far showed little capacity for removing sulfate from these highly salted waste solutions. The first baseline technology development need is an ion exchange resin with sufficient capacity to be functional in the process. The resin must be tested in laboratory scale tests with simulants and actual waste. Other technology development needs are similar to those described for Cs-137 and Tc-99 resins in the two previous sections, 6.3.4 and 6.3.5. The BNFL program includes all the technology development needs identified here.

Table 6.3.6.1
Sulfate Removal Technology Development Needs

Baseline
1. Laboratory scale tests with simulants and actual waste to attempt to develop a workable process with existing resin.
2. If/when a suitable resin is found, complete pertinent tests as outlined for Cs-137 and Tc-99.
3. Pilot-scale tests with simulants.
Improvements
1. Improve ion exchange resin capacity or find another resin with higher capacity and more selectivity.
Alternatives
1. Selective crystallization/precipitation of sodium or alkaline earth salts.
2. Handle sulfate in vitrification.
3. Blend with lower sulfate wastes to reduce effect of sulfate on glass volumes.

The only improvement to the baseline would be to develop a resin with greater selectivity and capacity for sulfate ions. Three alternatives to sulfate removal by ion exchange are listed in Table 6.3.6.1. Only one of the alternatives is a pretreatment process: selective crystallization or precipitation of sodium or alkaline earth salts. Two methods, freeze crystallization or evaporation to increase the overall sodium concentration, can precipitate sodium sulfate. Addition of Ca or Sr solutions with or without evaporation should precipitate sufficient sulfate. Carbonates, phosphates, and oxalates can precipitate at the same time. The other alternatives are to handle sulfate removal in vitrification or to blend high sulfate waste with low sulfate waste so the ILAW volume is not affected. An alternative not evaluated here is grouting the high sulfate wastes after pretreatment. This alternative would be a change in end state, which excludes it from consideration here.

Studies of various commercial anion exchange resins and research and development to find new, more selective, resins as an improvement could be pursued. Technology development activities could take 2-4 years and have a significant impact on the schedule for Phase I.

From the evaluation of alternatives, crystallization/precipitation was selected as the best alternative for pretreatment. Evaporation alone or partial evaporation and addition of Ca or Sr solutions to precipitate sulfate should also be investigated. Technology development needs are:

- initial testing on laboratory scale with simulants to determine which approach to take
- laboratory and pilot scale tests with actual waste including ultrafiltration to separate the solids
- washing of the solids to remove radioactivity
- characterization of solids to ensure they can be disposed through the effluent treatment facility.

Table 6.3.6.2
Evaluation of Improvements and Alternatives For Sulfate Removal

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Improved resin capacity/ selectivity	L	L	H	L	L	L
Alternatives						
1. Blending with other wastes	H	H	M	M	L	M
2. Selective precipitation/ crystallization of sulfate salts	L	L	H	L	L	M
3. Handle in vitrification	(a)					
(a) See LAW vitrification Table 6.4.2.1 for evaluation						

With sufficient resources, the work can be done quickly so that the schedule for Phase I would not be affected. BNFL is already funding work on alternative pretreatment processes for sulfate, which include evaporation studies and addition of Ca and Sr. The Team recommends that this work be emphasized. Other BNFL studies have evaluated dialysis, electrodialysis, reverse osmosis, and sulfate specific organic precipitants. Evaporation and addition of Sr solutions gave the most promising results.

6.3.7 Water Washing of Sludge

The purpose of water washing of sludge is to lower the concentration of water soluble salts in the liquid associated with the sludge so that such salts do not impact the volume of IHLW produced during vitrification. The wash solutions will be combined with other solutions for processing in the LAW pretreatment system.

The technology development areas of importance to water washing are listed in Table 6.3.7.1. Because of the simplicity of this operation, only one baseline technology development need was identified, and no improvements or alternatives were identified.

The need for a monitor to measure the solution concentration or ionic strength arises from the fact that washing to too low a salt concentration can lead to peptization of sludge solids, which could result in difficulties in ultrafiltration in the subsequent sludge concentration step. Measurement of the solution salt concentration/ionic strength will facilitate washing to the proper extent to avoid the peptization problem. Evaluation of some possible monitoring approaches has been included in a previous TFA-funded program, but no further work in this area is currently planned. BNFL has no known plans to develop a monitor.

Table 6.3.7.1
Water Washing of Sludge Technology Development Needs

Baseline
1. Develop a monitor to indicate solution concentration/ionic strength. (New task)
Improvements
N/A
Alternatives
N/A

6.3.8 Caustic Leaching of Sludge

The purpose of caustic leaching of HLW sludge is to dissolve portions of the contained Al, Cr, and phosphate so that the resultant vitrified IHLW volume will be decreased. The leach solutions, and subsequent water wash solutions, will be combined with other solutions in the LAW pretreatment system. Because the sludges to be processed in Phase I contain low concentrations of Cr and phosphate, the benefit of leaching these sludges will be markedly less than the benefit expected to result from leaching many of the SST sludges that will be processed in activities beyond Phase I.

The technology development areas of importance to caustic leaching are listed in Table 6.3.8.1. The baseline needs include: 1) determination of the conditions that give the "best" (relative to IHLW and ILAW disposal costs and to plant operating costs) leach conditions to be used for each type of sludge; and 2) development of an adequate understanding of how to avoid, or deal with, precipitate formation during leaching and when the solutions are cooled and/or mixed with other solutions.

Table 6.3.8.1
Caustic Leaching of Sludge Technology Development Needs

Baseline
1. Laboratory and pilot-scale testing with the pertinent sludges.
2. Solution stability studies to define conditions that avoid excessive solids formation and/or provide methods of handling such solids.
Improvements
1. Test acidic leaching of caustic-leached sludges to determine if additional IHLW volume reduction could be achieved.
Alternatives
1. Test oxidative methods to enhance leaching/dissolution of chromium, without dissolving excessive amounts of TRU elements. (Beyond Phase I)
2. Test acidic dissolution of sludges coupled with acid-side separation processing to remove radionuclides from the dissolved sludge solution. (Beyond Phase I)

Studies in both of these baseline areas have been supported in the past by TFA, but no further work in these areas is currently planned. Many of the sludges tested so far have shown markedly different rates and extents of leaching of the key components. BNFL is very cognizant of this precipitate-avoidance work, and is supporting similar work of its own.

The technology development need listed as an improvement is investigation of the possible use of acidic leaching, following caustic leaching, for the removal of non-caustic-leachable components such as iron and zirconium. It is of prime importance to dissolve the desired components without dissolving too much of the radionuclides contained in the sludges. No work has been done in this area.

Two technology development areas are included as alternatives. The first of these, enhanced leaching of Cr, could be very important in reducing the volume of IHLW in activities beyond Phase I, but is not important to Phase I activities because of the low Cr content of sludges to be processed in Phase I. The second of these alternatives could decrease the volume of IHLW by perhaps a factor of ten. This approach is to dissolve the sludge and treat the resulting solution to separate the necessary radionuclides from the other sludge components by solvent extraction and/or ion exchange methods. The higher pretreatment costs of such an approach would presumably be more than offset by lower HLW immobilization and disposal costs, to give a substantial life-cycle cost reduction. Promising advances in acid-side separation process have been made recently in EM-50 studies related to processing of waste at Idaho National Engineering and Environmental Laboratory (INEEL). For example, in a recent test with actual acidic tank waste, successful recovery of TRU elements, Sr-90, and Cs-137 was achieved in a single solvent extraction process. Successful development of such a process would provide substantial flowsheet simplification, and consequent cost reduction, compared to previously proposed flowsheets.

The Team's evaluations of the improvements and alternatives are summarized in Table 6.3.8.2.

Table 6.3.8.2
Evaluation of Improvements and Alternatives for Caustic Leaching

	Maturity of Technology		**Ability to Integrate**	**Life Cycle Cost Reductions**		**Maintain Schedule**
	Nuclear Industry	**Hanford**		**Phase I**	**Beyond Phase I**	
Improvements						
1. Sequential caustic and acidic leaching	L	L	M	M	M	H
Alternatives						
1. Enhanced chromium leaching	L	L	H[(a)]	N/A	H	N/A
2. Acidic dissolution and separations	L	L	L[(a)]	N/A	H	N/A

(a) For beyond Phase I alternatives, this rating refers to the ability to retrofit Phase I plant with this alternative for beyond Phase I work.

Technology development in the area of enhanced Cr leaching is desirable at this time because of the potentially extreme importance of Cr leaching in the activities to be conducted beyond Phase I. Of special importance would be testing of promising methods on real, high-Cr sludge samples as they become available in tank waste characterization activities. Such testing should include:

- small scale tests of Cr leaching kinetics using promising oxidants identified in earlier TFA-funded work, with various solution compositions and volume ratios, and at various temperatures
- measurement of radionuclide dissolution as well as Cr dissolution
- testing of the most promising conditions on the pilot-scale.

The work recommended for this improvement to the baseline should have no impact on the BNFL Phase I schedule.

6.4 Immobilization and Product Certification

6.4.1 LAW Feed Preparation

This operation involves the preparation of feed for the glass melter by blending evaporated LAW waste solutions with dry glass former materials and recycle streams (especially from offgas). Blending will need to be performed at a scale larger than most prior experience to support producing the planned 10 MT/day of glass per melter. Blended feed must be compositionally consistent and pumpable into the melter in a predictable manner. Target glass compositions of the feed blends will be selected from suitable formulations developed under the LAW Product Certification function (see Section 6.4.3). The process will need to be sufficiently adaptable to accommodate variations in waste feed compositions as different source tanks are retrieved.

The baseline items identified in the Table 6.4.1.1 are considered crucial for the success of the program, and most appear to be included in BNFL's program. The stability of melter operations, and the quality of the product, will depend on the ability of the feed system to deliver a uniform melter feed of the expected composition. Extensive characterization of feed in the blending vessels will be necessary to ensure that the equipment will reliably provide uniform feed over the range of conditions expected during Phase I. Design of the analytical facilities cannot proceed until sampling and analysis requirements are identified, and methods and equipment are specified.

It is almost a certainty that some batches of feed will be outside of specifications. A plan for dealing with this is needed, so that necessary tankage and process lines can be identified. Similarly, the feed to BNFL is likely to be much more variable than indicated by the LAW Envelope definitions. That is, the ratios of major waste components to each other will vary from tank to tank, and require frequent adjustments in batch makeup. The feed system must be able to tolerate likely transitions among different types of feed. Stability of melter operations as feed compositions are transitioned will require attention.

Blending of waste feed with glass formers produces a slurry which can have a range of properties, depending on solids concentration, particle characteristics, and solid-liquid interface chemistry. Waste feeds from different tanks may show different rheological properties. It is important that adequate characterization of blending behaviors and properties be performed, especially if the waste feed is to be evaporated prior to blending.

It is important that BNFL have a facility in which it can subject actual waste samples to the process in an integrated manner. This facility would be used whenever a major batch change occurred to check for any surprises, and to troubleshoot chemical problems arising during production. The High Level Cells at SRS provides this capability to the DWPF; its value cannot be overemphasized.

Table 6.4.1.1
LAW Feed Preparation Technology Development Needs

Baseline

1. Determine the homogeneity of melter feed through full-scale testing with simulant feeds.
2. Determine flow characteristics of all powdered raw materials, and of their blended mixtures.
3. Complete definition of sampling and analysis requirements, identify instrumentation, and develop analytical methods.
4. Define and test methods for dealing with out-of-specification feed.
5. Ensure that the process control scheme for the feed preparation area can tolerate realistic batch-to-batch variability, including heels and recycled material.
6. Ensure that the LAW feed evaporator will not foul (or that there is an adequate recovery methodology) through large-scale testing.
7. Use glass industry experience to specify dry chemical storage, blending, and feed systems.

Improvements

1. Establish the capability to carry out bench-scale integrated testing with actual waste whenever there is a major change in waste composition.
2. Incorporate evaporation capability into melter feed blending tanks.

Alternatives

N/A

An engineering study is recommended for incorporating evaporator capacity into feed blending tanks (similar to DWPF). The water content of the feed system may vary significantly from batch to batch, causing the evaporative load on the melter to vary, affecting both glass production rate and offgas pressure control. Batch blending and transfer characteristics may also be expected to vary with water content.

Table 6.4.1.2
Evaluation of Improvements and Alternatives for LAW Feed Preparation

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Establish bench scale capability for radioactive process testing	H	H	H	M	M	H
2. Incorporate evaporator capability into melter feed blending tanks	H	M	M	L	L	M
Alternatives						
N/A						

6.4.2 LAW Vitrification

The baseline technology consists of three identical joule-heated melters with nickel alloy (Inconel 690) plate electrodes on the walls, with chrome refractory linings, and a flat bottom without electrodes or drains. Nickel alloy bubblers are used to augment natural convection flows in the molten glass, enhancing the melting rate at the bottom surface of the cold cap. An airlift pumps glass from the bottom up through a channel in the refractory, allowing it to overflow onto an inclined trough, from which it drains into the container. The melter concept is based on designs used successfully for HLW vitrification at other DOE and foreign sites. The pilot melting program underway at GTS Duratek appears to be well planned and adequate to ensure success at Hanford. A parallel glass chemistry program at the VSL (BNFL's vitrification partners) also appears to be solid and valuable.

The baseline items identified in Table 6.4.2.1 are considered to be crucial for the success of the program. The possibility of forming a molten salt layer on top of the molten glass has both operational and safety ramifications, as described in Section 5.3.2. The research effort currently underway at VSL is essential to identify glass compositions that maximize sulfate and chloride solubility in the melt and redox conditions that maximize the decomposition of sulfate in the cold cap. A parallel major development effort is needed to learn to control redox and sulfate decomposition by batch additions of reductants and by operational control of the cold cap thickness and structure. Task Sheet E.2 gives a more detailed list of recommended actions related to the sulfate problem.

The LAW large scale pilot melter should be operated long enough to clearly establish the likely failure modes and lifetimes of key melter components. If pilot testing is inadequate, there will be a significant risk of premature failure of production melters. BNFL's present plans for pilot testing are excellent and will probably need to be extended. Realistic variations in feed composition should be explored, since it is unlikely that BNFL will receive any feed that will *exactly* match any of the feed

envelopes. The ability of the large-scale system, particularly the process/product control strategy, to tolerate swings in composition, interactions among different feed types (new batch added to a process heel of a previous batch), and recycle streams, must be demonstrated before starting production. BNFL's program also includes testing of melter materials. This is important to understand failure modes and to extend melter lifetimes.

Table 6.4.2.1
LAW Vitrification Technology Development Needs

Baseline

1. Find glass compositions that maximize solubility of salts (sulfates, chlorides) in LAW melts.
2. Determine operating conditions and reductants for optimum decomposition of sulfates with minimum volatilization or precipitation of other components.
3. Ensure that the process control strategy for the melter can tolerate realistic batch-to-batch variability, including heels and recycled material.[(a)]
4. Determine suitable bubbler locations for design, and operating parameters for production.[(a)]
5. Test resistance of melter materials of construction to corrosion by LAW glasses, and by other possible molten phases (e.g., sulfates and chlorides).
6. Refine melter design by determining failure modes and lifetimes through extended operation of pilot melters.[(a)]
7. Develop a strategy of continuous improvement of melter design, based on continuing pilot testing and careful examination of failed melters, to reduce production costs.[(a)]

Improvements

1. Evaluate continuous use of plenum heaters to increase glass throughput.
2. Develop "tools" to recover from melter component failures (e.g., airlift plugging).

Alternatives

N/A

(a) Comment applies to both LAW and HLW melters.

A strategy of continuous improvement of melter design could significantly reduce costs and boost production rates. Destructive examination of failed and heavily-used melters (such as the M-Area melter at SRS) would be an important complement to ongoing pilot tests of new design and operational ideas.

Two improvements to the baseline are recommended: 1) the use of plenum heaters to increase glass throughput, and 2) development of methods and equipment to recover from system failures.

Continuous use of plenum heaters could enhance glass production rates. SRS experience suggests that plenum heaters can double the glass production rate. The DWPF has had excellent service from Inconel 690 resistance heaters in the melter plenum (no failures). A design study is suggested to examine the cost-benefit of their continuous use, and to examine whether remote replacement of plenum heaters is truly needed.

The present vitrification development program is focused on refining the design of the equipment, and on gathering basic data for design from long-term melter testing. This extended testing also offers opportunities to develop and test workarounds for failures of various components (e.g., plugging of the airlift for glass pouring). We recommend formal determination of possible failure modes early in the design phase (shortly after the two 45-day runs planned in 1999), leading to definition of failure recovery methods. These should then be incorporated in the melter design and large-scale testing.

The Team's evaluation of the merits of these testing ideas is shown in Table 6.4.2.2. Although the financial impacts of the recommended improvements are modest, the cost/benefit ratios are low enough to make them attractive.

Two alternatives were considered but are not recommended: 1) other concepts such as high temperature joule-heated or induction-heated melters, and 2) incorporation of a mechanical means for removal of molten salt from the melter. The current LAW melter design is well-founded, based solidly on global experience with HLW melters that have Inconel 690 electrodes and high-chrome refractories. The extensive work done during the Westinghouse Hanford LAW melter vendor evaluation program in 1994 revealed several melter concepts which appeared attractive, but none is as simple and robust as the present design features, which are essential for reliable long-term operation. The Team sees no reason at this point for BNFL to re-examine the melter design. It is more likely that ILAW volumes and total project costs can be reduced by more attention to separation of waste loading-limiting components in pretreatment than by operation of high temperature melters. Similarly, incorporation of a mechanical method for molten salt removal would be difficult, and probably misguided - the resources used would be better expended on determining methods to prevent the molten salt layer.

Table 6.4.2.2
Evaluation of Improvements and Alternatives for LAW Vitrification

	Maturity of Technology		**Ability to Integrate**	**Life Cycle Cost Reductions**		**Maintain Schedule**
	Nuclear Industry	**Hanford**		**Phase I**	**Beyond Phase I**	
Improvements						
1. Use plenum heaters to increase glass throughput.	H	L	M	L	M	H
2. Develop methods and equipment to recover from component failures.	L	L	H	L	L	H
Alternatives						
N/A						

6.4.3 ILAW Product Certification

Product certification by BNFL involves establishing all necessary information to assure that the ILAW product meets applicable specifications. The focus in this area is on definition of a detailed strategy for compliance with product specification requirements. The strategy must include essential process/product control features, analytical sampling requirements and necessary qualification/testing activities. Establishing LAW glass formulation ranges with suitable properties and waste loading is a key part of this function. Both formulations and product control criteria are critical inputs to what must be accomplished under the LAW Feed Preparation and Vitrification operations. Determination of the specified characteristics of the glass-filled metal canister, the final waste form, must be accomplished through either qualification testing or acceptance testing on production canisters.

The baseline items in Table 6.4.3.1 are considered crucial for the success of the project. It is of paramount importance that BNFL develop a strategy for ensuring product acceptability as soon as possible. Both DWPF and WVDP experience shows that if development of this strategy significantly lags behind facility design, the risk of cost increases and unexpected delays is greatly increased. Early development of the qualification program which will demonstrate the ability to comply with product acceptability requirements is also important because it will establish many of the baseline requirements for facility startup testing. As part of this program, BNFL must demonstrate its ability to reliably fill, seal, decontaminate and transport the large LAW canisters. While efforts are planned to demonstrate reliable canister filling, there appears to be too little attention on the rest of the canister production activities.

Table 6.4.3.1
ILAW Product Certification Technology Development Needs

Baseline

1. Develop strategy for ensuring product acceptability.
2. Develop and carry out qualification program to demonstrate ability to comply with specifications during production.
3. Complete development of glass formulations for expected feeds.
4. Determine where recycle streams will be introduced into the process, and in what manner (e.g., continuous, occasional batch addition).
5. Ensure that product/process control strategy adequately addresses recycled material.
6. Demonstrate the ability to reliably fill, seal, decontaminate and transport full-scale ILAW canisters.

Improvements

N/A

Alternatives

N/A

An important part of the compliance strategy must be determination of how to deal with process recycle streams. During plant production, the recycle stream is likely to differ significantly in composition from the feed being delivered to the facility (particularly during feed transitions). The location and mode (batch, continuous) of introduction of the recycled material needs to be determined, and then addressed in the process/product control strategy. If not, there is a significant likelihood of unstable operating conditions and out-of-specification product.

It is also important that BNFL complete the glass formulation development program planned by Catholic University. Formulations must have properties that satisfy both process constraints and product requirements. This program needs to address the feed delivery sequence proposed by PHMC, including average compositions for each feed type and realistic transitions between feed types. This program must also consider what chemicals will be available for feed makeup.

Some of the critical procurement specification requirements for the LAW waste form are related to the disposal system Performance Assessment. However, the most significant specification, that for glass durability as measured by the PCT test, is recognized as an insufficient prediction of long-term disposal performance. The TFA, in coordination with ORP, is supporting studies of the relationship between glass formulations and long-term disposal performance. This effort, if closely coordinated with Catholic University's work for BNFL and carried to completion, has potential for reducing uncertainties for the current Performance Assessment. Balancing the glass performance needs with optimization of glass formulations for processibility and waste loading should receive continued analysis.

6.4.4 LAW Offgas

The baseline process for offgas treatment has recently changed. The present concept involves a primary system consisting of a film cooler, submerged bed scrubber (SBS), and wet electrostatic precipitator (WESP) to remove solid particles and condensable vapors. A standby system containing a quencher and a metallic filter is used only when abnormal offgas flow or melter pressure overloads the primary system. A secondary system, consisting of HEPA filters, a caustic scrubber, selective catalytic reduction (SCR) unit, and catalytic oxidation unit, removes acid gases and organics before the cleaned offgas is vented to the atmosphere.

The baseline items identified in Table 6.4.4.1 are considered to be crucial for the success of the program. The composition of the recycle streams must be determined under realistic melter operating conditions through full-scale pilot testing combined with process modeling. A strategy for removal of volatile elements having limited solubility in the glass melt has not yet been defined. A purge point (process step where material exits the system) must be defined for each component that can not be recycled. Elimination of the SO_2 and SO_3 produced in the melter is of greatest concern.

Testing of the offgas system on a large scale is also essential to ensure that design DFs are achieved. The likelihood of line plugging due to condensation of volatiles needs to be determined. If any plugging is deemed likely, recovery modes need to be developed and tested at scale. This testing is also the only reliable means to determine whether offgas constituents will react with offgas system components in a deleterious manner during production.

A particular area of concern is poisoning of the catalyst in the SCRs. Large-scale testing will be needed to show that the upstream units are capable of removing heavy metals and other potential poisons to a level that the catalyst can tolerate. Susceptability of catalysts to poisons can be determined by bench-scale testing. Long-term testing of offgas system materials under process conditions seems to be well provided for in BNFL's development program.

Table 6.4.4.1
LAW Offgas Technology Development Needs

Baseline
1. Determine the composition of recycle streams.[(a)]
2. Ensure that there is a purge point for components that can not be recycled (e.g., S, Cl).
3. Carry out large-scale testing to demonstrate that the offgas system delivers design DFs.[(a)]
4. Carry out large-scale testing of SBS to ensure consistent solids recovery and reliable pressure control.[(a)]
5. Determine likelihood of line plugging due to condensation of volatiles, and develop and demonstrate recovery methods if plugging is found to be likely.[(a)]
6. Determine expected life of SCR catalysts.[(a)]
7. Carry out long-term testing of materials at process conditions to enhance equipment longevity.[(a)]
Improvements
1. Evaporate scrubber liquid and dispose of solid salts.
2. Dispose of scrubber liquid in grout.
3. Remove S and Cl from scrubber liquid by ion exchange.
Alternatives
1. Ionizing wet scrubber may be better than the SBS and electrostatic precipitator combination.[(a)]
2. Hydrosonic scrubber has proved reliable in DWPF for fine particulate removal. It appears that it may provide higher DFs more consistently than the current choices.[(a)]
(a) Comment applies to both LAW and HLW offgas treatment.

Three ideas are proposed as improvements to address the problem of removing sulfur and chlorine from the primary offgas system. The SBS and WESP are expected to capture most of these elements and collect them in the SBS liquor. This could be disposed of directly by evaporating to produce a dry powder, or by preparing a grout. It may also be possible to separate these elements from the liquid by ion exchange.

Two alternatives are proposed to the current primary offgas system, to overcome a potential problem of scale-up (possibility of channeling) with the SBS. An ionizing wet scrubber, which has been used on nuclear waste incinerators, could replace both the SBS and WESP. A hydrosonic scrubber could replace the WESP, in combination with either an SBS or an alternative quench scrubber. Hydrosonic scrubbers are used in the DWPF (along with a venturi quench scrubber), are scaled up rather easily, and are more effective than the SBS for the 0.1 to 1 micron particle size range.

Table 6.4.4.2
Evaluation of Improvements and Alternatives for LAW Offgas

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Evaporate scrubber liquid	H	L	M	L	L	M
2. Grout scrubber liquid	H	L	M	L	L	M
3. Ion exchange scrubber liquid to remove S, Cl	L	L	L	L	L	L
Alternatives						
1. Ionizing wet scrubber	M	L	H	L	L	H
2. Hydrosonic scrubber	H	L	H	L	L	H

These ideas are rated against the evaluation criteria in Table 6.4.4.2. The improvements are preliminary ideas relative to the sulfate problem. Task Sheet E.2 on Sulfate Accommodation gives a more comprehensive list of actions to address this problem. The design of the offgas system is still in flux. These alternatives are proposed to take advantage of experience gained at the DWPF and WVDP.

6.4.5 HLW Feed Preparation

This operation involves the preparation of feed for the glass melter by evaporating and blending HLW waste sludge, dry glass formers, recycle streams (especially offgas) and separated radionuclide concentrate streams from LAW pretreatment. Blended feed must be compositionally consistent and pumpable into the melter in a predictable manner. Target glass compositions for the melter feed batches will be selected from suitable formulations developed under the IHLW Product Certification function (Section 6.4.7). Some form of batch composition control algorithm, analogous to the Product Composition Control System (PCCS) used in DWPF needs to be developed. The process will need to be sufficiently adaptable to accommodate variations in waste feed compositions as different source tanks are retrieved.

Although significant differences exist in the waste feed constituents and the scale of operation between HLW and LAW feed preparation, the basic issues and development needs are almost the same. The discussion of Section 6.4.1 and the Tables 6.4.4.1 and 6.4.4.2 applies to the HLW feed preparation, with a few variations and exceptions. BNFL intends to concentrate the HLW feeds by ultrafiltration, in contrast to the plan to evaporate the LAW waste feed. It is likely that variations in solids concentration and characteristics in HLW feed will have a much larger effect on melter feed blending and rheology than is the case for LAW. This may require a larger testing effort and may impose a stronger incentive to look at the recommended improvement of providing evaporation capability in the feed blending tank.

The integrated process testing capability for radioactive samples recommended as an improvement under the LAW Feed Preparation section is perhaps even more important for the HLW case. If properly designed, a bench-scale integrated process test system in a hot cell should be capable of performing vitrification process tests for both LAW and HLW waste feed samples. The tank-to-tank variations in important waste constituents and properties are likely to be greater for HLW, which increases the incentive to establish actual processing responses for these feeds prior to production.

6.4.6 HLW Vitrification

The baseline technology consists of a joule-heated melter, similar to one section of the LAW melter, with a chrome refractory lining and nickel alloy (Inconel 690) plate electrodes on the walls. Lower sidewalls, sloped at 45º, and a bottom plate electrode (but without a drain) form a sump that is intended to collect any solid noble metals and spinels that can not be kept in suspension by convection. Nickel alloy bubblers are used to augment natural convection flows in the molten glass, enhancing the melting rate at the bottom surface of the cold cap. An airlift pumps glass from the bottom up through a channel in the refractory, allowing it to overflow onto an inclined trough, from which it drains into the canister. The melter concept is based on those used successfully for HLW at other DOE and foreign sites, and closely follows the WVDP design. A development program is underway at VSL, using existing pilot melters of about 1/30 and 1/3 scale (based on melt surface area and melting rate). These melters do not incorporate the sloped sidewalls, bottom electrode and bubblers, and bottom accumulation features that are being counted on to prevent accumulation of noble metals. While the program appears to be well designed and integrated with the glass chemistry program at VSL, the lack of plans for full-scale tests prior to design and construction of the production melter is a concern.

The baseline items identified in Table 6.4.6.1 are considered crucial for the success of the program. The principal need is to complete the testing of the approach selected to prevent excessive accumulation of solid noble metal and spinel deposits in the bottom of the melter. Large-scale testing of the HLW melter – including deposit formation – is imperative. While the bench-scale tests will be good indicators of failure, it is less likely that they can provide the needed confidence in the success of the 45° slope design. Experience at Karlsruhe, Germany, indicates that steeper slopes are needed to move the deposits out of the electric current path, even though smaller scale tests indicated that a 45° slope was adequate. However, it is possible that with judicious location of bubblers, the metals may be kept in suspension and swept from the melter.

Silver concentration may be high enough in some wastes to cause it to precipitate as a molten metal that could penetrate bottom joints. Tests are needed to establish the long-term effect of molten silver deposits on the Inconel-690 bottom electrode and the refractory joints around it. We also recommend that BNFL have its HLW melter bottom design reviewed by commercial glass industry personnel knowledgeable in current practices for dealing with molten metal deposits. This would be rather inexpensive insurance.

Table 6.4.6.1
HLW Vitrification Technology Development Needs

Baseline

1. Demonstrate ability to keep noble metal and spinel-containing precipitates in suspension so they can be removed continuously from the melter.
2. Ensure that the process control strategy for the facility can tolerate realistic batch-to-batch variability, including heels, ion exchange eluates, and recycled material.[(a)]
3. Define and demonstrate methods for glass chemistry control (cold cap control, melt redox).
4. Determine suitable bubbler location for design, and operating parameters for production. [(a)]
5. Test resistance of melter materials of construction to corrosion by HLW glasses, and by other possible molten phases (e.g., silver).
6. Determine whether Hg-influenced corrosion will occur at melter penetrations.
8. Refine melter design by determining failure modes and lifetimes through extended operation of pilot melters. [(a)]
9. Develop a strategy of continuous improvement of melter design, based on continuing pilot testing and careful examination of failed melters, to reduce production costs. [(a)]

Improvements (for Beyond Phase I)

1. Extend temperature limit of melter by water- or air-cooling the Inconel electrodes and immersed devices (bubblers, thermocouple sheaths).
2. Substitute materials capable of higher temperatures (e.g., molybdenum, Al-doped Inconel-690, coated materials) for plate electrodes and immersed devices in the present melter concept.

Alternatives for Phase I:

1. Employ a bottom-drain, cold bottom approach to noble metals, similar to the Japanese.
2. Employ a highly sloped melter bottom, similar to the German design.
3. Consider chemical removal of glass prior to disposal, or vault storage and disposal of failed melters.

Alternatives for Beyond Phase I:

4. Use a cold crucible induction melter for troublesome compositions (e.g., Cr, Zr, P in high-Al glass).

(a) Comment applies to both LAW and HLW melters.

Hg concentrations in the plenum may be sufficient to cause abnormal attack on metal devices. SRTC has observed severe localized attack associated with Hg on metal pieces at their point of penetration into the melter. The formation of a molten salt layer on top of the molten glass is less likely than with LAW because of the lower levels of S and Cl in the wastes. Other baseline items are similar to the LAW melter, and are discussed in Section 6.4.2.

The team identified two potentially useful improvements to the baseline, primarily for processing after Phase I. Both are aimed at extending the operating temperature of the present melter concept by cooling metal components or by substituting more refractory materials for the Inconel components. Electrode cooling is used in commercial glass melting to extend temperature limits, and GTS Duratek has

discussed the idea of adding cooling and thermocouples to electrodes to improve control and life. The wastes selected for immobilization in Phase I probably would not benefit from the higher temperature capabilities, but it is a logical direction for development given the greater tolerance to process upset which they afford and the more difficult HLW compositions to be faced later. Suggested actions are listed on Task Sheet E.8 , Higher Temperature HLW Vitrification.

Three alternatives are proposed for Phase I processing. Two techniques for noble metal removal used at foreign sites deserve consideration. The Japanese approach in which noble metal deposits are trapped in a colder viscous layer of glass near the bottom and then periodically heated and flushed, should be considered as an alternative to the present strategy of constant suspension by convection. A more highly sloped bottom, similar to that developed at Karlsruhe, offers yet another approach to moving deposits away from the electrodes (but at the cost of a significant increase in melter height). It should be noted that a pilot scale matter with a 60° sloped bottom is currently in storage at SRS, and is available for testing.

An alternative is suggested to the current BNFL concept for disposal of failed melters by dismantling them for disposal in canisters (this is a potentially messy process, fraught with possibilities for the spread of contamination). The Team recommends that trade studies be carried out comparing the current approach to two alternatives:

a) Dedicated vault disposal on the Hanford site. This is the DWPF approach. It has the advantage of minimizing processing of the failed melter. However, if a melter is filled with glass and cannot be drained at the time of failure, this alternative implies disposal of HLW glass at the site.

b) Chemical cleaning of the inside of the melter to remove glass, and disposal of the cleansed melter as LLW. Tests at SRTC have shown that HLW glasses are easily removed from metal surfaces, and removed with more difficulty from refractory surfaces, by chemical agents (e.g., oxalic acid).

Depending on the results of the trade studies, some development work will probably be needed, either to optimize methods for segregation of melter materials into HLW and LLW fractions for disposal, or to gain data for a disposal performance assessment.

An additional alternative is proposed that may be valuable for processing beyond Phase I. Cold crucible induction melters have been taken to the full-scale pilot testing stage by the French. There seems to be little justification for considering this technology for Phase I processing, but some specific wastes to be processed beyond Phase I might be immobilized in much less glass if melting temperatures were significantly higher. Cold crucible induction melters are less well understood, but are attractive for wastes containing elements that attack the electrodes of high temperature joule-heated melters. They also have the advantage in that it is easier to make a reliable bottom drain in a cold wall than in a hot ceramic wall melter, and it may be easier to avoid noble metal deposits in a bottom-drained melter. However, the time required to make induction heating a useful approach for processing especially difficult wastes beyond Phase I suggests that its progress should be followed now, and serious work undertaken well before the end of Phase I. Suggested actions are detailed in Task Sheet E.12 on Cold Crucible Melters.

The merits of these ideas are evaluated in Table 6.4.6.2. None have strong financial justification in Phase I, but those with higher long-term potential payoff or low cost/benefit ratios should be included in future plans.

High temperature joule heated ceramic melters were considered as an alternative for HLW vitrification, but are not recommended. The problem of electrode reaction (usually molybdenum) makes them attractive only when the waste compositions are known to contain only very low levels of easily-reduced elements (e.g., Ag, Cd, Sb, As, Pb, Bi, Se, Zn, Hg). The Hanford wastes are not of this type.

Phosphate glasses were also considered as an alternative but are not recommended. They appear to be a potential logical matrix for disposal of some of the high-P wastes scheduled beyond Phase I. The magnitude of this problem is not yet well-defined, since it depends on specific tank compositions and the efficiency of removal in pretreatment by caustic leaching. However, the alkali content of the wastes makes it unlikely that waste loading would be high enough in phosphate glass to justify developing these compositions with all the attendant changes in other parts of the flowsheet.

Table 6.4.6.2
Evaluation of Improvements and Alternatives for HLW Vitrification

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Water- or air-cooling of devices	L	L	H	L	M	H
2. Higher temperature materials	M	M	H	L	M	L
Alternatives for Phase I:						
1. Japanese approach to noble metals	H	L	H	L	L	M
2. Highly sloped bottom for noble metals	M	L	M	L	L	M
3. Alternative failed melter disposition	M	L	M	L	L	M
Alternatives for Beyond Phase I						
4. Cold Crucible Melter	M	L	L	L	M	L

6.4.7 IHLW Product Certification

Product certification by BNFL involves establishing all necessary information to assure that the IHLW product meets applicable specifications. The core requirements are those established by the HLW repository program in their WASRD and further amplified by DOE-EM in the form of Waste Acceptance Product Specifications (WAPS). Requirements from the WAPS have been incorporated in the ORP privatization procurement specifications. The focus in this area is on BNFL's definition of a detailed

strategy for compliance with product specification requirements. The strategy must include essential process/product control features, analytical sampling requirements and necessary qualification/testing activities. Establishing HLW glass formulation ranges with suitable properties and waste loading is a key part of this function. Both formulations and product control criteria are critical inputs to what must be accomplished under the HLW Feed Preparation and Vitrification operations. Qualifying the stainless steel canister and the final glass-filled canister waste form product must also be accomplished. Some combination of qualification tests and/or actual product sampling, measurements and inspections must be selected and applied.

The baseline items in Table 6.4.7.1 are considered crucial for success of the project. As with LAW, it is extremely important that BNFL develop a strategy for ensuring product acceptability as soon as possible. Catholic University is developing glass formulations having properties which satisfy process/product requirements. This effort should extend to cover the waste compositions projected for the individual tanks and blends (reflecting tank heels and residuals) defined by the PHMC waste staging and delivery plans. Generic formulations derived to encompass the Envelope D component levels will not be sufficient. Results from the current TFA sponsored program to develop glass formulations for improved waste loading for SRS and INEEL wastes should be utilized by BNFL when appropriate. Early development of the qualification program (which will demonstrate the ability to comply with the WAPS) is also important because it will establish many of the baseline requirements for facility startup testing.

Table 6.4.7.1
IHLW Product Certification Technology Development Needs

Baseline

1. Define strategy for ensuring product acceptability.
2. Develop glass formulations consistent with waste feeds, process constraints and product requirements.
3. Define and carry out qualification program.

Improvements

1. Consider solid blasting the canisters for decontamination.

Alternatives

N/A

One improvement to the baseline is recommended: perform an evaluation of substituting solids blasting for ceric solution decontamination. The solid to be used could either be one of the batch ingredients (e.g., sand, mineral) or a solid, such as CO_2 pellets. In either case, solids blasting would have the advantage of adding no new chemicals, which would have to be incorporated into the glass. The equipment necessary for blasting probably would be no more extensive than that required for ceric solution treatment. The technology for both CO_2 blasting and blasting with batch components is well-developed and is in use in nuclear applications. A study of solids blasting for decontamination would probably take 1.5 years. An initial trade study to determine potential costs and benefits would probably extend for three months. Assuming a favorable outcome, a downselection based on comparison of commercial CO_2 blasting equipment and a thorough review of solids blasting of DWPF canisters could be

completed in approximately eight more months. The remainder of the time would be required for incorporation of this change in the detailed design.

Table 6.4.7.2
Evaluation of Improvements and Alternatives for IHLW Product Certification

	Maturity of Technology		Ability to Integrate	Life Cycle Cost Reductions		Maintain Schedule
	Nuclear Industry	Hanford		Phase I	Beyond Phase I	
Improvements						
1. Solid blasting for decontamination	H	L	M	L	L	H
Alternatives						
N/A						

6.4.8 HLW Offgas

The baseline process for HLW offgas treatment is essentially the same as for LAW offgas, discussed in Section 6.4.4. The baseline items shown in Table 6.4.8.1 are the same as those in Table 6.4.4.1 except

Table 6.4.8.1
HLW Offgas Technology Development Needs

Baseline

1. Determine the composition of recycle streams.[(a)]
2. Ensure that there is a purge point for key problem components (e.g., Hg, possibly S and Cl).
3. Carry out large-scale testing to demonstrate that the offgas system delivers design DFs. [(a)]
4. Carry out large-scale testing of SBS to ensure consistent solids recovery, and reliable pressure control. [(a)]
5. Determine likelihood of line plugging due to condensation of semi-volatiles, and develop and demonstrate recovery methods if plugging is found to be likely. [(a)]
6. Determine expected life of SCR catalysts. [(a)]
7. Long-term testing of materials at process conditions is needed to ensure equipment longevity. [(a)]

Improvements

N/A

Alternatives

1. Ionizing wet scrubber may be better than the SBS and WESP combination. [(a)]
2. Hydrosonic scrubber has proved reliable in DWPF for fine particulate removal. [(a)]

(a) Comment applies to both LAW and HLW offgas treatment.

for the additional problem of Hg in HLW, and the less severe problem with sulfates. As with LAW offgas, the most important tasks involve full-scale pilot testing under realistic melter operating conditions.

No improvements were identified for the HLW, since the development of the baseline system is in an early stage. The alternatives listed above are the same as those discussed in Section 6.4.4 for LAW offgas. The evaluation of alternatives in Table 6.4.4.1 apply also to HLW offgas.

A Level 1 Heading

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Appendix A

DOE Letters Requesting Technical Alternatives Assessment

Appendix A

DOE Letters Requesting Technical Alternatives Assessment

(08-93)

United States Government **Department of Energy**

memorandum

DATE: January 29, 1999

REPLY TO ATTN OF: EM-50 (Cooley:3-7276)

SUBJECT: Request for Recommendation on Alternatives Needed to Reduce High Investment Risks for Hanford High-Level Waste

TO: Robert M. Rosselli, Assistant Manager for Science and Technology
DOE Richland Operations Office

In recent discussions, James Owendoff, Acting Assistant Secretary for Environmental Management, has asked that DOE Headquarters identify technical improvements and alternatives to the Hanford High-Level Waste (HLW) program in the event that our current privatization strategy to treat Hanford HLW is unsuccessful. To aid our response, we are requesting that a report from the Tank Focus Area (TFA) be prepared to provide independent recommendations on the technical alternatives for the Hanford HLW program. The Tank Focus Area should bring together nationwide expertise to provide these recommendations.

We need to reach agreement in February 1999 on the planned content of the TFA report and the schedule of transmittal for the report. The TFA should provide to the Office of Waste Management and the Office of Science and Technology at Headquarters a briefing on the final recommendations. Please keep in mind we are calling upon the technical expertise of the TFA to help Headquarters prepare an independent analysis of alternatives should our current privatization strategy for the Office of River Protection (ORP) be unsuccessful. We are not asking TFA to rank the recommended alternatives using complex-wide priorities as TFA normally conducts their evaluations. Further, TFA should rank the maturity of each technology using a process similar to the evaluation of the contractor proposals performed in Part-A of the Tanks Waste Retrieval System (TWRS) privatization contract.

In our view, the challenges include the following:

1) capability to prepare and deliver HLW storage tank contents to the contractor for treatment on an agreed schedule (logistics);
2) capability to achieve separation of the waste into a high-activity waste (HAW) fraction and a low-activity waste (LAW) fraction suitable for vitrification and disposal on site;
3) capability to achieve vitrification and packaging of the HAW fraction for storage and eventual disposal in a geologic repository;
4) capability to achieve high-throughput vitrification and packaging of the LAW fraction for storage and on site disposal on an economically attractive schedule; and
5) acceptability of the HLW and LAW waste forms for long-term storage and disposal.

There may be others that should be identified and discussed in the report.

With the anticipated Department of Energy investment of billions of dollars to move the Hanford HLW from tank storage into a vitrified state, the alternative approaches must be effective and consistent with the ORP and British Nuclear Fuels Limited (BNFL) schedule, and have likely reductions in risks related to the above challenges. In having the TFA report prepared, it is not the intent that we consider whether BNFL is or should be doing certain work, but only that the TFA identify the alternatives and views based on experience. Two aspects of technical alternatives should be considered: (1) baseline risk reduction; and (2) complete technical alternatives. Baseline risk reductions are those that can be added or inserted into the baseline process should the baseline process, or other alternatives recommended by BNFL, not succeed. Technical alternatives should include both short-term and long-term development of alternatives. The potential for reduction in, and uncertainty of, life-cycle costs including final storage costs are important for either aspect.

Thoughts for your consideration are briefly described below.

ORP will provide Phase I privatization flowsheet, technology baselines, and previous assessments of technical risks associated with each baseline process step as input to this report. This report will identify ORP and BNFL baseline for each process step and provide the following:

1. The preferred technical alternative(s) for the TWRS identified high risk portions of the baseline and why the recommended alternatives are preferred.

2. A short description of each proposed alternative. Identify what technical work is currently covered in the TFA or ORP programs and what additional work would need to be covered to be consistent with BNFL schedules or as a long-range alternative, e.g., using a needs format, including estimated schedule impacts.

3. For technical alternatives, a recommended prioritization listing of new work required with highest priority first.

4. Method used and listing of nationwide resources engaged in making your recommendations.

Ralph Lightner, Office of Waste Management, is taking the lead for that office. He can be reached at (301) 903-7180. Herb Sutter is assisting Ralph Lightner and can be reached at (301) 601-5609. Carl Cooley of the Office of Science and Technology is the point of contact related to technology. He can be reached at (301) 903-7276. Please contact them as needed.

Mark W. Frei
Acting Deputy Assistant Secretary
for Waste Management
Office of Environmental Management

Gerald G. Boyd
Acting Deputy Assistant Secretary
for Science and Technology
Office of Environmental Management

United States Government **Department of Energy**

memorandum

Richland Operations Office

DATE: MAR 22 1999

REPLY TO ATTN OF: STP:BMM/99-STP-203

SUBJECT: RECOMMENDATION ON ALTERNATIVES NEEDED TO REDUCE HIGH INVESTMENT RISKS FOR HANFORD HIGH-LEVEL WASTE (HLW)

TO: G. G. Boyd, EM-50
M. W. Frei, EM-34

Pursuant to your request of January 29, 1999, The Tanks Focus Area (TFA) has prepared the attached action plan for recommending technical alternatives to the Hanford HLW treatment program. The TFA will convene a review panel of national experts to conduct an independent assessment and provide recommendations on technical improvements and alternatives to the Hanford HLW program, in the event that the current privatization strategy to treat the HLW is unsuccessful. This assessment will require the Office of River Protection's (ORP) support in providing technical materials and briefings to the review panel.

The cost of the assessment is currently estimated at $250K. The TFA does not currently have the scope or funds identified to cover this cost. The TFA is requesting your agreement and authorization of the scope in the attached action plan, and identification of funding for this effort. Upon authorization and funding, TFA will begin discussions with ORP to obtain all necessary baseline technical information. The proposed review team leader will also be engaged, review team members selected and contracted, and the assessment efforts will begin. The duration of the review is approximately four months. Assuming funding and authorization are provided before March 31, 1999, TFA proposes to provide a formal briefing to your offices before the end of July 1999, and a final formal report in August 1999.

Ted Pietrok, TFA Program Manager, will coordinate with Ralph Lightner and Carl Cooley of your staff to implement this assessment. If you have any questions, please contact me, or you may contact Mr. Pietrok on (509) 372-4546.

Robert M. Rossell, Assistant Manager
for Science and Technology

Attachment

RECEIVED
T.M. BROUNS
MAR 23 1999
FILE TFA C5.2.1 / TFA A1.6.1
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cc w/attach:
R. G. Lightner, EM-45
C. R. Cooley, EM-50
T. M. Brouns, PNNL
R. L. Gilchrist, PNNL
J. H. Westsik Jr., PNNL

United States Government **Department of Energy**

memorandum

RECEIVED
T.M. BROUNS
MAY 03 1999
FILE TFA C52.1/TFA V8.1.3.1
CC RECORDS

DATE: April 8, 1999

REPLY TO ATTN OF: EM-50 (Cooley:3-7276)

SUBJECT: Authorization to Conduct Hanford Technical Alternatives Review

TO: Robert M. Rosselli, Assistant Manager for Science and Technology
DOE Richland Operations Office

You are authorized to conduct the proposed study with the following clarifications:

1. The scope of the review should include technology for the retrieval and transport of waste from the high-level waste (HLW) storage tanks associated with Phase I of the British Nuclear Fuels Limited (BNFL) contract (double shell tank waste) as requested by the Office of Waste Management.

2. The review will not address the storage or disposition of HLW or low activity waste received from BNFL or other waste forms.

3. Each unit operation will be evaluated and technical alternatives will be identified for the high risk operations.

Based on the high priority of this review within the Office of Environmental Management, we authorize you to fund up to $300,000 out of the Tanks Focus Area (TFA) budget in FY 1999 for this effort. The report of the review should be available to the Office of Waste Management and the Office of Science and Technology by July 30, 1999.

We intend that some members of the National Academy of Sciences Committee on Technologies for Cleanup of High-Level Waste in the DOE Complex will be involved as separate advisors to your review panel at no cost to the TFA program. Accordingly, please keep Dr. Kevin Crowley, Director, Board on Radioactive Management ((202) 334-3066), advised on the schedule of your technical alternatives review and the suggested opportunities for members of the Committee to advise the review panel concerning the Hanford Privatization Phase I. Phase II and associated end states will not be included in this review.

You have our assurance that the support for the information you need from Richland's Office of River Protection will be provided without cost to the TFA.

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If you have further questions or need additional information, please contact Ralph Lightner, Office of Hanford Operations at (301) 903-7180, Carl Cooley, Office of Science and Technology at (301) 903-7276, Theodore Pietrok, Field Lead for the TFA at (509) 372-4546, or Neil Brown, Office of River Protection at (509) 372-2323.

Mark W. Frei

Mark W. Frei
Acting Deputy Assistant Secretary
for Waste Management
Office of Environmental Management

Gerald G. Boyd

Gerald G. Boyd
Acting Deputy Assistant Secretary
for Science and Technology
Office of Environmental Management

cc:
T. Pietrok, DOE RL
N. Brown, DOE RL
H. Sutter, SAIC
D. Oakley, FSU
D. French, ORP

B Level 1 Heading

THIS PAGE CONTAINS A LEVEL 1 HEADING WHICH ACTIVATES THE APPENDIX LETTER IN THE PAGE NUMBER. THE HEADING 1 STYLE MUST BE MODIFIED IN ORDER TO CHANGE THE APPENDIX LETTER.

PLEASE RECYCLE THIS PAGE.

Appendix B

PHMC and BNFL Process Description

Appendix B

PHMC and BNFL Process Description

B.1 PHMC Feed Delivery

B.1.1 HLW Feed Delivery

The current reference or baseline HLW feed delivery plan is as defined by the PHMC *in "Tank Waste Remediation System Operation and Utilization Plan*" (HNF 1999). That plan is discussed here. However, it should be noted that the PHMC has evaluated alternative feed plans, "*Alternatives Generation and Feed Analysis for Phase I High-Level Waste Feed Tanks Selection*," (HNF 1999a) and has recommended revised reference HLW feed plan. DOE is currently evaluating that recommendation.

HLW feed delivery operations generate five large blends. BNFL receives these materials in a series of batch transfers originating from Tanks AZ-101 and -102. The number and size of these batches is governed by agreements between DOE and BNFL.

The PHMC creates the five blends by recovering HLW sludge from selected DSTs (AZ-101, AZ-102, AY-102, C-106, C-104, and C-102). Alternative feed sources are identified by the PHMC in *Tank Waste Remediation System Operation and Utilization Plan* (HNF 1999). Figure 3.4-2 of *Tank Waste Remediation System Operation and Utilization Plan* (HNF 1999) illustrates the major facilities, tanks and piping configurations needed to perform the PHMC HLW processing, and Figure 3.4-3 of the same document diagrams the chronological series of transfers and blends comprising Phase I feed delivery. The sequence is as follows:

- Sluice C-106 sludge into AY-102.
- Mobilize AZ-101 as-is with mixer pumps and deliver the blend to BNFL.
- Mobilize AZ-102 as-is with mixer pumps and deliver the blend to BNFL.
- Transfer half of the C-106/AY-102 composite to AZ-101.
- Sluice half of C-104 to AY-101 to make a C-106/AY-102/C-104 composite.
- Sluice the other half of C-104 sludge to AY-102.
- Mobilize the C-106/AY-102/C-104 composite in AZ-101 and deliver the blend to BNFL.
- Transfer the C-106/AY-102/C-104 composite in AY-102 to AZ-102.
- Sluice C-102 into AY-102.
- Mobilize the C-106/AY-102/C-104 composite in AZ-102 and deliver the blend to BNFL.
- Transfer the C-102 composite in AY-102 to AZ-101.
- Mobilize the C-102 composite in AZ-101 and deliver the blend to BNFL.

B.1.2 Low-Activity Waste Feed Delivery

The PHMC recovers LAW feed from AZ-101, AZ-102, AN-107, AN-105, AN-102, AN-104, AW-101, AN-103, and SY-101 (a contingent tank to ensure that DOE's minimum order requirements are met). Figure 3.4-4 of *Tank Waste Remediation System Operation and Utilization Plan* (HNF 1999) illustrates the major facilities, tanks and piping configurations needed to perform the PHMC LAW processing. Some LAW source tanks are on the flammable gas safety watch list. Before retrieving liquids from these tanks, mixer pumps operate to mobilize the sludge layer and release the retained gas.

The liquids in AZ-101 and -102 are transferred directly to BNFL with the initial HLW transfers. Pretreated LAW originating from AZ-101 and -102 was originally planned to be returned by BNFL and stored in AP-108 for pretreatment at the end of Phase I. DOE is currently in the process of changing the BNFL work scope to include interim storage of this liquid, as well as entrained solids. Each of the remaining LAW source tanks contains a liquid layer and a solids layer. No attempt will be made during Phase I to retrieve mineral solids, but salt solids will be dissolved and retrieved.

The PHMC retrieves LAW feed tanks into AP-102 and -104. Liquid layers are close to or at saturation if specific gravity is near 1.43. Saturated liquids are subject to cooling-induced precipitation. Consequently, saturated liquids are transferred with at least 30 vol% in-line dilution.

After decanting the liquid, the solid salt layer in selected tanks is dissolved. Salt dissolves in place with a bulk addition of water, typically 70 vol% or more, depending on the solids content of the salt. Salt dissolution is rapid. The bulk water addition is calculated to result in a final liquid concentration that is suitable for transfer without further dilution. Some solids in each tank persist after dissolving the salts. Consequently, salt needs to be dissolved well in advance of the scheduled retrieval date to allow a month or more for gravity settling to recover the clarified liquid layer. In the current transfer schedule, at least three months are available to prepare the dissolved salt liquor for transfer. Dissolved salt liquor is typically retrieved into AP-104.

The staging strategy for LAW feed enables BNFL to operate its facilities continuously, avoiding the inefficiency of plant shutdowns and restarts between discrete batches of feed. LAW feed delivery transfers are diagrammed in Figure 3.4-5 of *Tank Waste Remediation System Operation and Utilization Plan* (HNF 1999).

B.2 BNFL Process Description

B.2.1 Pretreatment System

LAW feed and HLW feed will be treated in the pretreatment system. As shown in Figure 3.2.1, the pretreatment system is divided into a LAW component and HLW component. Liquid removed from the HLW feed will be incorporated into the LAW feed. The Sr/TRU elements, Cs, Tc, and solids removed during LAW pretreatment will be incorporated into the HLW melter feed. Any sulphates removed during

LAW pretreatment will be transferred to the PHMC for disposal. The pretreatment system will be sized to allow maximum throughput to the vitrification processes. The system is expected to initially operate below capacity, followed by a ramp-up period leading to maximum throughput.

B.2.1.1 Low-Activity Waste Feed Pretreatment

Pretreatment of the LAW feed includes process steps for reducing the volume of waste fed to the LAW treatment system, and for removing Sr/TRU, entrained solids, Cs, Tc, and sulfate from the feed. These removed constituents, with the exception of sulfate, and possibly entrained solids, will be incorporated into the HLW melter feed. Entrained solids may be returned to the Hanford facilities, but more likely will be incorporated in the HLW or LAW melter feeds. Removed sulfate will be transferred to the PHMC facilities for disposition. The following sections address, in greater detail, LAW feed pretreatment.

B.2.1.1.1 Low-Activity Waste Feed Evaporator

The LAW feed evaporator process receives LAW feed from the feed staging tank, permeate liquor from processing HLW, and miscellaneous recycle streams from the BNFL facility.

To minimize throughput to the ultrafiltration process and subsequent downstream unit processes, the feed stream to the LAW pretreatment system will be concentrated by evaporation. The LAW feed evaporator will be a continuous forced-circulation vacuum evaporation system. A typical daily feed to the LAW feed evaporator will consist of a batch of the LAW feeds (Envelope A, B, or C), a batch of Envelope D permeate, and any recycled material. Waste feed will be transferred in batches to one of the LAW feed evaporator feed tanks.

After the LAW feed is sufficiently concentrated within the evaporator system, it will be pumped out of the evaporator system through a heat exchanger for cooling. The concentrated LAW stream will be discharged into an LAW concentrates buffer tank.

B.2.1.1.2 Ultrafiltration (entrained solids and Sr/TRU precipitation)

Following evaporation, the concentrated LAW feed will be sent to the ultrafiltration process. Entrained solids will be removed in order to protect downstream ion exchange beds, and to reduce the overall radionuclide loading in the BNFL facility and ILAW. Entrained solids removed in the ultrafiltration process will be transferred to other Hanford Site facilities, or characterized and subsequently vitrified in the HLW or LAW vitrification processes.

Additionally, using precipitation and filtration, the ultrafiltration process will remove complexed Sr and TRU, particularly from Envelope C feed. The Sr/TRU precipitate will be washed and then sent to the HLW immobilization. Figure 3.2.1 depicts these processes. The ultrafiltration system will be located in-cell and consist of two parallel ultrafiltration trains. One train is used for operation while the other is in a

cleaning cycle. During the cleaning cycle, the ultrafilters will be cleansed by back-pulsing with high-pressure air, washing with nitric acid, or washing with water.

B.2.1.1.3 Ion Exchange

To comply with regulatory agreements, the radioactive Cs and Tc content of the LAW feed must be reduced. The reduction of these constituent levels in the permeate from ultrafiltration will be accomplished by passing the feed through successive ion exchange systems, first to remove Cs and then to remove Tc. Each system (Cs and Tc) will consist of four ion exchange columns arranged in two parallel series of two columns each. In each system, one series will process feed while the other undergoes elution to remove the adsorbed constituent and subsequent resin regeneration for reuse. When the desired column loading has been achieved, the flow to that series of columns will be suspended, and the LAW feed diverted to the other series of columns in that system.

The Cs and Tc will be eluted from the loaded columns with dilute nitric acid or with water. Caustic will be used to regenerate the resin for reuse. The resins have finite useful lives; spent resin will be removed from the columns and replaced with fresh resin. The removed resins will be transferred to another Hanford facility for disposal.

B.2.1.1.3.1 Cs Ion Exchange

The Cs ion exchange system selected for the removal of Cs from the LAW feed will use four ion exchange columns operating as two parallel series of two columns each. At any given time, one series in the system will operate to collect Cs while the other undergoes regeneration or resin replacement.

The ion exchange system is located in-cell and includes the following operations:

- Removal of Cs ions by passing LAW feed through ion exchange columns containing a fixed bed of resin beads
- Regeneration of resin beds by chemical additions and rinse steps
- Removal and replacement of spent resins.

The Cs removal step results in loading of the resin with Cs ions. When the loading on a column approaches saturation, Cs begins to break through the column. When Cs is detected in the effluent from the lead ion exchange column, the active series of columns in the system will be switched.

After switching the loading operation to the alternate series of columns, the loaded series will be regenerated. A regeneration cycle will include the following steps:

- Displacement of residual fluid in the bed by rinsing with caustic solution
- Rinsing with water to remove caustic
- Elution of Cs ions with nitric acid
- Rinsing with water to remove the acid

- Regeneration of the resin with caustic solution.

After a series of loading and regeneration cycles, the resin in the column becomes spent, and must be replaced. The spent resin will be flushed out as a slurry with water, and fresh resin will be slurried into the column for bed replacement.

B.2.1.1.3.2 Technetium Ion Exchange

The Tc ion exchange system selected for the removal of Tc from the LAW feed will use four ion exchange columns operating as two parallel series of two columns each. At any given time, one series in the system will operate to collect Tc while the other undergoes regeneration or resin replacement.

The Tc ion exchange system will be comprised of the following major components:

- Feed breakpot
- Four identical ion exchange columns
- Three treated LAW collection tanks
- Two transfer pumps

B.2.1.1.3.3 Sulfate Removal

The presence of sulfate in the LAW melter feed may lead to the formation of a separate sulfate phase in the LAW melters. The presence of this sulfate layer may have the undesirable effect of decreasing the useful life of the melters by increasing melter corrosion, decreasing the waste loading in the ILAW, or decreasing the ILAW quality. In addition, the presence of a continuous molten sulfate layer on the surface of the glass melt introduces a safety issue (steam explosion) which must be addressed. Current design plans call for sulfate removal by ion exchange. However, precipitation is considered a contingency operation in the event that ion exchange proves to be impractical.

Development continues on an ion exchange resin that is selective for sulfate. In the final design, the primary functions of the system will remain unchanged but the equipment size and type, reagents used, and interactions with other systems may change once the ion exchange development work is completed.

In addition, LAW vitrification studies may impact the development of the sulfate removal process. The addition of reductants or modification of the current glass former composition may effect the degree of sulfate removal required. These studies will need to be considered with the ion exchange development studies in developing the final sulfate removal process.

Feed for the sulfate removal system will collect in a buffer vessel and will be routed to the sulfate ion exchange column. The sulfate ion exchange system consists of two columns in parallel. One column will be loading while the second is being eluted and regenerated. The sulfate deficient stream exiting the ion exchange column will be routed to one of the treated LAW collection vessels. The loaded ion exchange column will be eluted with weak nitric acid. The eluate will be collected in a separate vessel. A dilute

caustic solution will be added to this vessel to neutralize the acid eluate before this stream is routed to the condensate/plant wash and drain system where it will be combined with other effluents and washing streams from pretreatment operations.

B.2.1.1.4 Low-Activity Waste Melter Feed Evaporator Product Concentration

The primary purpose of the LAW melter feed evaporator system is to concentrate feed to the LAW melters. Concentrating the feed will decrease the heat burden from the LAW melters, decrease the size of the LAW melter feed buffer tanks, and decrease the volume of offgas treated by the LAW melter offgas treatment system. The degree of evaporation may be different for each waste envelope, and will be determined from sampling and process engineering.

The forced circulation, vacuum evaporation system has the ability to handle a wide range of feed flows and compositions, and variable evaporation rates. The evaporator will be operated under vacuum to lower the boiling temperature of the process and thereby reduce corrosion.

The LAW melter feed evaporator system receives feed from the sulfate removal system. The evaporator vessel will be operated under a vacuum continuously. Heat will be added to the evaporator reboiler via the low-pressure steam system. Sufficient hydrostatic head will be maintained to suppress the boiling point inside the evaporator reboiler. As the flow enters the evaporator vessel the hydrostatic head will diminish, and flash evaporation will occur. The liquid stream will continue to circulate in this closed loop (becoming more concentrated), while the vapor stream passes to the primary condenser.

The resulting vapor from the primary condenser will be routed through a series of heat exchangers before entering an aftercondenser. The steam ejectors and heat exchangers will be employed to create the vacuum condition in which the evaporator operates. The resulting vapor stream from the aftercondenser will be routed to the vessel ventilation system. Condensate from the condensers and heat exchangers will be routed to the process condensate hold vessel before transfer to the condensate drain system.

The concentrated LAW feed product from the LAW melter feed evaporator will be collected in a concentrate hold vessel. Depending on the waste feed envelope being concentrated, the concentrate will be routed to one of two different systems. If the LAW feed is Envelope A or C, the concentrate will be routed to one of the LAW concentrate feed preparation hold vessels to await vitrification. For Envelope B, when the LAW vitrification system is not operating, the concentrate will be routed to the entrained solids hold vessel, and transferred to another Hanford facility. If the LAW vitrification system is operating, pretreated Envelope B feed will be vitrified.

B.2.1.2 High-Level Waste Feed Pretreatment and Blending

The purpose of the HLW pretreatment system is to treat, as needed, the HLW feed received from the PHMC. Treated HLW solids will be blended with other HLW feed components (Sr/TRU solids, Cs and Tc solution, potentially entrained solids, and HLW melter system recycle streams) as feed for the HLW melter feed system. Pretreatment may include interim storage, concentration by ultrafiltration, solids

water washing, partial solids component dissolution by NaOH, and HLW melter feed component blending.

Depending on the feed composition, the feed may require the following:

- Concentration of the solids by ultrafiltration
- Solids (sludge) washing by water to remove sodium and other soluble ions
- Partial solids dissolution (including aluminum, phosphates, or chromium) by caustic leaching.

Pretreated solids may be stored in storage tanks before processing in the HLW vitrification system, if necessary. Figure 3.2.1 provides a simplified process flow diagram of the BNFL facility treatment processes, including HLW feed pretreatment.

B.2.1.2.1 High-Level Waste Pretreatment

Steps used in HLW pretreatment depend on the source and physical characteristics of the feed. Envelope D feed will enter one of the HLW ultrafiltration feed vessels from the Envelope D receipt vessel. From the HLW ultrafiltration feed vessel, the feed will be circulated through one of two ultrafiltration loops by the associated HLW ultrafiltration feed pump. A single ultrafilter module will perform ultrafiltration. After passing through the ultrafilter, the circulating stream will be passed through a water-cooled heat exchanger to maintain the stream temperature, and then be returned to the HLW ultrafiltration feed vessel. Current estimates indicate the solids can be concentrated to about 25%. The concentrated solids will be washed with water to remove interstitial, soluble components (LAW Envelope A, B, or C feed).

Permeate from the ultrafilter will be collected in one of the HLW ultrafiltration permeate collection vessels. The ultrafiltration permeate collection vessel will have the same capacity as the ultrafiltration feed vessel, thus providing sufficient capacity to hold the entire contents of the ultrafiltration feed vessel in the event of ultrafilter failure. The ultrafiltration feed vessel will also be provided with cooling coils to maintain the temperature of the contents. At the end of the ultrafiltration cycle, permeate will be discharged, by reverse flow diverter, from the ultrafiltration permeate collection vessel to one of the LAW feed evaporator feed vessels. At the end of the ultrafiltration cycle, reverse flow diverters will transfer the dewatered Envelope D feed via the Envelope D receipt vessel to one of two HLW feed blending vessels. If the HLW vitrification system is not operational, the waste can be alternatively stored in one of the feed vessels.

If the feed does not have the appropriate composition to be blended into melter feed because of high soluble solids content, then the solids will be washed. Washing the solids is similar to concentrating the solids, except at the end of the concentration cycle, water is added to the HLW ultrafiltration feed vessel and mixed with the solids. The concentration cycle will be repeated.

Washing by the addition of water and subsequent concentration by filtration will be repeated to remove the necessary amount of soluble solids. When washing is completed, the solids may be sampled

to confirm adequate washing before being routed to the Envelope D receipt vessel for subsequent movement to storage or HLW feed blending. The HLW feed composition and the extent of waste concentration will determine the volume of wash water used per wash cycle and the number of water washes performed in the ultrafiltration system.

If Envelope D feed requires partial chemical dissolution of solids such as Al, P, and Cr to limit IHLW volume, the dissolution will be performed in the ultrafiltration system. Dissolution of Envelope D solids is similar to water washing the solids; however, in one of the wash cycles, NaOH is used in place of water and the wash slurry is held at reaction conditions prior to concentration. Following the initial wash and concentration step, a NaOH solution preheated to approximately 80°C will be added to the HLW ultrafiltration feed vessel. The solids and NaOH wash solution will be well mixed by feed tank mixing and circulation through the ultrafiltration unit to ensure good contact for reaction. During the contact time, no permeate will be removed from the ultrafilter and the slurry will be maintained at approximately 80°C. Once the reaction is complete, the solids will be concentrated by filtration. Solids washing will then be performed as described previously. The first water wash may contain some NaOH to inhibit Al from reprecipitating. All permeates will be routed from one of the HLW ultrafiltration permeate collection vessels to one of the LAW feed evaporator feed tanks as the permeate batch is collected.

B.2.1.2.2 High-Level Waste Feed Blending

After pretreatment, Envelope D solids will be transferred from the HLW ultrafiltration feed vessel to the Envelope D receipt vessel for interim storage. From the Envelope D receipt vessel, Envelope D solids can be transferred to one of the Envelope D receipt tanks for extended storage. Envelope D solids will then be transferred to the HLW feed blending vessel. After process sampling, Sr/TRU precipitate and Cs and Tc concentrate will be added and blended into Envelope D solids.

HLW melter offgas quencher solution will also be recycled to the feed blending vessel for blending. After mixing and characterization, the blended HLW feed will be transferred to the HLW melter feed preparation vessel where glass-forming chemicals will be added. The blended melter feed will be combined to a relatively constant composition to enable use of premixed glass forming chemicals.

HLW melter feed components (Envelope D solids, Sr/TRU precipitate, Cs and Tc concentrate, and selected HLW melter systems recycle) will be blended in suitable proportions in an HLW feed blending vessel. Two melter feed blending vessels will operate in sequence. One will receive and blend waste while the other transfers blended waste to the melter feed preparation vessel.

B.2.2 Low-Activity Waste Immobilization System

The purpose of the LAW treatment process is to convert blended waste slurry and glass formers into molten glass, and treat the offgas to levels that are protective of human health and the environment. Several systems will be associated with the LAW treatment processes. The following sections discuss each of these systems in detail.

B.2.2.1 Low-Activity Waste Melter Feed System

The LAW melter feed system will mix the concentrated LAW feed (previously pretreated to remove radioactive Cs, Tc, and Sr/TRU) with blended glass formers and sucrose, and feed this mixture to the LAW melter. The LAW melter feed system will consist of the LAW concentrate hold vessels, blended chemical feed hoppers for glass formers and sucrose, feed preparation tanks, and LAW melter feed tanks.

B.2.2.1.1 Concentrate Hold Vessels

Concentrate from the LAW melter feed evaporator will be received in one of the LAW concentrate hold vessels. These tanks will be steam jacketed to prevent the highly concentrated waste from cooling and precipitating solids. The LAW melter feed concentrate will be pulse jet agitated to suspend the insoluble solids. Reverse flow diverters will be used to transfer the LAW concentrate from the concentrate hold vessels to the LAW melter feed preparation vessels.

B.2.2.1.2 Low-Activity Waste Melter Feed Preparation Vessels

The purpose of the LAW melter feed preparation vessels is to mix blended dry glass forming chemicals and sucrose with the LAW feed to produce a pumpable slurry that can be fed to the LAW melter. A 24-hour batch of sampled LAW concentrate from the LAW evaporator concentrate collection tanks will be transferred into one of the LAW melter feed preparation tanks. Dry chemicals will be metered from the blended chemical feed hoppers through the feed lock hopper directly into the eye of the mixer impeller. A slight vacuum will be created by the rotating impeller, drawing the glass formers into the mix. The mass of the glass former and sucrose addition will be measured by weight loss of the batch in the blended chemical feed hopper. After blending is complete, the slurry will be pumped to the LAW melter feed vessel.

B.2.2.1.3 Melter Feed Vessels

The three LAW melter feed vessels will be sized to allow continuous feed to the LAW melters, taking into account the need for analysis of process samples. Each melter feed vessel will be located in the LAW melter cave, which will be equipped with crane and power manipulator access. Each melter feed vessel will have an agitator that may be replaced by remote handling. Feed pumps located in each of the three LAW melter feed vessels supply waste feed to the LAW melter.

The LAW melter feed vessels will be equipped for tank clean out. An ejector drawing from the low point of the vessel will empty the residual heel from the vessel. A pipe with spray nozzles will circumscribe the inside of all tanks, including the LAW melter feed vessels. Spray will be directed at the tank wall to clean the inside of the tank.

B.2.2.2 Low-Activity Waste Vitrification System

The purpose of the LAW melter system is to convert blended waste slurry and glass formers into molten glass. The molten glass will be poured into canisters where it will cool to form a durable glass

waste form. The scope of the melter system is the melter vessel, feed nozzles, and associated instrumentation and support equipment. The melter will be a refractory-lined rectangular tank with an outer steel casing. It will have three compartments: a glass tank, a discharge chamber, and a plenum. The tank will be lined with refractory designed to withstand molten glass corrosion. The steel casing for the glass tank area will be fitted with water cooling jackets to maintain a thermal gradient in the bricks for corrosion control, to suppress migration of glass through the bricks, and reduce heat load to the process cell. The discharge chamber will have a trough connected to the glass tank for pouring molten glass into canisters. The plenum, which will contain the headspace above the glass tank, will be lined with refractory to withstand hot corrosive gases, thermal shock, and glass splatter.

Pretreated LAW feed will be blended with feed chemicals in one of the LAW melter feed preparation vessels. The pretreated LAW feed will then be transferred in batches to one of the melter feed vessels. Each of the three LAW melter feed vessels will be fitted with feed pumps, each supplying a separate feed nozzle on a LAW melter. The design feed rate to each melter will be approximately 1.14 metric tons/hour (includes weight of water, waste, and all additives), which corresponds to about 10 metric tons of glass production per day for each melter. The LAW melter design may incorporate redundancy for components critical to continuous operation.

Each melter will start up with a batch of cullet (frit) or other glass forming material. Radiant heaters mounted on the roof of the melter will provide heat for startup. When a conducting path is established between the electrodes, joule-heating can be initiated. When the molten glass pool has reached the minimum acceptable operating temperature and level, slurry feeding will begin.

During steady state processing, the average feed rate and the average glass pour rate will be approximately matched, in order to maintain a constant melter pool level. The level will be monitored with a pneumercator (a bubbler tube system that measures the static head in the melt pool) or visually using closed circuit television.

The melter plenum will be maintained at a constant vacuum to ensure radiological containment and avoid pressurization. This vacuum will be measured and a signal sent to a control valve or fan speed controller to regulate the draft in the melter exhaust line.

The glass melt pool temperature will be approximately 1000°C to 1150°C. The temperature will be measured with thermocouples in thermowells submerged in the pool at various locations. The power to the electrodes will be regulated to maintain the temperature at the desired value. The melter plenum temperature will likely be in the range of 400°C to 600°C during steady state processing.

The LAW melter process follows:

- Slurry will be introduced to the melter through feed nozzles in the melter lid. The slurry will be discharged through the plenum and will drop onto the molten glass surface to form a cold cap, a layer of dry material that floats on top of the melt. As the cold cap dissolves into the melt, new slurry will be introduced, thus establishing a steady inventory of cold-cap material.

- Aerosols will be generated from the interaction of feed and molten glass. The particulate matter will have an opportunity to settle in the melter plenum before escaping to the flue. Gases will be evolved from decomposition of salts, hydrated compounds, and organic compounds in the feed.

- The melter glass tank will be heated by passing 60 hertz alternate current through the molten glass pool using electrodes, built into the refractory of the glass tank.

- Each melter will contain two discharge chambers. Glass waste will be discharged by air or nitrogen lift, or a vacuum lift system. Discharge chambers will raise the glass level in the discharge riser causing it to overflow into the discharge trough. Glass waste will flow down the trough and drain through the discharge chamber into a container.

ILAW glass waste will be cooled, the container sealed, decontaminated if necessary, and stored before transfer to a permitted storage facility. This process will yield ILAW in the form of durable borosilicate glass.

An offgas treatment system will provide quenching and cleanup for melter exhaust. A standby offgas system will also be provided.

B.2.2.3 Low-Activity Waste Offgas Treatment System

The purpose of the LAW vitrification offgas treatment system is to cool and treat the offgas produced by the LAW melters and vessel ventilation system to a level that is protective of human health and the environment. The offgas treatment system will also provide a pressure confinement boundary that will control melter pressure and prevent vapor release to the cell. The offgas system will be designed to treat normal offgas flow and intermittent surges of seven times steam flow and three times noncondensible gas flow.

Melter offgas will be generated in the process of vitrification of LAW slurry feed by a joule-heated ceramic melter. This offgas will primarily consist of the following:

- Air from melter bubbler operation and leakage into each melter

- Water vapor evaporated from the melter feed

- Acid gases generated from metal nitrate decontamination, primarily nitrogen oxides (NOx), chloride, fluoride, and sulfur oxides

- Aerosols from dried melter feed and melter cold-cap reaction solids.

In the event of an off-normal occurrence in the LAW melter, the melter offgas generation rate may increase to several times normal flow. This melter offgas surge may be a transient increase in steam

generation when the melter feed stream is exposed directly to the melt surface through cracks in the melter cold cap. These surges normally will be accommodated by the primary offgas treatment system. However, in the event a predetermined loss in melter vacuum is reached, the melter offgas will be diverted to the standby offgas treatment system to protect the melter from becoming pressurized.

The LAW vessel ventilation system treats offgas from the LAW feed makeup and handling system and other waste handling vessels within the LAW treatment process. Process vessels are maintained at a negative pressure relative to their respective containment cell by drawing a vacuum on the tanks. The offgas generated by the vessel ventilation system will consist primarily of air, water vapor, and minor amounts of aerosols generated by the agitation or movement of vessel contents. Vessels that contain high concentrations of solids, such as the melter feed makeup tank and the melter feed tank, will have washable demisters to minimize the movement of aerosols into the vessel ventilation system. These aerosols will contain radionuclides and other chemicals, similar to the melter offgas.

There will be four process areas in the LAW offgas treatment system. Each of these systems will be designed for specific purposes and therefore use unique technologies. These systems are defined below:

- Primary LAW Melter Offgas Treatment System
  - film cooler
  - SBS
  - WESP
  - HEPA filter

- Standby LAW Melter Offgas Treatment System

- Secondary LAW Offgas Treatment System
  - caustic scrubber
  - selective catalytic reduction (SCR) unit with catalytic oxidation (CO) unit

The primary melter offgas treatment system effluent and the vessel ventilation system effluent will be combined for treatment by the secondary offgas treatment system. After treatment by the secondary offgas treatment system, the combined LAW offgas will be discharged to the building ventilation system for filtration by the main facility HEPA filters before being monitored and discharged to the environment through the main stack. A simplified process flow diagram of the entire BNFL facility treatment process is provided in Figure 3.2.1.

B.2.3 High-Level Waste Immobilization System

The purpose of the HLW treatment process is to convert blended waste slurry and glass formers into molten glass, and treat the offgas to levels that will be protective of human health and the environment. These systems are discussed in detail in the following sections.

B.2.3.1 High-Level Waste Melter Feed System

The HLW melter feed system will prepare feed for the HLW melter. The process will consist of mixing appropriate amounts of glass forming chemicals and sucrose with the blended radioactive feed and verifying the melter feed composition. The melter feed system will consist of the blended glass former feed hopper, the HLW melter feed preparation vessel, and the HLW melter feed vessel. The system will be sized for a throughput of 1.5 metric tons of glass per day; the batch makeup will be sized for 48 hours of melter operation at full capacity.

The feed to the HLW melter will consist of a blended slurry (concentrated HLW slurry, Sr/TRU precipitate, Cs concentrate, Tc concentrate, recycle from the HLW melter quencher sump), and a blended mixture of dry glass forming chemicals and sucrose. The HLW feed system will receive glass formers and mix the glass formers with pretreated HLW feed slurry. The mixed feed slurry will be transferred to the melter feed tank. The slurry will be pumped to the HLW melter and distributed across the melt pool surface.

There will be three components to the HLW melter feed system: the HLW melter blended chemical feed hopper, the HLW melter feed preparation vessel, and a melter feed vessel.

B.2.3.1.1 High-Level Waste Melter Blended Chemical Feed Hopper

The blended chemical feed hopper will receive blended glass formers from the HLW melter blending transporter and sucrose from the sucrose weigh hopper. The blended chemical feed hopper will hold a 48-hour supply of blended glass formers. The glass formers will be metered by screw conveyer into the HLW melter feed preparation vessel via the HLW melter feed lock hopper. The quantity of chemicals added to the feed preparation vessel will be measured by loss in weight of the blended chemical feed hoppers. The feed lock hopper will be fitted with double block valves on the discharge to prevent backflow from the feed preparation vessel when chemicals are not being fed.

B.2.3.1.2 High-Level Waste Melter Feed Preparation Vessel

The purpose of the HLW melter feed preparation vessel is to mix the blended dry glass forming chemicals with HLW concentrate to produce a pumpable slurry that can then be fed to the HLW melter. A batch of characterized HLW concentrate from one of the HLW feed buffer vessels will be transferred into the HLW melter feed preparation. This vessel will be equipped with an agitator for mixing chemicals to a homogeneous blend. Dry chemicals from the blended chemical feed hopper will be fed into the eye of the mixer impeller. The action of the impeller will produce a slight vacuum on the hopper assisting the flow of dry chemicals. The action of the impeller design is capable of efficiently slurrying glass formers with waste concentrate. An additional impeller may be required in each vessel to maintain the entire contents in suspension. Process samples of the batch will be obtained to confirm the composition of the contents of the HLW melter feed preparation vessel. Once the process sample results have been received and the composition confirmed, the entire melter feed preparation vessel contents will be transferred by the HLW melter feed transfer pump to the HLW melter feed vessel, under level switch control.

B.2.3.1.3 Melter Feed Vessel

The melter feed vessel will be sized to accept a 48-hour supply of makeup feed. To ensure adequate mixing, the feed vessel will normally operate above 40% of the working volume. The HLW melter feed vessel will be fitted with feed pumps that supply waste feed to the HLW melter.

B.2.3.2 High-Level Waste Vitrification System

The purpose of the HLW melter system is to convert blended waste slurry and glass formers into molten glass. The glass will be poured into containers where it will cool to form a durable glass waste form. The scope of the melter system is the melter vessel, feed nozzles, and associated instrumentation and support equipment.

The melter will be a refractory-lined rectangular tank with an outer steel casing. It will have three compartments: a glass tank, a discharge chamber, and a plenum. The tank will be lined with refractory designed to withstand corrosion by molten glass, and will have sufficient capacity to accommodate noble metals that may settle to the bottom. The steel casing for the glass tank area will be fitted with water cooling to maintain a thermal gradient in the bricks, controlling corrosion, suppressing migration of glass through the bricks, and reducing heat load to the process cell. For pouring molten glass into canisters, the discharge chamber will have a trough connected to the glass tank. The plenum will contain the headspace above the glass tank, and will be lined with refractory to withstand hot corrosive gases, thermal shock, and glass splatter.

Pretreated HLW feed will be blended with feed chemicals in the melter feed prep tank, then transferred in batches to the melter feed tank. This tank will always have a charge of slurry to maintain continuous feed to the melter. The slurry will be fed to the melter through one or more feed nozzles. The continuous feed rate will be about 240 kilograms per hour, which corresponds to approximately 1.5 metric tons of glass per day. The feed system will be capable of adjusting the melter feed rate to comply with throughput or melter requirements, clear feed tube restrictions, or respond to anomalous conditions. The melter will heat the pretreated HLW feed mixture to approximately 950°C to 1,250°C to form molten glass.

The melter will startup with a batch of cullet (frit) or other glass forming material. Radiant electric heaters mounted on the roof of the melter will provide heat for startup. When a conducting path has been established between the electrodes, joule heating can be initiated. When the molten glass pool has reached sufficient temperature and level, slurry feeding will begin.

During steady state processing, the average feed rate and the average glass pour rate will be approximately matched, so as to maintain a constant melter pool level. The level will be monitored with a pneumercator (a bubbler tube system that measures the static head in the melt pool) or visually by closed circuit television.

The melter plenum will be maintained at a constant vacuum to ensure radiological containment and avoid pressurization. This vacuum will be measured and a signal sent to a control valve or fan speed controller to regulate the draft in the melter exhaust line.

The glass melt pool temperature will be approximately 1000°C to 1150°C. Temperature will be measured with thermocouples in thermowells submerged in the pool at various locations. Power to the electrodes will be regulated to maintain the temperature at the nominal value. Melter plenum temperature will likely be in the 400°C to 600°C range during steady state processing.

The HLW melter process is as follows:

- Slurry will be introduced to the melter through feed nozzles in the melter lid. The slurry will fall through the plenum and rapidly evolve water to form a layer of dry material known as the cold cap. New slurry will be introduced to the melter at about the same rate as the cold cap dissolves, thus establishing a steady inventory of cold cap material.

- Aerosols will be generated from the interaction of feed and molten glass. Gases will be evolved from decomposition of salts, hydrated compounds, and organic compounds in the feed.

- The melter glass tank will be heated by passing 60 hertz alternate current through the molten glass pool using electrodes built into the refractory of the glass tank.

- The molten glass pool will be agitated to aid in mixing, maintaining uniform temperature, and increase melter performance.

- Each melter will have two discharge chambers. Glass waste will be discharged by air or nitrogen lift, or vacuum lift system. Discharge chambers will raise the glass level in the discharge riser causing it to overflow into a discharge trough. Glass waste will flow down the trough and drain through one of the discharge chambers into a canister.

IHLW glass waste will be cooled and the container sealed, inspected, decontaminated if necessary, and stored for up to approximately 90 days before transfer to a permitted storage facility. This process will yield IHLW in the form of durable borosilicate glass. An offgas treatment system will provide quenching and cleanup for melter exhaust.

B.2.3.3 High-Level Waste Offgas Treatment System

The purpose of the HLW vitrification offgas treatment system is to remove aerosols and acid gases from the HLW melter offgas and the vessel ventilation system. After treatment, this offgas will be released to the building ventilation system for HEPA filtration, monitoring, and release to the HLW vitrification building stack.

Melter offgas will be generated by the vitrification of HLW slurry feed in a joule-heated ceramic melter. This melter will generate offgas that primarily consists of the following:

- Air from melter bubbler operation and inleakage into the melter
- Water vapor evaporated from the melter feed
- Acid gases generated from anion decomposition (i.e., NOx, CO_2, SO_2, P_20_4, etc.)
- Aerosols from dried melter feed and melter cold-cap reaction solids.

In the event of an off-normal occurrence in the HLW melter, the melter offgas generation rate may increase to several times normal flow. This melter offgas surge is a transient increase in steam generation when the melter feed stream is exposed directly to the melt surface through cracks in the melter cold cap. These surges normally will be accommodated by the primary offgas treatment system. However, in the infrequent event that a predetermined melter pressure is reached, the melter offgas will be diverted to the standby offgas treatment system. The offgas treatment system will be designed to handle surges of seven times normal steam flow and three times normal noncondensible gas flow.

The HLW vessel ventilation system will manage offgas generated by the HLW melter feed makeup and handling system and other waste handling vessels within the HLW treatment process. Process vessels will be maintained at a negative pressure relative to their respective containment cell by drawing a vacuum on the tanks. The offgas handled by the vessel ventilation system will consist primarily of air, water vapor, and minor amounts of aerosols generated by the agitation or movement of vessel contents. These aerosols contain radionuclides and other chemicals similar to the melter offgas.

There will be four process areas in the HLW vitrification offgas treatment system. Each of these systems is designed for specific purposes and will use technologies suited to those purposes. These systems are described below:

- Primary HLW Melter Offgas Treatment System
  - Film cooler
  - SBS
  - WESP
  - HEPA filtration

- Stand-by HLW Melter Offgas Treatment System

- Secondary HLW Offgas Treatment System
  - condenser
  - caustic scrubber
  - catalytic oxidizer
  - HEPA filtration

Vessel ventilation system emissions will be combined with the melter offgas before the HEPA primary treatment system. The HLW melter system emissions will be further treated in the secondary

offgas treatment system. After treatment by the secondary offgas treatment system, the combined HLW offgas will be discharged to the building ventilation system for filtration by the main facility HEPA filters before being monitored and discharged to the environment through the main stack. A simplified process flow diagram of the entire BNFL facility treatment process is provided as Figure 3.2.1.

B.2.3.4 Immobilized High-Level Waste Canister Decontamination

The purpose of the IHLW canister decontamination system is to remove smearable radionuclide surface contamination from the filled and sealed IHLW canister. A cerium (Ce) decontamination system has been selected as the current reference process. A final decision on the type of decontamination system to be used has not been made.

The IHLW canister decontamination will start at the weld station where each canister lid will be welded in place. Visual examinations will be made at the weld station, by eye and by closed circuit television, for the presence of visible glass on the canister. In the unlikely event that any glass is found, a wire brush or other mechanical tool will be used to remove the glass. After the lid has been welded to the canister, the filled and sealed IHLW canister will be moved to the canister decontamination system where the following operations will be performed:

- Inspect the canister for the presence of visible glass, and physically remove it if present.
- Open the lid on the canister decontamination tank, lower canister into the empty tank, and replace the lid.
- Establish sparge airflow in the decontamination tank and accept transfer of decontamination solution (solution of nitric acid and eerie nitrate) made up in the out-of-cell mix station.
- Adjust the temperature of the canister decontamination solution to approximately 65°C (via heating and cooling coils) and maintain temperature for six hours.
- Transfer the spent decontamination solution to the neutralizer tank.
- Remove the decontamination tank lid and grapple the canister.
- Initiate nitric acid spray wash flow (to remove solution residue from the canister) and lift the canister through the spray rings. When the canister is clear of the spray rings, shut off the spray. Transfer the acid rinse to the neutralizer tank. Lower the canister back into the decontamination tank.
- After transferring the wash (rinse) solutions to the decontamination tank, add hydrogen.
- Peroxide to deactivate the spent decontamination and wash solutions and transfer the contents to the waste handling system for possible pretreatment prior to recycle for vitrification.

- Repeat spray wash procedure using water. Return the canister to the empty decontamination tank to dry.

- Smear test the air-dried canister according to approved procedures.

- Transfer the decontaminated canister to storage.

Safety and interlock features have been identified for the LAW canister decontamination system; these are preliminary and will be finalized upon completion of design. The preliminary safety and interlock features include tank liquid level monitoring (level indication and interlocks), and tank temperature monitoring.

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Appendix C

Documents Reviewed

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Documents Reviewed

C.1.1 Front Material and Review Team Guidance

Review Correspondence and Action Plan

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Cooley. June 1999. Comments on the Report Outline – Technical Alternatives to Reduce Risk in the Hanford Phase 1 River Protection Project.

C.1.2 Program Description

Report To Congress: Treatment and Immobilization of Hanford Radioactive Tank Waste, July 1998

An End State Methodology for Identifying Technology Needs for Environmental Management With an Example from the Hanford Site Tanks, March 1999.

Tank Waste Remediation System Retrieval and Disposal Mission Readiness-to-Proceed Memorandum, HNF-2019 Rev. 1.

Tank Waste Remediation System Retrieval and Disposal Mission Key Enabling Assumptions. January 1998. HNF-1945.

Management Assessment of Tank Waste Remediation System Contractor Readiness to Proceed With Phase 1B Privatization. January 1998. HNF-2021.

96-WDD-029, J. Kinzer to Dr. AL Trego, "Office of Tank Waste Remediation System (TWRS) High-Level (HLW) Canister Projection Assessment and Project Baseline Guidance."

DRAFT ORP Plan for Developing Hanford Tank Waste Processing Alternatives, Rev. 0, May 7, 1999.

USDOE, Richland Operations News Release, *DOE and BNFL Inc. Sign Contract for Hanford Tank Waste Treatment, Environment and Local Community to Benefit* August 24, 1998.

C.1.3 PHMC Technical Baseline

TWRS Technical Baseline Summary Description, January 1998, HNF-2016 Rev. 0.

Tank Waste Remediation System Retrieval and Disposal Mission Technical Baseline Summary Description, January 1998, HNF-1901.

TWRS Retrieval & Disposal Mission Waste Feed Delivery Plan, January 1998, HNF-1881, Rev. 0.

HNF-SD-WM-SP-012, Rev. 1 Vol. I and II - Tank Waste Remediation System Operation and Utilization Plan; May 5, 1999.

DOE/RL-97-69 Rev. 0, Performance Assessment/Key Assumptions –

WHC-SD-WM-TI-737, Rev. 0, Tank Waste Remediation System Optimized Processing Strategy with an Altered Treatment Scheme.

LAW and HLW Risks

Presented by PHMC but not provided at May 12 meeting

- Feed Delivery E Drawings
- Project W-211 Initial Tank Retrieval System

C.1.4 BNFL Flowsheet and Product Description

BNFL Contract TWRS Privatization Contract No. DE-AC06-96RL13308- Mod No. A006

Tank Waste Remediation System Privatization Project: Technical Report – Volume 1. 1998.

BNFL Phase IA Supporting Documentation for Technical Report and Waste Products and Secondary Wastes Plan (3 Binders).

Tank Waste Remediation System Privatization Project: Wastes Products and Secondary Wastes Plan. 1998.

WSRC-MS-98-00589 Research and Development Activities in Support of Hanford Privatization – SRTC Program (U).

BNFL, Inc., *Preliminary TWRS-P Facility Dangerous Waste Permit Application,* BNFL-5193 RCRA-01, Rev. 0C, May 7, 1999.

PL-W375-TE00002, Rev. 0, TWRS-P Project Development Requirements Document.

SD-W375LV-PR00004, LAW Melter Offgas System Description, T. Anderson; E. Berrios

BNF-003-98-0041 Rev: 1, BNFL Interim Report on Candidate Technetium Analyzers, February 22, 1999.

C.1.5 Retrieval and Characterization Technology Evaluations

Mixer Pump Issues; Peter Gibbons

ASTD/Tank Sludge Retrieval, Conditioning, & Transfer – Appendix A.

Nested, Fixed-Depth Fluidic Sampler for Representative Sampling of Waste Feed Staging Tanks; Tom Thomas, June 3, 1999.

HNF-4219 Rev. 0 – Alternatives Generation and Analysis for Phase 1 High-Level Waste Feed Tanks Selection, May 1999.

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http://ost.em.doe.gov/tms/Home/Frameset.asp

Characterization, Monitoring, and Sensor Technology Crosscutting Program technology descriptions in TMS database. http://ost.em.doe.gov/tms/Home/Frameset.asp

C.1.6 Pretreatment Technology Evaluations

Assessment of Commercially Available Ion Exchange Materials for Cesium Removal From Highly Alkaline Wastes, September, 1994, TWRSPP-94-095.

Comparison of Organic and Inorganic Ion Exchangers for Removal of Cesium and Strontium from Simulated and Actual Hanford 241-AW-101 DSSF Tank Waste, January 1996, PNL-10920.

Review of Technologies for the Pretreatment of Retrieval Single-Shell Tank Waste at Hanford, August 1992, PNL-7810.

Review and Assessment of Technologies for the Separation of Strontium from Alkaline and Acidic Media, January 1994, PNL-9053.

Memorandum: High Level Waste Salt Disposition Alternatives Roadmaps. November 30, 1998.

Memorandum: Salt Alternatives Phase III Technical Review (U), SRT-WPT-98-0026.

DOE/ID-10672 Independent Assessment of the Savannah River Site High-Level Waste Salt Disposition Alternatives Evaluation.

HLW Salt Disposition Alternatives Identification Preconceptual Phase II Summary Report.

US DOE Fact Paper – Cesium Treatment Approaches at the Savannah River and Hanford Sites, September 21, 1998.

WHC-SD-WM-ES-321, Rev. 0, In-Tank Processes for Destruction of Organic Complexants and Removal of Selected Radionuclides.

Latest BNFL Pretreatment Development Status Packet:

Crossflow Filtration and Complexant Chemistry with an AN107 Simulant; C.A. Nash, S.W. Rosencrance, B.W. Walker.

Status of Sr/TRU Precipitation Scoping Tests; W.R. Wilmarth, V.B. Dukes

Cross-Flow Filtration Studies; Kriston Brooks, Rich Hallen

Hanford TWRS Privatization Ion Exchange and Mixing Study Update; Daniel J. McCabe, nequib M. Hassan, William D. King, John L. Steimke, Micheal A. Norato, L. Larry Hamm, Frank G. Smith

Ion Exchange Batch Contacts; Dean Kurath, DL Blanchard, JR Bontha

TFA Pretreatment Activities; C.P. McGinnis, June 2, 1999

Efficient Separations and Processing Crosscutting Program technology descriptions on TMS database. http://ost.em.doe.gov/tms/Home/Frameset.asp

C.1.7 Vitrification Technology Evaluations

Literature Review of Arc/Plasma, Combustion, and Joule-Heated Melter Vitrification Systems, July 1995, PNL-10666.

Melter System Technology Testing for Hanford Site Low-Level Tank Waste Vitrification, WHC-SA-3092-FP.

WHC-EP-0847, HLW Melter Technologies

WHC-SD-WM-TI-768, Processibility Assessment Report

WHC-SD-WM-ER-498, LLW Melter Evaluation

SRT-ITS-99-0001 – Tanks Focus Area Product Delivery Expectations Improve Waste Loading in HLW Glasses; E.W. Holtzscheiter, February 3, 1999.

Improve Waste Loading in HLW Glasses; Bill Holtzscheiter

Testing and Prediction of Long Term Waste Glass Performance; Bill Holtzscheiter

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Radioactive Isolation Consortium, LLC. 1999. Executive Summary of the Results of the AVS Phase 1 Program. http://www.ricllc.com/doc.htm

C.1.8 Other Technology Evaluations

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TWRS Technetium Workshop. 1998

Packet ORPSAS (ORP Decision Papers, April 1999)

- Optimization of Treatment System and Facility Concepts – Phase I Capacity
- Optimization of Treatment System and Facility Concepts – Capability for Phase II Expansion
- Selection of ILAW Waste Form for TWRS Phase I Privatization
- LAW Feed Receipt Tank Decision Paper
- Entrained Solids Storage Tank Decision Paper
- Management of Envelope B Low- Activity Waste
- Incorporation of Hanford Cs and Sr Capsule Treatment and Immobilization in the BNFL Privatization Contract
- Cesium- 137 Low- Activity Waste Envelope Definition Concentration Limit
- Minimum Sodium Concentrations Specification in the Low-Activity Waste Feed
- Americium- 241 High-Level Waste Envelope Definition Limit
- Minimum Solids Concentration Specification in the High-Level Waste
- Alternative ILAW Packaging Optimization Study Decision Paper
- Alternative Vitrified Waste Forms Optimization Study Decision Paper
- Non-Radioactive, Non-Dangerous Liquid Effluent Buffer Capacity Decision Paper
- Radioactive, Dangerous Liquid Effluent Buffer Capacity Decision Paper
- IHLW Transportation and Interim Storage Paper
- Immobilized Low-Activity Waste (ILAW) Lag Storage Capacity Decision Paper
- Immobilized High-Level Waste (IHLW) Lag Storage Capacity Decision Paper

Tanks Focus Area technology descriptions in TMS database.
http://ost.em.doe.gov/tms/Home/Frameset.asp

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Appendix D

Resumes of Assessment Team Members

Appendix D

Table D.1. Technical Alternatives Assessment Team

Dr. Harry D. Harmon, Team Leader Harmon Consulting HLW Programs at Hanford and SRS, Separations Chemistry, Tank Operations, Systems Integration, Technology Development, Formerly Chairman of TFA User Steering Group	Mr. John L. Swanson Private Consultant Radionuclide Separation Process Development for Hanford Tank Wastes at PNNL, Member of TFA Technical Advisory Group
Dr. James H. Lee Sandia National Laboratories Formerly TFA Technical Integration Manager for Retrieval, International Waste Management and Nuclear Programs	Dr. Larry L. Tavlarides, Professor, Syracuse University, Department of Chemical Engineering and Materials Science, Participant in Efficient Separations Program, Member of Independent Review Team on Cesium Removal Alternatives at SRS, Member of TFA Technical Advisory Group
Dr. M. John Plodinec DIAL / Mississippi State University Vitrification Experience at SRS with DuPont and Westinghouse Savannah River Company, DWPF Waste Qualification, Formerly TFA Technical Integration Manager for Immobilization	Dr. Major C. Thompson Savannah River Technology Center Radionuclide Separations, Fuel Reprocessing, Participant in Efficient Separations Program, Member of WSRC Independent Review Team on Cesium Removal Alternatives, Member of TFA Technical Advisory Group
Mr. John H. Roecker Private Consultant Tank Waste Remediation System and Other Waste Management Experience at Hanford With Westinghouse Hanford and Rockwell, Process and Systems Integration, Member of National Research Council Committee on End States	Dr. E. Thomas Weber Private Consultant Vitrification Experience at Hanford and other DOE Sites, Glass Performance, Product Acceptance, Member of TFA Technical Advisory Group
Mr. Wally W. Schulz W2S Company, Inc. Waste Management Experience at Hanford, Tank Operations, Characterization, Pretreatment, Member of Independent Review Team on Cesium Removal Alternatives at SRS, Chairman of TFA Technical Advisory Group	Dr. Frank E. Woolley Corning Incorporated (Retired) Industrial Glass Melter Operations and Development, Specialty Glass Composition Development, Previous Reviews of Hanford Vitrification Alternatives

HARRY D. HARMON
20 Midlothian Court East
Aiken, South Carolina 29803
803-641-0407
e-mail: hdharmonl@aol.com

EDUCATION: B.S., Chemistry, 1968, Carson-Newman College, Jefferson City, TN
Ph.D., Inorganic and Nuclear Chemistry, 1971, University of Tennessee, Knoxville, TN

WORK EXPERIENCE:

1998 - Present **Senior Consultant, Harmon Consulting**.
Providing technical and management consulting in the areas of waste management, environmental programs, nuclear processing, separations chemistry and engineering, actinide chemistry, and technology development in these and related areas.

1997-1998 **Senior Program Manager, Savannah River and Oak Ridge Programs, NUKEM Nuclear Technologies**.
Managed NUKEM's activities in pursuing waste management, environmental remediation, and nuclear processing contracts at these DOE Sites. Directed proposal development and provided technical input and specific knowledge of site operations.

1996-1997 **Vice President, Tank Waste Programs, M4 Environmental Management, Inc**.
Managed M4 programs in support of the Hanford Tank Waste Remediation System Phase 1 A privatization contract. Also, led efforts to pursue other major tank waste programs such as the Melton Valley Storage Tanks and TRU Solid Waste Procurement.

1994-1996 **Technical Director, High Level Waste Management Division, Westinghouse Savannah River Company**.
Provided expert technical advice and process overview for all High Level Waste activities and programs. Ensured that a cost effective, innovative, technology development program was conducted in support of the High Level Waste Management Division. Represented WSRC as Chairman of the User Steering Group for the High Level Waste Tank Remediation Focus Area. Strived to leverage external resources to meet WSRC HLWM technology needs.

1992-1994 **Vice President, Tank Waste Remediation System Division, Westinghouse Hanford Company**.
Expanded the organization described below to include the long-term disposal of tank wastes—retrieval, pretreatment, vitrification, and grout processing. This formed the overall system required to safely manage the waste tanks and process the waste for ultimate disposal. A detailed New Technical Strategy for tank waste was developed based on a system engineering approach. The 1200-member organization included program control, operations, engineering and projects. The FY-93 budget was $490 million and exceeded $600 million in FY-94.

1990-1991 **Vice President, Waste Tank Safety, Operations & Remediation, Westinghouse Hanford Company**.
Organized a new division in Westinghouse Hanford Company to focus on mitigation and remediation of the high visibility waste tank safety issues. The organization was also responsible for the ongoing operations of the 177 waste tanks, the waste evaporator, and restoration and upgrades of the tank farm equipment. The position demanded extensive interface and presentations to external review groups and significant interactions with the media, including monthly media briefings. The organization consisted of about 615 people with an equivalent number of matrix support in other divisions; the FY-91 budget was $155 million.

1989-1990 **Manager, Chemical Processes and Environmental Technology Department, Savannah River Laboratory, Westinghouse Savannah River Company**.
Responsibilities same as previous position except non-reactor facility safety oversight and safety analyses moved to another organization.

1987-1989 **Program Manager, Chemical Process and Environmental Technology, Savannah River Laboratory, E.I. du Pont de Nemours & Company**.
Program Manager for five divisions (Actinide Technology, Analytical Development, Non-Reactor Safety Evaluation, Environmental Sciences, and Environmental Technology) consisting of about 130 exempt and 90 non-exempt employees. Major program areas included fuel reprocessing process and equipment development, safety analyses, on-line analyzers, process control, analytical services, non-reactor facility safety oversight, emergency response, environmental dosimetry, low-level measurement techniques, terrestrial and aquatic ecology, groundwater characterization, and biotechnology. Also, responsible for small Budget Group and SRL Library.

1986-1987	**Research Manager, Interim Waste Technology Division, Savannah River Laboratory**. Managed process and equipment research and development for all SRP waste management operations excluding the Defense Waste Processing Facility. Work included in-tank processing, effluent treatment technology, low-level waste, transuranium waste, hazardous waste, and safety analysis reports for these operations.
1980-1986	**Research Manager, Actinide Technology Division, Savannah River Laboratory**. Managed process and equipment research and development for the SRP fuel reprocessing areas including canyon operations, plutonium finishing, Neptunian finishing, and transplutonium recovery. Also, responsible for preparation of safety analysis reports for all Separations Area facilities.
1980	**Research Manager, Fuel Cycle Technology Division, Savannah River Laboratory**. Managed the development of LWR and breeder fuel reprocessing technology and the development of alternative waste forms for SRP high-level waste. Interfaced extensively with Oak Ridge National Laboratory and other DOE sites.
1977-1979	**Area Superintendent and Assistant Department Superintendent, Separation Department, Savannah River Plant** As Area Superintendent in Separations Department, led startup of Multi-purpose Processing Facility (MPPF) to meet production commitment of Am-241 and supervised the plutonium metal fabrication area (FB-Line). After promotion to Assistant Superintendent of Separations Department, was administrative head of H-Area (about 850 people at that time) and directly in charge of H-Canyon Reprocessing Plant, Receiving Basin for Off-site Fuel, and Tritium Facilities.
1973-1977	**Research Chemist and Research Supervisor at Savannah River Laboratory**. As a research chemist, conducted research in fuel reprocessing areas including dissolution of nuclear fuels, Pu02 dissolution, solvent extraction, and stability and reactions of tributylphosphate during thermal denitration of uranyl nitrate. Became research supervisor in 1976 and supervised the fuel-reprocessing group for about one year. Then moved to supervise a waste management group in the same division that was responsible for vitrification and ion exchange development in support of the Defense Waste Processing Facility.

1971-1973	**Assistant Professor of Chemistry, Walters State Community College, Morristown, TN** Began chemistry program in new institution.
1965-1971	Summer employment and Ph.D. Thesis with Union Carbide in Chemical Technology Division, Oak Ridge National Laboratory
1966-1968	(Part-time) Organic Synthesis in Cancer Research Program at Carson-Newman College

PUBLICATIONS
DR. HARRY D. HARMON

1. J. McDowell and H. D. Harmon, "Sodium and Strontium Extraction from Sodium Nitrate Solutions by n-Octane Solutions of a Branched Aliphatic Monocarboxylic Acid: Mechanism and Equilibria," J. Inorg. Nucl. Chem., **31** 1473-85 (1969).

2. C. T. Banner, D. H. Brotherton, M. K. Brotherton, H. D. Harmon, N. H. Bingham, L. M. Rives and S. L. Watson, Journal of Medicinal Chemistry, **13**,1240 (1970).

3. W. J. McDowell and H. D. Harmon, "Unsymmetrical Dialyki Sulfoxides as Extractants," J. Inorg. Nucl. Chem., **33**, 3107-3117 (1971).

4. H. D. Harmon, Thiocyanate and Chloride Complexes of Some Trivalent Actinides, "ORNL-TM-3486," Oak Ridge National Laboratory, July 1971.

5. H. D. Harmon, J. R. Peterson, W. J. McDowell, and C. F. Coleman, 'The Tetrad Effect: The Thiocyanate Complex Stability Constants of Some Trivalent Actinides, J. Inorg. Nucl. Chem. **34** 1381-1397 (1972).

6. H. D. Harmon, J. R. Peterson, J. T. Bell, and W. J. McDowell, "A Spectrophotometric Study of the Formation of Americium Thiocyanate Complexes," J. Inorg. Nucl. Chem., **34**,1711-1719 (1972).

7. H. D. Harmon, J. R. Peterson, and W. J. McDowell, The Stability Constants of the Monochloro Complexes of Bk (III) and Es (III)," Inorg. Nucl. Chem. Letters, **8**, 57-63 (1972).

8. Carl T. Bahner, Norma H. Bingham, David H. Brotherton, Jane Cline, Dan Darby, Harry D. Harmon, Lydia M. Rives, Bill L. Stump, and Stuart L. Watson, "Anticancer Compounds. Further Analogs of 1-(4-Dimethylaminobenzylidene) indene," Journal of Medicinal Chemistry, **16**, 421-425 (1973).

9. H. D. Harmon, "Hydrothermal Precipitation of $Ce0_2$ from Ceric Ammonium Nitrate-Nitric Acid Solution," Inorg. Nucl. Chem. Letters, **10**, 1031-1038 (1974).

10. H. D. Harmon, "The Decontamination of Dissolved U-Al Fuel by Simultaneous Treatment with Gelation and $Mn0_2$," DP-1376, Savannah River Laboratory, March 1975.

11. H. D. Harmon, "Dissolution Of PuO_2 with Cerium (IV) and Fluoride Promoters," DP-1 371, Savannah River Laboratory, October 1975.

12. H. D. Harmon, "Evaluation of Fluoride, Cerium (IV), and Cerium (IV)-Fluoride Mixtures as Dissolution Promoters for $Pu0_2$ Scrap Recovery Processes," DP-1383, Savannah River Laboratory, October 1975.

13. H. D. Harmon, J. R. Peterson, W. J. McDowell, and C. F. Poleman, "Phosphine Oxide and Quaternary Ammonium Extraction of Americium (III) from Concentrated Chloride Solutions," J. Inorg. Nucl. Chem., **38**, 155-159 (1976).

14. G. A. Burney, H. D. Harmon, and M. L. Hyder, "Recovery of Americium-241 from Aged Plutonium," DP-1419, Savannah River Laboratory, July 1976.

15. H. D. Harmon, M. L. Hyder, B. Tiffany, L. W. Gray, and P. A. Soltys, "Behavior of Tributylphosphate in A-Line Processes," DP-1418, Savannah River Laboratory, August 1976.

16. Carl Tabb Bahner, Truett C. Patterson, Lydia M. Rives, and Harry D. Harmon, "Platinum and Palladium Derivatives for Chemotherapy Studies," Journal of Medicinal Chemistry, **22**, 575-577 (1979).

17. H. D. Harmon, "Trends in Actinide Processing at Hanford," Presented at Actinides-93 International Conference, Santa Fe, New Mexico, September 19-24, 1993, (published in Conference Proceedings).

18. H. D. Harmon and Marilyn C. Druby, "Hanford's Latest Achievements: Mixer Pump and New Long-Term Waste Treatment Plans," Radwaste, **1,** 36-41 (1994)

JOHN H. ROECKER
N. 17123 Brookside
Colbert, WA 99005
Telephone (509) 468-2291
FAX (509) 468-2291
email: jroecker@unix.ieway.com

CAREER OBJECTIVE

To make a significant contribution as a part-time technical staff member or consultant for an operating, engineering, program management, or consulting organization in nuclear waste technology and/or management.

SUMMARY OF QUALIFICATIONS

- Experienced and successful management of large engineering, operating, and program organizations for complex high technology operations.
- Broad technical background.
- Directed engineering development of process improvements leading to increased plant throughput and long-term waste disposal cost savings.
- Directed development of integrated systems engineering management for large, diverse organization.
- Experienced with development and management of customer and contractor interfaces.
- Recognized and respected as developer of young management and technical talent.

PROFESSIONAL CREDENTIALS

- Bachelor of Science Degree, Engineering Physics, University of Illinois - 1956
- Graduate Studies, Physics, University of Illinois - 1957
- Registered Professional Nuclear Engineer (1975 - 1996)

COMMUNITY AND PROFESSIONAL INVOLVEMENT

Member - American Nuclear Society
Member - Executive Board, ANS Power Division (1984)
Member - ANS National Planning Committee (1984)
Member - National Management Association (1977 - 1987)

SECURITY CLEARANCE LEVEL

U.S. Department of Energy, Q-Clearance, (1958-1993)

WORK EXPERIENCE

More than 40 years of experience in engineering, operations, and program management, including radioactive and hazardous waste management, nuclear chemical processing, space nuclear auxiliary power systems, breeder reactors, and commercial nuclear systems.

- Includes more than thirteen years of executive-level experience in complex nuclear and chemical engineering and management, and more than 21 years of project and program management experience.

As self-employed consultant participated in critical reviews of nuclear waste management and technology programs at Hanford and Savannah River Sites (1/93-Present).

- High-Level Waste Committee, National Academy of Science
- TWRS Preliminary Safety Analysis Report, Lockheed Martin Co.
- TWRS Privatization Proposal, Lockheed Martin Co.
- Project Hanford Management Contract Proposal, Lockheed Martin Co.
- High-Level Waste System Review, Westinghouse Savannah River Co.
- TWRS Alternative Configuration Study Review, Westinghouse Hanford Co.
- TWRS Systems Engineering Review, Westinghouse Hanford Co.
- TWRS Multiyear Program Plan Review, U.S. Department of Energy, Richland
- Systems Engineering Course, Systems Management and Development Co.

As manager of Tank Waste Remediation System (TWRS) Program Integration, Westinghouse Hanford Company was responsible for management of program planning and integration, systems engineering, integrated technology planning, and NEPA and regulatory permit planning and integration. Responsibilities included senior management level support to the interface with the Department of Energy. Managed a staff of approximately 35 professional personnel and an annual budget of approximately $14 million (1/92-10/93).

- Prepared and maintained the TWRS Decision Plan.
- Introduced and initiated application of systems engineering principles within the TWRS program.
- Developed the TWRS New Technical Strategy (NTS).
- Provided lead technical support to the USDOE during Hanford Federal Facility Agreement and Consent Order negotiations.

As deputy manager-of Defense Waste Remediation, Westinghouse Hanford Company was responsible for providing management and technical support to the manager and other senior Westinghouse management (1/91-1/92).

- Provided management and technical leadership in the development of the Tank Waste Disposal Redefinition Study.

- -- Provided impetus to management for the integration of the Double Shell Tank Waste Disposal Program and the Tank Safety Program into a single integrated Tank Waste Remediation System program.

As Assistant to the Vice President, Environmental and Waste Management, Westinghouse Hanford Company was responsible for providing technical staff support (11/90 - 11/91).

As director of Plutonium Recovery Modification Project, Rocky Flats Plant, Rockwell International was responsible for project and technical management of the upgrading and modification of the plutonium recovery facility. Responsibilities included day-to-day management of the architect-engineer, identification and coordination of the supporting technology development needs, day-to-day management of the construction contractor. Managed a staff of approximately 60 professionals and an annual budget of approximately $30 million (7/87 to 10/90).

As director of Defense Waste Management and Decontamination and Decommissioning Operations, Rockwell Hanford Operations, was responsible for executive-level management of programs and operations, including long-range waste disposal planning, near term program budget and schedule planning and control, waste disposal technology, site-wide hazardous waste management, project management of new facilities construction and modifications to existing facilities, development of public information programs, and safe and economical operations of waste handling facilities. Responsibilities also included principal executive-level interface with Department of Energy as well as other on site contractors for defense waste and decontamination and decommissioning programs. Managed a staff of approximately 550 professional and craft personnel and an annual budget of approximately $130 million (1986-1987).

- -- Organized Hanford Environmental Management Program Office for site-wide management of hazardous waste compliance program.
- -- Managed design of Hanford Waste Vitrification Facility. Capital expenditure approximately $650 million.
- -- Operating facilities achieved record production and safety records.
- -- Initiated hazardous waste compliance actions meeting agency schedule commitments.

As director, Research and Engineering, Rockwell Hanford Operations, was responsible for providing technical direction and engineering support for Rockwell Hanford Operations chemical processing and waste management programs and plant operations, including systems engineering; engineering analysis; equipment development and design; and process chemistry development and control. Responsibility also included providing engineering management of construction projects, as well as managing and implementing company-wide engineering policies and procedures. Managed a staff of approximately 675 with an annual budget of approximately $80 million (1979-1986).

- -- Directed engineering of process changes resulting in an-increase of PUREX headend throughput capability by more than 30 percent.

- -- Established a close, constructive working relationship with Kaiser Engineers Hanford Company on engineering and design activities for construction projects.
- -- Established a close, constructive working relationship with Pacific Northwest Laboratory on chemical processing and waste management technology development.
- -- Redesigned the engineering management system to incorporate a systems engineering approach to program/project management.
- -- Managed the development and preparation of the waste management and chemical processing technology and program plans.
- -- Introduced the Triad of Excellence Program to enhance pride, innovation, and quality

As program director, Defense Waste Management Program, Rockwell Hanford Operations, was responsible for the direction and control of all program management associated with the interim management of radioactive wastes, as well as planning and development of programs to enhance operational performance of facilities. Defense Waste Management had an annual budget of approximately $40 million (1977-1979).

- -- Managed waste management program activities leading to the successful completion of the tank farm "currency" program in 1977, a Department of Energy Congressional commitment.
- -- Initiated development activities in cesium and strontium processing that led to significantly improved production rates. Six-month production run exceeded one half of prior four-year total production.
- -- Initiated development activities that resulted in significantly improved salt-well jet pump performance.

As a project manager on the Prototype Large Breeder Reactor, Atomics International, was responsible for the management of the architect/engineer contractor, providing engineering support for the balance-of-plant and for the development of overall plant criteria and requirements, fuel handling system design, and plant cost estimates (1975 -1977).

- -- Managed maintenance engineering studies for repair, removal, and replacement of large components for both loop and pool-type LWBRs.

As a senior engineer at Southern California Edison Company, was responsible for systems and equipment engineering for the San Onofre Nuclear Generating Station and for providing technical direction on contract negotiations with the Nuclear Steam Supply System contractor (1973-1975).

As project manager of FFTF Closed Loop System, Atomics International, was responsible for the systems engineering analysis and design, component design and procurement, remote maintenance engineering studies, and module mockup fabrication (1969-1973).

As manager of Nuclear Test Engineering, Atomics International, was responsible for analysis and evaluation of test data from all nuclear testing (1966-1969).

As project engineer of SNAP Nuclear Test Operations, Atomics International, was responsible for nuclear ground testing of the SNAP 8 Reactor, including design, construction, and operation of test facilities (1960-1966).

Experienced and successful management of engineering, operations, and programs.

JAMES H. LEE, Jr.
505-844-6937 (O)
505-286-2823 (H)

Education/Professional Accreditation:

B.S. United States Military Academy (West Point), 1966
M.E. (Nuclear Engineering) Texas A&M University, 1968
Ph.D. (Nuclear Engineering) Texas A&M University, 1973
Registered Professional Engineer, Virginia 1977-Present

Summary of Qualifications:

Profile:

- Proven ability to organize and direct large, complex development programs.
- Proven capability to create and manage highly technical research programs in the competitive private market place.
- Experienced in marketing technical research programs.
- Expertise in nuclear materials control and protection.
- Recent experience and strong success as a UN Weapons Inspector in Iraq.
- 20 years of diverse technical and military leadership positions with the United States Air Force and Army to include.
- Additional experience as a college professor in Math, Physics, Thermodynamics, and Nuclear Engineering.
- Strong academic background in Nuclear Engineering (Ph.D., M.E.).
- Recognized expert in nuclear safety of space reactors and satellite survivability. Expertise in environmental remediation technologies.
- Demonstrated ability to quickly assimilate new technology areas, efficiently coordinate diverse groups and complex projects.

Oct 1997-Present: In FY98 selected as the Department Manager (Department 6413) for 12 personnel involved in accident and consequence analysis for a variety of customers including the Nuclear Regulatory Commission as well as the DOE/DP. Major projects include risk assessment for commercial power reactors and safety assessments in support of the Nuclear Weapons Program at Sandia Labs. Continued as the SNL project leader for the MPC&A efforts at Krasnoyarsk-26 with the mission of providing Physical Protection Upgrades to a site with multiple metric tons of weapons grade Plutonium and a annual budget of $ 3.2 M. Project leader of two Initiatives for Proliferation Prevention (IPP) projects involving the consortium of Russian Radiochemistry Institutes. Served two months in Iraq as a National expert on the IAEA Action team. Was cited for setting a new standard of technical excellence in the on-going monitoring and verification of the Iraqi Nuclear Weapons Program.

April 1996-Sept 1997: Department Manager, Sandia National Labs. Program Manager for the $9M Retrieval and Closure Program of the DOE EM-50 Tanks Focus Area. This program developed state of the art environmental cleanup technologies for use in High Level Waste (HLW) Tanks. Included are the first deployment of the Light Duty Utility Arm System (LDUA) (deployed in September 1996) in an actual HLW tank at Hanford, deployment of

the LDUA and a Confined Sluicing End Effector (CSEE) at ORNL(deployed in June 1997), and the Cleaning and Closing of a tank at SRS (Tank 20 at SRS started closure in May 1997) . Additionally, served in FY97 as the SNL lead scientist for Material, Protection, Control, and Accountability (MPC&A) projects at two Russian Sites (Krasnoyarsk-26 and Krasnoyarsk-45). The SNL budget for these two sites were approximately $1.5 M per year in FY 97 and $3 M for FY 98. These projects are focused on upgrading physical protection systems for large caches of weapons grade materials in Russia. Acting Manager for the Systems Reliability Department while Manager was on special assignment creating the Center For System Reliability. Created in 1997 a consortium of six Russian Radiochemistry Institutes and SNL to pursue High Level Waste Tank Remediation business in the U.S. DOE Complex.

April 1994-April 1996: Sandia National Laboratories with duty assignment at the DOE Hanford Site. Program Element Manager for Retrieval Programs in the Technology Development Program Office of the Tank Waste Remediation System (TWRS). Developed Technology Programs to safely and cost effectively remove 61 million gallons of highly radioactive nuclear waste from 177 underground high level waste storage tanks. Focus was on reducing the projected $10 Billion Retrieval cost for this site while successfully removing 99% of the stored waste. Selected in October 1994 as one of the lead scientists for the new DOE National Tank Focus Program with emphasis on defining, designing and executing Retrieval and Closure strategies for the High Level Tank Waste Storage Systems at four major DOE sites. In May 1995 selected as the Technology Integration Manager for both Retrieval and Closure with responsibility for the planning and execution of a $ 12 M program to deliver a new robotic arm system, to develop and deliver new retrieval and characterization end effectors for use with this arm and to clean and close a waste tank at Savannah River Site. The first of these state-of-the-art robotic arms was successfully delivered to the Hanford site in April 1996. The Tanks program also received a DOE Outstanding Rating for FY95.

Jan 1993-April 1994: Sandia National Laboratories; Department Manager for the Space Nuclear Power Department. Manager for 15 research personnel and a budget of over $4 M in the area of space power sources and radiation hardened electronics. Manager of Program Development for the Nuclear Energy Technology Center, 6400. Responsible for initiating new research programs in such diverse areas as Silicon Carbide Electronics, Risk Assessment applied to non-nuclear systems, Decontamination and Decommissioning of Nuclear Power plants, and others.

March 1992-Jan 1993: Sandia National Laboratories; on assignment to the US Air Force Phillips Laboratory, Albuquerque, New Mexico. Project Manager for the $70 M Topaz Reactor Flight Project. Responsible for acquisition, safety analysis to obtain launch approval, directing system modifications to meet U.S. flight and safety standards, and conducting flight qualification and delivery of a Russian Space Reactor, Topaz II, to the Nuclear Electric Propulsion Space experiment spacecraft. Directed the technical efforts of over 50 personnel. TOPAZ team members included personnel from Los Alamos, Sandia National Labs, the Air Force Phillips Laboratory, three Russian Institutes and several private U.S. companies. Produced an outstanding Preliminary Safety Assessment of the flight mission and conducted a detailed Concept Design Review for needed reactor modifications. Active interface with Russian institutes, DoD, DOE, OMB, Congressional Staff, and National Space Council.

June 1991-Mar 1992: Sandia National Laboratories, group supervisor for the Space Nuclear Power and Safety Group. Research at SNL focused on thermionic space nuclear reactors and space reactor safety. Consultant to the Strategic Defense Initiative Organization on space power technology, international aspects of use of space nuclear power and orbital debris. Project manager of a design, development and construction project for a special purpose facility to test nuclear fuel elements for the Space Nuclear Thermal Propulsion (SNTP) program. This facility (PIPET) was also designed for ground based testing of various nuclear rocket concepts. Supervised 80 technical and support personnel on this project. Led this team in a highly successful effort to design this nuclear test facility to a

Preliminary Design Review (PDR) level of detail in February 1992. Active interface with various levels of DoD, DOE, NASA, OMB and National Space Council.

March 1990-June 1991: Sandia National Laboratories; on assignment to the Strategic Defense Initiative Organization (SDIO), Washington, DC. Served as the Technical Adviser and Deputy Program Manager for the SDIO Power and Power Technologies Program. The Power and Power Technologies Program had an annual budget of over $60M, was at the forefront of worldwide development of power technologies, and was an essential element of major national defense initiative. While at SDIO, served as a member of a technical delegation to the United Nations on the safety of space nuclear power. Represented the Department of Defense and SDIO on two delegations to the Soviet Union to negotiate the purchase and transfer of the TOPAZ space nuclear power source. Supported the Interagency Committees reviewing U.S. policy of acquisition of Soviet technology.

1987-1990: Vice-President, S-Cubed, a Division of Maxwell Laboratories; Albuquerque, NM. Supervised over 50 scientists, engineers, technicians, and support personnel as well as over $6.5M in research per year. Research areas included design of special instruments for Underground Nuclear Tests (UGT), state-of-the-art environment monitoring systems, expert computer systems and system survivability studies of SDIO space platforms. Initial work there involved survivability analysis for the Strategic Defense Initiative Organization (SDIO), and analysis of special purpose terrestrial nuclear power sources for the Defense Nuclear Agency. Designated in 1987 by SDIO as the focal point for all survivability issues associated with prime power systems. Also established a new 18 person research group investigating design, safety, and survivability of special space and terrestrial power sources. Served as a technical editor to DOE/DP-3 to review the major study on the Modernization of the U.S. Nuclear Weapons Complex.

1986-1987: Sandia National Laboratories, Member of the Technical Staff. Leader of the Independent Safety Group for the National Space Reactor Program, SP-100. Emphasized safety analysis of space reactor during on-orbit accidents. Performed detailed analysis of on-orbit loss of cooling events for the SP-100 reactor. Also led a major independent assessment of a small reactor for DoD terrestrial application. The study team consisted of 11 experts from three national laboratories and private industry. The study reviewed the neutronic and thermodynamic design of the power system, its inherent safety, its development costs, and the length of its development program. Results of this successful independent assessment were briefed to the Assistant Secretary of Defense, C3I.

Prior to July 1986: Served as an officer in both the Army and Air Force. Career has included a variety of challenging leadership and technical positions. Prior to retirement in 1986, served in the Chief of Technical Directors for the Defense Nuclear Agency (DNA) underground (UGT) and above ground testing (AGT) programs. Managed 14 personnel and was responsible for the experimental programs on six DNA weapons effects tests. A single UGT test typically had a $60M experimental effort. Also responsible for the in-house and contractor efforts to design the nuclear test environment as well as test diagnostics.

1979-1984: Served as a scientific program manager and line manager at the Air Force Weapons Laboratory (now Phillips Laboratory). Led the Air Force group that performed independent nuclear safety analysis of NASA Galileo and Ulysses missions due to their use of a radioisotope, themoelectric generators (RTG). Served as a member of the National Space Reactor Safety Advisory Committee for two years. Managed the Air Force's Phase I and II Nuclear Weapons Development Activity from 1982-1984. Initiated a new nuclear weapons study to replace the existing SRAM system. Developed, organized and executed several large (>$10M/year) experimental hardened missile silo programs in support of the Air Force MX program. Led numerous experimental efforts to define the nuclear air blast, ground shock and crater environments for DNA. Organized and led two major national study efforts which included up to eight DOE laboratories and three Air Force Laboratories to define power options to support the

emerging Strategic Defense Initiative (1984) and terrestrial nuclear power options to support Deep Basing of Strategic Missiles.

Prior to 1979: Successful in ever-increasing positions of command and leadership. Commanded three combat units of the United States Army to include its original tank company, a combat engineer company in the elite 82nd Airborne Division and a 360 man troop of the 10th U.S. Cavalry engaged in combat in the Republic of Vietnam. Often cited for leadership excellence and was awarded two Bronze Stars while in Vietnam. As an engineer officer responsible for planning, design and construction of numerous roads, airfield extensions and modifications, facilities and small bridges on military installations and in surrounding communities. Military career also included such leadership, management, and technical positions as Director of the Computer Center for Fort Knox, Kentucky; Engineering Staff Officer, XVIII Airborne Corps, Fort Bragg, North Carolina; and Assistant Professor of Physics at the United States Military Academy (West Point). At West Point was recognized as one of the two outstanding faculty members from over 600 professors in 1979. Recognized for academic excellence by receiving an Atomic Energy Commission Fellowship in Nuclear Science and Engineering in 1966 and being named a Distinguished Graduate of the Air Command and Staff College, Maxwell Air Force Base in 1980.

PUBLICATIONS*

"Anisotropic Scattering Corrections to the Eigenvalues and Extrapolated End-point in the P3- Approximation of Neutron Transport Theory " Nuclear Science and Engineering, November, 1969.

"Stress Analysis in Cylindrical Pressure Vessels," Award winning paper presented to the American Nuclear Society Student Conference, Tucson, AZ, March, 1968.

Strength of Materials and Beam Design. Textbook, Engineering Design Division, U.S. Army Engineer School, Fort Belvoir,VA, 1973.

"Extension of the Theory of Vibrating Plate-Type Nuclear Reactor Fuel Elements," Ph.D Dissertation, Texas A&M, 1973.

"Nuclear Power for Deep Basing of Missiles, "Proceedings of the National Academy of Sciences Committee on Advanced Compact Reactors for Military Application, Washington, DC, November, 1982.

"Space Nuclear Power: A Summary of the State-of-the-Art, " Transactions, American Nuclear Society Winter Meeting, Washington, DC, November, 1982.

"Safety Issues for Space Nuclear Power," Proceedings of the Air Force Office of Scientific Research's Symposium on Space Prime Power, Norfolk, VA, February,1982.

"The Role of Solid Damping in Fluid-Structure Interaction," Proceedings, Symposium on Recent Advances in Fluid-Structure Interaction. ASME, San Antonio, TX, June, 1984

"Strategic Defense Initiative Organization Multi-Megawatt Space Prime Power Technology Development Plan," (Classified SECRET), Sandia National Laboratories Report, RS6432/84/046, July, 1984

"Nuclear Power for Deep Basing: A Comparative Study," Air Force Weapons Laboratory, AFWL TR 84-121, 1984.

"AFWL Design for a Multi-Megawatt Space Reactor," (Classified SECRET), Air Force Weapons Laboratory, AFWL TR 84-104, 1984.

"An Approach to Space Reactor System Selection and Design," Proceedings: First Symposium on Space Nuclear Power, University of New Mexico, Albuquerque, NM, January, 1984.

"Some Thoughts on the Commercial Use of Reactors in Space," Proceedings of the 21st Intersociety Energy Conversion Engineering Conference, 1986

"Inherently Safe Space Reactors," Proceedings of the Fourth University of New Mexico Symposium on Space Nuclear Power, January, 1987.

Independent Assessment of Project DISTANT HUNT. SNLA Report SAND87-2785, December, 1987.

"Analysis of SP-100 Environment Interactions", S-Cubed Report, SSS-R-88-9197, S-Cubed, December, 1987.

"Power Systems Survivability (Unclassified)", S-Cubed Report to AFWL, SSS-CDPR-89-10187, Classified (S/RD/NOFORN/WNINTEL), February, 1989.

"Survivability Assessment of SP-100", paper, University of New Mexico Nuclear Power Symposium, January, 1989.

"Multi-Megawatt Space Reactor Survivability Studies," Final Contractual Report to Grumman Aerospace, S-Cubed Document, February, 1989.

"Project SIREN: Technology and Infrastructure for Space Nuclear Disposal and Debris Management," Report to the Strategic Defense Organization, October 1989.

"Technology Requirements for the Disposal of Space Nuclear Power Sources and Implications for Space Debris Management Strategies," American Institute of Aeronautics and Astronautics (AIAA) Conference on Orbital Debris, 16-19 April 1990, paper number 90-1368.

NSPWG-Recommended Safety Requirements and Guidelines for SEI Nuclear Propulsion," AIAA/SAE/ASME/ASEE 28th Joint Propulsion Conference, 6-8 July 1992, Nashville, Tn., Paper AIAA 92-3697.

Preliminary Design Considerations for Safe, On-Orbit Operations of Space Nuclear reactors. SNLA Report, SAND87-0865, 1994.

"Aerospace Nuclear Safety: An Introduction and Historical Overview," International Topical Meeting- Advanced Reactor Safety, American Nuclear Society, Pittsburgh, Pennsylvania, April 17-21, 1994.

Tank Waste Remediation System Integrated Technology Plan, DOE/RL-92-61, REV 2; PNL-10092, REV 1; February 28, 1995. (10 authors)

Commercial Experience with Facility Deactivation to Safe Storage, Sandia Report SAND96-2255, September 1996.

“Light Duty Utility Arm System: A Case Study of Technology Deployment,” Paper # 86, American Chemical Society Industrial and Chemistry Division, Fall Meeting, Las Vegas, Nevada, September 1997.

“Material Protection, Control, and Accounting Enhancements at the Mining and Chemical Combine Through the Russian / US Cooperative MPC&A Program,” 38th Annual Meeting of the Institute of Nuclear Materials Management, Phoenix, Arizona, July 20-24, 1997.

"Retrieval of Sludge from an Iraqi Tank," American Nuclear Society Topical Meeting on Robotics and Remote Systems, Pittsburgh, Pa., April 1999

* most of these publications were written with co-authors

Major C. Thompson, Ph.D.
Westinghouse Savannah River Company
Bldg. 773-A, C140
Aiken, SC 29802
(803) 725-2507
e-mail: major.thompson@srs.gov

Education Ohio State University: Ph.D., Inorganic Chemistry
Ohio State University: M.S., Inorganic Chemistry
Birmingham Southern College: B.S., Chemistry

Occupation

Senior Advisory Scientist

Employer

Savannah River Technical Center - Aiken, South Carolina

Representative Skills and Experience

Dr. Thompson has worked at the Savannah River Technology Center (SRTC) for >35 years in support of plant operations at the Savannah River Site. His principal expertise is in chemical separations, including solvent extraction, precipitation/filtration, ion exchange, and pyrochernical operations. He has worked on a wide variety of assignments in support of plant operations and projects. He has also been involved with actinide and fission product chemistry in Savannah River waste, technical review of waste management projects and operations and nuclear safety review for waste management at Hanford and Savannah River, and support of separations of nuclear materials at SRS. He is presently a member of the core management group for the DOE Efficient Separations and Processing Crosscut Program and a member of the Technical Advisory Group for the Tank Focus Area. He received the Glenn T. Seaborg Actinide Separations Award in 1997 in recognition of his work in separations.

Publications

Mr. Thompson has written 16 journal articles and book chapters; 35 technical reports.

Professional Associations

American Chemical Society and Sigma Xi

WALLACE W. SCHULZ
12704 Sandia Ridge Place, N.E., Albuquerque, New Meydco 87111
Telephone: *(505) 856-7928*

PROFESSIONAL OBJECTIVE

Nuclear Consultant: Provide valuable, authoritative counsel on nuclear waste management/disposal and chemical separations technology to government, industrial, and academic organizations.

OUTSTANDING STRENGTH

Recognized world-class authority on nuclear chemical separations and waste disposal technology.

48+ years broad experience in all parts of back-end of nuclear fuel cycle.

Experienced technical consultant to management.

Creative/innovative. An idea person. Twenty-one patents.

Prolific writer. Eleven books, 100+joumal papers and research reports.

Excellent communicator and mentor.

Highly qualified technology evaluator and analyzer.

OVERVIEW OF PROFESSIONAL EXPERIENCE

Dates	Organization	Highest Position
1988-Present	W2S Co., Inc.	President/consultant
1987-1988	Westinghouse Hanford Co.*	Advisory Scientist
1977-1987	Rockwell Hanford Co.*	Sr. Scientific Advisor
1969-1977	*Atlantic* Richfield Hanford*	Principal Chemist
1965-1969	Battelle Pacific Northwest Laboratory*	Sr. Research Scientist
1950-1965	General Electric *Co.* -Hanford*	Research Scientist
*Prime contractors to the US. Department of Energy (or its predecessor agencies, e.g. Atomic Energy Commission) at the Hanford Site.		

EDUCATIONAL BACKGROUND

University of Nevada B.S., (1949), M.S. (1950)
Reno, Nevada Major: Chemistry

Other Training- Joint Center for Graduate Study, Richland, WA (1950-1975), completed coursework equivalent to Ph.D. degree.

HONORS AND AWARD

Rockwell International Corporation "Engineer of the Year", 1987.

Glenn Seaborg Award in Actinide Separations, 1987.

IR-100 Awards, 1984 & 1987.

Westinghouse Hanford Co. "Signature Award", 1990.

American Chemical Society-Richland Section, "Chemist of the Year", 1986.

Plenary Lecturer, International Solvent Extraction Conference, Moscow, USSR, 1988.

Member Phi Kappa Phi Honorary Society.

Listed in American Men of Science.

MEMBERSHIPS AND AFFILIATIONS

American Nuclear Society

American Chemical Society: Industrial & Engineering Chemistry Division (Technical Program Chairman 1991-Present; Chairman, 1988); Separation Science & Technology Subdivision (Chairman, 1985).

The Metallurgical Society

Sigma Xi

References and publications available on request.

LAWRENCE L. TAVLARIDES
CURRICULUM VITAE
Professor of Chemical Engineering
Syracuse University
Syracuse, NY 13244
HISTORICAL DATA

Education Ph.D., Chemical Engineering, University of Pittsburgh 1968
M.S., Chemical Engineering, University of Pittsburgh 1964
B.S., Chemical Engineering, University of Pittsburgh 1963

Postdoctoral, Hogeschool of Delft, Holland, Laboratorium Voor Chemische Tech. with Professor P. M. Heertjes on photochemical reactions, 1968

Academic Experience

Associate Dean, Graduate Affairs and Research, L.C. Smith College of Engineering & Computer Science, Syracuse University	1995-1996
Professor, Department of Chemical Engineering and Materials Science, Syracuse University	1985 - Date
Chairman, Department of Chemical Engineering and Materials Science, Syracuse University	1981- 1985
Professor, Department of Chemical Engineering, Illinois Institute of Technology	1980- 1981
Associate Professor, Department of Chemical Engineering, Illinois Institute of Technology	1975- 1980
Faculty-Research Fellowship, IIT, Academic Year	1974- 1975
Assistant Professor, Department of Chemical Engineering, Illinois Institute of Technology	1969-1975

Industrial Experience

Research Engineer, CPC International, Moffett Technical Center, Argo, IL	Summer 1971
Research Engineer, Gulf Research and Development Center	Summer 1968
Engineer, Gulf Research and Development Co., Hamarville, PA	1964- 1966
Process Engineer, Mobay Chemical Co., Pittsburgh, PA	Summer 1962

Consulting Experience

Battelle, Pacific Northwest Laboratories (Member, Tank Focus Area - Technical Advisory Group. This committee advises the National Tank Focus Area committee on technical issues in regards to the clean-up of radioactive nuclear waste stored in tanks throughout the Department of Energy Complex, viz, Hanford Site in Richland, WA, Savannah River Site in Aiken, S.C., Oak Ridge Reservation in Oak Ridge, TN and Idaho Falls National Engineering and Environmental Laboratories in Idaho Falls, ID)	1995 - present
Battelle, Pacific Northwest Laboratories (Member, Waste Processing Architecture Group (WPAG): This committee guides the Tank Waste Remediation System Technology Development Office for the Department of Energy to develop technologies to remediate the nuclear waste stored at the Hanford Site in Richland, WA. The project is expected to cost $20-200 BILLION over the next 30 years.)	1993-1995
Martin Marietta Energy Systems, Inc. (Reviewer for D.O.E., Efficient Separation Program, Office of Environmental Management and Technology Development)	1993 - 1995
Dow-Corning, USA	1994 - present
Dow Chemical Co. Inc.	1993- 1994
Exxon Research and Engineering Company, Florham Park, NJ	1988- 1992
Hercules, Inc., Radford, VA	1988- 1989
Agway Inc., Syracuse, NY	1985- 1986
EXXON Research and Engineering Company, Florham Park, NJ	1984-1986
CPC International, Moffett Technical Center, Argo, IL	1971- 1978
Illinois Institute of Technology Research Institute, Chicago, IL	1974- 1977
Daubert Chemical Co., Chicago, IL	1976- 1977
Institute of Paper Chemistry, Appleton, WI	1977- 1979
Kraft, Inc., Kraft Court, Glenview, IL	1979- 1980

ARCO, Inc., 400 E. Sibley Blvd., Harvey, IL 1979- 1980

HONORS AND RECOGNITIONS

Chancellor's Citation Award for Excellence in Academic Achievement 1994
Syracuse University

Pacific Northwest Laboratories, Affiliate Staff Scientist (PASS) 1994-1997

Anaren Microwave Award for Excellence in Scholarship 1993
L.C. Smith College of Engineering and Computer Science, Syracuse University

Fellow, American Institute of Chemical Engineers 1990

Who's Who in Science and Engineering, Listed June 1997

RESEARCH SPECIALIZATION

Supercritical Extraction and Water Oxidation for Soil Decontamination
Metal Ion Separations from Waste Streams by Inorganic Chemically Active
Beads and Impregnated Ceramic Membranes
Mass Transfer and/or Reactions in Dispersions
Acoustical Instrumentation Development for Measurements of Liquid
Liquid/ Liquid-Solid Dispersions
Metal Ion Interfacial Reactions and Equilibrium in HSE
Plasma Reaction Models of Electrostatic Corona Discharge Reactors
Ceramic Membranes for Gas Separations and Catalytic Reactors
Dispersed Phase Mixing Effects on Selective Metal Extraction
Turbulence Models for Two Phase Flows
Kinetics of Fischer-Tropsch Synthesis Reaction
Biochemical Separations with Solvent Extraction

CONTRIBUTIONS TO RESEARCH

Books

1. L. L. Tavlarides - Process Modifications for Industrial Pollution Source Reduction, Lewis Publishers, Inc., Chelsea, MI (1985).

Co-Editor for Symposium Volume

1. T.W. Chapman, L.L. Tavlarides, G.L. Hubred, R.M. Wellek, editors, "Fundamental Aspects of Hydrometallurgical Processes," AICHE, Symposium Series, Vol. 74, 173 (1978).

2. L. L. Tavlarides, J. D. Miller, "Fundamental Aspects of Solvent Extraction," section editors in Hydrometallurgical Recovery of Metals from Ores, Concentrates, and Secondary Sources, AIME, Inc., New York, p. 86 (1981).

Other Publications/Patents

13 Patents, 98 Research Publications, 37 Non-Refereed Publications, 6 Recognition of Published Works, 199 Papers Presented and Invited Seminars, 29 Co-Chairman of International, National, and Regional Symposia.

CURRICULUM VITA
M. J. PLODINEC

Dr. M. J. Plodinec is currently Director of the Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University. He is an internationally recognized expert in waste management and glass science. He has made important contributions which range from waste characterization to glass durability modeling. During his 22 year involvement with the Defense Waste Processing Facility (DWPF) program - the United States' first and the world's largest radioactive waste vitrification facility - he has had an impact on every aspect of the DWPF process, from chemical characterization of the waste to proof testing of the canister closure. He helped to design, and then operated, the first four glass melters at SRS . Many of the features on the current DWPF melter are a direct result of his work (use of cameras for viewing, plenum heaters to improve melter throughput, prevention of direct current to extend melter life).

Dr. Plodinec was also the primary technical lead for the DWPF product qualification program. This program required the effective management of several multi-million dollar pilot plant testing programs, and their close integration with the construction and startup of a $2 billion facility. He was co-developer of the DWPF Startup Test Program, and then served on the Joint Test Group overseeing all testing on the facility (he was certified as a Level III Startup Test Engineer under INPO guidelines). An important part of this effort was development and implementation of a quality assurance program meeting the requirements of ANSI/ASME NQA1, and of 10 CFR 50 (NRC QA requirements) to cover this multi-faceted, multi-organizational program.

Dr. Plodinec also prepared the technical case which led the US Environmental Protection Agency to declare vitrification to be the Best Demonstrated Available Technology for HLW and for heavy metals. He was one of the Department of Energy's primary authors for the Waste Acceptance Product Specifications, which govern all of the HLW glass products produced in the US. This approach has been copied by the IAEA, and recommended for use worldwide. He is regularly consulted by other DOE sites (Hanford, Idaho, Fernald in the last year), by DOE headquarters, and by external groups such as the Defense Nuclear Facilities Safety Board, and the National Academy of Sciences. In 1994, he led a team reviewing the waste form programs for INEEL HLW. In 1995, he served on the Hanford LLW Melter Technical Advisory Panel. He played a leadership role on the Independent Review Team empanelled by the Fernald site in 1997, which provided direction for the immobilization of Fernald silo wastes. In 1998, he was a key player on two DOE assessment teams examining various aspects of the decision to privatize treatment of the highly dangerous wastes at the Hanford (WA) site.

Education Doctor of Philosophy, Physical Chemistry, University of Florida, Gainesville, FL, 1974. Dissertation on excited state properties (ion pairing and hydrogen bonding) of carbanion salts.
Bachelor of Arts, chemistry, Franklin and Marshall College, Lancaster, PA, 1968. Thesis on metal electrode/solution interactions.

Experience

1997-99: Director of Diagnostic Instrumentation and Analysis Laboratory, Mississippi State University. Laboratory is a primary contractor of DOE for technology verification (particularly those involving high temperatures), and for development of instrumentation for unusual environments.

1994-97: Technology Integration Manager for Immobilization for EM-50's Tanks Focus Area. Responsible for coordinating HLW immobilization programs for DOE complex.

1989-97: Manager and Senior Advisory Scientist, Westinghouse Savannah River Co., Aiken, SC, in charge of Glass Technology Group, studying radioactive and chemically hazardous waste vitrification processes and products. Primary concentration on waste characterization, process control, and achieving glass durability. Served on Joint Test Group overseeing DWPF Startup Test Program.

1980-89: Various supervisory positions with E. I. DuPont de Nemours, Aiken, SC, Savannah River Laboratory (SRL), in charge of Glass Technology Group. Developed Startup Test Program for DWPF.

1976-80: Research scientist, SRI, studying high-level waste vitrification. In particular, composition development and glass melting research. Oversaw all engineering-scale melting operations at SRL.

1974-76: Research scientist~ SRL, various waste management projects.

1968-69, 1971-74: Graduate student, University of Florida, in physical chemistry.

1969-71: US Army, interrogation of POWs in Republic of Viet Nam.

Miscellaneous

Member, Materials Research Society, American Ceramic Society, American Chemical Society, and Sigma Xi. Fellow of the American Ceramic Society.

Member of the Technical Advisory Panel for the Hanford LLW melter selection board.

Member, Department of Energy's Waste Acceptance Committee.

Member, Technical Review Group for West Valley Demonstration Project, West Valley, NY.

Awarded Bronze Star three times.

Presented invited testimony to DNFSB as an expert on actinide vitrification, and characterization of HLW at Hanford.

Invited presentations to National Academy of Sciences' Board on Radioactive Waste Management on status of vitrification technology.

Publications

Over 90 published papers, primarily dealing with waste vitrification and thermodynamics of waste management.

Patent on device to sample high-level nuclear waste, and on slurry feeding device for glass melter.

John Swanson
1318 Cottonwood
Richland, WA 99352
(509) 946-3188
e-mail: johnlswanson@worldnet.att.net

Education
Reed College: B.A., Chemistry

Occupation
Consultant - Richland, Washington

Mr. Swanson retired from the Pacific Northwest Laboratory in 1995, following a 44-year career at the Hanford Site of the U.S. Department of Energy. This career began shortly after his 1951 graduation from Reed College with a BA degree in Chemistry. He also completed several graduate level courses during his employment at Hanford.

For most of his Hanford career he was a "process development chemist", working primarily on various problems in the areas of nuclear fuel reprocessing and radioactive waste management; most recently in the area of pretreatment of Hanford tank wastes. These activites ranged from basic chemistry studies, to flowsheet development, to interaction with engineers involved in plant operations. During the last several years of his Hanford career he was involved in "paper studies" addressing more complete systems aspects of the waste management problems.

Other activities in his Hanford career included studies on the chemistry of actinide elements in the environment, on the effect of organic complexants on the mobility of toxic elements in soils, on the technology aspects of systems studies comparing the costs and risks of radioactive waste treatment and disposal options, and on the degradation of spent Hanford N Reactor fuel during extended water basin storage.

Towards the end of his Hanford career, his major focus was in the area of "technology development" review and planning activities, primarily as a member of national review groups. Such activities have continued since his retirement; he is currently a member of two such groups for the DOE's Office of Environmental Management, Office of Technology Development. These are the Review Panel for the Efficient Separations and Processing Cross-Cutting Program, and the Technical Advisory Group for the Tanks Focus Area.

Publications
Mr. Swanson has authored or co-authored 46 published papers, articles, and technical reports.

Affiliations
American Chemical Society and American Nuclear Society

Frank E. Woolley
114 Weston Lane
Painted Post, NY 14870
(607) 962-4060 (phone/fax)
frankwoolley@hotmail.com

Dr. Woolley is a technical consultant specializing in glass melting processes, glass technology courses, and management of process R&D. He retired from a position as Manager of Melting Research in the Science and Technology Division at Corning Incorporated. His group investigated the fundamental processes of glass melting and developed new industrial melting processes for Corning's domestic and international glass melting.

He received B.S. degrees in Chemical and Metallurgical Engineering from the University of Michigan in 1962, a M.S. in Metallurgical Engineering in 1963, also from Univ. of Michigan, and a Sc.D. in Chemical Metallurgy from the Massachusetts Institute of Technology in 1966. He received a M.B.A. degree from Syracuse University in 1980.

Dr. Woolley was with Corning since 1966, except for service as a Powder Metallurgist with the U.S. Army at Frankford Arsenal from 1967 to 1969. He has managed various groups in RD&E at Corning, NY involved with research and development of glass compositions, laboratory and pilot melting and forming, vapor deposition of glasses for optical fibers, and ceramic processing. From 1975 to 1978 he managed a melting, forming and ophthalmic product development group at the Corning France laboratory at Fontainebleau, France. His most recent assignment prior to the position from which he retired involved managing a group in Melting Technology which tests and selects refractories and raw materials and resolves problems for Corning's production melters. He has taught glass technology as an Adjunct Associate Professor at Alfred University, as a Lecturer of the Center for Professional Advancement, East Brunswick, NJ and Amsterdam, Netherlands, and as a consultant to the U.S. Department of Energy.

His special interests are the high temperature chemical and transport processes in glass melting and forming, and their impact on the design and operation of commercial glass making processes.

Dr. Woolley is a Fellow of the American Ceramic Society. He is a member of ASTM Committee C-8 on Refractories, the Society of Glass Technology, and the American Institute of Chemical Engineers. He is past chairman of Technical Committee 14 on Gases in Glass of the International Commission on Glass.

E. Thomas Weber
6622 W. Victoria
Kennewick, WA 99336
Phone: (509)-783-3789

Education Ph.D., Ceramic Science, 1964, Rutgers University, New Brunswick, N.J. Thesis Title: "Viscoelastic Properties of Alkali Silicate Glasses"
B.S., Ceramics, 1960, Rutgers University

Professional History General Electric Corp. at Hanford 1964
Battelle Northwest Laboratory 1965 to 1970
Westinghouse Hanford Company 1970 to retirement 12/1994

Started at the Hanford Laboratory with General Electric in September 1964 as a Senior Research Scientist engaged in development of ceramic fuels and materials for nuclear reactors. Became a Battelle employee in Hanford contractor change, performing research in properties, synthesis, and fabrication of ceramic fuels, including plutonium compounds. Led a team initiating irradiation testing of uranium-plutonium nitride fast reactor fuel pins.

In 1968 assumed a management position with responsibilities for oxide fuel processing and test fuel fabrication for development of fast breeder reactor cores, especially the Fast Flux Test Facility at Hanford. Transferred to Westinghouse Hanford Company (WHC in 1970 as Manager of Reactor Ceramics, with responsibility for laboratory research support to fast reactor fuel fabrication, design and in-reactor testing. This involved operational responsibility for plutonium laboratories. Development work also included non-fuel nuclear ceramics such as neutron absorbers, insulators and oxygen meter solid electrolytes.

From 1976 to 1987, responsibilities increased to management of multiple functions, leading to a department level position, directing organizational components performing research, conducting irradiation testing programs and operating nuclear facilities. Management cognizance included: hot cell facilities, fabrication laboratories, high temperature research and plutonium laboratories, off-site irradiation testing programs, FFTF core component performance testing and several DOE international cooperative research programs. Technical cognizance included: design and development of hot cell testing and examination equipment; fuel, absorber and tritium breeder/blanket materials properties studies and fabrication technologies; experimental assessment of higher actinide incineration in reactors; reactor fuel safety performance analysis and testing; core assembly and materials behavior under reactor accident conditions; breeder reactor fuel and absorber assembly performance assessments; irradiation performance testing of advanced liquid metal reactor and space reactor fuels.

From 1987 to 1989, management assignments involved responsibilities for reactor and nuclear facility safety features of the new Westinghouse Hanford consolidation contract at Hanford. This included managing evaluation of lessons from the Chernobyl accident for Hanford's N Reactor. Managed WHC

programs providing direct support to Department of Energy Headquarters for updating and revising their nuclear safety policies and Orders.
From 1989 to 1993, held the position of Manager, Applied Technology for the Hanford Waste Vitrification Plant (HWVP) project. This position focused on providing the technological base for vitrification processes and plant engineering work. Responsibilities addressed identification of domestic and foreign technology sources to meet HWVP process and facility systems needs. This included defining technology development requirements and providing technical direction to performers, primarily Battelle-Pacific Northwest Laboratory. Managed interfaces and monitored developer performance leading to data application in design, process qualification, and waste form qualification. Responsibilities also included definition of HWVP waste compliance plans, interfaces with the high level waste geological repository program and technical interfaces with other DOE and foreign vitrification programs. Chaired Westinghouse Corporate GOCO coordination group for sharing experience and technology between DOE high level waste sites. Led evaluation of foreign vitrification technology as alternatives to DOE technologies for HWVP. Member of DOE delegation for vitrification technology exchange with Russia in 1991 and participant in US-Japan and US-German exchanges.

From 1993 to 1994, managed Vitrification Development for the Hanford Tank Waste Remediation System (TWRS), following close-out of HWVP. Responsible for replanning Hanford waste vitrification technology requirements and approach to fulfill 1993 Tri-Party Agreement milestones. Managed low-level waste melter technology evaluation, vendor contracting and requirements for supporting technology. Coordinated replanning of high-level waste technology requirements and assessments to meet TWRS higher capacity vitrification plant needs.

Professional Societies

American Ceramic Society: Fellow - 1976; Nuclear Division Program Chairman - 1975; Nuclear Division Chairman - 1978; Trustee - 1980 to 1983; Vice President for Engineering and Technology - 1990/91
American Nuclear Society: Member

E Level 1 Heading

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Appendix E

Technology Development Task Sheets

Appendix E

Technology Development Task Sheets

E.1 Technology Development Task Sheets

The Technology Development Task Sheets that follow describe the recommended technology development programs for highly ranked improvements and alternatives for Phase I (see Section 6.1, Table 6.1.1) and for highly ranked technologies for application beyond Phase I (see Section 6.1, Table 6.1.2). The individual tasks or program steps outline the major activities required to complete the recommended development work. [(a)]

Individual task and total program durations have been estimated based upon Team members' experience. The total duration given on the Task Sheets assume that several activities can proceed in parallel, but no detailed critical path schedules were prepared to support our estimates. Also, the durations assume the availability of adequate manpower and funding. Preparation of more detailed program plans and resource-loaded schedules is beyond the scope of this study.

The Team's current understanding of funding for the activities described in the Task Sheets, is summarized in Table E.1.1.

(a) One Team member believed that the technologies described in Task E.3.a, Partial Oxidation; oxidants other than permanganate, and Task E.11, Acidic Dissolution and Separations, are not needed and therefore should not be developed.

E.2 Sulfate Accommodation in LAW

Baseline approach: Remove some sulfate by ion exchange in pretreatment; dilute excess sulfate by lowering waste loading in vitrification.

Sulfate Removal in Pretreatment

Alternative approach: Replace baseline with a crystallization/precipitation process for removal of sulfate. Approach involves evaporation and/or addition of Ca or Sr solutions.

TASK	TIME (yrs)
1. Initial testing on laboratory scale with simulants to determine the most promising approach.	0.3 - 0.5
2. Laboratory and bench-scale tests with actual waste including ultrafiltration to separate the solids.	0.5 - 1
3. Solids washing studies to remove residual radioactivity.	0.3 – 0.5
4. Characterization of solids to ensure they can be disposed through the effluent treatment facility.	0.2 – 0.3

Total development time, assuming overlapping tasks: 1 – 1.5 years

Sulfate Removal in Vitrification and Offgas

Alternative approach: Separate sulfur from LAW glass by decomposing sulfate under reducing conditions in the cold cap of the melter to release SO_2 gas, which is in the offgas system and separated from radionuclides for disposal as secondary waste.

VITRIFICATION TASKS	TIME (yrs)
1. Identify glass compositions that maximize sulfur solubility.	0.5 - 1
2. Quantify effect of reductants and cold cap conditions on sulfate decomposition; find conditions which minimize volatilization or precipitation of metals.	0.5 - 1
3. Conduct pilot-scale melter tests with simulated wastes to: • establish a process control strategy for the cold cap • confirm DF for sulfate • determine offgas composition under range of conditions • confirm metal losses and precipitation • determine impact of sulfate removal on melter failure modes and lifetime.	1 - 2

Total development time, assuming overlapping tasks: 2-3 years

OFFGAS TASKS	TIME (yrs)
1. Develop strategy/concept for capture and removal of S (and some Cl) from offgas for disposal, while separating and recycling all radionuclides and hazardous elements to the melter.	0.5 – 1
2. Acquire data to predict capture of S and other elements in each part of offgas system.	0.5 - 1
3. Conduct pilot-scale melter tests with simulated waste to: • establish a process control strategy • confirm capture and separation under a range of offgas and process conditions • determine impact of operation for S removal on failure modes and lifetime of offgas system components.	1 – 2

Total development time, assuming overlapping tasks: 2 - 3 years

E.3.a Partial Oxidation; oxidants other than permanganate

Baseline approach: TRU elements are removed from tank waste solutions containing high concentrations of organic complexants by the addition of permanganate, which apparently oxidizes a portion of the organic material and in the process is reduced to MnO_2. The combined actions of: 1) carrier precipitate formation, 2) partial destruction of the complexants, and 3) good precipitate filterability, result in efficient removal of TRU elements from solution. Sr-90 removal is accomplished by addition of non-radioactive Sr solution to precipitate $SrCO_3$.

Improvement to baseline: Use of material other than permanganate to accomplish partial oxidation of organic complexants.

TASK	TIME (yrs)
1. Identify suitable potential oxidants that allow selective oxidation of complexants.	0.3 – 0.5
2. Test candidate oxidants with simulated waste solutions to determine DF and solids filterability.	0.5 - 1
3. Verify process with real wastes.	0.2 – 0.5
4. Optimize conditions to be used (concentration, time, temperature) to give adequate DF and solids filterability.	1-2
5. Test most promising conditions at bench-scale with real waste.	0.5 – 1

Total development time, assuming overlapping tasks: 2 - 4 years

E.3.b TRU Sorbent After Partial Oxidation

Baseline approach: TRU elements are removed from tank waste solutions containing high concentrations of organic complexants by the addition of permanganate, which apparently oxidizes a portion of the organic material and in the process is reduced to MnO_2. The combined actions of: 1) carrier precipitate formation, 2) partial destruction of the complexants, and 3) good precipitate filterability, result in efficient removal of TRU elements from solution. Sr-90 removal is accomplished by addition of non-radioactive Sr solution to precipitate $SrCO_3$.

Alternative approach: Use sorbents to remove TRU elements from complexant solutions that have undergone partial oxidation.

TASK	TIME (yrs)
1. Identify suitable potential oxidants that allow selective oxidation of complexants.	0.3 – 0. 5
2. Identify potential existing sorbents.	0.2 – 0.5
3. Test candidate oxidants and sorbents with simulated waste solutions to determine DF (and solids filterability if batch contact mode is employed).	0.5 – 1
4. For elutable sorbents, small column tests with real waste, including cycling studies.	0.5 – 1
5. For elutable sorbents, scaled-up column tests using simulants to develop engineering design information (sorption kinetics, mechanical integrity and transport properties, column hydraulics).	0.5 - 1
6. Verify process with real wastes.	0.2 – 0.5
7. Evaluate chemical and radiolytic stability of sorbent.	0.5 – 1
8. Optimize total process conditions with real waste solutions.	1 - 2
9. Test at bench-scale with real waste.	0.5 - 1

Total development time, assuming overlapping tasks: 3 - 5 years

E.3.c Strong TRU Sorbents

Baseline approach: TRU elements are removed from tank waste solutions containing high concentrations of organic complexants by the addition of permanganate, which apparently oxidizes a portion of the organic material and in the process is reduced to MnO_2. The combined actions of: 1) carrier precipitate formation, 2) partial destruction of the complexants, and 3) good precipitate filterability, result in efficient removal of TRU elements from solution. Sr-90 removal is accomplished by addition of non-radioactive Sr solution to precipitate $SrCO_3$.

Alternative approach: Use sorbents with high affinity for TRU elements to remove TRU elements from untreated complexant solutions.

TASK	TIME (yrs)
1. Identify existing sorbents for this application.	0.2 – 0.5
2. Measure Kd for TRU elements with existing sorbents and real waste solutions.	0.2 – 0.5
3. Develop eluate, if needed, that is compatible with HLW vitrification.	0.2 – 0.5
4. Synthesis and testing of new sorbents, if needed.	2 - 3
5. Small column tests of selected sorbents with real waste (including cycling studies if sorbent is elutable).	0.5 – 1
6. Scaled-up column tests using simulants to develop engineering design information (sorption kinetics, mechanical integrity, and transport properties, column hydraulics).	0.5 - 1
7. Evaluate chemical and radiolytic stability.	0.5 – 1
8. Test at bench-scale with real waste.	0.5 – 1

Total development time, assuming overlapping tasks and existing sorbent is used: 2 - 4 years
Total development time, assuming overlapping tasks and new sorbent is used: 4 - 7 years

E.4 Enhancements to Mixing in Sludge Retrieval Operations

Baseline approach: Mobilization and mixing in the waste feed tanks with two, 300 hp long-shaft mixer pumps.

Improvement to the baseline: Use supplemental mixing and mobilization technologies to reduce risk and costs of waste feed operations.

TASK	TIME (yrs)
1. Review the test plans of project W-151, the waste characteristics of Tank AZ-101, and the waste characteristics of other feed tanks. Establish demonstration requirements.	0.2 – 0.4
2. Select the supplemental mobilization and mixing technology to be demonstrated.	0.3 – 0.5
3. Develop the test objectives plan for the supplemental mobilization and mixing technologies for Tank AZ-101.	0.2 – 0.3
4. Design and integrate selected mobilization and mixing technologies into Tank AZ-101 and the project W-151 test.	0.3 – 0.5
5. Deploy selected technologies into Tank AZ-101.	0.3 – 0.5
6. Conduct supplemental mixing and mobilization technologies tests.	0.2 – 0.3
7. Analyze test data and predict the performance of these technologies on other PHMC waste feed tanks.	0.3 – 0.5

Total development time, assuming overlapping tasks: 2 – 2.5 years

Note: If it is not possible to deploy these technologies for testing on Tank AZ-101, the PHMC should consider conducting this test on another waste feed tank or at the Tank Retrieval Demonstration Center at Krasnoyarsk-26 in Siberia.

E.5 Crystalline Silicotitanate (CST) Non-elutable Sorbent

Baseline approach: Cesium removal is accomplished through elutable ion-exchange with SuperLig® 644 resin.

Alternative approach: Substitute the non-regenerable CST sorbent for the baseline resin.

TASK	TIME (yrs)
1. Examine results of CST studies related to SRS Cs removal for application at Hanford.	0.2 – 0.5
2. Laboratory-scale column breakthrough studies for Phase I wastes.	0.5 - 1
3. Scaled-up column tests using simulants to develop engineering design information (sorption kinetics, mechanical integrity and transport properties, column hydraulics).	0.5 – 1
4. Evaluate chemical stability of CST with real waste.	0.2 – 0.5
5. Determine maximum CST loading for acceptable glass to minimize IHLW volume.	0.5 – 1

Total development time, assuming overlapping tasks: 1- 2 years

E.6 Sequential Caustic and Acidic Leaching

Baseline approach: Leach sludge with hot caustic solutions to remove portions of inert caustic-leachable components (e.g., Al, Cr, and P) without removing radionuclides such as Sr-90 and TRU elements.

Improvement to the baseline: Follow caustic leaching with acidic leaching to remove some of the non-caustic-leachable inert sludge components (e.g., Fe and Zr) without removing excessive amounts of radionuclides.

TASK	TIME (yrs)
1. Obtain samples of sludges to be processed in Phase I.	0.2 – 0.5
2. Perform small scale leach tests with minimal quantities of acid at various solution compositions and volume ratios, at various times and temperatures. Measure radionuclide and inert element dissolution. Emphasize testing with real sludges.	0.2 – 0.5
3. Evaluate impact of acid leach solution on LAW vitrification.	0.5 – 1
4. Evaluate the merit of the approach.	0.1 – 0.2
5. If warranted, test promising conditions at radioactive bench-scale.	1 – 2

Total development time, assuming overlapping tasks: 1 – 2 years

E.7 Enhanced Chromium (Cr) Leaching

Baseline approach: Leach sludges with hot caustic solutions to dissolve Cr-containing compounds (as well as Al- and P-containing compounds).

Alternative approach: Perform leaching under similar conditions with oxidants added to enhance conversion of Cr(III) to Cr(VI)

TASK	TIME (yrs)
1. Obtain high-Cr sludge samples from pertinent tanks.	1 – 3
2. Review results of previous TFA-funded work.	0.2 – 0.4
3. Assess potential impact of dissolved Cr on other pretreatment steps; develop flowsheet changes to resolve difficulties as necessary.	1 – 2
4. Perform small scale tests of Cr (and radionuclide) leach kinetics with promising oxidants at various solution compositions and volume ratios, and at various temperatures. Emphasize testing of actual high-Cr tank sludges.	1 – 3
5. Test most promising conditions at bench-scale with real waste.	1 – 2

Total development time, assuming overlapping tasks: 2-4 years

E.8 Higher Temperature HLW Vitrification

Baseline approach: Vitrify HLW in joule-heated melter in which temperature is limited to 1150ºC by uncooled Inconel-690 electrodes and devices.

Improvement to the baseline: Raise maximum melting temperature to 1200-1300ºC by cooling Inconel components and/or by substituting more refractory materials to permit higher waste loading in some of the more troublesome HLW waste streams expected after Phase I.

TASK	TIME (yrs)
1. Identify specific wastes and glass compositions that allow significantly higher waste loadings but that require higher melting temperatures; estimate potential cost savings due to reduced IHLW volume.	0.5
2. Develop design concepts for air- or water-cooled electrodes, bubblers and thermocouple holders to maintain these components below 1200ºC.	0.5 – 1
3. Identify and collect data on candidate high temperature materials and composites (e.g., molybdenum, Al-doped Inconel-690, coated materials); conduct lab tests to evaluate and rank performance.	0.5 – 1
4. Build prototypes of all components; test in pilot melter.	1 – 2
5. Refine designs, select best combination of cooling and new materials, build full-scale components.	1 – 2
6. Test full-scale components in pilot melter to: • confirm safe operation of components • develop operating strategy for cold cap and convection control with cooled components • identify failure mode and lifetime issues.	1 – 2

Total development time, assuming overlapping tasks: 3 - 4 years

E.9 Combined Cesium (Cs) and Technetium (Tc) Solvent Extraction

Baseline approach: Cs and Tc removal in separate ion exchange systems.

Alternative approach: Remove Cs and Tc together by a solvent extraction process.

TASK	TIME (yrs)
1. Identify existing solvent for this application, based on previous EM-50 work.	0.1 – 0.2
2. Laboratory studies of chemical stability of solvent with alkaline waste simulants, scrub and strip solutions.	0.5 – 0.8
3. Laboratory tests and studies to determine selectivity over interfering ions.	0.2 – 0.4
4. Laboratory studies of radiation stability of solvents with process solutions.	0.5 – 0.8
5. Batch distribution tests to determine effect of chemical and radiolytic decomposition products.	0.5 – 0.8
6. Identification of chemical and radiolytic decomposition products.	0.4 – 0.6
7. Batch distribution test with actual waste supernates.	1 – 1.5
8. Batch counter-current test of process.	0.3 – 0.5
9. Design flowsheet and test in small centrifugal contactors with simulants and then actual waste solution to determine operability and limits.	1 – 1.5
10. Demonstrate integrated flowsheets, including solvent recycle.	0.5 – 1
11. Develop commercial sources of extractants and other components of the solvent.	1 – 2
12. Test process at pilot scale with commercial solvent and simulants.	0.2 – 0.5

Total development time, assuming overlapping tasks: 2 – 4 years

E.10 Chemically Assisted Sludge Heel Removal

Baseline approach: None

Alternative approach: Use chemical additions to waste to alter physical properties of the sludge to facilitate mobilization and transfer.

TASK	TIME (yrs)
1. Identify candidate chemicals and chemical processes for assisting with heel removal of expected sludges	0.6 – 1
2. Develop plans for testing these chemicals on sludges at the Tank Retrieval Demonstration Center. Test candidate chemicals on simulated sludge.	1 – 2
3. Evaluate impact of chosen chemicals on downstream unit operations such as pretreatment and vitrification.	0.5 – 0.6
4. Test retrieval chemicals on actual sludge at the Tank Retrieval Demonstration Center at Krasnoyarsk-26.	1 – 2
5. Analyze data and make recommendations on the viability of this chemical retrieval approach.	0.5 – 0.6

Total development time, assuming overlapping tasks: 2 – 4 years

E.11 Acidic Dissolution and Separations

Baseline approach: Leach sludges with caustic solutions to remove portions of inert caustic-leachable components (e.g., Al, Cr, and P) without removing radionuclides such as Sr-90 and TRU elements.

Alternative to the baseline approach: Dissolve all sludge components in acid and treat the resulting solution to separate the necessary radionuclides from the other sludge components by solvent extraction and/or ion exchange methods.

TASK	TIME (yrs)
1. Evaluate potential cost savings to result from significantly reduced volume of IHLW.	0.5 – 1
2. Obtain sludge samples from pertinent tanks.	3 – 5
3. Develop methods for near-complete dissolution of sludges. Emphasize work with real sludges.	5 – 6
4. Develop the required radionuclide separation processes; behavior of dissolved real sludge solutions to be emphasized. Build on recent EM-50 programs for processing of acidic wastes at INEEL.	2 – 3
5. Test dissolution and separation flowsheets at bench-scale with real waste.	1 – 2

Total development time, assuming overlapping tasks: 6 - 8 years

E.12 Cold Crucible Melter (CCM) for HLW Vitrification

Baseline approach: Vitrification of HLW in a joule-heated melter with pool-level discharge chamber and production temperature limited to 1150°C.

Alternative approach: Increase maximum melting/pouring temperature to 1500-1600°C, and provide bottom drain capability to maximize waste loading with low solubility components. This is not a substitute for the present low-temperature joule-heated melter, but rather an additional capability to deal with difficult waste compositions.

Step 1: Establish process viability	**TIME (yrs)**
1. Perform waste feed calcine tests with simulants reflecting high Cr, high Zr, tank waste compositions.* • Select tanks and potential retrieval/blending strategies/scenarios to define a probable series of high Cr and high Zr waste composition • Prepare simulants for above waste compositions • Run calcine tests (CEA 40 lb/h equipment or equivalent) on selected feeds. *Note: selection of tank wastes to be simulated should include all projected compositions which have high concentrations (combinations) of low solubility components.	1 – 2
2. Formulate glass compositions which optimize waste loading for high Cr, high Zr (or other low solubility components) for high temperature melting conditions.	1 – 2
3. Perform CCM melting tests (CEA 550mm diameter CCM or equivalent) with selected calcined high Cr, high Zr waste feeds, including emphasis on offgas characterization for volatile components carryover.	0.5 – 1.5
4. Perform CCM tests on glasses with less than complete solubility of all components. Define pouring characteristics and characterize product glasses.	0.5 – 1
Step 2: Develop production-scale equipment	**TIME (yrs)**
1. Modify existing prototype CCM unit or build a prototype production-scale CCM and perform tests necessary to support production unit design.	1 – 1.5
2. Design and fabricate a production scale (~50kg/h) integrated calciner and CCM equipment system, capable of remote operation.	1 – 2
3. Install production scale equipment in a pilot plant test facility.	0.5 – 1
4. Perform testing of production scale equipment with selected high Cr, high Zr waste simulants and appropriate glass formulations with waste loading optimized based on data from Step 1 CCM tests.	1 – 2
5. Perform production scale CCM test with slurry (typical liquid content) feed to establish production rate penalty for this alternative feed.	0.5 – 1
6. Complete qualification of production scale calciner CCM insert for installation in production facility.	0.5 - 1

Step 1 total duration with overlapping tasks is estimated to be ~2.5 years.
Step 2 duration with overlapping tasks is estimated to be 4-5 years.
Overlapping Steps 1 and 2 results in estimated total duration of 5-6 years.

Table E.1.1
Funding for Highly Ranked Improvements and Alternatives

TASK SHEET	IMPROVEMENTS AND ALTERNATIVES	FUNDING
E.2	Sulfate Accommodation in LAW • Removal in Pretreatment • Removal in Vitrification • Separation from Offgas	 Present BNFL scope Present BNFL scope Status uncertain
E.3.a	Partial Oxidation; oxidants other than permanganate	None known at present
E.3.b	TRU Sorbent After Partial Oxidation	EM-50 funding of one potential sorbent (monosodium titanate for SRS wastes)
E.3.c	Strong TRU Sorbents	None known at present. Past EM-50 work has developed potential sorbents.
E.4	Enhancements to Mixing in Sludge Retrieval Operations	EM-50 funding alternate mixing tests at SRS and sludge mixing and mobilization at several sites. No other known funding.
E.5	Crystalline Silicotitanate (CST) Non-elutable Sorbent • Tasks 1-4 • Task 5	 None known at present for Hanford waste. EM-50 and EM-30 funded CST work for SRS Waste; past EM-50 funded CST work on Hanford waste. EM-50 funded work for SRS glass. None known for Hanford glass.
E.6	Sequential Caustic and Acidic Leaching	None known at present.
E.7	Enhanced Chromium Leaching	None known at present. Previously funded by TFA.
E.8	Higher Temperature HLW Vitrification • Task 1 • Tasks 2-6	 EM-50 funded work to improve waste loading in HLW glass partly applicable. No other known funding. None known at present.
E.9	Combined Cs and Tc Solvent Extraction	Funded by EM-50 through FY99. No funding in FY00 and beyond.
E.10	Chemically Assisted Sludge Heel Removal	None known at present. EM-50 funding of chemical cleaning methods for SRS is applicable.
E.11	Acidic Dissolution and Separation • Tasks 1 and 2 • Task 3 • Task 4 • Task 5	 None known at present. No known present funding. EM-30 funding in the past. EM-50-funded flowsheet development for INEEL waste partially applicable. None known at present.
E.12	Cold Crucible Melter (CCM) for HLW Vitrification	None known at present