DOE/ORP-2007-02

Technology Maturation Plan for the Waste Treatment and Immobilization Plant

Volume I

August 14, 2007

Office of River Protection
U.S. Department of Energy
Richland, Washington 99352

SUMMARY

The U.S. Department of Energy (DOE), Office of River Protection (ORP) and the DOE Office of Environmental Management (EM), Office of Project Recovery have completed three Technology Readiness Assessments (TRA) for the Hanford Waste Treatment and Immobilization Plant (WTP) facilities. The methodology and concepts used in these assessments were adapted from detailed guidance contained in the Department of Defense (DoD) *Technology Readiness Assessment Deskbook*[1]. The purpose of these assessments was to evaluate the maturity of WTP critical technology elements (CTE). The WTP TRAs are provided in Volume II. The technology readiness process is being piloted within the DOE on the WTP project.

In addition, the WTP Contractor completed an independent assessment of the process flowsheet technology readiness of the WTP in March 2006. This review was conducted by an External Flowsheet Review Team (EFRT).

The results from these two separate assessments have been evaluated using a risk and value engineering approach to ensure that the planned technology maturation work will reduce the technology risk and result in a life-cycle cost benefit to DOE. The results from the evaluation of these two separate assessments have been used to prepare this Technology Maturation Plan (TMP).

This TMP identifies eight technologies that require further maturation based on the results of the TRAs. These are identified below along with the associated WTP facility.

- Rapid Analysis of Radioactive Waste Samples (Analytical Laboratory)
- Waste Solids Separation and Treatment (Pretreatment)
- Radioactive Cesium Removal (Pretreatment)
- Cesium and Nitric Acid Management (Pretreatment)
- Waste Slurry Mixing (Pretreatment and High-Level Waste [HLW] Vitrification)
- HLW Melter Offgas Treatment (HLW Vitrification)
- Low-Activity Waste (LAW) Container Closure (LAW Vitrification)
- LAW Container Decontamination (LAW Vitrification)

This TMP:

- Presents an overview of planned technology development and engineering activities to mature CTEs identified in the DOE completed TRAs, which have not received a Technology Readiness Level of 6.

- Describes the approach to manage the closure of the technology maturity issues.

- Presents and reconciles the technology issues identified in the TRAs with those identified by the EFRT assessment.

The estimated budgets to close the EFRT and the TRA identified technology maturity requirements are $224 million and $33 million, respectively. The technology maturation activities are to be managed to complete the closure of the EFRT and TRA technology issues within the DOE approved WTP cost baseline.

---

[1] DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005

ACRONYMS

AHL	Analytical Hot Cell Laboratory Equipment System
CD	Critical Decision
CNP	Cesium Nitric Acid Recovery Process System
CO_2	carbon dioxide
CTE	Critical Technology Element
CXP	Cesium Ion Exchange Process System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DWPF	Savannah River Defense Waste Processing Facility
EFRT	External Flowsheet Review Team
EM	Office of Environmental Management
FEP	Waste Feed Evaporation Process System
FRP	Waste Feed Receipt Process System
HEME	high-efficiency mist eliminator
HLP	HLW Lag Storage and Feed Blending Process System
HLW	High-Level Waste [Vitrification Facility]
HOP	HLW Melter Offgas Treatment Process System
IHLW	immobilized high-level waste
ILAW	immobilized low-activity waste
IRP	issue response plan
LA-ICP-AES	Laser Ablation-Inductively Coupled Plasma-Atomic Emission Spectrometer
LAW	Low-Activity Waste [Vitrification Facility]
LFH	LAW Container Finishing Handling System
Mo	molybdenum
NASA	National Aeronautics and Space Administration
ORP	Office of River Protection
PJM	pulse jet mixer
PT	Pretreatment [Facility]
PUREX	Plutonium-Uranium Extraction Plant
PVV	Process Vessel Vent Exhaust System
PWD	Plant Wash and Disposal System
RCRA	*Resource Conservation and Recovery Act of 1976*
RF	resorcinol-formaldehyde
RLD	Radioactive Liquid Waste Disposal System
SEWG	Science and Engineering Working Group
SIC	sulfur-impregnated carbon
TCP	Treated LAW Concentrate Storage Process System
TLP	Treated LAW Evaporation Process System
TMP	Technology Maturation Plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
UFP	Ultrafiltration Process System
WESP	Wet Electrostatic Precipitator
WTP	Waste Treatment and Immobilization Plant
WVDP	West Valley Demonstration Project

CONTENTS

This page intentionally left blank.

1.0 Introduction

The U.S Department of Energy (DOE), Office of River Protection (ORP) is constructing a Waste Treatment and Immobilization Plant (WTP) for the treatment and vitrification of the underground tank wastes stored at the Hanford Site in Washington State. Hanford tank waste consists of approximately 190 million curies of radioactivity in approximately 50 million gallons of waste. The tank waste includes solids (sludge), liquids (supernatant), and saltcake (dried salts that will dissolve in water forming supernatant). The tank waste will be treated and immobilized to protect the environment and meet regulatory requirements.

1.1 Purpose of the Waste Treatment and Immobilization Plant

The WTP is being constructed to remediate Hanford Site tank waste by:

- Pretreating the waste to separate it into two fractions, low-activity waste (LAW) and high-level waste (HLW);
- Immobilizing the LAW as a vitreous waste form for onsite disposal; and
- Immobilizing the HLW as a vitreous waste form for ultimate disposal in the national repository.

The first tank waste fraction, LAW, is comprised of the tank waste liquids (and dissolved saltcake) and contains the bulk of the tank waste chemicals and certain radionuclides (e.g., cesium, strontium, and transuranics) that must be removed prior to immobilizing the waste. LAW is a mixed, characteristic, and listed waste regulated under the *Resource Conservation and Recovery Act of 1976* (RCRA), and must meet certain treatment standards and performance standards for onsite disposal of the final waste form.

The second tank waste fraction, HLW, is comprised of the long half-life radioactive tank waste solids and the radionuclides separated from the LAW fraction. HLW must meet specific treatment and performance standards for storage and repository disposal of the final waste form.

The WTP is comprised of five major facilities:

- Pretreatment (PT) Facility to prequalify the waste feeds and separate the tank waste into HLW and LAW process streams
- LAW Vitrification Facility to immobilize the LAW fraction
- HLW Vitrification Facility to immobilize the HLW fraction
- Analytical Laboratory to support the operation of the treatment facilities
- Balance of Facilities that provide utilities and other support services to the treatment facilities

The WTP Project is DOE’s largest capital construction project with an estimated cost of $12.263 billion and a project completion date of November 2019.

1.2 Purpose of the Technology Maturation Plan

The purpose of this Technology Maturation Plan (TMP) is to describe:

- Activities and schedules to resolve the WTP technology maturity issues
- Relationship of the Technology Readiness Assessments (TRA) and External Flowsheet Review Team (EFRT) issues
- Plan to manage the closure of the WTP technology issues

This page intentionally left blank.

2.0 Technology Assessments of the WTP

The maturity of the WTP process flowsheet and technologies have been assessed by the WTP Contractor (Bechtel National, Inc.), independent WTP contractor review teams and the DOE in design review and oversight processes. The most notable assessments were the:

- *Comprehensive External Review of the Hanford Waste Treatment Plant Flowsheet and Throughput*[1] completed in March 2006. This assessment, termed the "External Process Flowsheet Review," identified 28 separate issues. These issues included technology, design, operational, and programmatic topics. A number of these issues originated from the immature state of the technologies that comprise the WTP flowsheet.
- Three separate TRAs were conducted by the DOE. These TRAs were patterned after guidance established in the U.S. Department of Defense (DoD) *Technology Readiness Assessment Deskbook*[2] (DoD 2005).

Major results from these assessments are summarized below. A crosswalk of the issues identified in these separate assessments is provided in Appendix A.

2.1 External Process Flowsheet Review

An independent External Process Flowsheet Review Team (EFRT), reporting to the WTP Contractor, conducted a review to determine if the design of the WTP will achieve its waste treatment capacity requirements. The EFRT was comprised of technical experts from industry, academia, and scientific laboratories.

The EFRT conducted a comprehensive review of the entire WTP process flowsheet to address three principal questions:

1. Are there any major issues that will prevent the WTP from operating?
2. Are there any major issues that will prevent the WTP from achieving contract-specified treatment rates with commissioning and future feeds?
3. Are there any potential issues that could prevent the WTP from achieving contract-specified treatment rates with commissioning and future feeds?

From their assessment, the EFRT concluded:

- Plugging of process piping from solids and precipitation could result in unplanned outages that prevent the WTP from operating consistently. If this major issue is corrected, there are no other issues that will keep the WTP from operating.
- Sixteen other major issues were identified that could prevent the WTP from achieving contract treatment rates with commissioning and future feeds. These issues include mixing vessel erosion, mixing system adequacy, process operating limit definition, and design issues with the PT Facility Ultrafiltration Process System (UFP). Fixing these major issues will ensure the WTP will achieve the design treatment rates for all presently identified waste feeds.

---

[1] CCN:132846, *Comprehensive External Review of the Hanford Waste Treatment Plant Flowsheet and Throughput,* March 2006, Bechtel National Inc. Richland, Washington

[2] DoD 2005, *Technology Readiness Assessment (TRA) Deskbook,* Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005

- Eleven potential issues were identified that could also prevent the WTP from achieving contract treatment rates with commissioning and future feeds. The potential issues included undemonstrated decontamination factors for the evaporators, process recycle management, and process control system design adequacy. Fixing these potential issues provides additional assurance in achieving design treatment rates.

The EFRT concluded that all of the issues identified have solutions and do not require development of new technologies. However, maturation of selected WTP technologies (e.g., ultrafiltration and cesium ion exchange) is required.

2.2 WTP Technical Readiness Assessments

The DOE has independently completed three separate TRAs for the WTP. These TRAs are identified below and are included in Volume II of this TMP.

- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities*, 07-DESIGN-042, U.S. Department of Energy, Richland, Washington
- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) HLW Waste Vitrification Facility*, 07-DESIGN-046, U.S. Department of Energy, Richland, Washington
- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Pretreatment Facility*, 07-DESIGN-047, U.S. Department of Energy, Richland, Washington

The methodology used for conducting the WTP TRAs was based upon detailed guidance contained in the DoD *Technology Readiness Assessment Deskbook*. The assessments utilized a slightly modified version of the Technology Readiness Level (TRL) Calculator[3] originally developed by Nolte et al. (2003) to determine the TRL for the critical technology elements (CTE). The three TRAs consisted of three parts:

1. Identifying the CTEs.
2. Assessing the TRLs of each CTE using the technical readiness scale used by DoD and the National Aeronautics and Space Administration (NASA) and adapted by the assessment team for use by DOE.
3. Recommendations for required work to bring immature technologies to appropriate maturity levels. This third part is the subject of this TMP.

A TRA and CTE summary shown below identifies the number of WTP systems considered in the TRAs, number of systems determined to be CTEs, and the number of CTEs determined to have a TRL less than 6.

---

[3] Nolte, William L., et al., *Technology Readiness Level Calculator*, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003

WTP Area	Number of Systems considered in TRA as Potential CTEs	Number of CTEs selected for Detailed Technology Assessment	Number of CTEs with a Technology Maturity Level less than 6
Pretreatment	33	9	9
Analytical Laboratory	20	1	1
Balance of Facilities	20	1	0
LAW Vitrification	33	5	2
HLW Vitrification	30	5	2
WTP Common	50	0	0
Total	185	21	14 (8 [a])

[a] Common mixing issues were identified for the following systems: Cesium Ion Exchange Process System (CXP), Waste Feed Evaporation Process System (FEP), Waste Feed Receipt Process System (FRP), HLW Melter Offgas Treatment Process System (HOP), HLW Lag Storage and Feed Blending Process System (HLP), Treated LAW Evaporation Process System (TLP), and Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD). The mixing issues are combined in this TMP resulting in 8 total CTEs with TRL less than 6.

2.3 Definition of TRL Levels

The TRL scale used in the TRAs is based on the DoD and NASA scales. Minor modifications have been made to reflect the chemical processing function of the WTP.

Testing is recommended in this plan to ensure that the eight identified technologies will be matured to a TRL 6. To achieve a TRL 6, testing must be completed at an engineering- or pilot-scale, with a testing system fidelity that is similar to the actual application and with a range of simulated wastes and/or limited range of actual waste, if applicable.

Obtaining additional information and understanding of the behavior of the tank wastes and process stream compositions is critical to defining the operational environment and evaluating the WTP technologies. This information requirement is being addressed by detailed activities being conducted to resolve the EFRT issues.

Technology Readiness Levels used in WTP Assessments

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full-scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in a relevant environment.	Representative engineering-scale model or prototype system, which is well beyond the lab-scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory-scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

2.4 Technology Heritage

One of the primary missions of the DOE and its predecessor agencies is to conduct waste treatment operations for waste generated from nuclear research and the production of nuclear materials. To support this mission, DOE has an active technology development program to test and evaluate candidate technologies for nuclear waste treatment. This development program provided the basis for establishing the technical requirements and identification of candidate technologies for the WTP. The technologies that comprise the WTP process flowsheet have either been previously used in nuclear waste treatment operations in DOE facilities or are adaptations of commercial technologies.

The technology maturation activities described in this TMP comprise only a part of the technology development required to support the final WTP design. A significant technology development and testing effort has already been completed by DOE and the WTP Contractor to provide the basis for the WTP design and to support operational planning. The results of this existing program have resulted in the maturation of a majority of the technologies required for the WTP. These technologies include the glass melters in the LAW Vitrification and HLW Vitrification Facilities and the waste feed evaporators in the Pretreatment Facility. The WTP Project is also taking advantage of other sources of technology from other DOE funded technology programs and private industry to support the development of the WTP flowsheet.

2.5 WTP Project Activities and Technology Maturation

The WTP facility design is comprised of a facility structure with supporting services and utilities, and installed technologies (e.g., equipment systems) located within the facility structure. The purpose of the WTP facility structure is to provide shielding for personnel from the radioactive material being processed, and containment and confinement of radioactive materials. Based on design concepts for radiochemical facilities, including the WTP, the design of the facility is developed in parallel with the initial selection of technologies. This design process results in the specification of the physical interfaces between the facility and the technologies. This design approach provides an opportunity to mature and insert technologies during construction, and provides the flexibility to accommodate modified and alternative technologies at a future date. This approach was used in the WTP to reduce the overall project completion schedule.

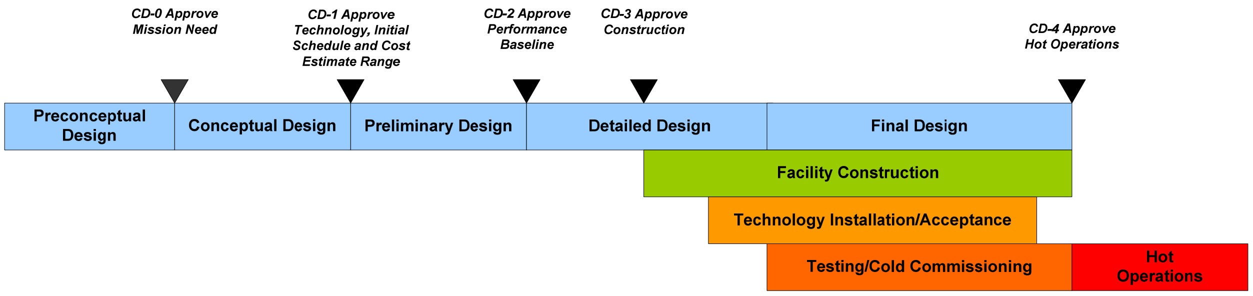
The figure below shows the DOE O 413.3[4] project management process, as applied to the WTP, and the technology maturation process. This figure shows the relationship of the Critical Decision (CD) process with major project activities (e.g., design, construction, commissioning, and operations) and the desired maturity level of critical technologies. This figure illustrates that technology demonstration (e.g., testing to achieve a TRL 5 or 6) can be in progress during the final design and facility construction phase. However, technologies that have not achieved a TRL 6 represent a risk to the facility design. This risk was evaluated in the development of the TMP. Where required, the need to develop alternative technologies has been specified.

Technology performance risks also exist during the cold and hot commissioning phases of the WTP project. These risks will be identified and mitigated during technology installation and acceptance, and cold and hot commissioning, of the actual plant equipment systems.

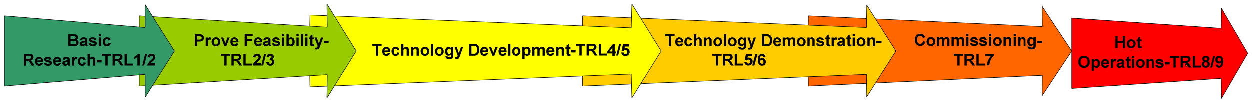
---

[4] DOE O 413.3, *Program Management and Project Management for the Acquisition of Capital Assets*, January 3, 2006, U.S. Department of Energy, Washington D.C.

DOE's Project Management Process as applied to WTP



Technology Maturation Process



2.6 Management of Technology Maturity

Oversight of technology maturation will be conducted by a technical interface product team comprised of staff from the DOE and the WTP Contractor. The team will:

- Oversee the planning and completion of the technology testing and engineering work identified in this TMP associated with closure of the EFRT and TRA issues.
- Identify and evaluate additional WTP technology development requirements using a risk assessment and value engineering process.
- Ensure the closure of technology issues.
- Develop the budget for WTP technology maturation.

New technology opportunities will be identified and evaluated, and approaches to evaluate and consider them will be defined. Technology opportunities will be identified through value engineering analysis. Technology development requirements will be recommended where required.

Detailed issue response plans (IRP) will be prepared to provide the planning basis to resolve technology issues identified in this TMP. The IRPs will provide the detailed activities, schedule, budget, and technology maturation and issue closure criteria. IRPs were also prepared to document the plan, schedule, and budget for closure of the EFRT issues.

3.0 Technology Maturation Plan

3.1 Development of Technology Maturation Requirements

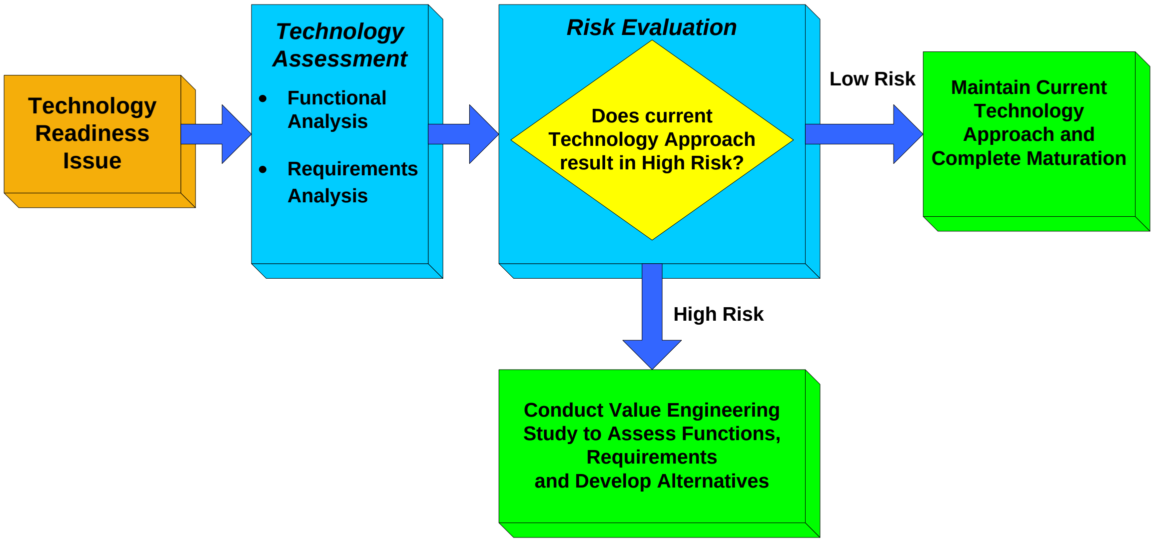
The development of the maturation plan for the CTEs used qualitative risk assessment and value engineering techniques to ensure that:

- Maturation plans for the CTEs were developed using a systematic approach.
- WTP project-specific and life-cycle implications of maturing the CTEs were understood.
- The current plan, and potential alternative strategies, for closing the technology risks considered the requirements, system functions, cost, and life cycle operations.
- Opportunities for improving operational performance, reducing cost, or simplifying the system were identified and considered.

The approach used to establish the maturation plans for the CTEs involved a re-assessment of their functions and critical design requirements, an evaluation of the risk of technology failure, and a determination of the acceptability of the current development plan. This approach provided an understanding of the uncertainties and assumptions used in the CTE requirements, the design, and operational interfaces within the WTP. It also provided the background for a “first order” risk evaluation of the CTE.

The risk evaluation was designed to determine the qualitative probability and consequences of not maturing the CTE to a TRL 6 prior to completion of WTP Project construction. The outcome of the analysis, either a low or high risk, was used to determine the preference for maintaining the current development plan or the identification and examination of an alternative plan based on potential impacts.

If determined necessary, based on a high risk, a more detailed value engineering study was identified in the TMP. The value engineering study is a planned, detailed evaluation of the functions and requirements of the technology to identify a preferred approach to improve the performance of the technology solution. The purpose of the value engineering study is to determine more completely if the current technology plan is acceptable and identify and select an alternative for development.



3.2 Life-Cycle Benefit

The use of the TRA approach to assess and plan technology maturation for the WTP results in:

- Reduced overall project costs by resolving technology maturity issues and avoiding engineering re-work and potential delays in WTP commissioning.
- Higher confidence that the WTP design will achieve program mission operating requirements by the assessment of technology readiness and the completion of required technology maturation activities.
- Higher confidence that the WTP will meet its operating goals at a reduced life-cycle operating cost.

Technology maturation costs are small compared to impacts from design re-work and potential delays in the WTP operating schedule (estimated at over $1 billion per year). The TRA process is also designed to ensure that future performance issues associated with the technology systems are identified and resolved before operations.

3.3 Specific Technology Maturation Plans

3.3.1 Rapid Analysis of Radioactive Waste Samples – Analytical Laboratory

Key Technology Addressed

Laser Ablation-Inductively Coupled Plasma-Atomic Emission Spectrometer (CTE: LA-ICP-AES)

Objectives

Achieving the waste treatment capacities of the WTP requires the development of the LA-ICP-AES technology to support the analysis of waste treatment process samples. The LA-ICP-AES uses a laser to ablate and analyze particulates from the surface of a prepared glass coupon (which will be prepared from waste stream samples) for elemental species in the waste streams. The laser ablation sample preparation and analysis technique was selected for application in the WTP because the analysis turnaround time associated with LA-ICP-AES technology (less than 10 hours) is significantly shorter than traditional wet chemistry techniques (range from 22 to 55 hours). These wet chemistry techniques are used in current and previous DOE waste processing plants (West Valley Demonstration Project [WVDP] and Savannah River Defense Waste Processing Facility [DWPF]), where chemical sample analysis of melter feeds was completed by dissolving the slurry by acid dissolution, converting the slurry to glass or dissolving the glass with a caustic fusion (both potassium and sodium), and analyzing the dilute fusion solutions using LA-ICP-AES technologies.

Approach

Based on WTP method development work and previous testing at DOE national laboratories, sufficient information was available to proceed with prototype LA-ICP-AES specifications for testing to optimize the final design of the laser ablation sample preparation system. The WTP Project has initiated a full-scale test in the Hanford 222-S Laboratory to verify and validate LA-ICP-AES analytical method for hot samples. The task involves installation and testing of a WTP-procured LA-ICP-AES glovebox system properly configured in the adjacent hot cell for remotely ablating HLW samples and adaptation of the developed LA-ICP-AES method to routine operational requirements. This system will be a full-scale prototype of the WTP Project system to analyze actual tank waste.

Scope

- Construct prototype LA-ICP-AES test system
- Test prototype LA-ICP-AES test system
- Develop calibration and operating procedures for WTP LA-ICP-AES

Current State of the Art TRL 5

Initial feasibility tests of the LA-ICP-AES system were completed in two independent studies conducted at Savannah River National Laboratory and Battelle's Pacific Northwest National Laboratory.
The studies supported rapid turnaround time requirements, and evaluated the capability of the LA-ICP-AES to provide sufficient sample turnaround time, accuracy, and precision for waste processing within the WTP.

	Milestones	Performance Targets	TRL Achieved at Milestone
2007	Construct and assemble LA-ICP-AES prototype	Plant-scale prototype of LA-ICP-AES assembled in radiochemical facility at the Hanford Site (e.g., 222-S Laboratory)	5
2008	Demonstrate LA-ICP-AES on actual tank waste samples in prototypic operating environment	LA-ICP-AES achieves throughput and quality performance targets for the plant	6

3.3.2 Waste Solids Separation and Treatment – Pretreatment Facility

Key Technology Addressed

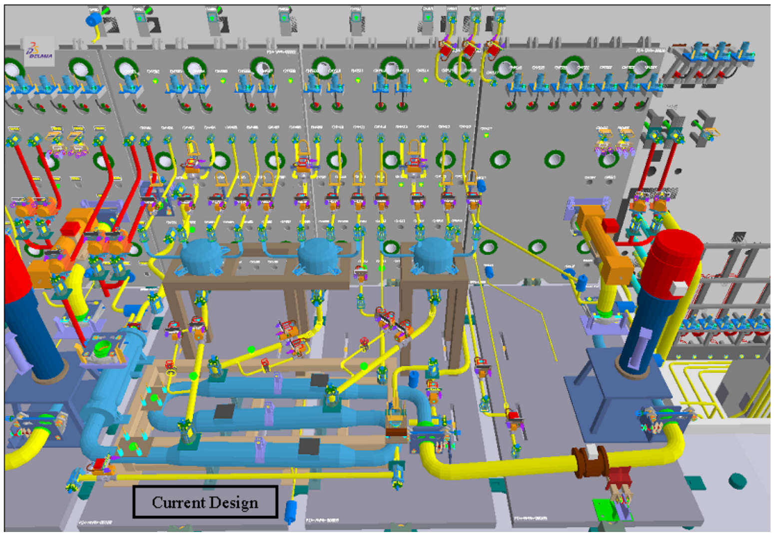
Separation of HLW Solids and Liquids, Treatment of Solids to Remove Non-Radioactive Components (CTE: UFP)

Objective

The purpose of the Ultrafiltration Process System (UFP) is to separate Hanford Site tank HLW solids from the liquids, and treat the solids by caustic and oxidative leaching processes. The production rate and quality of the downstream operations of both the LAW Vitrification Facility and the HLW Vitrification Facility are directly related to the performance of UFP.

The purpose of the caustic and oxidative leaching processes is to wash and dissolve materials (aluminum, chromium, and other components) that would affect the performance of the HLW vitrification system. High solids slurry feed (~20 % solids) to the HLW melter is desired to reduce volatiles and increase throughput. While testing has shown it is possible to maintain HLW vitrification melt rates with lower concentration feeds, this mode of operation could lead to offgas system plugging, especially in the film cooler.

Optimum leaching conditions for the HLW solids are not known without testing. The HLW glass canister production can be minimized by increasing the effectiveness of the leaching processes. If the HLW sludge is not effectively leached, an excessive number of immobilized high-level waste (IHLW) canisters will be produced; or, if extra leaching chemicals are required to support leaching, an excessive number of LAW glass containers could be produced. The ability to meet WTP Project throughput, and shorten the WTP mission duration will be enhanced by understanding the leaching processes.



Some of the feeds to the leaching operation will contain significant amounts of alumina, oxalates, and other materials that could precipitate. There is the possibility that aluminum solids will form in the leach tank itself or in other streams from the leaching operation if unfavorable conditions occur.

Approach

The maturation approach for the UFP is to demonstrate through testing of the prototypic design and process flowsheet. An engineering scale test system is being designed and built and will begin operation in early 2008. Laboratory testing with actual radioactive tank waste samples is also required to demonstrate the process flowsheet. The testing activities will be supported by process modeling using chemistry-based computer codes.

Alternative technologies will be identified, evaluated, and developed to perform the functions of the UFP due to the low maturity of this technology and the current risk to WTP performance.

Scope

- Radioactive testing of sludge treatment process at laboratory scale
- Prototypic testing of UFP pilot plant to confirm design and process
- Process modeling to simulate operation and performance of plant-scale UFP
- Identify, evaluate, and develop an alternative technology for the UFP

Current State of the Art TRL 3

The UFP was determined to be a TRL 3 because the WTP ultrafiltration technology design has only been conceptualized on paper; integrated caustic/oxidative leaching has not been completed; there is very little data on the filtration of caustic leached waste and no filtration data on oxidatively leached waste; and prototypic integrated system equipment testing to demonstrate process feasibility has not been completed.

	Milestones	Performance Targets	TRL Achieved at Milestone
2007	Complete radioactive laboratory-scale leaching and filtering tests	Demonstrate leaching and filtering with actual tank waste at laboratory scale	4
2008	Develop representative non-radioactive simulants for use in pilot-scale testing	Representative simulants for pilot-scale mixing, leaching, and filtering tests developed	5
2009	Complete initial pilot-scale testing of ultrafiltration system using non-radioactive simulants	Demonstrate ultrafiltration and leaching design concept with prototypic process flowsheet and pilot-scale testing system	6
2009	Complete a value engineering study to identify and evaluate an alternative technology for the UFP	Identify an alternative technology to perform the same functional requirements as specified for the UFP	4

3.3.3 Radioactive Cesium Removal – Pretreatment Facility

Key Technology Addressed

Cesium Removal from Filtered Liquid Wastes using Ion Exchange System (CTE: CXP)

Objective

The primary purpose of the Cesium Ion Exchange Process System (CXP) is to remove radioactive cesium (Cs-137) from the UFP permeate using an ion exchange process prior to immobilization of the permeate (e.g., treated LAW) as LAW glass.

Approach

Current activities to demonstrate adequacy of the CXP technology are divided into an ongoing effort to develop and qualify ion exchange media (resin) for use in the system, and physical design of the WTP system.

The maturation approach for the CXP will include a combination of additional design review, value engineering, flowsheet modeling, laboratory-scale testing, and prototype testing to confirm design concepts. Further maturation of the technology is needed to test and evaluate: column head space inerting and flammable (e.g., hydrogen) gas removal; removal of 99% of spent resin from columns; and additional assessments of cesium ion exchange resin (spherical resorcinol formaldehyde) resin for physical degradation due to radiation damage, allowable Cs-137 concentrations in the nitric acid eluate, impact of organics species on performance and impact of precipitates on ion exchanger, and ion exchanger column performance.

Scope

- Assess design and technology concepts for the hydrogen venting subsystem, select reference
- Conduct prototypic testing of hydrogen venting subsystem
- Demonstrate 99% removal of spent ion exchange resin
- Assess solids precipitation in ion exchange feed
- Assess impact of solids and organics on ion exchanger performance
- Complete radiation stability testing on ion exchange resin
- Establish detailed cesium ion exchange column design features

Current State of the Art TRL 5

Significant testing of the CXP technology to demonstrate adequacy has included an ongoing effort to develop and qualify ion exchange media (resin) for use in the system, and physical design of the equipment system. The CXP was determined to be a TRL 5 due to incomplete demonstration of the process and equipment technology and incomplete testing of the cesium ion exchange resin. Technology testing will include the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the ion exchange columns, the capability to remove 99% by volume of the spherical ion exchange resin from a prototypic column, and evaluating the potential for formation and management of solids in the CXP.

	Milestones	**Performance Targets**	**TRL Achieved at Milestone**
2008	Complete value engineering assessment of hydrogen removal system design concept	Select design concept for hydrogen removal system	5
2009	Test prototypic hydrogen removal system	Verify hydrogen concentration levels can be maintained below flammability levels in ion exchange system	5
2009	Complete radiation stability testing of cesium ion exchange resin	Determine if performance of resin is adequate following anticipated radiation dose	5
2009	Assess solids precipitation and mitigation approaches in ion exchange feed	Demonstrate solids management is adequate in ion exchange system	5
2009	Determine allowable Cs-137 concentration in nitric acid used for elution (Note: tied to Cesium Nitric Acid Recovery Process System [CNP] issue resolution)	Demonstrate maximum Cs-137 level in nitric acid used for ion exchanger elution	5
2009	Test ability of ion exchange system to process UFP permeate containing solids and organic materials	Demonstrate maximum capability of ion exchange system to process permeate containing solids and organics	6

3.3.4 Cesium and Nitric Acid Management – Pretreatment Facility

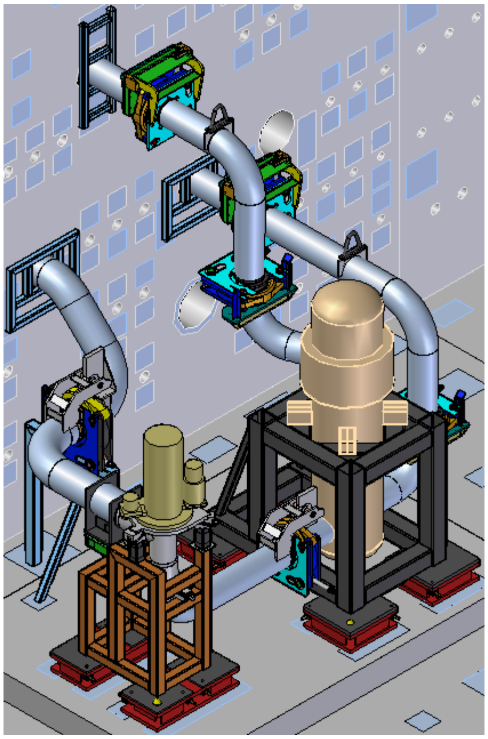
Key Technology Addressed

Treatment of Cesium Ion Exchange Eluate to Separate Cesium-137 and Nitric Acid (CTE: CNP)

Objective

The purpose of the Cesium Nitric Acid Recovery Process System (CNP) is to support uninterrupted and continuous operation of the CXP by receipt and vacuum concentration of as-produced eluate from the CXP, by recovery of (~ 0.5M, essentially cesium-free) nitric acid for reuse as CXP eluent, and by transfer of concentrated (cesium-rich) eluate to the process used to make HLW melter feed.

Approach



The current design for the CNP is supported by material and energy balances, engineering calculations, limited lab-scale testing, vendor recommendations, past Hanford Site evaporator experience from B Plant and Plutonium-Uranium Extraction (PUREX) Plant operations, plus general industrial experience with nitric acid concentration and rectification. The CNP equipment (evaporator vessel including demisters, reboiler, reboiler pump, rectifier, condensers, and vacuum system) is designed and supplied by the vendor, based on engineering specifications prepared by the WTP Contractor. Vendor shop tests include limited testing of fabricated equipment only. Removal (but not replacement) of demisters will be demonstrated. Integrated system acceptance tests are planned after installation, during cold commissioning of the PT Facility.

The technology maturation activities include a comprehensive CNP design review, pilot testing of the integrated CNP process to support final design specification, fabrication and testing, followed by installation, and commissioning. Alternative operating modes for the CNP will also be evaluated.

The design review will evaluate the current design including the control system, and level and entrainment control. If warranted, following the design review, pilot testing will be completed to confirm the CNP equipment concepts, management of foaming in the evaporator, achievable decontamination factors for cesium in the rectifier, use of specific gravity process control and upcomer design adequacy. The current surge tankage may be adequate if pilot testing shows that flow variations necessary to accommodate the batch/continuous CNP operations are comfortably within the capacity of supporting vessels. If not, addition of CNP feedstock vessels and/or recovered acid storage may be required.

Maintenance of evaporator internals will also be demonstrated. Testing at larger scale than pilot (10% full-scale) is probably not justified since the features to be demonstrated (integrated operations, control system, surge volumes, etc.) are not particularly scale-sensitive. Review of commercially available pilot facilities would be prudent, since the individual equipment items to be tested are standard process equipment. Test equipment and test conditions should be specified which closely match the planned CNP design and operations, in order to provide a test environment very close to the anticipated operational environment.

Scope

- Complete computer simulation of control system to establish control requirements
- Assess alternative operating modes and design concepts for the CNP
- Complete design assessment of the CNP and proposed integration into PT Facility processes
- Complete prototypic testing of CNP if required

Current State of the Art TRL 3

The CNP was determined to be a TRL 3 because testing has only been completed on a laboratory scale to measure the physical properties of the anticipated process solutions to provide information for thermodynamic modeling. Confirmation testing of the CNP equipment components (reboiler, separator vessel, and condenser; demisters and rectifier column) has not been completed. Computer simulation of the CNP operation has not included the full composition range of feed solutions. Proposed changes to the CNP flowsheet including the neutralization of the cesium concentrate product and impacts of the change to the use of resorcinol-formaldehyde (RF) resin have not been evaluated.

	Milestones	**Performance Targets**	**TRL Achieved at Milestone**
2008	Complete value engineering design assessment of the CNP, and alternative design concept, with proposed integration into PT Facility processes	Review performance requirements for CNP design and operations concept	4
2009	Complete computer simulation of CNP control system and alternative CNP operating modes	Confirm control system concept for concentration of cesium and separation of nitric acid	5
2009	Complete prototypic testing of CNP design concept if required	Demonstrate the design of the CNP and characterize performance of the CNP in all anticipated operating modes	6

3.3.5 Waste Slurry Mixing – Pretreatment and HLW Vitrification Facility

Key Technology Addressed

Mixing of Process Waste Streams Using Pulse Jet Mixer (PJM) and other Mixing Devices (CTEs: PJM, CXP, FEP, FRP, HOP, HLP, PWD, TCP, TLP, RLD, UFP)

Objective

The function of the PJM system is to mix waste streams comprised of liquid and solids in specially designed vessels to dissipate gases, blend liquids and solids, and suspend solids for sampling and transport.

PJM devices are long cylindrical vessels that draw in fluid by a vacuum and then pressurize to partially eject the fluid to cause mixing; much like a syringe draws in and expels fluid. These devices have been shown to be reliable and have no moving parts that require maintenance. Thus, the PJM was selected to be used in vessel systems that were designed to have no maintenance over the 40-year operational design life of the WTP.

Approach

PJM technology maturation is divided into two activities: (1) an ongoing development effort to develop and qualify PJMs for use in WTP vessels and (2) physical design of the PJM systems.

The mixing system design will be addressed by testing in scaled prototypes to verify the ability to resuspend settled waste following a mixing system shutdown with bounding conditions of waste characteristics and PJM performance factors. Data from these tests will be used to determine mixing times associated with the various mixing functions of each Newtonian vessel, and production model runs, including confirmed mixing times demonstrating required plant throughput. Testing will also be done to confirm that the post-design basis event mixing adequately disturbs settled solids to release hydrogen from a settled solids layer. Testing will confirm that Newtonian vessel mixing systems are sufficient to produce the degree of waste homogeneity required by mixing success criterion.

Vessels located in black cells that do not have mixing but have the potential for solids formation will be evaluated to establish a technology solution. This includes evaluating the definition of conditions that lead to solids formation; process flowsheet options to preclude solids formation; physical changes that will preclude solids formation (e.g., operating solvent-rich or at higher temperature to prevent precipitation); and selection of design features (flowsheet changes, operating changes, and equipment changes) that mitigate solids formation.

Scope

- Confirm mixing requirements for WTP process vessels
- Confirm the mixing system design of PJM vessels containing Newtonian and non-Newtonian fluids to resuspend settled waste following a mixing system shutdown
- Develop testing information that allows accurate prediction of required mixing time for various vessel-mixing functions
- Confirm that post-design basis event mixing of vessels that use one-half of the PJMs for mixing adequately releases hydrogen
- Demonstrate that normal process PJM mixing successfully meets mixing requirements for vessels containing Newtonian and non-Newtonian fluids
- Identify and confirm mixing requirements for vessels that do not currently have mixing requirements

Current State of the Art TRL 4

Confirmatory testing to validate the mixing performance of PJM mixed vessels containing low solid concentrations (e.g., Newtonian solutions) has not been completed. Specific, quantifiable design requirements for the PJM technology have not been established to support testing evaluation and design confirmation. The mixing requirements will consider the functional requirements (e.g., safety, environmental, and process control) of the vessels and the anticipated waste characteristics in the vessel.

	Milestones	Performance Targets	TRL Achieved at Milestone
2008	Complete value engineering process to confirm mixing requirements for PJMs	Review performance requirements for PJM mixed vessels based on safety, functional requirements and waste compositions	5
2009	Complete prototypic testing on PJM design configurations	Prototypic testing complete	5
2009	Confirm adequacy of mixing in PJM mixed vessels	Confirm adequacy of PJM vessel design concepts to meet mixing requirements based on prototypic testing and engineering analysis	6
2009	Identify and confirm mixing requirements for vessels that do not have mixing capability using value engineering	Establish and demonstrate mixing system design for vessels that do not currently have mixing capability	6

3.3.6 HLW Melter Offgas Treatment – HLW Vitrification Facility

Key Technology Addressed

Treatment of Melter Offgas to Remove Contaminants (CTE: HOP/PVV)

Objective

The function of HLW Melter Offgas Treatment Process System (HOP) is to remove hazardous particulates, aerosols, and gases from the HLW melter offgas and vessel ventilation process offgas. The function of the Process Vessel Vent Exhaust System (PVV) is to provide a pathway for vessel offgas to the HOP for treatment. Confinement barriers are provided by maintaining a vacuum on vessels and associated piping for the safety of plant staff. The combined primary and vessel ventilation offgas stream is discharged to the secondary offgas system, and then exhausted to the atmosphere from the facility stack. These systems treat the HLW melter offgas so that it conforms to relevant federal, state, and local air emissions requirements at the point of discharge from the facility stack.

Approach

The development and testing activities for the HLW offgas system are divided into two activities: (1) an ongoing development effort to develop and qualify equipment and (2) physical design of the components currently undergoing detailed design and procurement. Specific details for the three technology maturation activities, film cooler cleaning, carbon sulfur bed qualification, and material corrosion issues with the Wet Electrostatic Precipitator (WESP), are described below.

Film cooler operating ranges will be determined based on analysis of existing experimental data. The design criteria for the film cooler cleanout device will be established and a prototypic film cooler cleaner designed and tested to confirm the final design of the film cooler cleanout device.

Prototype testing will be performed for the sulfur-impregnated carbon (SIC) bed material using HLW gas simulant and prototypic adsorbent materials. Testing is planned to encompass: removal efficiency for elemental mercury, breakthrough time, and loading profile throughout the adsorbent bed; and removal efficiency, breakthrough time, and loading profile for mercury, naphthalene, and allyl alcohol; as well as temperature increases associated with nitric oxide (NO_x) and allyl alcohol.

A revised corrosion evaluation will be completed to demonstrate the viability of 6% molybdenum (Mo) stainless steels for WESP internals and vessels in the WTP offgas environment. Selection of corrosion resistant alloy for WESP vessels and internals is of critical importance to support the 40-year design life. In addition, piping and valving arrangements will be completed to allow direction of offgas directly from the melter to the high-efficiency mist eliminator (HEME) or to the HEME through the WESP in the event of premature failure of the WESP.

Scope

- Design, test, and confirm design for HLW melter film cooler cleaner
- Qualify the carbon-sulfur absorbent for mercury removal
- Complete corrosion assessment for the WESP
- Identify alternative operating approach in the event of premature WESP failure

Current State of the Art TRL 5

Extensive testing of a prototypic HLW offgas system was completed to support development of the HLW melter. Technology risks remain with the HLW melter film coolers, submerged bed scubber, carbon-sulfur bed columns, and the WESP design.

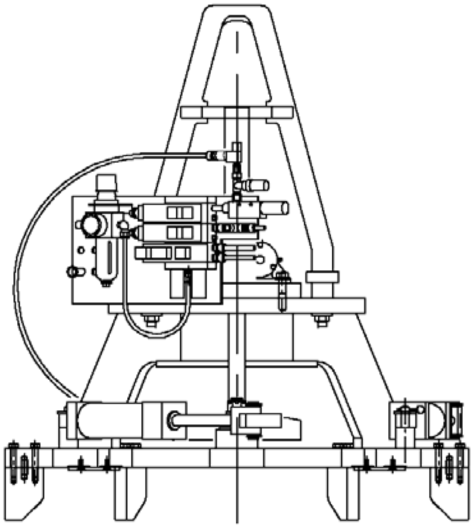
	Milestones	Performance Targets	TRL Achieved at Milestone
2008	Develop and test a prototypic film cooler cleaner	Demonstrate film cooler cleaner design concept	5
2008	Complete testing of candidate SIC bed material to demonstrate adequacy for mercury removal	Testing results that confirm adequacy of SIC bed material	5
2008	Complete evaluation of the WESP materials of construction, complete testing if required	Confirm adequacy of materials of construction for WESP	5
2008	Complete value engineering assessment of alternative operating concept in event of premature WESP failure	Design assessment report identifying an alternative design/operating configuration	6

3.3.7 LAW Container Sealing – LAW Vitrification Facility

Key Technology Addressed

Closure of the LAW Container to Prevent Radioactive Contamination Spread (CTE: LFH Container Sealing Subsystem)

Objective



The LAW Container Finishing Handling System (LFH) container sealing subsystem, located in the LAW Vitrification Facility, is used to provide container closure. The closure allows handling and transportation to the Hanford disposal site, maintains void fill requirements, and supports decontamination.

Approach

The technology maturation activities include a re-assessment of the closure requirements and remote mockup testing.

Value engineering studies will be completed to re-assess the LAW container closure requirements. This will consider: traditional leak rate estimates for shipping (considering the physical properties of the glass source term); defining the Hanford Site shipping requirements; Hanford Site burial ground requirements; container integrity requirements; ability to prove closure qualification over the 40-year lifetime of the plant (repair of the lidding equipment, modification or new equipment, human error); and the ability to control canister contamination. The source and type of expected contamination will be identified as part of the work identified in the LAW Container Decontamination section (Section 3.3.8).

Assuming canister closure leak test criteria is specified, consideration should then be given to determine whether some additional testing during commissioning and operation is required. The WTP will have to prove the closure technique (special process) meets or exceeds the leak criteria and does not require periodic testing or a method of sampling the lid seal leak rate.

Additional testing in a mockup will be required to mature the technology to a TRL 6 (if the existing technology remains or an alternative technology is selected that has not been demonstrated).
An integrated prototypic testing of the closure system will be performed, including the inert fill, seal cleanliness, and lidding machine operation (retrieving a lid from the lid magazine, installing, visual verification of closure, and leak test of the closure).

Scope

- Complete value engineering assessment on requirements and design solution for LAW container sealing subsystem
- Complete prototypic testing of LAW container sealing subsystem

Current State of the Art TRL 5

The design of the LFH container sealing subsystem has been completed. High-fidelity prototype testing of the sealing system and interfacing subsystems (e.g., glass level measurement, inert filling, inspection design) has not been completed.

	Milestones	**Performance Targets**	**TRL Achieved at Milestone**
2008	Complete value engineering assessment of requirements and design solutions for LFH container sealing subsystem	Re-assess and define performance requirements for sealing of the LAW containers	5
2009	Complete prototypic testing of container sealing	Prototypic testing complete	6

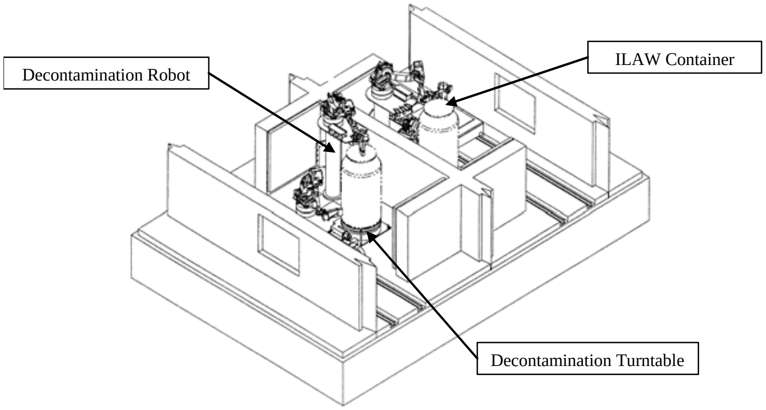
3.3.8 LAW Container Decontamination – LAW Vitrification Facility

Key Technology Addressed

Decontamination of LAW Container following Radioactive Glass Filling (CTE: LFH Container Decontamination Subsystem

Objective

The objective of the LFH container decontamination subsystem is to remove radioactive contamination from filled and sealed LAW containers to a smearable contamination level that allows movement of the containers to the Hanford Site burial ground.



The decontamination process uses abrasion to remove smearable radioactive contamination from the external surfaces of the sealed immobilized low-activity waste (ILAW) container. The abrasive media are solid carbon dioxide (CO_2) pellets. The CO_2 abrasion process uses a localized decontamination approach in which the CO_2 spray is applied through spray nozzles located inside a containment shroud. The shroud is designed to contain the CO_2 vapor (from sublimation of the solid CO_2) and the loose radioactive contamination. The CO_2 and the loose contamination are continuously removed from the shroud using a vacuum system. The contamination is packaged as solid waste.

Approach

The technology maturation activities include a re-assessment of the decontamination requirements, a laboratory test or analysis to define the contamination basis, and prototypic (remote) mockup testing in a relevant environment to demonstrate technology. A value engineering evaluation will be completed to review the basis for the existing decontamination level requirements, methods of achieving the required smearable contamination levels (fixative in some or all places), and methods of responding to decontamination requirements failure, as well as provide recommendations on the testing scope to mature the technology

The LAW container decontamination subsystem, as presently designed, will be prototypically tested to confirm vacuum shroud airflows and travel rates, and CO_2 nozzle velocities and offset distances with simulated operating conditions. Integrated testing will be done in a facility suitable for operators to run the equipment system as expected during production. Lessons learned will be fed back into the design, operation, and operating procedures.

Scope

- Identify expected contamination levels on the LAW containers (type, amount, and adherence mechanism)
- Assess requirements for decontamination of the LAW container
- Define scope of testing for prototypic testing
- Complete prototypic testing of LAW container decontamination system

Current State of the Art TRL 4

The LAW container decontamination subsystem design is being finalized. Limited laboratory-scale testing has been completed to demonstrate proof of concept. Only pieces of the system tested have been tested on a laboratory scale.

	Milestones	Performance Targets	TRL Achieved at Milestone
2008	Re-assess requirements for LAW container decontamination using a value engineering assessment; evaluate alternative technologies	Develop performance requirements for LAW container based on expected contamination levels and contamination mechanism; identify, evaluate and select preferred technology	4
2009	Complete prototypic testing of LAW container decontamination subsystem	Prototypic testing completed that demonstrated adequacy of technology	6

4.0 Technology Maturity Schedule

The Technology Maturity schedule for the activities described is shown below. The TMP activities are scheduled to demonstrate acceptable technology maturity required to support completion of construction and commissioning of the WTP on its current baseline schedule of February 2019.

Critical Technology Element	**Calendar Year**									
	2007		**2008**				**2009**			
	3rd QTR	**4th QTR**	**1st QTR**	**2nd^{t} QTR**	**3rd QTR**	**4th QTR**	**1st QTR**	**2nd QTR**	**3rd QTR**	**4th QTR**
Rapid Analysis of Radioactive Waste Samples (Analytical Laboratory)	🟩	🟩	🟩	🟩	🟩					
Waste Solids Separation and Treatment (Pretreatment)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Radioactive Cesium Removal (Pretreatment)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cesium and Nitric Acid Management (Pretreatment)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Waste Slurry Mixing (Pretreatment and High-Level Waste [HLW] Vitrification)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
HLW Melter Offgas Treatment (HLW Vitrification)	🟩	🟩	🟩	🟩	🟩	🟩				
Low-Activity Waste (LAW) Container Closure (LAW Vitrification)		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
LAW Container Decontamination (LAW Vitrification)		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

This page intentionally left blank.

5.0 Technology Maturity Budget

The Technology Maturity budget for the activities described in this TMP is shown below as indicated by the heading "Additional TMP Cost". This budget is compared with the currently approved budget for resolution of respective technology maturity issues noted as "Current Technology Development Cost". A majority of the CTEs require additional technology maturity budget. All technology maturity costs for the "Rapid Analysis of Radioactive Waste Samples" are included in the current WTP approved budget.

Critical Technology Element	Current Technology Development Scope Cost ($K)[1]	Additional TMP Cost ($K)[2]
Rapid Analysis of Radioactive Waste Samples	$3,700	$0
Waste Solids Separation and Treatment	$57,100	$970
Radioactive Cesium Removal	$4,670	$14,540
Cesium and Nitric Acid Management	N/A[3]	$7,780
Waste Slurry Mixing	$17,700	$1,950
HLW Melter Offgas Treatment	$1,500	$2,210
LAW Container Closure	N/A[3]	$1,780
LAW Container Decontamination	N/A[3]	$4,030
Total	$84,670	$33,260

[1] Budget based on current IRPs. The estimated cost to resolve all EFRT issues is estimated to be $224 million. See Appendix A for technology crosswalk between TRAs and EFRT recommendations.

[2] Additional TMP scope cost includes all identified potential activities to bring the CTE to a TRL 6.

[3] Does not apply. These technologies were not identified for technology development by EFRT.

This page intentionally left blank.

APPENDIX A. Crosswalk of WTP Technology Readiness Assessments and External Flowsheet Review Team Issues

Appendix A summarizes additional detail on the eight technology maturation issues discussed in the body of the Technology Maturation Plan (TMP). This discussion presents a summary from the U.S. Department of Energy (DOE)-conducted Technology Readiness Assessments (TRA) and External Flowsheet Review Team (EFRT)-conducted reviews of the technologies, maturity approach, and estimated maturation budget.

Included are two separate tables that list (1) the technology maturation topics that were identified by both the DOE completed TRAs and the EFRT assessment in which there was agreement and (2) the EFRT issues that have been grouped as Design, Operations, and Programmatic.

<table>
<tr><th colspan="3">Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment</th></tr>
<tr><td>Facility: Analytical Laboratory</td><td>CTE: LA-ICP-AES</td><td>TRL: 5</td></tr>
<tr><td>DOE TRA Assessment</td><td colspan="2">The prototypical Laser Ablation-Inductively Coupled Plasma-Atomic Emission Spectrometer (LA-ICP-AES) system should be tested to demonstrate achievable detection limits for chemical elements of interest and satisfy turnaround time requirements on actual high-level waste (HLW) sludge samples in a relevant environment to support the final design of the actual Analytical Laboratory subsystems. The LA-ICP-MS can be qualified in the Analytical Hot Cell Laboratory Equipment System (AHL) after laser ablation technology has been implemented with ICP-AES in the AHL and is fully operational.
Testing is recommended to confirm that the design of the LA-ICP-AES will meet its functional requirements. Design optimization for AHL implementation should continue following demonstration of the prototype. This testing is included in the Waste Treatment and Immobilization Plant (WTP) baseline.</td></tr>
<tr><td>External Flowsheet Review Team (EFRT) Assessment</td><td colspan="2">No related issues identified; part of baseline development plan.</td></tr>
<tr><td>Maturity Approach</td><td colspan="2">• Design prototype LA-ICP-AES test system
• Test prototype LA-ICP-AES test system
• Develop calibration and operating procedures for WTP LA-ICP-AES</td></tr>
<tr><td>Budget Estimate</td><td colspan="2">$3,700K included in WTP baseline</td></tr>
</table>

Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment

Facility: Pretreatment	**CTE:** UFP, Ultrafiltration Process System	**TRL**: 4
DOE TRA Assessment	Development and testing at a laboratory scale with actual wastes, and at an engineering scale with simulants, should be completed in prototypical process and equipment testing systems to demonstrate all detailed flowsheets for the Ultrafiltration Process System (UFP) prior to final design. The testing should validate the scaling methodology for mixing, chemical reactions, and filter surface area sizing; determination of process limits; and recovery from off-normal operating events. Note: This planned testing work is in the WTP baseline as part of the testing identified in EFRT issue M-12, “Undemonstrated Leaching Process,” and WTP baseline testing of the oxidative leaching process. Evaluation of a vertical modular equipment arrangement for the UFP filter elements for increasing the filter surface area should be continued. The design configuration (currently proposed horizontal or vertical orientation of the filters) that has the highest probability of successfully achieving performance requirements should be thoroughly tested in high-fidelity, prototypical engineering-scale tests using simulants that represent a range of tank waste compositions. Testing scope should include all filtration system operations, process flowsheets (caustic and oxidative leaching and strontium/transuranic precipitation), high-temperature filtration, and filter back pulsing, cleaning, draining, and replacement. Based on the results of this testing, a design concept (either the horizontal arrangement proposed by the Contractor or the vertical arrangement conceptualized by Energy*Solutions*) should be selected for final design. The strategy and method to scale the ultrafiltration processes (mixing, chemical reaction, and filter surface area) to predict performance of the ultrafiltration system should be established to ensure a high-fidelity UFP engineering-scale test platform and support useful interpretation of the testing results.	
External Flowsheet Review Team (EFRT) Assessment	*Undemonstrated Leaching Process* - Experiments to define the leaching steps have been carried out using only 50-250 ml samples. Scale-up of the processes using these data has not been demonstrated (M-12). *Inadequate Ultrafiltration (UF) Area and Flux* - For wastes requiring leaching, a combination of inadequate filter flux and area will likely limit throughput to the High-Level Waste (HLW) or Low-Activity Waste (LAW) Vitrification Facilities (M-13).	
Maturity Approach	• Radioactive testing of sludge treatment process at laboratory scale • Prototypic testing of UFP pilot plant to confirm design and process • Process modeling to simulate operation and performance of plant-scale UFP • Identify, evaluate, and develop an alternative technology for the UFP	
Budget Estimate	$57,100K includes testing to mature current baseline technology and complete design changes for the WTP	

<table>
<tr><th colspan="3">Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment</th></tr>
<tr><td>Facility: Pretreatment</td><td>CTE: CXP, Cesium Ion Exchange Process System</td><td>TRL: 5</td></tr>
<tr><td>DOE TRA Assessment</td><td colspan="2">Prototypic equipment testing should be completed, prior to continuing design of the hydrogen venting subsystem (nitrogen inerting and hydrogen gas collection piping system, control system) for removing hydrogen and other gases from the cesium ion exchange columns to demonstrate this design feature over the range of anticipated operating conditions.
The adequacy of the design concept for CXP-VSL-00001 should be re-evaluated and a determination made if this vessel should be modified to include mixing, chemical addition, and heating/cooling to mitigate anticipated process flowsheet issues with precipitation of solids in the CXP feeds (to be evaluated as part of the mixing system).
Testing of spherical resorcinol-formaldehyde (RF) resin should be conducted to: (1) assess physical degradation for irradiated resin samples; (2) assess effects from anti-foaming agent and separate organics present in the feed to the CXP; and (3) assess the impact of particulates on ion exchange column performance.
All currently planned testing and documentation of test results for spherical RF resin should be completed.
(Note: This planned work is in the WTP baseline.)
Additional research should be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate.
The engineering specification for the ion exchange columns should be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the EFRT recommendations for the CXP.</td></tr>
<tr><td>External Flowsheet Review Team (EFRT) Assessment</td><td colspan="2"><i>Instability of Baseline IX Resin</i> - The baseline ion exchange resin will not provide acceptable performance because of rapid degradation of its mechanical stability (M-14).
<i>Questionable Column Design</i> - In the preliminary drawings submitted by the vendor, the process fluid distribution/collection piping for removing fluids from the column does not permit complete displacement of one process fluid by another. This may result in undesirable contamination/ mixing of the process fluids (M-10a).</td></tr>
<tr><td>Maturity Approach</td><td colspan="2">• Assess design and technology concepts for the hydrogen venting subsystem, select reference
• Conduct prototypic testing of hydrogen venting subsystem
• Demonstrate 99% removal of spent ion exchange resin
• Assess solids precipitation in ion exchange feed
• Assess impact of solids and organics on ion exchanger performance
• Complete radiation stability testing on ion exchange resin
• Establish detailed cesium ion exchange column design features</td></tr>
<tr><td>Budget Estimate</td><td colspan="2">Current budget for WTP baseline work $4,670K; additional TMP work scope $7,240K</td></tr>
</table>

Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment

Facility: Pretreatment	**CTE:** CNP, Cesium Nitric Acid Recovery Process System	**TRL**: 3
DOE TRA Assessment	The design of the Cesium Nitric Acid Recovery Process System (CNP) should be discontinued until: (1) a re-assessment of the design and operational requirements for the CNP is completed; (2) the engineering specification for the CNP is revised to reflect operational conditions; and (3) the technology concept, which includes the process equipment and control system, is demonstrated through integrated prototypic testing. The CNP should be functionally tested prior to installation in the black cell. The testing should include: testing with representative process feed compositions; verification of the process control system concept; ability to control and monitor the composition of the nitric acid product; demonstrate the cesium decontamination factor of 5 million; and ability to adequately decontaminate the demister pads using the sprays installed in the separator vessel. The specific gravity operating limit for controlling the concentrated cesium eluate in the CNP separator to a maximum of 80% saturation should be re-evaluated. Based on the WTP Contractor's plan to neutralize cesium concentrate in the separator, and thereby create solids, this operating constraint may not be required. The engineering specification for the CNP should be modified to include: (1) the estimated variable feed composition; and (2) factory acceptance testing to demonstrate removal and installation of the demister pads from the separator vessel. The Contractor should re-assess the corrosion evaluations for the CNP vessels and piping based the operating conditions of the system.	
External Flowsheet Review Team (EFRT) Assessment	No related issues identified.	
Maturity Approach	• Complete computer simulation of control system as establish control requirements • Assess alternative operating modes and design concepts for the CNP • Complete design assessment of the CNP and proposed integration into Pretreatment (PT) Facility processes • Complete prototypic testing of CNP	
Budget Estimate	TMP work scope $7,780K	

Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment

Facility: Pretreatment	**CTE:** PJM, Waste Slurry Mixing in Pretreatment and HLW Vitrification	**TRL**: 4
DOE TRA Assessment	Clear, quantitative, and documented mixing performance requirements for all pulse jet mixer (PJM)-mixed vessels in the PT Facility and HLW Vitrification Facility should be established. The requirements should be established for all vessel systems even though only those associated with Waste Feed Receipt Process System (FRP), HLW Lag Storage and Feed Blending Process System (HLP), Plant Wash and Disposal System (PWD), Treated LAW Evaporation Process System (TLP), and Waste Feed Evaporation Process System (FEP) were discussed in this assessment. PJM demonstration testing planned, as part of Issue Response Plan (IRP) M-3, "Inadequate Mixing System Design," should be completed. The testing information, supplemented with analysis, should be used to determine the design capability of each PJM mixed vessel and identify any required design changes. Process modeling to project the performance of the WTP and confirm design capability should use realistic assumptions on the effectiveness of mixing (both time and efficiency of mixing).	
External Flowsheet Review Team (EFRT) Assessment	*Inadequate Mixing System* – Current mixing system designs will result in insufficient mixing and/or extended mixing times (M-3).	
Maturity Approach	• Confirm mixing requirements for WTP process vessels • Confirm the mixing system design of PJM vessels containing Newtonian and non-Newtonian fluids to resuspend settled waste following a mixing system shutdown • Develop testing information that allows accurate prediction of required mixing time for various vessel-mixing functions • Confirm that post-design basis event mixing of vessels that use one-half of the PJMs for mixing adequately releases hydrogen • Demonstrate that normal process PJM mixing successfully meets mixing requirements for vessels containing Newtonian fluids and non-Newtonian • Identify and confirm mixing requirements for vessels that do not currently have mixing requirements	
Budget Estimate	Current budget for WTP baseline work $17,700K; additional TMP work scope $1,950K	

Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment		
Facility: HLW Vitrification	**CTE:** HOP/PVV Melter Offgas System	**TRL**: 5
DOE TRA Assessment	Testing of a prototypical HLW film cooler and film cooler cleaner should be completed to demonstrate the adequacy of the equipment concepts prior to cold commissioning. Note: This testing is part of the planned work to resolve the EFRT issue M-17, "HLW Film Cooler Plugging," dealing with film cooler blockages. Further testing of the Wet Electrostatic Precipitator (WESP) is recommended to address operational modes. The Vitreous State Laboratory of the Catholic University of America tests indicated difficulties restoring power to the WESP electrodes may be related to the melter feed composition (24590-101-TSA-W000-0009-174-00001). In some cases, the WESP electrodes could not be brought back up to full voltage after significant operation with LAW feeds. While no problems were observed with HLW simulants during DM1200 tests, operational information should be confirmed for the HLW feed to understand if feed properties caused the problems. Further evaluation is also recommended to prove the viability of 6% molybdenum (Mo) stainless steels for WESP internals and vessels in the WTP offgas environment. Selection of a corrosion resistant alloy for WESP vessels and internals is of critical importance, because the WESP vessel is not accessible for maintenance (except for the electrode connectors) or removable for the 40-year life of the HLW Vitrification Facility. The WESP vessel and internals are constructed of 6% Mo stainless steel (24590 HLW-N1D-HOP-00002). The article by Phull (2000) was the basis for the selection of the 6% Mo for the WTP in the WESP corrosion evaluation (24590-HLW-N1D-HOP-00002). Phull showed that even 6% Mo stainless steels exhibited very slight susceptibility to corrosion attack after 656 days of exposure to flue gases. Data from Phull implies that a 6% Mo alloy or greater stainless steel is needed in corrosive environments where long life is mandatory. Activated carbon vendor testing should be completed to confirm the behavior of organics, acids (nitrogen oxide [NO_x,] sulfur dioxide [SO_2], and halogen), sulfur, and mercury within the carbon bed. Note: Testing on the carbon bed material is scheduled to be completed as part of the WTP baseline within the next 12 months. Any problems identified by vendor testing of the activated carbon bed material may potentially impact the WTP design and the WTP environmental performance test plan (CCN:128559).	
External Flowsheet Review Team (EFRT) Assessment	*HLW Film Cooler Plugging* - Plugs will likely form in the melter film cooler or the transition line to the offgas system. These plugs will be difficult to remove and could constrain glass production (M-17).	
Maturity Approach	• Design, test, and confirm design for HLW melter film cooler cleaner • Qualify the carbon-sulfur absorbent for mercury removal • Complete corrosion assessment for the WESP • Identify alternative operating approach in the event of premature WESP failure	
Budget Estimate	Current budget for WTP baseline work \$1,500K; additional TMP work scope \$2,210K	

Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment		
Facility: LAW Vitrification	**CTE:** LFH, LAW Container Finishing Handling System Container Sealing Subsystem	**TRL**: 5
DOE TRA Assessment	Integrated prototypic testing of the actual immobilized low-activity waste (ILAW) container inert filling, flange cleaning, inspection, and lidding/delidding equipment system in a simulated remote environment should be completed prior to installation in the LAW Vitrification Facility to verify that the equipment system will perform as required.	
External Flowsheet Review Team (EFRT) Assessment	No related issues identified.	
Maturity Approach	• Complete value engineering assessment on requirements and design solution for LAW container sealing subsystem • Complete prototypic testing of LAW container sealing subsystem	
Budget Estimate	Additional TMP work scope $1,775K	

Summary of Issues from Technology Readiness Level Assessment and EFRT Assessment		
Facility: LAW Vitrification	**CTE:** LFH, LAW Container Finishing Handling System Container Decontamination Subsystem	**TRL**: 5
DOE TRA Assessment	Integrated prototypic testing of the actual ILAW container decontamination and smear testing systems in a simulated remote environment should be completed following fabrication of equipment components to verify the equipment system will perform as required and will achieve the WTP Project-specified surface decontamination levels (less than 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma). This testing program should be supplemented with laboratory-scale testing to define the operational parameters for the carbon dioxide (CO_2) decontamination system.	
External Flowsheet Review Team (EFRT) Assessment	No related issues identified.	
Maturity Approach	• Identify expected contamination levels on the LAW containers (type, amount, and adherence mechanism) • Assess requirements for decontamination of the LAW container • Define scope of testing for prototypic testing • Complete prototypic testing of LAW container decontamination system	
Budget Estimate	Additional TMP work scope $4,025K	

Technology Issues Identified by both the DOE TRAs and EFRT Assessments	**Issue Type**
Plugging in Process Piping – Piping that transports slurries will plug unless it is properly designed to minimize this risk. This design approach has not been followed consistently, which will lead to frequent shutdowns due to line plugging.	Technology
Mixing Vessel Erosion – Large dense particles will accelerate erosive wear in mixing vessels. The effects of such particles on vessel life must be re-evaluated.	Technology
Designed for Commissioning Waste Rather Than Mission Needs – The WTP has not demonstrated that its design is sufficiently flexible to reliably process all of the Hanford Site tank farm wastes at design throughputs.	Technology
Must Have Feed Prequalification Capability – Without waste feed pre-qualification, each new batch of waste will require additional time for WTP to evaluate unit process responses and adjust operating parameters to define efficient processing. Bench-scale testing of unit operations with actual wastes would identify unexpected results and prevent potential plant problems.	Technology
Process Operating Limits Not Completely Defined – Many of the process operating limits have not been defined. Further testing is needed to define process limits for WTP unit operations. Without this more complete understanding of each process, it will be difficult or impossible to define a practical operating range for each unit operation.	Technology
Lack Of Comprehensive Feed Testing During Commissioning – The current plans for commissioning, which do not include leaching, do not adequately support WTP's future processing requirements.	Technology
Potential Gelation/Precipitation – Some of the feeds to the leaching operation will contain significant amounts of aluminum and other materials that could precipitate. There is the possibility aluminum gel will form in the leach tank itself or in other streams from the leaching operation if unfavorable leaching conditions occur.	Technology
Inadequate Process Development – The effects of process variables, such as concentration of hydroxide, potassium, aluminum, and recycles along with flow rates and temperature, have not been determined experimentally.	Technology
Undemonstrated Sampling System – The sampling system may not prove adequate for handling slurries.	Technology

Design, Operational and Programmatic Issues Identified by the EFRT Assessment	**Issue Type**
Questionable Cross-Contamination Control – Elution utilizes the same piping as loading. Small quantity of trapped eluate can cause serious cross-contamination.	Design
Complexity of Valving – The design of the ion exchange system has >80 valves, many of which are interlocked to prevent processing in the event of incorrect valve line-up. This complexity increases the risks of processing outages and decreases expected availability.	Design
Cesium-137 Breakthrough - The design of Cs-137 breakthrough monitoring is questionable.	Design
Pretreatment Facility Availability – The PT Facility will be difficult to reliably operate and maintain and may have less than desired availability.	Design
Inconsistent Short-Term vs. Long-Term Focus – DOE and the WTP Project have made design choices without consistently taking into account life-cycle costs. These decisions appear to be more focused on capital cost than on long-term operating cost and throughput.	Design
Incomplete Process Control Design – Adequacy of system performance due to documentation differences defining design basis, lack of agreed upon control strategy, and loss of experienced personnel needed to review system specifications.	Design
Inadequate Evaporator Control Scheme – Inadequate density measurement to control sodium concentration over the range of feeds.	Design
Misbatching of Melter Feed - There is a significant risk of misbatching the LAW melter feed, leading to premature melter failure. This risk can best be eliminated through analysis of the melter feed.	Operational
Limited Remotability Demonstration - Planned remotability testing will not provide confidence that subcomponents in hot cells can be remotely changed out many years after commissioning.	Operational
Glass Formers Analysis at the Silos – Lack of analysis before unloading glass-forming chemicals (GFC) into silos.	Operational
Critical Equipment Purchases – Project must carefully evaluate critical material and equipment purchases (e.g., ion exchange columns and ultrafilters) to ensure the best equipment is purchased.	Programmatic
Loss of WTP Expertise Base – Loss of the WTP expertise base is already evident and likely to lead to a lengthy start-up and arduous operation. Because of the length of the WTP project and history of its funding, the continuity of the technical resources is impacted.	Programmatic
Lack of Spare LAW Melter – If a melter failure occurred, the WTP would have to operate at reduced throughput for an extended time (exceeding one year). This would severely impact completing the Hanford Site mission.	Programmatic
Lack of Spare HLW Melter – If a melter failure occurred, the WTP would have to operate at reduced throughput for an extended time (exceeding one year). This would severely impact completing the Hanford Site mission.	Programmatic

Appendix References

1. 24590-101-TSA-W000-0009-174-00001, Rev 00A, *Summary of DM1200 WESP History and Performance*, August 7, 2006, Bechtel National Inc., Richland, Washington.

2. 24590-HLW-N1D-HOP-00002, Rev. 2, *WESP Corrosion Evaluation*, December 22, 2005, Bechtel National, Inc., Richland, Washington.

3. CCN:128559, “White paper on the Analysis of Naphthalene Destruction and Removal Efficiency (DRE) Testing at the Vitreous State Laboratory (VSL),” December 15, 2005, Bechtel National, Inc., Richland, Washington.

4. Phull, B.S., W.L. Mathay, and R.W. Ross, 2000, “Corrosion Resistance of Duplex and 4-6% Mo-Containing Stainless Steels in FGD Scrubber Absorber Slurry Environments,” presented at Corrosion 2000, Orlando, Florida, March 26-31, 2000, NACE International, Houston, TX 77218.

DOE/ORP-2007-02

Technology Maturation Plan - Technology Readiness Assessment Reports for the Waste Treatment and Immobilization Plant Project Facilities

Volume II

August 14, 2007

Office of River Protection
U.S. Department of Energy
Richland, Washington 99352

Volume II
Technology Maturation Plan - Technology Readiness Assessment Reports for the Waste Treatment and Immobilization Plant Project Facilities

The U.S. Department of Energy (DOE) has completed the following three Technology Readiness Assessments (TRA) for the Waste Treatment and Immobilization Plant (WTP) Project:

- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities*, 07-DESIGN-042, U.S. Department of Energy, Richland, Washington
- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) HLW Waste Vitrification Facility*, 07-DESIGN-046, U.S. Department of Energy, Richland, Washington
- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Pretreatment Facility*, 07-DESIGN-047, U.S. Department of Energy, Richland, Washington

These TRAs represent months of careful and arduous review of the five WTP facilities, as well as the project as a whole. The Assessment Teams were comprised of staff who have worked on the Hanford WTP Project and related nuclear waste treatment and immobilization technologies for more than 30 years, and are independent of the WTP design and construction project.

This page intentionally left blank.

07-DESIGN-042

Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities

L. Holton
D. Alexander
C. Babel
H. Sutter
J. Young

March 2007

Prepared by the
U.S. Department of Energy
Office of River Protection
Richland, Washington, 99352

07-DESIGN-042

Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities

L. Holton
D. Alexander
C. Babel
H. Sutter
J. Young

March 2007

Prepared by the
U.S. Department of Energy
Office of River Protection
under Contract DE-AC05-76RL01830

Summary

The U.S. Department of Energy (DOE), Office of River Protection (ORP) and the DOE Office of Environmental Management (EM), Office of Project Recovery have completed a Technology Readiness Assessment (TRA) for three Hanford Waste Treatment and Immobilization Plant (WTP) facilities; Analytical Laboratory (LAB), Balance of Facilities (BOF), and Low-Activity Waste Vitrification Facility (LAW). The purpose of this assessment was to determine if the maturity of critical technology elements (CTE) is sufficient to be incorporated into the final design of these facilities.

The methodology used for this TRA was based upon detailed guidance for conducting TRAs contained in the *Department of Defense, Technology Readiness Assessment Deskbook*[1]. The assessment utilized a slightly modified version of the Technology Readiness Level (TRL) Calculator[2] originally developed by Nolte et al. (2003) to determine the TRL for the CTE. Mr. Nolte was present during the initial TRA sessions and guided the Assessment Team through the use of the TRL Calculator; Mr. Nolte also reviewed this report.

The TRA consisted of three parts:

1. Identifying the CTEs
2. Assessing the TRLs of each CTE using the technical readiness scale used by the U.S. Department of Defense (DoD) and National Aeronautics and Space Administration (NASA), and adapted by the Assessment Team for use by DOE (Table S-1)
3. Evaluating, if required, technology testing or engineering work necessary to bring immature technologies to appropriate maturity levels.

CTEs are those technologies that are essential to successful operation of the facility, and are new or are being applied in new or novel ways or environments. The CTE identification process was based upon the definition of WTP systems and considered 20 systems from the LAB, 18 systems from BOF, and 32 systems from LAW. Seven of these were identified as CTEs as described below. An identification of systems evaluated and CTEs is presented in Appendix B.

- Two LAB systems were determined to be CTEs: the Autosampling System (ASX), and the Laser Ablation Inductively Coupled Plasma Mass Spectrometry/Laser Ablation Inductively Coupled Plasma Atomic Emission Spectrometry (LA-ICP-MS/LA-ICP-AES) subsystems of the Analytical Hot Cell Laboratory System (AHL), which provide the analytical equipment systems for the LAB.
- No BOF systems were judged to be CTEs because the BOF systems do not use new technologies, or do not use standard technologies in new or novel ways.
- Five LAW systems were determined to be CTEs: the LAW Melter Feed Process System (LFP) used to prepare the LAW melter feed; the LAW Melter System (LMP), which includes the LAW melter; the LAW Melter Offgas/Secondary Offgas and Vessel Vent Process Systems (LOP/LVP) used to treat the LAW melter offgas; the ILAW Container Finishing Handling System (LFH) container closure subsystem; and the LFH container decontamination subsystem.

---

[1] Department of Defense*, Technology Readiness Assessment (TRA) Deskbook*, May 2005, prepared by the Deputy Undersecretary of Defense for Science and Technology (DUSD(S&T)).

[2] Nolte, William L., et al., "T*echnology Readiness Level Calculator*," October 20, 2003, Air Force Research Laboratory, presented at the NDIA Systems Engineering Conference.

The TRL of each CTE was evaluated against a scale developed for this assessment, termed the DOE-EM Scale. This is shown in Table S-1. The DOE-EM Scale was developed to support assessment of radioactive waste treatment technologies and is consistent with the scales originally developed by NASA and the DoD. A comparison of the three TRL scales is contained in Appendix A

Table S.1. DOE Technology Readiness Level Scale

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in a relevant environment.	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
Technology Development	**TRL 5**	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
	TRL 4	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

The DoD and NASA normally require a TRL of 6 for incorporation of a technology into the design process. This is done based upon the recommendations of an influential report[3] by the U.S. General Accounting Office (GAO) that examined the differences in technology transition between the DoD and private industry. It concluded that the DoD takes greater risks and attempts to transition emerging technologies at lesser degrees of maturity than private industry. The GAO also concluded that use of immature technology increased overall program risk and recommended that the DoD adopt the use of NASA's TRLs as a means of assessing technology maturity prior to transition into final design. Based upon the precedence set by DOD, this assessment used TRL 6 as the basis for determining that a technology is sufficiently mature for incorporation into the final design.

A TRL Calculator was used to provide a structured and consistent assessment to determine the TRL of each CTE identified. The TRL Calculator tabulates responses to a standard set of questions addressing hardware, software, program, and manufacturability. The TRL Calculator is implemented in Microsoft Excel™ and produces a graphical display of the TRL achieved. It was adapted for this assessment by adding and modifying existing questions to make it more applicable to DOE waste treatment equipment and processes. The TRL Calculator is described in Appendix C. Specific responses to each of the TRL questions for the CTEs evaluated in this TRA are presented in Appendix D. The CTEs were not evaluated to determine if they had matured beyond TRL 6. The results of this TRL determination are presented in Table S-2.

The Assessment Team concluded that the critical technology elements of the LAB, BOF, and LAW facilities are sufficiently mature to continue to advance the final design of these facilities. However, based upon the results of this assessment, the following recommendations for specific technologies are made:

1. The prototypical Laser Ablation Inductively Coupled Plasma Atomic Emission Spectrometry (LA-ICP-AES) subsystem should be tested to demonstrate achievable detection limits for chemical elements of interest and satisfy turnaround time requirements on actual HLW sludge samples in a relevant environment to support the final design of the actual LAB subsystems. The LA-ICP-MS can be qualified in the Analytical Hot Cell system (AHL) after laser ablation technology has been implemented with ICP-AES in the AHL and is fully operational.

   Testing is recommended to confirm that the design of the LA-ICP-AES will meet its functional requirements. Design optimization for AHL implementation should continue following demonstration of the prototype. This testing is included in the WTP baseline.

2. Integrated prototypic testing of the actual immobilized low-activity waste (ILAW) container inert filling, flange cleaning, inspection, and lidding/delidding equipment system in a simulated remote environment should be completed prior to installation in the LAW Vitrification Facility to verify that the equipment system will perform as required.

   The mechanical processing steps of the container lidding sealing system used to seal the containers uses new equipment concepts that have not been previously tested in a remote operational environment. Waiting to complete the testing at cold commissioning represents a significant cost and schedule risk to the LAW Facility if the technology does not perform as intended. Fabrication acceptance testing is planned. However, this testing will not be prototypical of the remote operational environment.

---

[3] GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Can Improve Weapon System Outcomes*, July 1999, United States General Accounting Office.

Table S.2. Technology Readiness Level Summary for LAB, BOF, LAW Critical Technology Elements

Critical Technology Element/Description	Technology Readiness Level	Rationale
LA-ICP-MS/LA-ICP-AES The LA-ICP-MS/LA-ICP-AES subsystem will be used to verify HLW melter feed and LAW Facility waste compositions and is the only analytical system that uses new or novel instrumentation or methods. Analytical turnaround times of less than 9 hours for these analyses are essential in meeting WTP requirements.	**5**	A prototypical LA-ICP-MS/LA-ICP-AES system has not been demonstrated in a relevant environment. A full scale prototypical LA-ICP-AES system is scheduled for testing beginning in 2007. The LA-ICP-MS subsystem will be tested after the LA-ICP-AES becomes fully operational in the LAB.
Autosampling System (ASX) The ASX automatically retrieves liquid samples from process streams and transfers them to the LAB.	**6**	Similar systems are in use in relevant operating environments at the Sellafield Nuclear Site (UK) and LaHague (France).
LFH Container Sealing Subsystem The LFP container sealing subystem press fits and locks a flat circular lid into a circular groove in the container neck.	**5**	The container sealing system design is based on existing technologies but has not been demonstrated as an integrated prototypical system in an operating environment.
LFH Decontamination Subsystem The LFH decontamination subsystem sprays carbon dioxide (CO_2) pellets at ILAW container surfaces to remove radioactive contamination. The sublimed CO_2 and dislodged contamination are contained by a vacuum system and shroud.	**4**	The ILAW container decontamination design is based on existing technology concepts, but has not been demonstrated as an integrated, prototypical system in a relevant environment. Testing on a laboratory scale of the CO_2 spray to decontaminate flat-metal specimens has been completed; testing did not demonstrate the WTP Project's requirement on surface decontamination levels. Integrated testing of the robot, CO_2 spray, and shrouding system has not been carried out on the complex surfaces of the ILAW container.
LAW Melter Feed Process System (LFP) The LFP mixes LAW Facility waste and glass formers to provide feed for the LAW melters.	**6**	There has been extensive WTP and vendor testing to demonstrate the adequacy of the mixing systems.
LAW Melter System (LMP) The LMP is the LAW melter system that melts mixtures of LAW and glass formers.	**6**	The LAW melter has a significant development basis in previous DOE projects and developmental tests for the WTP. However, risk remains with the availability of MA758, a high chromium (Cr) alloy used for the LAW bubbler assembly. An alternate bubbler material of construction should be identified.
LOP/LVP The LOP/LVP is the LAW Melter Offgas and Vessel Vent Process Systems that remove aerosols, gases, and particulates generated by the LAW melters and vessel vent streams.	**6**	The LOP/LVP have a significant technology basis. Two of 12 maximum achievable control technology (MACT) destruction and removal efficiency (DRE) tests for naphthalene conducted on a prototypical system did not attain the required destruction efficiency. Engineering analysis shows that the WTP system should attain MACT standards based on higher capacities of the plant unit operations as compared to the pilot plant unit operations.

3. Integrated prototypic testing of the actual ILAW container decontamination and smear testing systems in a simulated remote environment should be completed following fabrication of equipment components to verify the equipment system will perform as required and will achieve the WTP Project-specified surface decontamination levels (less than 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma). This testing program should be supplemented with laboratory scale testing to define the operational parameters for the carbon dioxide (CO_2) decontamination system.

   The ILAW container decontamination subsystem relies on a localized surface decontamination approach using a CO_2 pellet spray contained within a series of specialized shrouds. A robot is used to position the shrouds against the surfaces of the ILAW container. A vacuum is used to recover loosened contamination and sublimed CO_2. Proof of concept testing using flat-metal coupons was completed. However, there remains a high risk that the removal of the contamination from the container oxide film will not be effective due to the complex shapes on the container design, and the requirement that the shroud system effectively contain loosened contamination. A loss of control of the removed contamination in the areas adjacent to the container decontamination station may result in re-contamination of the container. Subsequent decontamination of the work area may also result in impacts to the LAW Facility production.

   Based upon the limited testing completed and the unique operating requirements for this system, there is a high probability that the current design concept may not perform as intended and will require significant design changes. Problems with this system may not be identified until hot commissioning of the LAW Facility. Design modifications at this time will be expensive and time consuming. An inability of the CO_2 decontamination system to perform its function has the potential to shut down low-activity waste processing and the entire WTP.

   The testing of the ILAW container decontamination subsystem should include testing with full scale containers at the anticipated operating temperatures. Particular attention in the testing program should be focused on the use of the localized decontamination shroud system and its ability to maintain contamination control and achieve full decontamination of the container. The ability of the shroud tools to decontaminate all container surfaces should be demonstrated.

4. It is recommended that a backup LAW melter bubbler design, using materials of construction other than the high nickel MA758 alloy be identified and qualified for use in the LAW melter.

   This recommendation is based upon recent issues in fabricating acceptable MA758 alloy and risks identified by the WTP Contractor in the long term availability of this alloy.

WTP software and control systems were not included in this TRA.

This assessment is the first of several TRAs planned for the WTP. Additional TRAs are planned for the Pretreatment and HLW Facilities.

Acknowledgement

The Assessment Team wishes to thank Mr. William Nolte of the Air Force Research Laboratory for consultation, guidance, and direct support in the application of the NASA and DoD Technology Readiness Level (TRL) process to DOE's first use of this process to the Waste Treatment and Immobilization Plant (WTP). Mr. Nolte also provided, and supported, the Assessment Team in the adaptation of a TRL Calculator that he authored, ensuring consistency between the NASA, DoD, and DOE applications of the TRL Assessment process.

Contents

Figures

Tables

Acronyms and Abbreviations

ADS	air displacement slurry
AHL	Analytical Hot Cell Laboratory Equipment System
ARL	Analytical Radiological Laboratory Equipment System
ASME	American Society of Mechanical Engineers
ASX	Autosampling System
BNI	Bechtel National, Inc.
BOF	Balance of Facilities
CD	Critical Decision
CPS	Carrier Posting System
CRV	concentrate receipt vessel
CTE	Critical Technology Element
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DRE	destruction and removal efficiency
DWPF	Savannah River Defense Waste Processing Facility
EM	Office of Environmental Management
GAO	U.S. Government Accountability Office
GFR	Glass Formers Reagent System
HC	Hot Cell
HEPA	high-efficiency particulate air
HLW	high-level waste
IHLW	immobilized high-level waste
ILAW	immobilized low-activity waste
LAB	Analytical Laboratory
LA-ICP-AES	Laser Ablation Inductively Coupled Plasma Atomic Emission Spectroscopy
LA-ICP-MS	Laser Ablation Inductively Coupled Plasma Mass Spectroscopy
LAW	Low-Activity Waste Vitrification Facility
LCP	LAW Concentrate Receipt Process System
LFH	LAW Container Finishing Handling System
LFP	LAW Melter Feed Process
LMH	LAW Melter Handling System
LMP	LAW Melter Process System
LOP/LVP	LAW Melter Offgas System/LAW Secondary Offgas/Vessel Vent Process Systems
LPH	LAW Container Pour Handling System
MACT	maximum achievable control technology
MFPV	melter feed preparation vessel
MFV	melter feed vessel
NASA	National Aeronautics and Space Administration
ORP	Office of River Protection
P&ID	piping and instrumentation diagrams
PNWD	Pacific Northwest Division
PODC	Principal Organic Dangerous Constituents
PSAR	Preliminary Safety Analysis Report
PT	Pretreatment Facility
PTS	pneumatic transfer system
R&T	Research and Technology
RAMI	Reliability, Availability, Maintainability Index

RLD	Radioactive Liquid Waste Disposal System
RWH	Radioactive Solid Waste Handling System
SBS	submerged bed scrubbers
SCR	selective catalytic reduction
SRNL	Savannah River National Laboratory
SRTC	Savannah River Technology Center
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
VOC	volatile organic compound
VSL	Vitreous State Laboratory of the Catholic University of America
WESP	wet electrostatic precipitator
WTP	Hanford Tank Waste Treatment and Immobilization Plant
WVDP	West Valley Demonstration Project

Glossary

Critical Technology Element	A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel. Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.
Engineering Scale	A system that is greater than 1/10 of the size of the final application, but it is still less than the scale of the final application.
Full-Scale	The scale for technology testing or demonstration that matches the scale of the final application.
Identical System	Configuration that matches the final application in all respects.
Laboratory Scale	A system that is a small laboratory model (less than 1/10 of the size of the full-size system.
Model	A functional form of a system generally reduced in scale, near or at operational specification.
Operational Environment (Limited Range)	A real environment that simulates some of the operational requirements and specifications required of the final system (e.g., limited range of actual waste).
Operational Environment (Full Range)	Environment that simulates the operational requirements and specifications required of the final system (e.g., full range of actual waste).
Paper System	System that exists on paper (no hardware).
Pieces System	System that matches a piece or pieces of the final application.
Pilot Scale	The size of a system between the small laboratory model size (bench-scale) and a full-size system.
Prototype	A physical or virtual model that represents the final application in almost all respects that is used to evaluate the technical or manufacturing feasibility or utility of a particular technology or process, concept, end item, or system.
Relevant Environment	Testing environment that simulates the key aspects of the operational environment; e.g., range of simulants plus limited range of actual waste.
Similar System	Configuration that matches the final application in almost all respects.
Simulated Operational Environment	Environment that uses a range of waste simulants for testing of a virtual prototype.

1.0 Introduction

1.1 Background

The U.S Department of Energy (DOE), Office of River Protection (ORP) is constructing a Waste Treatment and Immobilization Plant (WTP) for the treatment and vitrification of the underground tank wastes stored at the Hanford Site in Washington State. The WTP Project is comprised of four major facilities: a Pretreatment (PT) Facility to separate the tank waste into high-level waste (HLW) and low-activity waste (LAW) process streams; a HLW Vitrification Facility to immobilize the HLW fraction; a LAW Vitrification Facility to immobilize the LAW fraction; and an Analytical Laboratory (LAB) to support the operations of all four treatment facilities. Additionally, there are the Balance of Facilities (BOF) operations that provide utilities and other support to the processing facilities. The WTP Project is DOE's largest capital construction project with an estimated cost of $12.263 billion, and a project completion date of November 2019 (DOE 2006).

Issues associated with the maturity of technology in the WTP have been evaluated by independent DOE Review Teams and in DOE's design oversight process. The most notable evaluation was the recently completed "Comprehensive External Review of the Hanford Waste Treatment Plant Flowsheet and Throughput" (CCN: 132846) completed in March 2006. This evaluation identified 28 separate technical issues, some of which had not been previously identified by the WTP Contractor or DOE. A number of these issues originated from limited understanding of the technologies that comprise the WTP flowsheet.

As a result of these reviews, and DOE's desire to more effectively manage the technology risks associated with the WTP, the DOE has decided to conduct a Technology Readiness Assessment (TRA) to assess the technical maturity of the WTP design. This TRA is patterned after guidance established by the U.S. Department of Defense (DoD) (DoD 2005) for conducting TRAs.

1.2 Assessment Objectives

The purpose of this TRA is to evaluate the technologies used in three major facilities of the WTP: LAB, BOF, and LAW. This TRA is intended to:

- Identify Critical Technology Elements (CTE)
- Determine the TRL associated with the CTEs
- Provide recommendations on how to improve the maturity level of technologies that require additional development.

The TRA was performed jointly by DOE ORP and the DOE Office of Environmental Management (EM), Office of Project Recovery.

1.3 Description of TRA process

1.3.1 Background

> "A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies [called Critical Technology Elements (CTEs)] used in systems." (DoD 2005)

In 1999, the U.S. General Accounting Office (GAO) produced an influential report (GAO/NSIAD-99-162) that examined the differences in technology transition between the DoD and private industry.

The GAO concluded that the DoD took greater risks, and attempted to transition emerging technologies at lesser degrees of maturity compared to private industry and that the use of immature technology increased overall program risk and led to substantial cost and schedule overruns. The GAO recommended that the DoD adopt the use of National Aeronautics and Space Administration's (NASA) Technology Readiness Levels (TRL) as a means of assessing technology maturity prior to design transition (see Appendix A for further discussion).

In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major programs. Guidance for assessing technology maturity was incorporated into the *Defense Acquisition Guidebook* (DODI 5000.2). Subsequently, the DoD developed detailed guidance for using TRLs in the 2003 *DoD Technology Readiness Assessment Deskbook* (updated in May 2005 [DOD 2005]). The DoD Milestone Decision Authority must certify to Congress that the technology has been demonstrated in a relevant environment prior to transition of weapons system technologies to design or justify any waivers. TRL 6 is also used as the level required for technology insertion into design by NASA. (See Appendix A for the DoD and NASA TRL definitions.)

Based upon historical use of the TRA process, the DOE has decided to use the DoD TRA process as a method for assessing technology readiness for the WTP.

1.3.2 TRA Process

The TRA process as defined by the DoD consists of three parts: (1) identifying the CTEs; (2) assessing the TRLs of each CTE using an established readiness scale; and (3) preparing the TRA report. If some of the CTEs are judged to be below the desired level of readiness, the TRA is followed by development of a Technology Maturation Plan that identifies the additional development required to attain the desired level of readiness. The process is usually carried out by a group of experts that are independent of the project under consideration.

The CTE identification process involves breaking the project under evaluation into its component systems and subsystems, and determining which of these are essential to project success and either represent new technologies, combinations of existing technologies in new or novel ways, or will be used in a new environment. Appendix B describes the CTE process in detail.

The TRL scale used in this assessment is shown in Table 1.1. This scale requires that testing of a prototypical design in a relevant environment be completed prior to incorporation of the technology into the final design of the facility.

The testing requirements used in this assessment are compared to the TRLs in Table 1.2. These definitions provide a convenient means to understand further the relationship between the scale of testing, fidelity of testing system, and testing environment and the TRL. This scale requires that for a TRL 6 testing must be completed at an engineering or pilot scale, with a testing system fidelity that is similar to the actual application and with a range of simulated wastes and/or limited range of actual waste, if applicable.

The assessment of the TRLs was aided by a TRL Calculator that was originally developed by the U.S. Air Force (Nolte et al. 2003), and modified by the Assessment Team. This tool is a standard set of questions addressing hardware, software, program, and manufacturability questions that is implemented in Microsoft Excel™. The TRL Calculator produces a graphical display of the TRLs achieved. The TRL Calculator used in this assessment is described in more detail in Appendix C.

Table 1.1. Technology Readiness Levels used in this Assessment

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot scale, similar (prototypical) system validation in a relevant environment.	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

Table 1.2. Relationship of Testing Requirements to the TRL

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot Scale < Full Scale (Typical)
   Lab Scale < 1/10 Full Scale (Typical)
2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)
3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

2.0 TRL Assessment

2.1 TRL Process Description

An Assessment Team comprised of staff from the DOE ORP, and technical consultants to ORP, and DOE EM's Office of Project Recovery completed the TRL assessment (see Appendix E for the identification of the Assessment Team and supporting contractor staff from the WTP). The Assessment Team staff has worked on the Hanford WTP Project and related nuclear waste treatment and immobilization technologies for more than 60 years, and is independent of the WTP design and construction project. The Assessment Team was assisted by William Nolte of the Air Force Research Laboratory, Wright Patterson AFB, who was present for the initial CTE and TRL evaluation sessions and guided the Assessment Team through the use of the TRL Calculator. Mr. Nolte also reviewed and commented on this report.

The WTP engineering staff (e.g., WTP Project Team) presented descriptions of the WTP systems that were assessed, participated in the identification of the CTEs, and participated in the completion of responses to individual questions in the TRL Calculator. Each response to a specific Calculator question was recorded along with references to the appropriate WTP Project documents. The Assessment Team also completed independent due-diligence reviews and evaluation of the testing and design information to validate input obtained in the Assessment Team and WTP Project Team working sessions. The Calculator results for each CTE can be found in Appendix D.

This Assessment Team evaluated the process and mechanical systems that are used to treat and immobilize the radioactive waste to complete the preparation of the immobilized low-activity waste (ILAW) product for disposal. The team did not evaluate the software systems used to control the process and mechanical equipment because these software systems have not been sufficiently developed and are not critical to the mechanical design of the facilities. The assessment of the technology readiness of the software systems will be completed at a later date.

2.2 Determination of CTEs

The process for identification of the CTEs for the LAB/BOF/LAW facilities involved two steps:

1. An initial screening by the Assessment Team of the complete list of systems in the LAB, BOF, and LAW facilities for those that have a potential to be a CTE. In this assessment, systems that are directly involved in the processing of the tank waste or handling of the primary products (ILAW and secondary wastes) were initially identified as potential CTEs. The complete list of systems and those identified as potential CTEs are provided in Appendix B, Tables B.1, B.2, and B.3 for the LAB, BOF, and LAW facilities, respectively.

2. A final screening of the potential CTEs was completed by the Assessment and WTP Project teams to determine the final set of CTEs for evaluation. The potential CTEs were evaluated against the two set of questions presented in Table 2.1. A system is determined to be a CTE if a positive response is provided to at least one of the questions in each of the two sets of questions.

Table 2.1. Questions used to Determine the Critical Technology Element for the LAB/BOF/LAW Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	5. Is the technology (system) new or novel? 6. Is the technology (system) modified? 7. Has the technology been repackaged so that a new relevant environment is realized? 8. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

The specific responses to each of the questions for each CTE are provided in Table B.5 of Appendix B. In this final assessment, the following systems were identified as CTEs.

- Analytical Hot Cell Laboratory Equipment/Analytical Radiological Laboratory Equipment Systems (AHL/ARL) - Laser Ablation-Inductively Coupled Plasma Mass Spectrometry/Laser Ablation-Inductively Coupled Plasma Atomic Emission Spectroscopy (LA-ICP-MS/LA-ICP-AES) subsystems
- Autosampling System (ASX)
- ILAW Container Finishing Handling System (LFH) container sealing subsystem
- ILAW Container Finishing Handling System (LFH) decontamination subsystem
- LAW Melter Feed Process System (LFP)
- LAW Melter Process System (LMP)
- LAW Primary Offgas Process and LAW Secondary Offgas Vessel Vent Process Systems (LOP/LVP)

2.3 Summary of the Technology Readiness Assessment

A TRL assessment was completed for each CTE, and the results are summarized in this section.

The TRL Calculator employs a two-step process to evaluate TRLs.

- First, a top-level set of questions was evaluated to determine the starting point, in terms of readiness level, for the TRL assessment (Appendix C). This evaluation showed that the identified CTEs all had achieved a TRL 4 or 5 status.
- Second, a more detailed assessment was completed using a series of detailed questions starting at TRL 4. This assessment indicated that all CTEs achieved a TRL 4. Next, the assessment evaluated the TRL 5 questions in detail and recorded responses. Finally, the assessment evaluated the TRL 6 questions in detail and recorded responses. The responses to the TRL questions are provided in Appendix D for each CTE.

For each CTE, the discussions below describe the CTE function and description, the relationship to other CTEs, the development history and status, the relevant environment, a comparison of the demonstrated and relevant environments, and the rational for the TRL determination and any recommendations.

2.3.1 Analytical Hot Cell Laboratory Equipment/Analytical Radiological Laboratory Equipment Systems (AHL/ARL)

2.3.1.1 Function of the AHL and ARL

The AHL is planned for supporting sample preparation and analysis of radioactive samples from the HLW and PT Facilities. The ARL is for supporting sample preparation and analysis of radioactive samples from the LAW Facility and certain AHL samples from hot cells. The evaluation of the critical technology elements for the AHL and ARL Equipment Systems (Appendix B) identified the LA-ICP-AES/LA-ICP-MS as CTE subsystems. The LA-ICP-AES system ablates and analyzes particulates from the surface of a prepared glass coupon (which will be prepared from waste stream samples) for elemental species in the waste streams. The LA-ICP-MS system similarly provides results for elemental and isotopic species in waste streams.

2.3.1.2 Description of the LA-ICP-MS and LA-ICP-AES Subsystems within the AHL/ARL

The AHL and ARL are two systems that provide analytical services to the WTP. The systems are defined in terms of the analytical equipment that is planned for installation into each system area.
The LA-ICP-MS and LA-ICP-AES are the only analytical systems planned for use in the AHL that are not fully developed and verified with radioactive sample material. Laser ablation will first be applied to the ICP-AES in the AHL. The current ARL design basis for analytical support to LAW utilizes acid dissolution and alkali fusions for sample preparation. Both wet chemistry procedures are conventional methods routinely used in DOE fuel processing and waste treatment facilities.

A schematic of the LA-ICP-AES subsystem as planned in a prototype is shown in Figure 2.1. Radioactive samples are first converted to a glass sample in a specially designed sample preparation furnace. The purpose of solidifying the sample is to simplify handling and to produce a homogenous sample for analysis. The cooled glass sample is subjected to a laser (e.g., laser ablation to “vaporize” sample material). An optical view system is used to observe and align the glass coupon for ablation. The vapor from the laser ablation is then drawn into an Atomic Emission Spectrometer for subsequent chemical and radiochemical analysis. Each of the individual components of the LA-ICP-AES subsystem is commercially available. However, the integration of these components to support a routine, radioactive, production scale analysis is unique to the WTP.

The LA-ICP-AES in the AHL will be used to analyze high-level waste (HLW) samples. Use of the LA-ICP-MS in the AHL is being considered after the LA-ICP-AES is fully operational in the LAB.
The ICP-MS would backup the LA-ICP-AES subsystems for the AHL to ensure availability.
The LA-ICP-AES technique will be used for elemental analysis, and it can be used for isotopic analysis when used in combination with traditional radiochemical counting techniques. The ICP-MS would be used for elements with low concentrations and isotopic analysis.

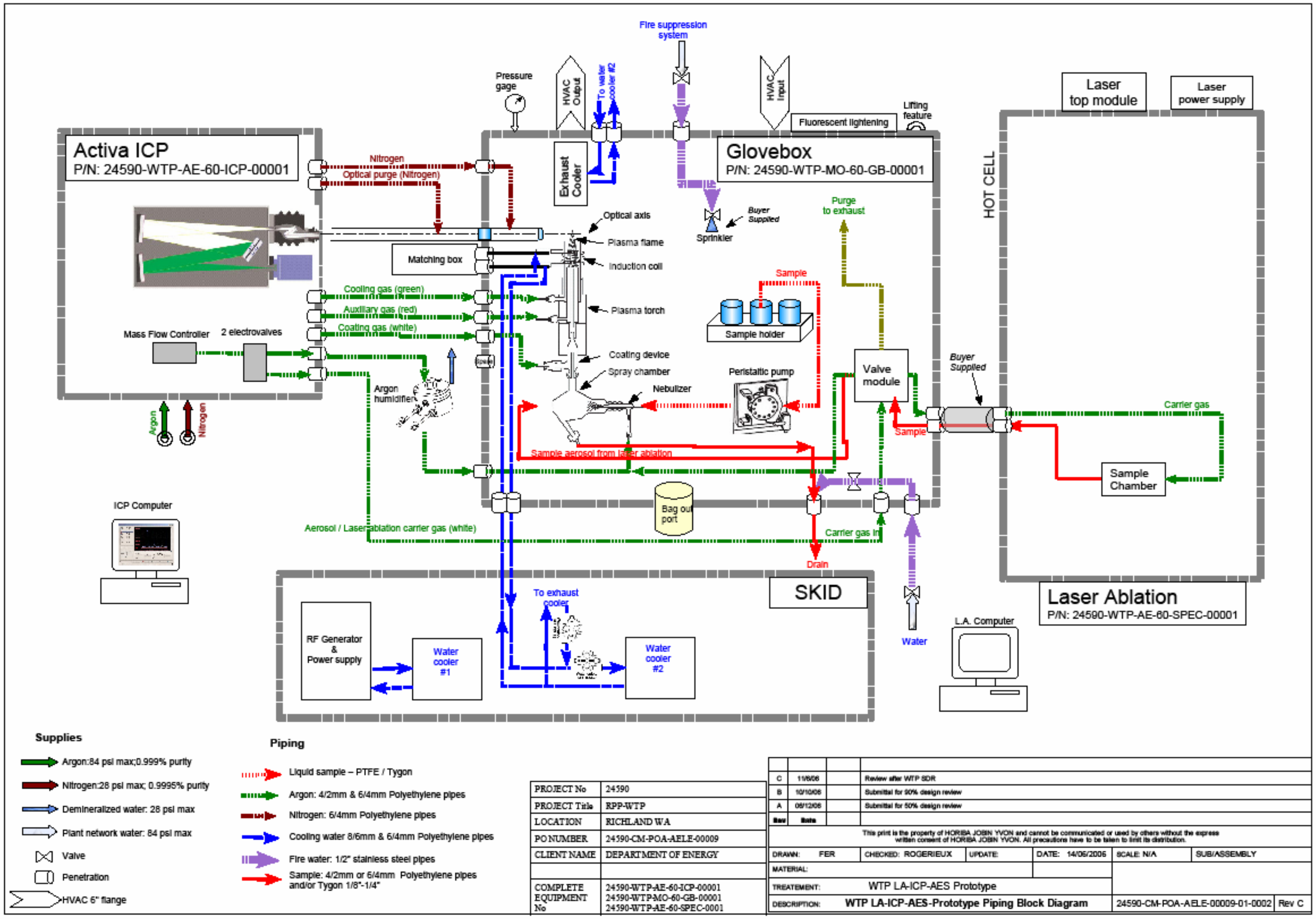


Figure 2.1. Schematic of the LA-ICP-AES Analytical Subsystem as Planned for the Prototype

The laser ablation sample preparation and analysis techniques were selected for application in the WTP because the analysis turnaround time associated with LA-ICP-AES technology is significantly shorter than traditional wet chemistry techniques (24950-WTP-RPT-0P-06-001, Rev. 0). In current and previous DOE waste processing plants (West Valley Demonstration Project [WVDP] and Savannah River Defense Waste Processing Facility [DWPF]), radiochemical chemical sample analysis of melter feeds was completed by dissolving the slurry by acid dissolution, converting the slurry to glass or dissolving the glass with a caustic fusion (both potassium [K] and sodium [Na]), and analyzing the dilute fusion solutions using ICP AES technologies. A fusion using both potassium hydroxide (KOH) and NaOH must be completed so that the interference associated with the Na can be characterized, and a complete analysis of the solution completed for the cations in the waste. The LA-ICP technology for sample preparation avoids the requirement for extensive wet chemistry sample preparation that can reduce the total sample analysis turnaround time.

2.3.1.3 Relationship to Other Systems

The ICP-MS and ICP-AES subsystems are integral components of AHL and ARL. The AHL is a set of 14 hot cells (HC) with the ICP-MS and ICP-AES subsystems integrated with HCs 12 and 13. A laser system is planned in a hot cell that will ablate particles from the surface of a glass coupon. The laser ablation system will be applied to the ICP-AES, but procedures may be developed that support laser ablation for the ICP-MS if needed. The ARL consists of 13 radiochemical laboratories with the ICP-MS and ICP-AES subsystems integrated into two of these laboratories. Wet chemistry dissolution methods will be used to prepare samples in AHL and ARL. If the dose rate of prepared or received samples is low, then the samples can be transferred to the ARL from the AHL facility (for analysis or preparation and analysis) for managing sample load.

The development and implementation of the LA-ICP-AES in the AHL is required to support rapid turnaround-time requirements for HLW melter feed preparation vessel samples. Achieving the relatively short sample analysis turnaround time for the HLW samples is essential to support the operations of the HLW Facility at the specified waste treatment capacity and thereby support continuous operations. Based upon current planning in the Integrated Sampling and Analysis Requirements Document, the AHL and ARL will be required to analyze approximately 10,000 samples per year. More than a third of these samples, about 3,700 samples per year are projected for collection from the HLW Facility melter feed preparation vessels (MFPV).

2.3.1.4 Development History and Status

Initial feasibility tests of the LA-ICP-AES and LA-ICP-MS systems were completed by the WTP Project in two independent studies conducted at Savannah River National Laboratory (SRNL) and Battelle Pacific Northwest Division (PNWD). The studies supported development of two approaches for providing the required elemental analyses of HLW melter feed samples: (1) optimization of conventional dissolution of samples followed by elemental analyses of solutions by ICP-AES to support rapid turnaround time requirements; and (2) laser ablation of samples followed by ICP-AES elemental analyses of the ablated material. Studies involving LA-ICP-MS were included mainly to evaluate the applicability of ICP-MS analysis to ablation of HLW sludge matrix samples. The PNWD study (24590-101-TSA-W000-0004-158-00002) evaluated the capability of the LA-ICP-AES and the LA-ICP-MS to provide sufficient sample turnaround time, accuracy, and precision for HLW processing within the WTP. Tests were performed on dried melter feed simulants and analytical reference glasses. For the LA-ICP-AES, only two analytes exceeded 30% of the wet chemistry values, Na was 31% high and zinc (Zn) was 70% low. For the LA-ICP-MS, Zn was low and elements below atomic mass unit (amu) 43.6 (aluminum [Al], K, magnesium [Mg], Na, silicon [Si], and phosphorus [P]) were not analyzed because of spectral ion interferences.

The results of SRNL tests conducted in two phases are documented in two reports (SCT-M0SRLE60-00-216-00001, Rev. 00A; SCT-M0SRLE60-00-216-00002, Rev. 00A). The SRNL work scope included the demonstration of laser ablation and cold sample preparation methods with HLW simulants (Phase I) to the demonstration of laser ablation and cold sample preparation methods with an actual HLW sludge matrix under remote conditions (Phase II). Due to extenuating circumstances, laser ablation of the radioactive samples in Phase II could only be analyzed using LA-ICP-MS. SRNL concluded that the testing successfully demonstrated laser ablation as a sample preparation technique for radioactive glass samples, and that LA-ICP-AES and LA-ICP-MS were feasible for analysis of the Hanford Site tank waste composition. LA-ICP-MS was most suited for elemental analysis of low concentrations as well as radionuclide isotopes. Approaches and results of method development are summarized in a report issued by WTP (CCN: 146465).

Based on WTP method development work and previous PNNL testing, sufficient information was available to proceed with prototype LA-ICP-AES specifications for WTP testing to optimize the final design of the laser ablation sample preparation system. The WTP Project has initiated a full scale test (CCN: 139427) in the Hanford 222-S Laboratory to verify and validate LA-ICP-AES analytical method for hot samples. The task involves: (a) installation and testing of a WTP-procured LA-ICP-AES glovebox system properly configured in the adjacent hot cell for remotely ablating HLW samples, and (b) adaptation of the developed LA-ICP-AES method to routine operational requirements. This LA-ICP-AES subsystem will be a full scale prototype of the WTP plant system to analyze actual tank waste. Results of the LA-ICP-AES tests will be applicable for configuring laser ablation unit to the ICP-MS system after establishing the LA-ICP-AES to support the HLW Facility.

2.3.1.5 Relevant Environment

The relevant environment for laboratory subsystems is described in the AHL system description (24590-LAB-3YD-AHL-00001) and the ARL system description (24590-LAB-3YD-ARL-00001). Requirements unique to the laser ablation unit are described in the AHL system description (24590-LAB-3YD-AHL-00001). The planned implementation for LA-ICP-AES subsystem is described as follows:

- The LA-ICP-AES subsystem shall operate for the WTP in the AHL.
- The LA-ICP-AES subsystem shall measure the suite of elements in the HLW melter feeds required for glass formulation.
- The LA-ICP-AES subsystem in the AHL shall be operated remotely in hot cells and gloveboxes to analyze highly radioactive samples.
- Before LA-ICP-AES analysis, AHL samples shall be converted to a homogenous glass solid that is representative of the melter feed.
- The uncertainties associated with the analytical measurement using LA-ICP-AES shall be low enough to ensure that acceptable waste glass is formed.
- After laser ablation technology has been implemented with ICP-AES in the AHL and is fully operational, it may be applied to ICP-MS in the AHL.

2.3.1.6 Comparison of the Relevant Environment and the Demonstrated Environment

The LA-ICP-AES subsystem has not been demonstrated in a relevant environment. The LA-ICP-AES technology is a unique application of existing commercially available technologies that require testing of integrated system for measurement accuracy and development of analytical procedures for rapid turnaround time in a remote operating environment. This includes confirmation that analytical results from the LA-ICP-AES system are comparable to ICP-AES results from samples prepared using well-developed wet chemistry dissolution technologies.

Component integration for the LA-ICP-AES will be demonstrated in the prototypic test planned in Hanford's 222S Laboratory (CCN: 139427). This test will compare wet chemistry sample preparation techniques versus laser ablation as a sample preparation technique, and determine the accuracy of the LA-ICP-AES analysis compared to traditional ICP-AES analysis for HLW melter feed and glass samples. The tests will be conducted using LA-ICP-AES prototype equipment operating remotely in hot cells and gloveboxes. The tests will demonstrate whether the LA-ICP-AES turnaround time requirements can be met in a remote environment using manipulators. Results will provide information on the achievable turnaround times and limits of detection for the LA-ICP-AES.

The LA-ICP-AES testing will use actual HLW tank waste sludge samples for testing the developed analytical procedure and prototype performance to ensure that the subsystem will produce reliable and consistent analytical results. Selected analytes of interest from the HLW Compliance Plan (24590-WTP-PL-RT-03-002) and the immobilized high-level waste (IHLW) Formulation Algorithm documentation (24590-HLW-RPT-RT-05-001) include: antimony, aluminum, boron, cadmium, magnesium, sulfur, manganese, thallium, nickel, thorium, phosphorous, titanium, chromium, iron, lithium, silicon [S], zinc, sodium [Na], zirconium, strontium, calcium, potassium [K], and uranium. Other analytes will be tested as part of ongoing methods development for the WTP.

The laser ablation technique for sample preparation for ICP-AES and ICP-MS methods are not planned for near term use to support LAW Vitrification, because the turnaround requirements for LAW vitrification allow the use of conventional wet chemistry methods for sample preparation. If LA-ICP-AES is used to support glass formulation for LAW vitrification, it must accurately measure cations associated with Na_2O, K_2O, and SO_3 that limit the loading of low-activity waste in glass (24590-LAW-RPT-04-0003). Radionuclide related constraints are satisfied by process control activities.

2.3.1.7 Technology Readiness Level Determination

The AHL was determined to be a TRL 5 because the high-fidelity prototype of the LA-ICP-AES analytical subsystem has not been tested in a relevant environment. Integrated prototypical testing of a full-scale LA-ICP-AES is planned at the Hanford 222-S Hot Cell Facility beginning in calendar year 2007 (CCN: 139427) to verify the final design concept prior to the completion of the design of the actual full scale LA-ICP-AES subsystems for AHL facility.

Recommendation 1

The prototypical LA-ICP-AES system should be tested to demonstrate achievable detection limits for chemical elements of interest and satisfy turnaround time requirements on actual HLW sludge samples in a relevant environment to support the final design of the actual LAB subsystems. The LA-ICP-MS can be qualified in the AHL after laser ablation technology has been implemented with ICP-AES in the AHL and is fully operational.

Testing is recommended to confirm that the design of the LA-ICP-AES will meet its functional requirements. Design optimization for AHL implementation should continue following demonstration of the prototype. This testing is included in the WTP baseline.

2.3.2 Autosampling System (ASX)

2.3.2.1 Function of the Autosampling System (ASX)

The ASX is designed to remotely collect representative radioactive process liquid samples from designated process vessels at each of the WTP process facilities (PT/LAW/HLW), and transfer those samples via a pneumatic transfer system (PTS) to the LAB for analysis.

2.3.2.2 Description of ASX System

The ASX is described in the ASX system description (24590-WTP-3YD-ASX-00001). The ASX is comprised of 10 autosamplers with supporting remote manipulators located inside specially designed gloveboxes; sample bottle and carrier systems; and the PTS, comprised of transfer piping, 4 diverters (routing valves integral to the transfer piping), 3 LAB receipt stations, PTS exhausters, and a standalone carrier posting system (CPS) station. A schematic layout of the ASX and its relationship to the WTP facilities is shown in Figure 2.2. A brief description of the ASX for each facility is given below:

- The ASX System is designed for remote operation inside the central control room of the Pretreatment (PT) Facility.
- The PT Facility houses five autosampler stations. The PT Facility samples are transported to the hot cell (HC) receipt station 00039 in the LAB.
- The HLW Facility houses three autosampler stations. The HLW samples are transported to the HC receipt station 00043 located in the LAB.
- The LAW Facility houses two autosampler stations and a CPS. The LAW samples are transported to a fume hood receipt station 00034 located in the LAB.
- The LAB houses two HC receipt stations and one fume hood receipt station.

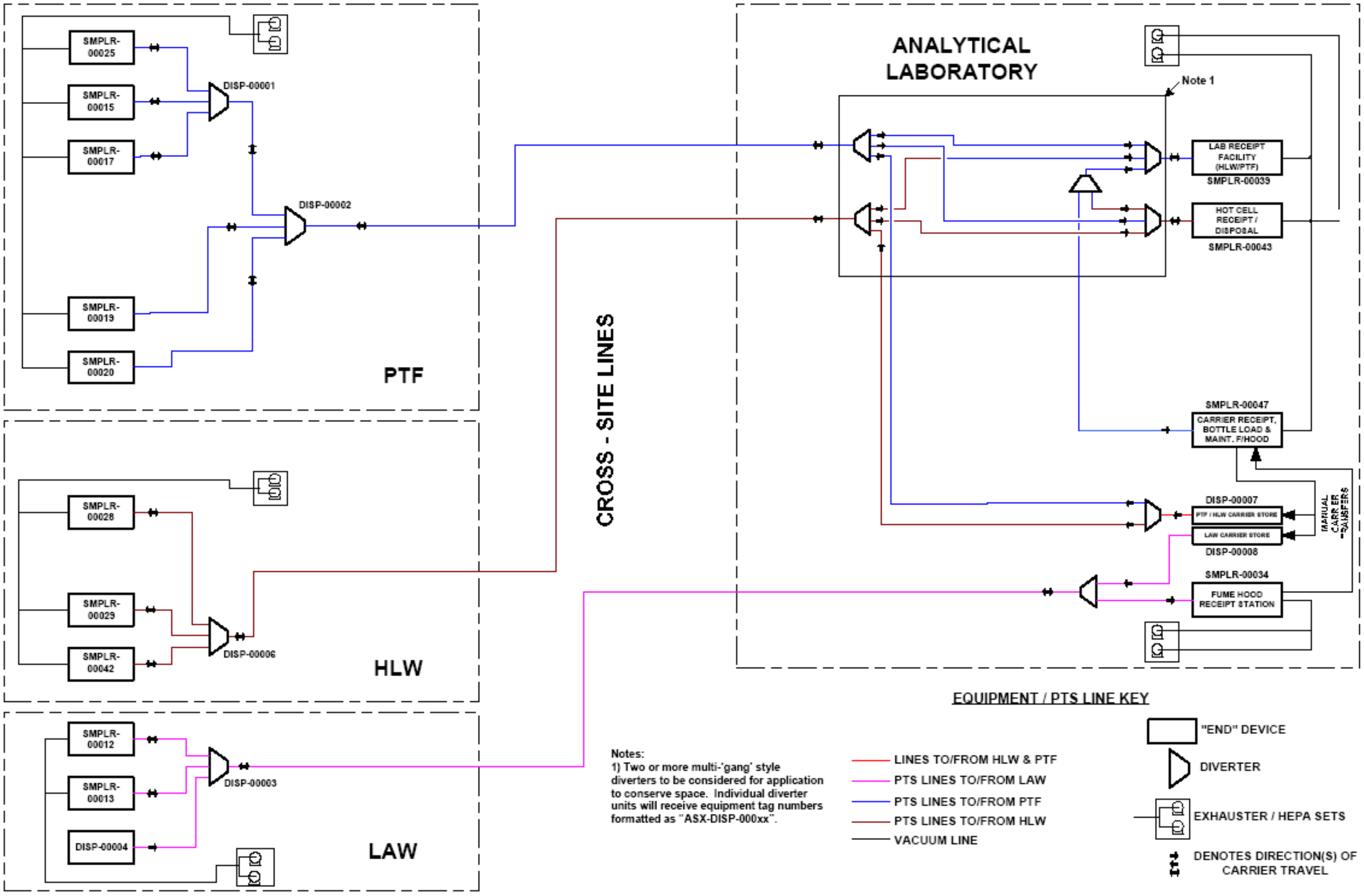
Each of the 10 autosampler stations includes a remote manipulator used to position sample bottles under a commercially available autosampler device (ISOLOCK sampler [4]). Sample bottles with unique labels and carriers are introduced into the autosampler stations thru a magazine loading station. Recirculation process fluid lines having diameters that vary between 2 to 3 inches from the vessels to be sampled will be routed into identified autosampler station.

Once a sample event is initiated for a specific vessel, the following steps occur:

- A pumping system is activated that recirculates process fluid/slurry between the vessel and the autosampling station.
- The remote manipulator removes a new sample bottle from the carrier and places it on the ISOLOCK sampler.
- A sample is obtained from the process stream by the ISOLOCK sampler, in 15 to 35 mL increments, to fill the sample bottle.

---

[4] Manufactured by Sentry Equipment Corporation.



Notes:
1) Two or more multi-'gang' style diverters to be considered for application to conserve space. Individual diverter units will receive equipment tag numbers formatted as "ASX-DISP-000xx".

Figure 2.2. Schematic of the Autosampling System, Pneumatic Transfer System, and WTP Facilities

- Once filled, the sample bottle is retracted slightly, and the sampler needle is flushed and vented.
- The filled sample bottle is placed in a sample carrier by the remote manipulator and the carrier is pneumatically transferred to the LAB.

The technology being evaluated as the CTE is the complete ASX.

The design and fabrication of the ASX is being completed by a commercial vendor (Energy*Solutions*) previously responsible for the design of the autosampling system for the THORP Nuclear Fuel Reprocessing facility at the Sellafield Site. Bechtel National, Inc. (BNI), the WTP Contractor, is designing the software for the control of this system.

2.3.2.3 Relationship to Other Systems

The ASX supports the operation of the WTP facilities by obtaining and transferring process solution samples to the LAB for analysis. The information from the sample analysis is essential for the operation of the WTP facilities. These sample results are used to confirm that the process fluid compositions are within the safety authorization basis assumptions, control process operation conditions, and control waste loading in the final ILAW and IHLW glass products.

The representativeness of the sample and the accuracy of the sample analysis are critical to the quality of the data obtained from the sample. The representativeness of the sample is dependent upon the homogeneity of the process solution being sampled and is directly related to the performance of the solution mixing systems for each vessel. The accuracy of the sample analysis results is directly related to the analysis techniques and procedures used in the LAB. These system interfaces, although critical to the analytical results, do not directly affect the performance of the ASX.

2.3.2.4 Development History and Status

The design and planned operation of the ASX for the WTP are based on designs used at the THORP Nuclear Fuel Reprocessing Plant at the Sellafield Site, UK and the LaHague Nuclear Reprocessing Plants, France (NHC-8373; NHC-8374; NHC-8375). These operating facilities reprocess spent nuclear fuel. The sampling systems are used for the sampling of process waste streams, which have radiation levels several orders of magnitude greater that the waste streams in the WTP.

The ISOLOCK sampler design being used in the WTP is a proven design that has been previously, and is currently, used in the nuclear, chemical, and food industry. The WTP Project will be adapting commercially available ISOLOCK samplers into specifically designed WTP glovebox design configurations.

2.3.2.5 Relevant Environment

Operating requirements are identified in the ASX system description (24590-WTP-3YD-ASX-00001) and the design requirements in the autosampler engineering specification (24590-WTP-3PS-MHSS-T0002, Rev. 0). The relevant environment of the ASX is:

- Use of the equipment systems with radioactive waste solutions that vary between low radiation and high radiation solutions, with low and high solids concentration waste slurries
- Remote operation of the sampling and transfer equipment
- High operational availability of the equipment systems required to support WTP process operations.

The WTP Project's design of these systems is consistent with previous applications of the technologies. A unique challenge discussed during this evaluation is the need to characterize the mixing of sampling slurries with the solids level of the WTP to understand if samples meet requirements for representativeness, and to determine how many samples are needed to provide measurements sufficient for process control and product quality verification.

2.3.2.6 Comparison of the Relevant Environment and the Demonstrated Environment

The ASX was demonstrated in a relevant environment. A comparison of the relevant environment and the demonstrated environment shows that the extensive use of an autosampling system at similar facilities is applicable to the demonstration of the final WTP design configuration in a relevant environment.

Automatic sampling systems are used at the THORP plant, Sellafield, UK, the LaHague fuel reprocessing facilities, France, and the DWPF at the Savannah River Site, South Carolina, in high radiation environments. The samplers used in the THORP plant (ISOLOCK) are from the same manufacturer as those proposed for use in the WTP and have an almost identical. Both the Sellafield and LaHague sites employ sampling systems that are automated and operated from a central control room. The Savannah River Site does not use a needle and seal for samples as in the ISOLOCK design, but uses a customized cup that is mounted on the head of the piston drive. Seals and needles similar to the WTP design are used at the THORP plant for radioactive, high solids, slurry streams.

Energy Solutions, the vendor for the ASX, completed testing of Hanford's ISOLOCK sampler using WTP-simulated waste compositions in their fabrication shop (24590-QL-HC4-HAHH-00001-05-00002). Additional shop testing of the autosampling equipment systems, including functional testing of the instruments and control systems using BNI developed software, is planned. A fully integrated test of the autosampler, PTS transfer system, receipt station, and exhauster systems will be performed during shop testing (24590-WTP-3PS-MHSS-T0002). Shop tests will be controlled using prototypic WTP control hardware and software to verify system performance and to make any required changes prior to installation in the WTP facilities.

DOE recently conducted a design oversight of the ASX (06-WTP-105) to evaluate the design in relationship to its functional and operational requirements. This study identified several design deficiency issues including system redundancy (enabling the system to function during maintenance or partial system failures), retrieval of broken or stuck sample carriers in the PTS; adequacy of shielding in the autosampler station and parts of the PTS; estimates of system availability; and software testing. However, these are design, not technology, issues; their resolution is part of the ongoing effort to finalize the ASX design.

The DOE Design Oversight Report (06-WTP-105) noted that additional testing of the equipment and software during cold and hot commissioning of the WTP may be required because the ASX relies heavily on automated systems for operation and control. Based on the results of this oversight, it is recognized that the design of the ASX is not complete and design issues unique to the WTP design are planned for resolution. A summary of the risks associated with the design is summarized in CCN: 133570, "Concurrence of ASX Risks and Risk Mitigation Strategy."

2.3.2.7 Technology Readiness Level Determination

The ASX was determined to be TRL 6 because there has been an extensive use of the remotely operated autosampling technology components in other relevant operating conditions at the Sellafield Nuclear Site, UK, and the LaHague Nuclear Site, France. The WTP design is being adapted from these design concepts.

2.3.3 ILAW Container Finishing Handling System (LFH) Container Sealing Subsystem

2.3.3.1 Function of the LFH Container Sealing Subsystem

The LFH receives the glass-filled ILAW containers from the ILAW Container Pour Handling System (LPH). The LFH performs the following functions required to ready the container for export from the LAW Facility and subsequent burial: weighing, glass-level determination, inert filling, container closure, container decontamination, container smear testing, and container radiation dose rate measurement.

The evaluation of the CTEs for the LFH (Appendix B) identified the ILAW container sealing subsystem as a CTE. The container sealing subsystem requires that the container be sealed to prevent the dispersal of radioactive contamination during the most severe conditions encountered during normal use and handling. The closure system must be designed to ensure that the seal remains intact for a storage period of 50 years in an ambient-temperature ventilated enclosure. The WTP Project use of subsystem technology is a unique application of exiting commercially available technologies and custom designs that when integrated result in a new technology system.

2.3.3.2 Description of the ILAW Container Sealing Subsystem

The ILAW container sealing subsystem is described in the system description for the LFH (24590-LAW-3YD-LFH-00001). The lidding process involves verification that the container-sealing surfaces are clean, and that the remote placement and sealing of the mechanical lid are complete.

The ILAW container flange is first visually inspected for debris by direct viewing through a shield window, and indirect viewing using remote cameras. If required, the container seal surface can be cleaned with power tools using a remote manipulator.

The filled ILAW container is closed and sealed by a mechanical lid and seal closure assembly. The assembly consists of a solid stainless steel lid with a metallic sealing ring attached to the bottom surface. The lid has spring-loaded locking bars located in slots on the lid side. A specialized lidding tool (Figure 2.3) has been designed to retrieve lids from a storage rack, and remotely place and seal the lid on the container. As the lid is pressed into position on the container flange sealing-surface, the bars first retract and then snap into a mating groove on the flange neck. The compressed sealing ring provides the pressure to maintain the closure seal. The seal compression is approximately 4,000 lb.

Visual verification of the position of the locking bars is used to confirm that the lid is correctly placed and sealed on the container.

A companion lid recovery tool has also been designed to remove an incompletely sealed, or damaged and installed lid. If the lid requires removal, the lid recovery tool can grab the container flange, push down on the lid, and release the locking bars. Pistons on the lid recovery tool allow an arm to rotate and grab the lid. The container flange surfaces can be cleaned and the lid reattached. Glass or inert fill found in the seal area can be removed with a seal preparation tool.

The LAW Facility has two ILAW lidding stations located as mirror images to each other. This was done to provide redundancy if one of the lidding stations is inoperable. The lidding equipment systems are designed for contact maintenance, which can occur following the removal of ILAW containers from the area.

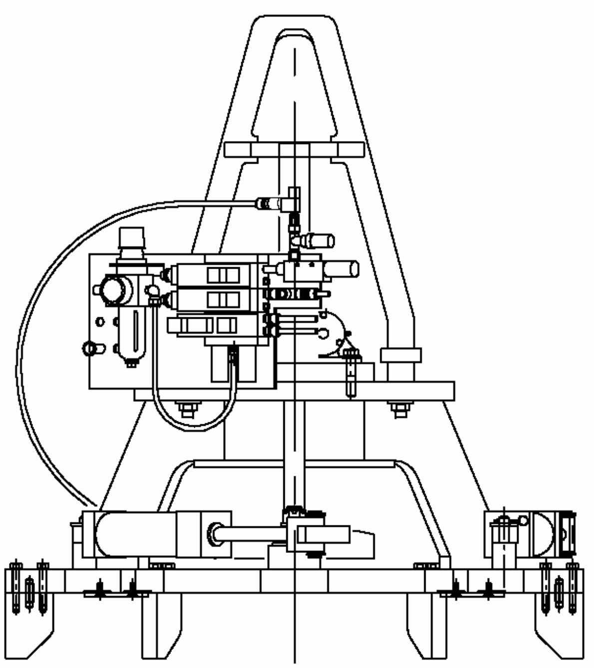


Figure 2.3. ILAW Container Lidding Tool

2.3.3.3 Relationship to other Systems

The ILAW container sealing system is a batch process subsystem that is located between an ILAW container glass level measurement and inert fill system, and an ILAW container decontamination subsystem. The successful operation of the ILAW container sealing subsystem is essential to the effective operation of the LAW Facility. If the lid sealing process fails, the containers must be over packed prior to transport.

Potential risks associated with the ILAW sealing system include:

- Adequacy of the sealing system design concept to meet leak test performance requirements
- Ability to efficiently and remotely operate the lidding equipment
- Ability to efficiently and remotely complete delidding
- Contamination spread from the gap between the container lid and the ILAW container sealing surface following decontamination.

2.3.3.4 Development History and Status

The WTP Project modified the ILAW container-sealing concept in 2004 (TN-24590-02-00665). Prior to that time, the sealing concept used an autogenous weld seal closure similar to the lid weld closure for the IHLW canisters. Based upon less stringent sealing requirements and a lower anticipated operating cost, the ILAW container-sealing concept was modified to a mechanical lid closure subsystem.

The design of the lid closure subsystem is based upon the integration of existing technologies. The seal is created by commercially available e-springs attached to the underside of the lid. The seal is made between the bottom of the lid and the flange of the ILAW container. Locking tabs are used to hold the lid with the compressed seal in place. The WTP design incorporates specialized lidding tools to position and seal the lid, and to remove an incompletely sealed or damaged and installed lid.

The lidding concept is based upon engineering judgment and analysis completed by the WTP Contractor. No testing of the design concept has been completed to date. Vendor contracts have been awarded for the container sealing system equipment in accordance with specification (24590-LAW-3PS-HCTH-T0001). Fabrication of the lidding equipment is in progress with an anticipated completion date of October 2007. As part of the fabrication contract, the vendor will functionally test the sealing system equipment. This factory acceptance testing is being completed to verify the functional features of the lidding and delidding equipment and will include:

- Verification of equipment functional requirements
- Use a mock container and lid for testing
- Verify proper operation of the controls
- Verify machine movement electrically and mechanically
- Complete cyclic test acceptance of lid pressing operation
- Lifting points/proof load testing acceptance
- Load testing of the lidding and delidding equipment to 125% of assembly weight
- Leak test on the container lid to verify a leak tightness of at least 1×10^{-2} std cc/sec

This testing will be completed by vendor staff with a WTP representative.

Integrated testing of the ILAW container sealing subsystem is planned for completion using the actual plant equipment during equipment acceptance and cold commissioning.

2.3.3.5 Relevant Operational Environment

Requirements for the LFH container sealing subsystem are included in the LFH system description (24590-LAW-3YD-LFH-00001). The relevant operational environment for the ILAW container sealing subsystem is the:

- Use of the equipment systems in a remotely operated environment using overhead cranes and master slave manipulators, and using a combination of prototypic direct viewing and remote viewing via cameras.
- Use of visual observation methods to monitor whether complex operations function correctly (flange, lid handling tool, and lid recovery tool).
- Use of a grinder to clean up the seal if the operator finds glass or inert fill in the seal area.
- Cleaning and sealing of ILAW containers at a temperature of up to 350°F.
- Handling and positioning of ILAW containers that weigh in excess of 6 MT.
- Minimum sealing pressure of 4,000 lb.

2.3.3.6 Comparison of the Relevant Environment and the Demonstrated Environment

The ILAW container sealing technology has not been demonstrated in a relevant prototypical environment. The ILAW container sealing subsystem is not planned for demonstration in a relevant environment until cold commissioning. The WTP Contractor is relying on factory acceptance testing by the equipment fabrication vendor to demonstrate the equipment prior to testing in the LAW Facility.

2.3.3.7 Technology Readiness Level Determination

The ILAW container sealing subsystem was determined to be a TRL 5 because a high-fidelity prototype of the sealing system has not been fabricated and tested in a relevant remote environment. The WTP Project is relying on the verification of the design concept as part of equipment component testing after installation in the LAW Facility.

Limited testing of the container sealing system is planned by the vendor (24590-LAW-3PS-HCTH-T0001) to verify portions of the final design concept as part of the shop acceptance of the equipment. However, integrated testing of the equipment system is not planned prior to cold commissioning.

> **Recommendation 2**
>
> Integrated prototypic testing of the actual immobilized low-activity waste (ILAW) container inert filling, flange cleaning, inspection, and lidding/delidding equipment system in a simulated remote environment should be completed prior to installation in the LAW Vitrification Facility to verify that the equipment system will perform as required.

2.3.4 ILAW Container Finishing Handling System (LFH) Decontamination Subsystem

2.3.4.1 Function of the LFH Decontamination Subsystem

The LFH receives the glass-filled ILAW containers from the LAW Container Pour Handling System (LPH). The LFH performs the following functions required to ready the container for export from the LAW Facility and subsequent burial: weighing, glass level determination, inert filling, container closure, container decontamination, container smear testing, and container radiation dose rate and temperature measurement.

The evaluation of the CTEs for the LFH (Appendix B) identified the ILAW container decontamination subsystem as a CTE. The function of the container decontamination subsystem is to remove radioactive contamination from filled and sealed ILAW container to a smearable contamination level less than 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma to allow movement of the containers to a truck lock (24590-WTP-DB-ENG-01-001, Table 5.2)

2.3.4.2 Description of the ILAW Container Decontamination Subsystem

The ILAW container decontamination subsystem is described in the system description for the LFH (24590-LAW-3YD-LFH-00001). The decontamination process uses abrasion to remove smearable radioactive contamination from the external surfaces of the sealed ILAW container. The abrasive media are solid CO_2 pellets. The CO_2 abrasion process uses a localized decontamination approach in which the CO_2 spray is applied through spray nozzles located inside a containment shroud. The shroud is designed to contain the CO_2 vapor (from sublimation of the solid CO_2) and the loose radioactive contamination. The CO_2 and the loose contamination are continuously removed from the shroud using a vacuum system. The contamination is packaged as solid waste.

The sealed ILAW container is positioned by an overhead crane and a specially designed boggie equipped with a turntable to provide access to all container surfaces for decontamination. The bottom of the container is decontaminated prior to placement on the boggie.

Once on the boggie, the sides and top of the container are decontaminated. The shroud system is positioned against the container by a specially designed robot. Several shapes of shrouds are being designed to seal against the various surfaces of the container. Figure 2.4 shows a schematic of the ILAW decontamination station.

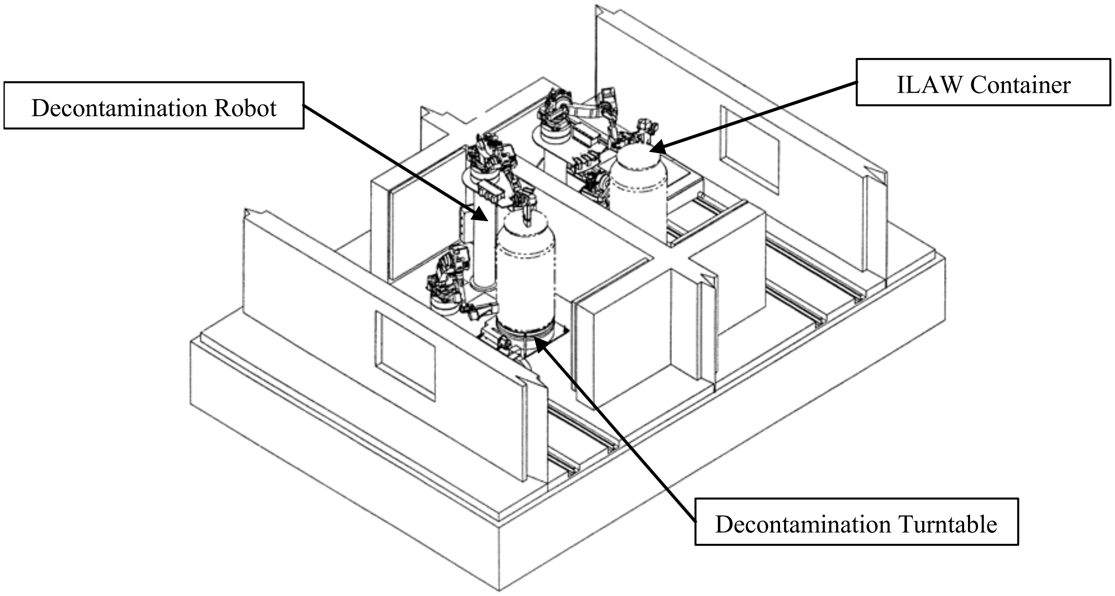


Figure 2.4. Schematic of the ILAW Decontamination Station

The decontaminated container is placed on a swabbing bogie and removed from the decontamination area. The operator selects the area to be swabbed for sampling purposes. Samples of the smear levels on the ILAW container are used to confirm that allowable contamination levels are not exceeded. Containers that do not pass the smear level test are moved back to the decontamination station, re-decontaminated, and smear tested again. This process is repeated up to two times. If the container does not pass the smear test after a third time, the container is placed in an overpack for removal from the LAW Facility.

2.3.4.3 Relationship to other Systems

The ILAW container decontamination system is a batch process subsystem that is located between the ILAW container sealing subsystem and the ILAW swabbing subsystem. The successful operation of the ILAW container decontamination subsystem is essential to the effective operation of the LAW Facility.

2.3.4.4 Development History and Status

The CO_2 decontamination process uses compressed air to fire solid CO_2 pellets at a surface in order to remove contamination. The pellets are typically cylinders 1/8-in. to 1/4-in. in diameter and 1/4-in. to 1/2-in. in length. Contaminants are loosened and removed from the surface by two mechanisms: mechanical impact similar to sand blasting, and a lifting action as the solid CO_2 sublimes to a gas at the surface. If the surface being decontaminated is hard, the method usually does not remove an appreciable amount of surface; e.g., when used to remove paint from aircraft surfaces, it does not remove any of the surface metal.

The use of CO_2 blasting for decontaminating surfaces is an established technology that has been commercially applied in the nuclear industry. CO_2 blasting has been used in a variety of other applications including paint removal from metal surfaces. Basic equipment such as CO_2 pelletizers, delivery systems, and nozzles are standard, off-the-shelf equipment. CO_2 pellets can be obtained in bulk commercially. Conversations with representatives of two commercial companies that use the technology for decontaminating radioactive surfaces indicate that the technology is very effective for removal of loose surface contamination, but it is not effective if the contamination is tightly adhered to the surface or covered by a tightly adhering layer[5].

The WTP Contractor performed non-prototypical laboratory scale tests on 2 in. by 4 in., contaminated, flat coupons of the stainless steel that will be used for the ILAW container (SCT-M0SRLE60-00-99-07, SCT-M0SRLE60-00-110-12). Testing involved radioactive cesium (Cs) that had been vapor deposited on the coupon surface followed by a heat treatment cycle to mimic the thermal history of the container surface. Cesium was successfully removed by CO_2 blasting to below system traditional non-smearable contamination levels (surface contamination less than 220 dpm/100 cm^2 alpha and less than 2,200 dpm/ 100cm^2 beta-gamma). However, the technique was not always successful at removing radioactive Cs that had been deposited on the coupon as a liquid solution. These tests did not employ a shroud system to contain the CO_2 and removed contamination. No engineering scale prototypical tests of the WTP system have been completed. In addition, the testing did not confirm that the WTP Project contamination surface levels of less than 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma could be achieved.

The design of the ILAW container decontamination subsystem is based upon limited testing, engineering analysis and commercially available design concepts, e.g., robots and limited technology testing. The engineering specification for fabrication of the equipment includes the boggie and robot for the decontamination system (24590-LAW-3PS-HDYR-T0001) and requires the vendor to shop test portions of the equipment system. However, no integrated testing of all components of the LAW decontamination system is planned until the equipment is installed in the LAW Facility. Full scale decontamination of a ILAW container is not planned until hot commissioning.

2.3.4.5 Relevant Environment

The operating environment for the LFH container decontamination subsystem is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C), the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1), and the LAW Preliminary Safety Analysis Report (PSAR) (24590-WTP-PSAR-ESH-01-002-03, Rev. 1). The relevant operational environment for the ILAW container contamination subsystem is:

- Operating the system shall prevent the release of contamination outside of the shroud system.
- Operator control of the decontamination system shall ensure that all surfaces are adequately decontaminated.
- Equipment systems in a remotely operated environment shall use overhead cranes and master/slave manipulators, and a combination of prototypic direct viewing and remote viewing via cameras lines of sight and angles.
- Decontamination shall transport, clean, and swab ILAW containers having surface temperature of up to 350°F.
- The crane and grapple shall handle and position ILAW containers that weigh in excess of 6 MT.

---

[5] Personal communication between H. Sutter and J. Wilson, UniTech Services Group, Inc., Springfield, MA; W. Briggs, Master-Lee Decon Services, Latrobe, PA, January 3, 2007.

- Shrouds around the various nozzle assemblies shall provide containment for removed contaminants during the decontamination operation.
- Swabbing robots shall access the top, side, and bottom areas.
- The decontamination room shall be clean enough after decontamination for container to be released.
- The decontamination system shall provide for disposal of solid waste.
- Rotating hooks shall not be degraded because of crane decontamination; therefore, sealed bearings will be used.

2.3.4.6 Comparison of the Relevant Environment and the Demonstrated Environment

The system has not been demonstrated in a relevant prototype environment. The ILAW container decontamination equipment has been tested on a laboratory scale in a simulated environment. Only a few pieces of the decontamination system have been tested. These include the use of the CO_2 spray to decontaminate simulated contaminated metal test specimens. The integrated CO_2 spray and shrouding system has not been tested

CO_2 blasting will be used to decontaminate the containers that have been filled with molten LAW glass at approximately 1100°C and have surface temperatures of approximately 700°C (24590-101-TSA-W000-0009-101-00007). The most likely contaminant is radioactive Cs. The most likely transfer mechanism for Cs contamination will be by vapor-phase deposition, although the possibility does exist for direct contamination through spills and spatters of glass. The ILAW container is a right cylinder of dimension 7.5 ft high with a 4-ft diameter and a neck with a press fit lid. The decontamination system will consist of a robotically controlled blasting nozzle and a shrouding system that will use a vacuum to capture CO_2 and contamination.

Although the CO_2 blast system has been used in many applications in the nuclear and other industries, the Assessment Team is not aware of any application that is similar to the proposed WTP system in terms of the thermal history of the contaminated surface, the configuration of the container, and the local shrouding system. The lab scale system used for the Savannah River Site specimen decontamination tests (SCT-M0SRLE60-00-99-07, SCT-M0SRLE60-00-110-12) was non-prototypical. These tests used 2-in. by 4-in. flat coupons of the container material. Half the coupons were contaminated by direct placement of a solution of radioactive Cs. These coupons were then heat-treated in an oven to a temperature of 950°C with an equivalent number of clean coupons that became contaminated by vapor deposition. The 950°C temperature was at least 200°C higher than the highest temperatures recorded during prototypical ILAW container pours carried out at Duratek Federal Services (24590-101-TSA-W000-0009-101-00007). The duration of exposure to elevated temperatures was a matter of minutes in the coupon tests versus greater than 5 hours expected in actual container filling operations. In addition, the testing report, SCT-M0SRLE60-00-110-12, also notes the following:

- Blast nozzle orientation to the contamination surface was not evaluated.
- Length and configuration of the CO_2 pellet delivery system was not evaluated.

No localized vacuum shrouding system was used in the testing.

The Assessment Team has identified the following risks with the ILAW decontamination system:

- Contamination spread from the gap between the container lid and the ILAW container sealing surface following decontamination.

- Containment of contamination removed from the container surface in the shroud system. This contamination could “dirty” the work area making the area unusable until it was decontaminated. Contamination generated by the blasting could “dirty” the decontamination cell to the extent that ILAW containers could not be released.

2.3.4.7 Technology Readiness Level Determination

The ILAW container decontamination subsystem was determined to be a TRL 4 because only pieces of the system have been tested, and only at a laboratory scale. Although the feasibility of the CO_2 decontamination has been tested for one set of heat-treated, flat surfaces, the use of the shrouding system to effectively contain the removed contamination to WTP Project requirements (100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma) has not been demonstrated. Of greatest concern is a limited understanding of the (1) ability of the CO_2 decontamination system to meet the WTP Project contamination level requirements; (2) efficiency of the decontamination process when applied to all surfaces of the ILAW container; (3) containment of the removed contamination in the shroud system; (4) understanding of the system operating parameters; and (5) demonstration of the entire equipment concept in an integrated test.

The components of the ILAW container decontamination subsystem are being fabricated by several vendors. These major components include the CO_2 generation system and the remote robots, boggies, and spray shroud system used to decontaminate the system. BNI is also independently developing the software to control this system. The WTP Project is relying on the verification of the design concept as part of equipment component testing after installation in the LAW Facility. No testing of the effectiveness of the system is planned until cold commissioning. Modification of the system during or after commissioning would be expensive and time consuming and could result in hot commissioning.

> **Recommendation 3**
>
> Integrated prototypic testing of the actual LAW container decontamination and smear testing systems in a simulated remote environment should be completed following the fabrication of the equipment components to verify that the equipment system will perform as required.
>
> This testing program should be supplemented with laboratory scale testing to define the operational parameters for the carbon dioxide (CO_2) decontamination system.

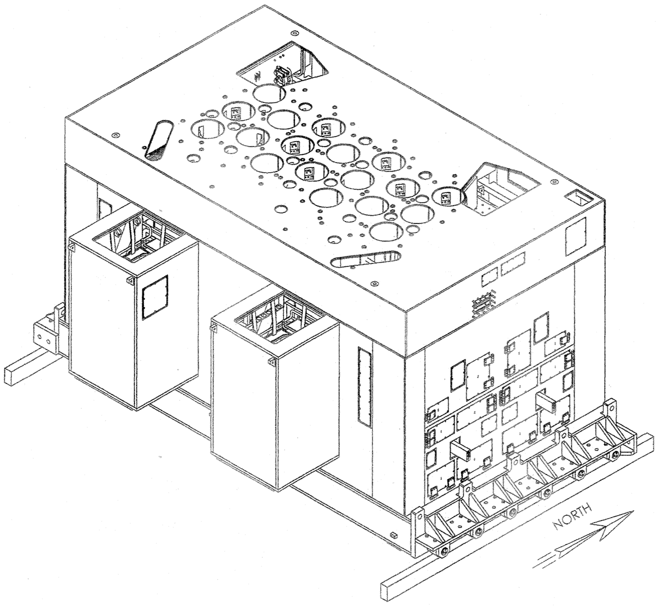
2.3.5 LAW Melter Process System (LMP)

2.3.5.1 Function of the LAW Melter Process System (LMP)

The function of the LAW melter is to convert a blended slurry of pretreated low-activity, liquid waste, and glass formers into molten glass and pour the glass into specially designed containers.

2.3.5.2 Description of the LMP Process

The LAW melter is described in the system description for the LMP (24590-LAW-3YD-LMP-00001). The LMP is comprised of two melters each with the same design. Also included in the LMP are the pour spouts that are attached to the discharge sections of each melter and the ILAW container level detectors. An isometric of the LAW melter is shown in Figure 2.5.



Source: 24590-QL-HC4-W000-00011-03-00523_Rev_00A

Figure 2.5. Isometric of the LAW Melter

The LMP can be divided into five subsystems: Containment, Joule Heating, Slurry Feed Delivery, Glass Discharge, and the Agitation System.

2.3.5.3 Relationship to Other Systems

The major process systems that interface with the LMP are the:

- LAW Melter Feed Process System (LFP)
- LAW Primary Offgas Process and Secondary Offgas Vessel Vent Process Systems (LOP/LVP)
- LAW Container Pour Handling System (LPH)

2.3.5.4 Development History and Status

The WTP LAW melter is a slurry-fed melter design using parallel plate Inconel 690™ electrodes. In these design features, the WTP melter is similar to HLW melters operated at other DOE sites, such as the DWPF melter at the Savannah River Site and the WVDP melter at West Valley New York. The WTP melter is most similar to the WVDP melter in that both melters use similar “air lift” glass discharge systems. However, the WTP LAW melter has a glass pool surface are of 10.0 m^2, which is much larger than the WVDP (2.2 m^2) and DWPF (2.6 m^2) high-level waste melters.

The design basis for the WTP LAW melter evolved from the design and operational experience of melters developed by DOE and Duratek in their projects used to treat waste at DOE sites. The most relevant designs are the DM-5000 melter (5.0 m^2 melt pool area) used at the Savannah River M-Area Site, South Carolina, to immobilize low activity waste and the DOE WTP LAW Pilot Plant melter (3.3 m^2 melt pool area) tested at the Duratek Columbia, Maryland, site.

The specific arrangement of bubblers mounted through the lid to enhance melting rate was first demonstrated in the second generation M-Area melter and was the basis for the bubbler designs later used in the WTP LAW pilot plant melter at Vitreous State Laboratory of the Catholic University of America

(VSL), and the DOE WTP LAW Pilot Plant melter (3.3 m^2 melt pool area). One of the most important results of the melter research and development efforts was the demonstration in the Duratek Columbia melter that a significant increase in glass output could be achieved if bubbler tubes were installed in the melter.

Bubblers were tested at the Research and Technology (R&T) subcontractor's facility, VSL, on the DM1200 melter. Key observations from LAW bubbler testing of Inconel 690 (24590-101-TSA-W000-0009-23-10) include:

- The melter feed material contains significant amounts of chlorides and fluorides. These compounds are known to diffuse into metal where they react to form low-melting point/low-vapor pressure compounds that end up leaving internal voids. These voids can coalesce to form larger voids and weaken the alloy.
- The melter feed material contains significant amounts of sulfur containing compounds. These compounds are known to react with the nickel, chromium, and iron of Inconel 690.
- The melter feed also contains other compounds of nitrates and phosphates. These compounds may contribute to the breakdown of the protective chromium scale and may lead to material corrosion.
- The feed also contains very high levels of sodium as well as potassium, lithium, calcium, and zinc. These materials tend to form molten salts in the cold cap, which can aggressively attack the bubbler support tubes.

Based on these observations, the service life of the bubblers in the LAW melter needed enhancements to meet the LAW performance requirements. A minimum service life of 26 weeks has been specified by the WTP Contractor.

The LAW melter bubbler design uses legs made of MA758 and shin guards made of Inconel 690. The MA758 is the preferred material for the bubbler legs due its resistance to corrosion by the LAW glass; thereby, maximizing the bubbler lifetime and reducing the replacement frequency. The use of Inconel 690 bubbler legs, which have a lower operating life, was considered as a potential means to reduce cost. However, a comparison of the total costs indicated that MA758 and Inconel 690 costs are comparable. Platinum-coated Inconel 690 was also evaluated; it has a lifetime cost less than MA758 but much greater than uncoated Inconel 690.

All of the melters use Monofrax K-3 fused-cast ceramic refractory as the glass contact refractory. The WTP melters also use Monofrax E fused-cast ceramic refractory for the airlift glass discharge riser block for maximum refractory durability in this high-wear area. These melters, excluding the DWPF melter, use an Inconel dam in the wall between the melt pool and the heated glass discharge chambers to prevent glass leakage through this hot wall, and an Inconel trough to transfer the glass through the dam from the airlift riser into the discharge chamber. Water-cooling of the melter based and exterior walls is common to these melters to provide enhanced assurance of glass containment.

The use of the LAW melter containment box, which provides localized shielding, is unique to the WTP. However, this design feature does not require development.

The WTP Research and Technology Program conducted extensive testing of the WTP LAW pilot plant melter to verify design features, glass chemistry, and operating requirements of the WTP LAW melter. A listing of the major technology development summary reports is provided in Appendix D, Table D.6.

2.3.5.5 Relevant Environment

The relevant operational environment for the LMP, as identified in the system description (24590-LAW-3YD-LMP-00001), is:

- The system shall melt, contain, and pour molten glass at temperatures up to 1250°C.
- The system shall vitrify wastes with a range of physical properties.
- The discharge chamber shall continuously heat the glass using lid mount heaters to avoid becoming clogged.
- An airlift system shall pour glass into the containers using a bubbler lance immersed in the riser glass.
- The container fill level shall be controlled using an infrared (IR) camera and software for an automatic shutoff.
- Contact maintenance of the LAW melter shall be conducted to periodically replace bubbler assemblies, thermowells, and waste feeding nozzles.
- Installing and replacing a melter system shall be conducted for a melter that weights approximately 200 MT.

2.3.5.6 Comparison of the Relevant Environment and the Demonstrated Environment

The technology for the LAW melter has been demonstrated in a relevant environment. The Duratek LAW pilot melter is essentially a third section version of the full-scale WTP LAW melter, with similar important operational dimensions, such as melt pool depth and width between the opposing electrode bearing walls. The melter is located at the R&T subcontractor's facility, VSL. The pilot test confirmed the performance and behavior of equipment components and different process flowsheets representative of the WTP mission. Equipment components tested included the melter and its specific design features: melter feed nozzle, melter thermowells, melter bubblers, melter pouring system, and representative instrument and control systems. These testing results showed that the LAW Melter System would support design requirements as specified in the WTP contract (DE-AC27-01RL14136). However, some changes to the full scale melter design will be implemented because of recommendations in the test reports identified in the response to the first question in Table D.7, Appendix D.

The LAW Melter Pilot Plant (approximately 630 days) testing was done in a "locked down" design configuration and with the LAW melter operated similar to the planned plant operation; e.g., operated from a remote control room with no operator intervention/visual cues. Cameras were employed throughout the DM3300 operating life, with some instances of camera outage. Usually images were described as too dark to discern anything. However, the IR camera and selected optics were demonstrated with prototypical full scale containers to 90% fill (24590-101-TSA-W000-0009-101-00007).

2.3.5.7 Technology Readiness Level Determination

The LMP was determined to be TRL 6 because of the extensive development of the melter concept for DOE projects and the extensive development and testing of the LAW Pilot Scale melter for the WTP.

There is uncertainty associated with the ability to reliably manufacture the LAW melter bubbler assemblies. The LAW melter operational concept uses bubblers manufactured from MA758. The WTP Project is experiencing difficulties obtaining qualified MA758 alloy (high chromium alloy) for the LAW bubbler assembly. Production problems on the composition of the alloy were identified in the initial MA758 procurement (CCN: 150410). Recent interactions between the WTP Contractor and Special Metals, the manufacturer of the alloy, indicate that an initial set of bubblers will be fabricated. The two additional sets of bubblers planned for fabrication by the WTP Contractor may not be available. In addition, issues remain with the long-term availability of the MA758, which were identified by the WTP Contractor (CCN: 078791).

Recommendation 4

It is recommended that a backup LAW melter bubbler design, using materials of construction other than the high nickel MA758 alloy be identified and qualified for use in the LAW melter. This recommendation is based upon recent issues in fabricating acceptable MA758 alloy and risks identified by the WTP Contractor in the long-term availability of this alloy.

2.3.6 LAW Melter Feed Process (LFP)

2.3.6.1 Function of the LAW Melter Feed Process System (LFP)

The function of the LAW Melter Feed Process System (LFP) is to prepare the LAW melter feed. LAW melter feed is prepared by blending the treated LAW received from the PT Facility with glass-forming chemicals.

2.3.6.2 Description of the LFP

The LFP is comprised of two sets of two vessels, arranged in parallel to support each of the two LAW melters. A schematic of the LFP for a single LAW melter is shown in Figure 2.6. The vessels are the melter feed preparation vessel (MFPV) and the melter feed vessel (MFV). Treated LAW is received from each of two LAW concentrate receipt vessels (CRV) into the MFPV. The LAW melter feed is prepared in the MFPV by blending glass-forming chemicals, primarily solid minerals with the treated LAW. The prepared melter feed is transferred to the MFV for eventual feeding to the LAW melter.

Each CRV is sized to hold a minimum of four MFPV batches of LAW concentrate. Before the first LAW concentrate batch is transferred to an MFPV, the CRV contents are thoroughly mixed and sampled. The sample is analyzed to confirm the chemical and radionuclide composition. A product control algorithm sets the amount of LAW concentrate and glass formers required to prepare a batch of melter feed that meets target ILAW compositions.

A single batch of glass formers is prepared at the glass former storage facility and transferred to the glass former mixer hoppers located in the LAW Facility. A batch of sampled LAW concentrate is transferred to an MFPV from one of the two CRVs at a nominal rate of 88 gal/min. Once the transfer is complete and the CRV sample analyses are available, the glass formers are added to the MFPV from the corresponding mixer hoppers at a nominal rate of 220 ft^3/hr.

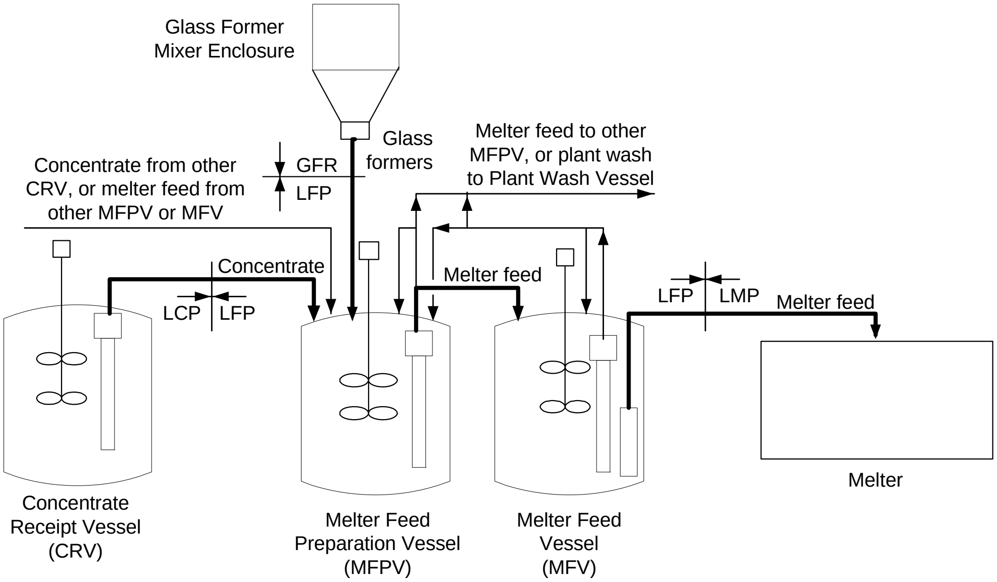


Figure 2.6. Process Schematic for LAW Melter Feed Process System (LFP)

The glass former batch may consist of any of the following glass formers: aluminum silicate, boric acid, calcium silicate, ferric oxide, lithium carbonate, magnesium silicate, silica, sodium carbonate, sucrose, titanium dioxide, zinc oxide, zirconium silicate (2459O-LAW-M4C-GFR-000013). The glass formers are mixed with the LAW concentrate using mechanical agitation.

Each MFPV has a melter feed batch capacity of 3,330 gal with a target cycle time of 16 hours (24590-LAW-M4C-20-00002). Batch cycle time will vary from batch to batch depending on the concentration of sodium in the concentrate and the waste loading of the glass. After a specified mixing duration, a batch of melter feed is transferred from the MFPV to the corresponding MFV at a nominal rate of 50 gal/min. The six air displacement slurry (ADS) pumps transfer the slurry from the MFV to the melter at a continuous rate of approximately 1 to 3.2 gal/min to meet the required plant throughput.

The MFPVs are standard designs for mechanically agitated vessels. Each MFPV is equipped with the following:

- Overflow line
- Vent line
- Sample return line
- One mechanical agitator
- Two vertical pumps
- Two spray nozzles

The MFPVs are constructed of 316 stainless steel, and have an inside diameter of 11 ft, 0 in., and a tangent-to-tangent height of 10 ft, 6 in. with American Society of Mechanical Engineers (ASME) flanged and dished heads. The mechanical agitator continuously mixes the vessel contents to keep insoluble solids in suspension. The time required for uniform blending of each batch is 2 hours (24590-QL-POA-MFAO-00001-10-00001, Test #2). The vertical pump discharges at a maximum flowrate of 50 gal/min through a valve bulge to route the concentrate, melter feed, or plant wash to one of the following: corresponding MFV, other MFPV (for melter shutdown or batch shimming), same MFPV (to recirculate for sampling), or a plant wash vessel for recycle to the PT Facility.

The MFVs have a maximum operating volume of 7,689 gallons for receiving blended melter feed from the MFPVs for feed to the corresponding LAW melter. Each MFV is equipped with the following:

- Overflow line
- Vent line
- Sample return line
- One mechanical agitator
- Six air displacement slurry (ADS) pumps
- One vertical pump
- Three spray nozzles

The MFVs are constructed of 316 stainless steel and have an inside diameter of 11 ft, 0 in., and a tangent-to-tangent height of 10 ft, 6 in. with ASME flanged and dished heads. The mechanical agitator continuously mixes the vessel contents to keep insoluble solids in suspension. Each LAW melter is fed with six ADS feed pumps (total) or two ADS feed pumps per each of the three melter zones. Control of the six ADS pumps is coordinated to provide uniform feed delivery and to help maintain and establish melter cold cap integrity. ADS pumps are designed with built-in redundancy. The melter is designed to allow one feed nozzle/ADS pump combination per melter zone to be inoperable.

2.3.6.3 Relationship to Other Systems

The primary interfacing systems for the LFP are the:

- Autosampling System (ASX), which receives waste samples from MFPVs and MFVs.
- Glass Formers Reagent System (GFR), which supplies glass formers to MFPVs.
- LAW Concentrate Receipt Process System (LCP), which supplies LAW concentrate to MFPVs.
- LAW Melter Process System (LMP), which immobilized waste feed slurry produced in the LFP.

None of these interfacing systems adds a new technology to the LFP.

2.3.6.4 Development History and Status

Extensive testing of the LAW melter feed system at the R&T subcontractor's facility, VSL, has provided the primary basis for the design of the LFP (24590-101-TSA-W000-0009-171-00001). Based on LAW pilot melter experience, the potential for solids collecting on the tank wall at the wetted liquid line was identified. As a result, water spray capabilities and acid wash/soak capabilities were maintained or added to the tank designs. Specific testing was also completed by the R&T testing at SCTC of the mixing system (SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02 Rev. 00C [cleared]) to test blending of glass-forming chemicals and simulated wastes. Testing performed at the Savannah River Technology Center (SRTC) indicate the glass-forming chemicals deposit on a liquid surface and are drawn below the surface; therefore, the MFPV mechanical agitator design required sufficient surface mixing (i.e., create a vortex at the shaft) to incorporate glass-forming chemicals into the waste slurry.

Testing of the proposed plant scale system was completed by Philadelphia Mixer to verify design performance. The mixing report from the vendor demonstrates the adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001). Additional testing is planned as part of the R&T Program to test homogeneity of mixed simulated waste and melter feed mixtures, as well as the ASX (VSL-06T1000-1). The purpose of this testing is to further characterize the homogeneity of waste by use of the mixing system to provide a basis for establishing the number of samples to obtain from the MFPV to support LAW Facility operations.

2.3.6.5 Relevant Environment

The operating environment for the LFP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001), the LFP system description (24590-LAW-3YD-LFP-00001), and the LAW PSAR (24590-WTP-PSAR-ESH-01-002-03). The relevant operational environment for the LFP is the:

- Remote operation of process fluid mixing equipment to prevent the release of radioactive liquids and solid materials
- Mixing of high solids slurries (approximately 50 wt% solids) that have high viscosities and shear strength
- Transfer of high solids slurries.

2.3.6.6 Comparison of the Relevant Environment and the Demonstrated Environment

The LFP was demonstrated in a relevant environment at SRTC and VSL. Summary reports describe the properties of feeds used for testing (SCT-M0SRLE60-00-193-02; 24590-101-TSA-W000-0009-172-00001; 24590-101-TSA-W000-0009-152-00001). The mixing system design was provided by the vendor. The vendor conducted testing of the agitation system based upon vessel design and mixing requirements. The mixing report from the vendor demonstrates the adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001). Additional testing is planned as part of the R&T Program to test the homogeneity of mixed simulated waste and sampling systems. In addition, the test reports identified in the response to the first question in Table D.6 of Appendix D, for the LAW melter feed process provide additional data on the performance of the system for mixing of simulated wastes.

2.3.6.7 Technology Readiness Level Determination

The LFP was determined to be TRL 6 because of the previous use of the waste and glass former mixing technology on other DOE projects (WVDP and DWPF), at VSL and SRTC, and the WTP Project-specific testing completed by Philadelphia Mixers (24590-QL-POA-MFAO-00001-10-00001) that provided the specification for the mechanical agitators for the plant scale system.

2.3.7 LAW Primary Offgas Process and Secondary Offgas Vessel Vent Process Systems (LOP/LVP)

2.3.7.1 Function of the LAW Primary Offgas Process and Secondary Offgas Vessel Vent Process Systems (LOP/LVP)

The function of the LAW Primary Offgas Process System (LOP) is to cool the offgas and remove aerosols generated by the LAW melters. The purpose of the LAW Secondary Offgas Vessel Vent Process System (LVP) is to remove almost all remaining particulates, miscellaneous acid gases, nitrogen oxides, volatile organic compounds (VOC), and mercury from the combined primary offgas and vessel vent streams.

2.3.7.2 Description of the LFP

The LOP and LVP are described in LOP/LVP system description (24590-LAW-3YD-LOP-00001). These systems are designed to treat the LAW melter offgas so that it conforms to relevant federal, state, and local air emissions requirements at the point of discharge from the facility stack. The principal gas generated by the melter is steam. Decomposition of salts and organic material also yields carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxide (NO_x), hydrogen chloride (HCl), and hydrogen fluoride (HF).

The NO_x is a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2) with trace amounts of nitrous oxide (N_2O).

A block flow diagram of the LOP/LVP is provided in Figure 2.7.

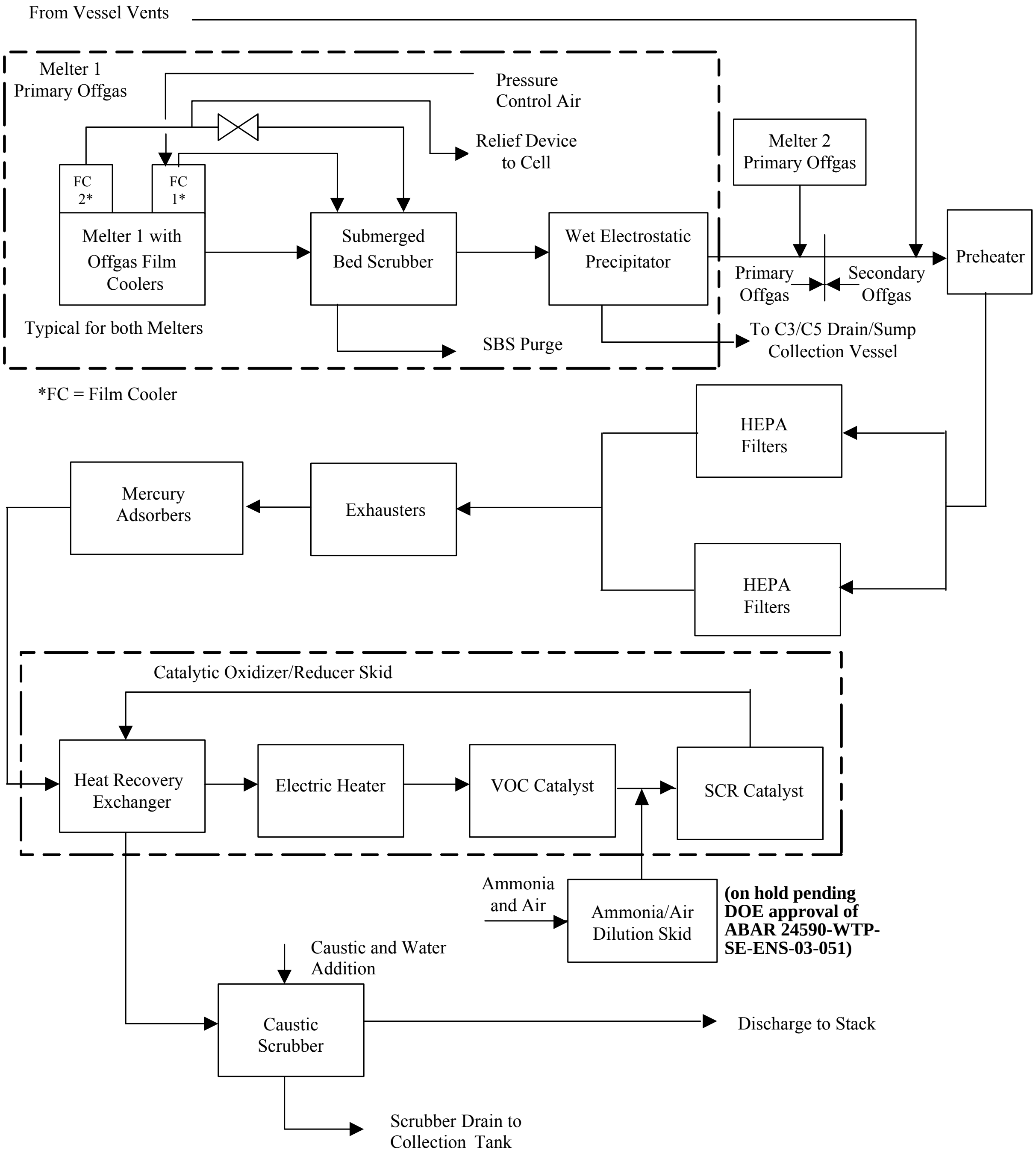


Figure 2.7. Block Flow Diagram for the LAW primary Offgas Process System (LOP)/ LAW Secondary Offgas/Vessel Vent Process System (LVP)

The LOP consists of the following major components for each melter:

- Offgas film coolers: When a cold cap is present in the melter, the offgas exits the melter at approximately 750°F and mixes with injection air in a primary offgas film cooler. The primary offgas film cooler cools the offgas below the glass-sticking temperature to minimize solids deposition on the offgas piping walls. This film cooler is a double-walled pipe designed to introduce air along the walls through a series of holes or slots in the inner wall. The injection air that flows along the pipe wall mixes with, and cools, the offgas to approximately 600°F.

- Submerged bed scrubbers (SBS): Offgas from the film coolers enters a packed bed column submerged in water for further cooling. Each melter has a dedicated SBS. The SBS column has a diameter of 6 ft, 2 in., and a packed bed height of 24 in. The SBS is 6.5 ft high (tangent to tangent) by 10 ft in diameter with a maximum operating volume of 3,690 gal. The SBS is a passive device designed for steam quenching, scrubbing of entrained particulates and partial removal of aerosols from melter offgas.

- Wet electrostatic precipitators (WESP): After the initial SBS, the cooled offgas is routed to a WESP for further removal of particulates and aerosols. Each melter system has a dedicated WESP. The WESP receives offgas at a nominal flowrate of 1,280 scfm at 122^{O}F and -49 in. WG. The design flow is 2,000 scfm based on the combined offgas from two idled melters. The WESP body, exclusive of electrode ducts, is 8 ft in diameter by 21.5 ft high (overall). The offgas enters the unit and passes through a distribution plate. The evenly distributed saturated gas then flows upward through the tubes of the WESP. The tubes act as positive electrodes. Each tube also has a single negatively charged electrode that runs down the center of the tube. A high-voltage transformer rectifier supplies the power to these electrodes. A strong electric field is generated along the electrode, supplying a negative charge to aerosols as they pass through the tubes. The negatively charged aerosols move toward the positively charged tube walls where they are removed. The inlet is also provided with a spray to enhance rundown and cleaning. The condensate then drains into a sump collection vessel. A deluge system is also provided at the top of the tube section for periodic washing as necessary to maintain performance.

The LVP system consists of the following major components:

- High-efficiency particulate air (HEPA) filters and preheaters: HEPA filters provide the final removal of radioactive particulates to protect downstream equipment from contamination. The combined offgas stream is passed through a preheater. The electric heaters increase the nominal gas temperature from 131°F to 149°F to avoid condensation in the HEPA filters. The heated offgas passes through HEPA filter housings forming two trains: a main train used in normal operations and an auxiliary train used as an installed backup. The HEPA filter housings in each train are arranged to form primary and secondary stages of filtration.

- Exhausters: Three multi-stage centrifugal blowers with adjustable speed drives are located downstream of the HEPA filters to provide vacuum to maintain the LOP system flow. Each exhauster is rated at 50% of the system capacity. Two exhausters will normally be running at a time with the third exhauster in standby.

- Mercury adsorbers: Activated carbon is used to remove mercury and acid gases. The offgas flows to two mercury adsorbers that are normally operated in series as part of a mercury mitigation equipment skid. Each adsorber is approximately 8 ft high by 11 ft wide by 26 ft long with an activated carbon bed volume of about 223 ft^3. The unit is designed to obtain a removal efficiency of greater than 97% for hydrochloric or hydrofluoric acid, and greater than 99% for iodine. The mercury concentration in the offgas is reduced to a maximum of 45 pg/dscm, and the outlet concentration is measured with a continuous emission monitor.

- Catalytic oxidizer/reducer: The offgas has high levels of NO_x because the melter decomposes the parent nitrate/nitrite compounds. Some of the resultant NO_x is decomposed to nitrogen and water in the melter, and some is removed by scrubbing in the SBS. VOCs are also present in the offgas stream. Both the VOCs and the remaining NO_x require removal. The offgas is passed through a catalytic oxidizer-reducer skid housing a heat recovery exchanger, an electric heater, VOC catalyst, and selective catalytic reduction (SCR) catalyst. Approximate dimensions for the skid are 36 ft long by 11 ft high by 8 ft wide, with a nominal inlet flowrate of 4,180 scfm at 216°F and 28 in. WG.

  The heated offgas is passed through the VOC catalyst to oxidize VOCs and carbon monoxide (CO) to carbon dioxide (CO_2) and water vapor. The VOC catalyst is a platinum-based material deposited on a metal monolith, which is held in frames, inserted, and removed through access doors.

  The offgas is then injected with a mixture of ammonia vapor and air. Following ammonia injection, the offgas is passed through the SCR catalyst to reduce NO_x to nitrogen and water vapor. The SCR catalyst is a titanium oxide-based material deposited on a metal monolith, which is held in frames and inserted/removed through access doors. The SCR catalyst is designed to achieve a NO, reduction of 98%.

- Caustic scrubber: A caustic scrubber further treats the offgas by removing acid gases (i.e., 97% removal efficiency for combined sulfur dioxide [SO_2] and sulfur trioxide [SO_3]), and providing cooling before discharge into the LAW Facility stack.

2.3.7.3 Relationship to other Systems

The primary interface with the LOP/LVP is the LAW Melter Process System (LMP). Primary and standby offgas film coolers receive LMP offgas. Other interfaces are with waste treatment systems. Condensate from the SBS water purge pumps, SBS condensate purge pumps, and WESPs are discharged to the Radioactive Liquid Waste Disposal System (RLD). Waste is discharged from the caustic collection tank to outside the PT facility. Solid wastes from the SBS, SBS condensate vessels, and WESPs are sent to Radioactive Solid Waste Handling System (RWH).

2.3.7.4 Development History and Status

The design of the LOP/LVP is based upon the use of most of these equipment systems for DOE's WVDP. The WVDP used a liquid-fed ceramic melter to vitrify actual radioactive tank wastes.

In addition, as part of the WTP development melter testing using the DM-1200 melter, a prototypically designed engineering scale melter, the offgas system was tested and evaluated. This testing evaluated the impact due to compositional variations of the simulated waste feeds and included testing to support regulatory permit requirements. Responses to specific questions in Appendix D, Table D.7 summarize the experimental testing reports for the engineering scale offgas system.

One of the WTP dangerous waste permit conditions requires the HLW and LAW Facilities melter and melter offgas systems meet the 4-9s destruction and removal efficiency (DRE) performance standard for principal organic dangerous constituents (PODC). Based on agreement between the WTP, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology, the PODCs selected to demonstrate DRE are naphthalene and allyl alcohol (CCN: 080128).

Prior to conducting the DRE tests, the DM1200 offgas system was modified to more closely represent the WTP process configuration. These modifications included the addition of a full-flow activated carbon adsorber bed and change of the thermal catalytic oxidizer catalyst media to match the WTP design. DRE tests were performed at the R&T subcontractor's facility, VSL, on the DM1200 from November 2004 through March 2005. The VSL DM1200 test results (VSL-05R5830-1) exceeded 4-9s DRE in all 12 allyl alcohol test runs and in 10 out of the 12 naphthalene test runs. The objective of at least 4-9s DRE was achieved for all test runs, except for two sampling periods, which had 99.987 and 99.978 % DRE for HLW and LAW, respectively. The naphthalene emission rate required to demonstrate 4-9s DRE in the VSL testing was 0.09 mg/min. The naphthalene emission rates for the failed runs were 0.11 and 0.2 mg/min for HLW and LAW, respectively. The passing runs had naphthalene emission rates that ranged from 0.02 to less than 0.002 mg/min.

The WTP Project has evaluated the impact of not achieving the DRE test requirements on the WTP design (CCN: 128559; 24590-WTP-RPT-ENV-03-00005) and has concluded that the actual WTP offgas system design is more robust compared to the DM-1200 offgas system. Based upon analysis, sufficient design contingency exists in the WTP design, and it is projected that the LAW Facility will achieve the DRE requirements in normal and challenge conditions.

The WTP Project has a risk item associated with the ability of LAW Facility to meet the DRE test requirements. This risk will remain open until actual testing of the LAW Facility is completed during cold commissioning.

2.3.7.5 Relevant Environment

The operating environment for the LOP/LVP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001) and the LOP/LVP system description (24590-LAW-3YD-LOP-00001). The relevant environment for the LOP/LVP is the:

- Operation of equipment system with high reliability
- Operation of the offgas system with high initial temperatures, high moisture levels and significant particulate loads, and the presence of corrosive acid gasses
- Use of fixed bed catalyst and absorber beds in the presence of trace poisoning agents
- Operation of the equipment system at a reduce pressure compared to atmospheric.

2.3.7.6 Comparison of the Relevant Environment and the Demonstrated Environment

The system was demonstrated in a relevant environment. The R&T was completed on a prototype LOP/LVP connected to the DM1200 melter, which is a one-eighth scale of the LAW Vitrification Facility offgas system. Equipment components tested included all prototypical offgas components (i.e., film cooler, SBS, high efficiency mist eliminator, WESP, sulfur-impregnated activated carbon bed for mercury removal, and the catalytic oxidizer/reducer for organic destruction and NO_x reduction, HEPA filtration, and a caustic scrubber). These testing results showed that the LOP/LVP will support design requirements as specified in the WTP contract.

2.3.7.7 Technology Readiness Level Determination

The LOP/LVP was determined to be a TRL 6 because of the previous demonstrated use of the offgas treatment components in the WVDP, and the extensive testing that was completed as part of the DM-1200 melter testing for the WTP. Issues associated with the offgas system not achieving the DRE test requirements have been evaluated and will be confirmed during cold commissioning of the LAW Facility.

Throughout DM1200 SBS testing at VSL (VSL-06R6410-2), the SBS was periodically drained and inspected for deposits and unusual wear. The most significant findings were accumulations of deposits in the downcommer and bottom of the SBS, the accumulation. VSL conducted tests of the WESP (24590-101-TSA-W000-0009-174-0000) that showed the decontamination factor (DF) degraded as a result of solids buildup on the electrode. Flushing the solids from the VSL WESP effectively removed the solids buildup, but resulted in the shorting of the electrical connections because the top insulators did not drain.

3.0 Summary and Recommendations

3.1 Summary

The TRA for the LAB, BOF, and LAW facilities determined that:

- Two LAB systems were determined to be CTEs and were evaluated; the ASX, and the LA-ICP-AES and LA-ICP-MS in the AHL, which provide the analytical equipment systems for the LAB.
- No BOF systems were judged to be CTEs because the BOF systems do not use new technologies, or use standard technologies in new or novel ways,
- Five LAW systems were determined to be CTEs: the LAW Melter Feed Process System (LFP) used to prepare the LAW melter feed, the LAW Melter System (LMP), which includes the LAW melter, the LAW Melter Offgas System/LAW Secondary Offgas/Vessel Vent Process Systems (LOP/LVP) used to treat the LAW melter offgas, the ILAW Container Finishing Handling System (LFH) container closure subsystem and the ILAW LFH container decontamination subsystem.

The results of the TRL assessment are summarized in Table 3.1. Consistent with NASA and DoD practice, this assessment used TRL 6 as the level that should be attained before the technology is incorporated in the WTP final design. The CTEs were not evaluated to determine if they had matured beyond level 6.

3.2 Recommendations

The Assessment Team concluded that the critical technology elements of the LAB, BOF, and LAW facilities are sufficiently mature to continue to advance the final design of these facilities. However, based upon the results of this assessment, the following recommendations for specific technologies are made:

1. The prototypical LA-ICP-AES system should be tested to demonstrate achievable detection limits for chemical elements of interest, and to satisfy turnaround time requirements on actual HLW sludge samples in a relevant environment to support the final design of the actual LAB subsystems. The LA-ICP-MS can be qualified in the AHL after laser ablation technology has been implemented with ICP-AES in the AHL and is fully operational.

   Testing is recommended to confirm that the development and design of the LA-ICP-AES will meet its functional requirements. Design optimization for AHL implementation should continue following demonstration of the prototype. This testing is included in the WTP baseline.

2. Integrated prototypic testing of the actual immobilized low-activity waste (ILAW) container inert filling, flange cleaning, inspection, and lidding/delidding equipment system in a simulated remote environment should be completed prior to installation in the LAW Vitrification Facility to verify that the equipment system will perform as required.

   The mechanical processing steps of the container lidding sealing system used to seal the containers uses new equipment concepts that have not been previously tested in a remote operational environment. Waiting to complete the testing at cold commissioning represents a significant cost and schedule risk to the LAW Facility if the technology does not perform as intended. Fabrication acceptance testing is planned; however, this testing will not be prototypical of the remote operational environment. The testing should validate the adequacy of the design concept prior to completing detailed design.

3. Integrated prototypic testing of the actual ILAW container decontamination and smear testing systems in a simulated remote environment should be completed following fabrication of equipment components to verify the equipment system will perform as required, and will achieve the WTP Project-specified surface decontamination levels (less than 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma). This testing program should be supplemented with laboratory scale testing to define the operational parameters for the carbon dioxide (CO_2) decontamination system.

   The ILAW container decontamination subsystem relies on a localized surface decontamination approach using a CO_2 pellet spray contained within a series of specialized shrouds. A robot is used to position the shrouds against the surfaces of the ILAW container. A vacuum is used to recover loosened contamination and sublimed CO_2. Proof of concept testing using flat-metal coupons was completed. However, there remains a high risk that the removal of the contamination from the container oxide film will not be effective due to the complex shapes on the container design and the requirement that the shroud system effectively contain loosened contamination. A loss of control of the removed contamination in the areas adjacent to the container decontamination station may result in re-contamination of the container. Subsequent decontamination of the work area may also result in impacts to the LAW Facility production schedule.

   Based upon the limited testing completed and the unique operating requirements for this system, there is a high probability that the current design concept may not perform as intended and will require significant design changes. Problems with this system may not be identified until hot commissioning of the LAW Facility. Design modifications at this time will be expensive and time-consuming. An inability of the CO_2 decontamination system to perform its function has the potential to shut down LAW processing and the entire WTP.

   The testing of the ILAW container decontamination subsystem should include testing with full scale containers at the anticipated operating temperatures. Particular attention in the testing program should be focused on the use of the localized decontamination shroud system and its ability to maintain contamination control and achieve full decontamination of the container. The ability of the shroud tools to decontaminate all container surfaces should be demonstrated.

4. It is recommended that a backup LAW melter bubbler design, using materials of construction other than the high nickel MA758 alloy be identified and qualified for use in the LAW melter. This recommendation is based upon recent issues in fabricating acceptable MA758 alloy and risks identified by the WTP Contractor in the long-term availability of this alloy.

Table 3.1. Technology Readiness Level Summary for the LAB, BOF, and LAW Critical Elements

Critical Technology Element/Description	Technology Readiness Level	Rationale
LA-ICP-MS/LA-ICP-AES The LA-ICP-MS/LA-ICP-AES system will be used to verify HLW melter feed and LAW waste compositions and is the only analytical system that uses new or novel instrumentation or methods. Analytical turnaround time of less than 9 hours for these analyses are essential in meeting WTP capacity requirements.	**5**	A prototypical LA-ICP-MS/LA-ICP-AES system has not been demonstrated in a relevant environment. A full scale prototypical LA-ICP-AES system is scheduled for testing beginning in 2007. The LA-ICP-MS subsystem will be tested after the LA-ICP-AES becomes fully operational in the LAB.
Autosampling System (ASX) The ASX automatically retrieves liquid samples from process streams and transfers them to the LAB.	**6**	Similar systems are in use in relevant operating environments at the Sellafield Nuclear Site (UK) and LaHague (France).
LFH Container Sealing Subsystem The LFP container sealing subystem press fits and locks a flat circular lid into a circular groove in the container neck.	**5**	The container sealing system design is based on existing technologies but has not been demonstrated as an integrated prototypical system in an operating environment.
LFH Decontamination Subsystem The LFH decontamination subsystem sprays carbon dioxide (CO_2) pellets at ILAW container surfaces to remove radioactive contamination. The sublimed CO_2 and dislodged contamination are contained by a vacuum system and shroud.	**4**	The ILAW container decontamination design is based on existing technology concepts, but has not been demonstrated as an integrated, prototypical system in a relevant environment. Testing on a laboratory scale of the CO_2 spray to decontaminate flat-metal specimens has been completed; testing did not demonstrate the WTP Project's requirement on surface decontamination levels. Integrated testing of the robot, CO_2 spray, and shrouding system has not been carried out on the complex surfaces of the ILAW container.
LAW Melter Feed Process System (LFP) The LFP mixes LAW Facility waste and glass formers to provide feed for the LAW melters.	**6**	There has been extensive WTP and vendor testing to demonstrate the adequacy of the mixing systems.
LAW Melter System (LMP) The LMP is the LAW melter system that melts mixtures of LAW and glass formers.	**6**	The LAW melter has a significant development basis in previous DOE projects and developmental tests for the WTP. However, risk remains with the availability of MA758, a high chromium (Cr) alloy used for the LAW bubbler assembly. An alternate bubbler material of construction should be identified.
LOP/LVP The LOP/LVP is the LAW Melter Offgas and Vessel Vent Process Systems that remove aerosols, gases, and particulates generated by the LAW melters and vessel vent streams.	**6**	The LOP/LVP have a significant technology basis. Two of 12 maximum achievable control technology (MACT) destruction and removal efficiency (DRE) tests for naphthalene conducted on a prototypical system did not attain the required destruction efficiency. Engineering analysis shows that the WTP system should attain MACT standards based on higher capacities of the plant unit operations as compared to the pilot plant unit operations.

4.0 References

1. 06-WTP-105, "Transmittal of U.S. Department of Energy, Office of River Protection (ORP) Design Oversight Report Number D-06-DESIGN-027: Review of Bechtel National, Inc.'s (BNI) Radiochemical Analytical Laboratory Pneumatic Autosampling System (ASX) Design," letter dated September 25, 2006, U.S. Department of Energy, Richland, Washington.

2. 24590-101-TSA-W000-0004-158-00002, Rev. A, *Laser Ablation Study for High Level Waste and Melter Feed Characterization*, March 9, 2006, Bechtel National, Inc., Richland, Washington.

3. 24590-101-TSA-W000-0009-101-00007, Rev. 00A, *RPP-WTP Pilot Melter Prototypic LAW Container and HLW Canister Glass Fill Test Results Report*, May 26, 2004, Bechtel National, Inc., Richland, Washington.

4. 24590-101-TSA-W000-0009-101-00007, Rev. 00A, "Prototypic LAW Container and HLW Canister Glass Fill Test Results Report," April 27, 2004, Bechtel National, Inc., Richland, Washington.

5. 24590-101-TSA-W000-0009-152-00001, Rev. 00A, *Characterization of Simulated WTP LAW Melter Feeds*, June 24, 2004, Bechtel National, Inc., Richland, Washington.

6. 24590-101-TSA-W000-0009-171-00001 Rev. 00A, *Summary of DM1200 Operation at VSL*, October 10, 2006, Bechtel National, Inc., Richland, Washington.

7. 24590-101-TSA-W000-0009-172-00001 Rev. 00A, *Review of Properties of Simulated Feeds Used for Melter Testing*, August 26, 2006, Bechtel National, Inc., Richland, Washington.

8. 24590-101-TSA-W000-0009-174-00001 Rev. 00A, *Summary of DM1200 WESP History and Performance*, August 7, 2006, Bechtel National, Inc., Richland, Washington.

9. 24590-101-TSA-W000-0009-23-10, Rev. 00C, *RPP-WTP Pilot Melter Bubbler Life Extension Test Results Report*, January 7, 2004, Bechtel National, Inc., Richland, Washington.

10. 24590-HLW-RPT-RT-05-001, Rev. 0, *Preliminary IHLW Formulation Algorithm Description, River Protection Project*, 2006, Bechtel National, Inc., Richland, Washington.

11. 24590-LAB-3YD-AHL-00001, Rev. 1, *System Description for the Analytical Hot Cell Laboratory Equipment (AHL)*, August 5, 2005, Bechtel National, Inc., Richland, Washington.

12. 24590-LAB-3YD-ARL-00001, Rev. 1, *System Description for the Analytical Radiological Laboratory Equipment (ARL)*, February 3, 2005, Bechtel National, Inc., Richland, Washington.

13. 24590-LAW-3PS-HCTH-T0001, *Engineering Specification for the LAW Product Container Lidding Equipment*, February 16, 2006, Bechtel National, Inc., Richland, Washington.

14. 24590-LAW-3PS-HDYR-T0001, *Engineering Specification for the Power Manipulators and Turntables*, July 11, 2005, Bechtel National, Inc., Richland, Washington.

15. 24590-LAW-3YD-LFH-00001, Rev. 0, *System Description for the System LFH-LAW Container Finishing Handling System*, October 13, 2006, Bechtel National, Inc., Richland, Washington.

16. 24590-LAW-3YD-LFH-00001, Rev. 0, *System Description for the System LFH-LAW Container Finishing Handling System*, October 13, 2006, Bechtel National, Inc., Richland, Washington.

17. 24590-LAW-3YD-LFP-00001, Rev. 0, *System Description for the LAW Melter Feed Process (LFP) System*, June 24, 2005, Bechtel National, Inc., Richland, Washington.

18. 24590-LAW-3YD-LMP-00001, Rev. 0, *System Description for the LAW Melter Process System (LMP)*, November 9, 2006, Bechtel National, Inc., Richland, Washington.

19. 24590-LAW-3YD-LOP-00001, Rev. 1, *System Description for the LAW Primary Offgas Process (LOP) and LAW Secondary Offgas/Vessel Vent Process (LVP) Systems*, March 23, 2005, Bechtel National, Inc., Richland, Washington.

20. 24590-LAW-M4C-20-00002, *LAW LCP and LFP Batch Volumes*, December 30, 2003, Bechtel National Inc., Richland, Washington.

21. 24590-LAW-M4C-GFR-00001, *LAW Blended Glass Former Average Densities*, November 21, 2005, Bechtel National Inc., Richland, Washington.

22. 24590-LAW-RPT-RT-04-0003, Rev. 0, *Preliminary ILAW Formulation Algorithm Description*, May 18, 2005, Bechtel National, Inc., Richland, Washington.

23. 24590-QL-HC4-HAHH-00001-05-00002, *ISOLOCK Sampler Device Component Performance Test Report*, April 1, 2005, Bechtel National, Inc., Richland, Washington.

24. 24590-QL-POA-MFAO-00001-10-00001, Rev. 00B, *Rotating Mechanical Agitators Test Report*, prepared by Philadelphia Mixers for Bechtel National Corp., March 17, 2004, Bechtel National, Inc., Richland, Washington.

25. 24590-WTP-3PS-MHSS-T0002, Rev. 0, *Engineering Specification for Autosampling System (ASX)*, June 16, 2004, Bechtel National, Inc., Richland, Washington.

26. 24590-WTP-3YD-ASX-00001 Rev. A, *System Description for the Autosampling System (ASX)*, April 2002. Bechtel National Inc., Richland, Washington.

27. 24590-WTP-DB-ENG-01-001, Rev. 1C, *WTP Basis of Design*, November 2006, Bechtel National, Inc., Richland, Washington.

28. 24590-WTP-PL-PR-04-0001, Rev. 0, *Integrated Sampling and Analysis Requirements Document*, December 8, 2004, Bechtel National, Inc., Richland, Washington.

29. 24590-WTP-PL-RT-03-002, Rev. 2, *IHLW Product Compliance Plan*, 2005, Bechtel National, Inc., Richland, Washington.

30. 24590-WTP-PSAR-ESH-01-002-03, Rev. 1, *Preliminary Safety Analysis Report to Support Construction Authorization; LAW Facility Specific Information*, September 30, 2003, Bechtel National, Inc., Richland, Washington.

31. 24590-WTP-RPT-ENV-03-00005, Rev. 0, Report, *4-9s Destruction and Removal Efficiency Assessment*, November 20, 2003, Bechtel National, Inc., Richland, Washington.

32. 24950-WTP-RPT-OP-06-001, Rev. 0., *LA-ICP Analysis Method for Hanford Vitrification Process*, August 2006, Bechtel National, Inc., Richland, Washington.

33. CCN: 132846, "Report of External Flowsheet Review Team for the Hanford Waste Treatment and Immobilization Plant-Final Report Titled: "Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput," letter dated March 17, 2006, Bechtel National Inc., Richland, Washington.

34. CCN: 139427, "Waste Treatment and Immobilization Plant/222-S Laser Ablation Test Plan," letter dated May 16, 2006, Bechtel National, Inc., Richland, Washington.

35. CCN: 133570, "Concurrence of ASX Risks and Risk Mitigation Strategy," letter dated March 9, 2006, Bechtel National, Inc., Richland, Washington.

36. CCN: 150410, "LAW Melter Bubbler Materials," letter dated January 23, 2007, Bechtel National, Inc., Richland, Washington.

37. CCN: 078791, "Consideration on Melter Materials," letter dated February 24, 2005, Bechtel National, Inc., Richland, Washington.

38. CCN: 080128, Letter, from R. J. Schepens, DOE ORP, to M. A. Wilson, Washington State Department of Ecology, "Request for Concurrence with Principal Organic Dangerous Constituents (PODCs) for Demonstrating a 99.99 Percent Organic Destruction and Removal Efficiency (DRE)," 03-AMWTP-164, dated December 17, 2003.

39. CCN: 128559, "White Paper on the Analysis of Naphthalene Destruction and Removal Efficiency (DRE) Testing at the Vitreous State Laboratory (VSL)," letter dated December 15, 2005, Bechtel National, Inc., Richland, Washington.

40. CCN:146465, "Laser Ablation-Inductively Coupled Plasma-Atomic Emission Spectroscopy Method Development Summary," letter dated October 30, 2006, Bechtel National, Inc., Richland, Washington

41. DOD 2005, *Department of Defense, Technology Readiness Assessment (TRA) Deskbook*, May 2005, Prepared by the Deputy Undersecretary of Defense for Science and Technology (DUSD(S&T)).

42. DODI 5000.2, *Acquisition System Guidebook*, November 2004, Department of Defense.

43. DOE 2006, Memorandum from Paul Bosco to James A. Rispoli, "Performance Baseline Validation and Transmittal of the External Independent Review Reports for the Waste Treatment and Immobilization Plant Project at Richland Washington," December 16, 2006, U.S. Department of Energy, Washington D.C.

44. GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Can Improve Weapon System Outcomes*, July 1999, United States General Accounting Office.

45. NHC-8373, *The Interlaboratory Pneumatic Transfer Network for Radioactive Samples Operated in the Analytical Laboratories of the COGEMA La Hague Reprocessing Plants (France)*, June 2001, Numatec Hanford Company, Richland, Washington.

46. NHC-8374, *The Computerized Data Management System Operated in the Analytical Laboratories of the COGEMA La Hague Reprocessing Plants (France)*, June 2001, Numatec Hanford Company, Richland, Washington.

47. NHC-8375, *Analysis Operating Times Observed in the Analytical Laboratories of the COGEMA La Hague Reprocessing Plants (France)*, June 2001, Numatec Hanford Company, Richland, Washington.

48. Nolte, William L., et al., "Technology Readiness Level Calculator," October 20, 2003, Air Force Research Laboratory, presented at the NDIA Systems Engineering Conference.

49. SCT-M0SRLE60-00-110-12, Rev. 0, *LAW Radioactive Coupon CO_2 Decontamination Test*, May 2003, Savannah River Technology Center, Aiken, South Carolina.

50. SCT-M0SRLE60-00-193-02, Rev. 00A, *Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste*, December 13, 2003, Savannah River Technology Center, Aiken, South Carolina.

51. SCT-M0SRLE60-00-99-07, *LAW Vendor Coupon CO_2 Blasting Tests*, June 2002, Savannah River Technology Center, Aiken, South Carolina.

52. SCT-MOSRLE60-00-216-00001, Rev. 00A; *The Development of Laser Ablation Inductively Coupled Plasma Atomic Emission Spectroscopy for the Analysis of Hanford High Level Waste: Phase I (U)*, September 27, 2005, Bechtel National, Inc., Richland, Washington

53. SCT-MOSRLE60-00-216-00002, Rev. 00A, *The Development of Laser Ablation Inductively Coupled Plasma Atomic Emission Spectroscopy for the Analysis of Hanford High Level Waste: Phase II (U)*, March 9, 2006, Bechtel National, Inc., Richland, Washington.

54. TN-24590-02-00665, *Mechanical Sealing of ILAW Container*, October 22, 2002, Bechtel National, Inc. Richland, Washington.

55. VSL-05R5830-1, Revision 0, *Regulatory Offgas Emissions Testing on the DM1200 Melter System Using HLW and LAW Simulants*, October 31, 2005, Vitreous State Laboratory, Washington D.C.

56. VSL-06R6410-2 Rev. 0, *Summary of DM1200 SBS History and Performance*, October 10, 2006, Vitreous State Laboratory, The Catholic University of America, Washington D.C.

57. VSL-06T1000-1, *Test Plan; Pretreated Waste and Melter Feed Composition Variability Testing Using HLW and LAW Simulants*, September 29, 2006, Vitreous State Laboratory, The Catholic University of America, Washington D.C.

58. WTP-RPT- 139, *Conventional Non-Dilute West Chemistry Dissolution ICP-AES Time Study*, M. W. Urie, B. M. Oliver, and C. Z. Soderquist, 2005,Battelle-Pacific Northwest Division (PNWD), Richland, Washington (proprietary).

59. WTP-RPT-140, *Laser Abation CP-AES Time Study*, S. K. Fiskum, M. L. Alexander, O. T. Farmer III, M. P. Thomas, and M. W. Urie, 2005, Battelle-Pacific Northwest Division (PNWD), Richland, Washington (proprietary).

Appendix A

Technology Readiness Level Development and Definitions

Appendix A
Technology Readiness Level Development and Definitions

A.1 TRL Development

Technology Readiness Levels (TRL) are measures used by some U.S. government agencies (most notably the U.S. Department of Defense [DoD] and National Aeronautics and Space Administration [NASA]) and many major companies to assess the maturity of evolving technologies prior to incorporating them into systems or subsystems. The primary purpose of using TRLs is to help management in making decisions concerning the development and transitioning of technology. TRLs provide a common understanding of technology status and are useful for risk management, making decisions concerning technology funding, and making decisions concerning the transition of technology from paper to laboratory to final application.

TRLs were originally developed by NASA in the 1980s. The United States Air Force adopted the use of TRLs in the 1990s. In 1995, John C. Mankins, NASA, wrote a report, *White Paper on Technology Readiness Levels*, that discussed NASA's use of TRLs and proposed descriptions for each TRL.

In 1999, the U.S. General Accounting Office (GAO) produced an influential report (GAO/NSIAD-99-162) that examined the differences in technology transition between the DoD and private industry. It concluded that the DoD takes greater risks and attempts to transition emerging technologies at lesser degrees of maturity than private industry. The GAO also concluded that use of immature technology increased overall program risk and recommended that the DoD adopt NASA's TRLs as a means of assessing technology maturity prior to transition.

In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed use of TRLs in new major programs. Guidance for assessing technology maturity was incorporated into the *Defense Acquisition Guidebook*. Subsequently, the DoD developed detailed guidance for using TRLs in the 2003 *DoD Technology Readiness Assessment Deskbook* (updated May 2005). The deskbook was used as guidance for this assessment.

A.2 TRL Definitions

TRL definitions vary somewhat from agency to agency and within agencies depending on the types of technologies being assessed. The most common definitions are those used by DoD and NASA. DoD has definitions for hardware, software, manufacturing technology, and biomedical technology. The DoD hardware definitions are given in Table A.1. See the DoD Technology Readiness Assessment (TRA) Deskbook for more information on DoD software, biomedical, and manufacturing TRLs. The NASA definitions are also given in Table A.1. The Federal Aviation Administration references TRLs in some of their documents, and seems to rely on the NASA definitions.

The DoD hardware definitions were modified for this assessment to make them more broadly applicable to U.S. Department of Energy (DOE) Office of Environmental Management (EM) projects that involve process chemistry, such as the WTP. The basis for the modifications is given in Table A.2.

Table A.1. WTP TRL Testing Requirements

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot Scale < Full Scale (Typical)
   Lab Scale < 1/10 Full Scale (Typical)
2. Identical System – configuration matches the final application in all respects.
   Similar System – configuration matches the final application in almost all respects.
   Pieces System – matches a piece or pieces of the final application.
   Paper System – exists on paper (no hardware).
3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

A.3 TRL Assessment Tools

A Technology Readiness Level Calculator was developed by the United States Air Force by Nolte et al. (2003). This tool is standard set of questions implemented in Microsoft Excel™ that produces a graphical display of the TRLs achieved. The Calculator was modified for this assessment with the assistance of Mr. Nolte to make it more applicable to chemical processing systems such as the WTP by adding processing questions and modifying some of the original questions. More details on the Calculator and modifications made for this assessment can be found in Appendix C.

A.4 References

GAO 1999, “Presentation to the S&T Conference on the Transition of Technology to Acquisition,” U.S. General Accounting Office, October 26, 1999.

GAO 2001, “Joint Strike Fighter Acquisition – Mature Critical Technologies Needed to Reduce Risk,” GAO-02-39, U.S. General Accounting Office, October 2001.

Nolte, William L., et al., 2003, *Technology Readiness Level Calculator,* October 20, 2003

“Air Force Research Laboratory,” presented at the NDIA Systems Engineering Conference.

DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, U.S. Department of Defense, May 2005.

DoD 2004, *Acquisition System Guidebook*, DODI 5000.2, U.S. Department of Defense, November 17, 2004.

GAO 1999, *Best Practices: Better Management of Technology Can Improve Weapon System Outcomes*, GAO/NSIAD-99-162, U.S. General Accounting Office, July 1999.

Graettinger, Caroline P., et al., 2002, *Using the Technology Readiness Levels Scale to Support Technology Management in the DoD's ATD/STO Environments: A Findings and Recommendations Report Conducted for Army CECOM*, *Carnegie Mellon Software Engineering Institute*, CMU/SEI-2002-SR-027, September 2002.

Mankins, John C., 1995, *Technology Readiness Levels: A White Paper*, NASA, Office of Space Access and Technology, Advanced Concepts Office, April 6, 1995.

Nolte, William L., et al., 2003, "Technology Readiness Level Calculator," Air Force Research Laboratory, presented at the NDIA Systems Engineering Conference. http://en.wikipedia.org/wiki/Technology_Readiness_Level, October 20, 2003.

Table A.2. Technology Readiness Level Definitions

DoD Hardware Technology Readiness Levels[1]		NASA Technology Readiness Levels[2]		DOE WTP Technology Readiness Levels[3]	
TRL	**Description**	**TRL**	**Description**	**TRL**	**Description**
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Example might include paper studies of a technology's basic properties.	1. Basic principles observed and reported	This is the lowest "level" of technology maturation. At this level, scientific research begins to be translated into applied research and development.	1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Example might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.	2. Technology concept and/or application formulated	Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be "invented" or identified. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.	2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	3. Analytical and experimental critical function and/or characteristic proof of concept	At this step in the maturation process, active research and development (R&D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute "proof-of-concept" validation of the applications/concepts formulated at TRL 2.	3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.	4. Component and/or breadboard validation in laboratory environment	Following successful "proof-of-concept" work, basic technological elements must be integrated to establish that the "pieces" will work together to achieve concept-enabling levels of performance for a component and/or breadboard. This validation must be devised to support the concept that was formulated earlier, and should be consistent with the requirements of potential system applications. The validation is relatively "low-fidelity" compared to the eventual system: it could be composed of ad hoc discrete components in a laboratory.	4. Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low-fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	5. Component and/or breadboard validation in relevant environment	At this level, the fidelity of the component and/or breadboard being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, subsystem level, or system-level) can be tested in a "simulated" or somewhat realistic environment.	5. Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.

Table A.2. (cont'd.)

DoD Hardware Technology Readiness Levels[1]		**NASA Technology Readiness Levels**[2]		**DOE WTP Technology Readiness Levels**[3]	
TRL	**Description**	**TRL**	**Description**	**TRL**	**Description**
6. System/ subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.	6. System/ subsystem model or prototype demonstration in a relevant environment (ground or space)	A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model or prototype system or system – which would go well beyond ad hoc, "patch-cord" or discrete component level breadboarding – would be tested in a relevant environment. At this level, if the only "relevant environment" is the environment of space, then the model/prototype must be demonstrated in space.	6. Engineering/ pilot scale, similar (prototypical) system validation in a relevant environment	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space). Examples include testing the prototype in a test bed aircraft.	7. System prototype demonstration in a space environment	TRL 7 is a significant step beyond TRL 6, requiring an actual system prototype demonstration in a space environment. The prototype should be near or at the scale of the planned operational system and the demonstration must take place in space.	7. Full scale, similar (prototypical) system demonstrated in a relevant environment	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
8. Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	8. Actual system completed and "flight qualified" through test and demonstration (ground or space)	In almost all cases, this level is the end of true "system development" for most technology elements. This might include integration of new technology into an existing system.	8. Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
9. Actual system "flight proven" through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	9. Actual system "flight proven" through successful mission operations	In almost all cases, the end of last "bug fixing" aspects of true "system development." This might include integration of new technology into an existing system. This TRL does *not* include planned product improvement of ongoing or reusable systems.	9. Actual system operated over the full range of expected conditions	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.

1. *DoD Technology Readiness Assessment (TRA) Deskbook* (May 2005)
2. Mankins, *Technology Readiness Levels: A White Paper*) (1995)
3. Holton, Sutter, *Developed for this Assessment* (December 2006))

Appendix B

Determination of Critical Technology Elements

Appendix B
Determination of Critical Technology Elements

The working definition of the critical technology element (CTE) as defined in the *Technology Readiness Assessment (TRA) Deskbook* (2005) was used as a basis for identification of CTEs for the Waste Treatment and Immobilization Plant (WTP). The working definition is as follows:

> *A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel.*
>
> *Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.*

The WTP Project is divided into five project elements:

- Analytical Laboratory (LAB)
- Balance of Facilities (BOF)
- LAW Waste Vitrification facility (LAW)
- HLW Waste Vitrification facility (HLW)
- Pretreatment (PT) Facility

Within each project element, the specific design features of the facility are divided into "systems." Thus, for convenience, the identification of the CTEs was done on a system basis. Most systems within the WTP facility are unique to the five project elements identified above. However, some selected systems are common to the treatment facilities (LAB, LAW, HLW, and PT). Where appropriate, these common systems were allocated to the five project elements identified above.

The process for identification of the CTEs for the Analytical Laboratory/Balance of Facilities/LAW Vitrification Facility (LAB/BOF/LAW) involved two steps. These were:

1. The complete list of systems for LAB/BOF/LAW was initially screened by the Assessment Team (Appendix E) for potential CTEs. Systems directly involved in the processing of the tank waste, or handling of the primary products (immobilized LAW and secondary wastes) were identified as potential CTEs. The complete list of systems and those identified as potential CTEs are identified in Tables B.1, B.2, and B.3 for the LAB, BOF, and LAW facilities, respectively.

2. The final set of CTEs was determined by assessing the potential CTEs against the two sets of questions presented in Table B.4. A CTE is determined if there is a positive response to at least one of the questions in each of the question sets. This final assessment of the CTEs was completed jointly by the Assessment Team and the WTP Project Technology and Engineering staff.

   The specific responses to each of the questions for each potential CTE are provided in Table B.5. The LAW Container Finishing Handling System was divided into five separate subsystems (1-Weigh, Inert Fill, and Glass Sampling; 2-Container Sealing; 3-Container Decontamination and Surface

Contamination Measurement; 4- Container Dose Rate and Temperature Measurements; and 5-Container Handling.

The rationale for the selection of each of the systems as a CTE is summarized below.

Analytical Hot Cell Laboratory Equipment System (AHL)/Analytical Radiological Laboratory Equipment System (ARL)

The only technologies in the AHL/ARL that are not readily commercially available are the Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) and the Laser Ablation Inductively Coupled Plasma Atomic Emission Spectrometry (LA-ICP-AES). These subsystems are used in the AHL to support analysis of highly radioactive samples. The equipment systems for these technologies require evaluation and confirmation of the specific sub-equipment designs and the testing and development of the operating procedures, including confirmation by independent testing using proven technologies, that analytical results from the LA-ICP-MS and the LA-ICP-AES systems are comparable to well-developed technologies. The development and implementation of the LA-ICP-AES is required to support WTP waste processing rate requirements.

Autosampling System (ASX)

The ASX is based upon the integration of existing technology concepts and commercially available technology components. The integrated ASX technology has been modified from previous applications to support operation of the WTP. Major areas of difference include: modification of the commercially available sampler, development of custom remote manipulators to place and remove sample vials from the sampler, the use of new sample vials and sealing lids, and reliance on automation to operate the system.

ILAW Container Finishing Handling System (LFH) -Container Sealing

The LFH uses commercially available and custom designed equipment, in an integrated equipment system that remotely places and seals a custom lid to the LAW container. The ILAW container sealing subsystem was determined to be a CTE due to the integration of many subcomponents into a new system. These components include custom lid-sealing surface for the ILAW container, custom lid with e-spring seal and locking tabs, lid emplacement tool that positions and presses the lid into place and locks mechanical tabs to create the seal, and the use of a de-lidding toll in the event that the lid must be removed. The system is designed to operate in a remote environment. A portion of the lidding system will be tested following fabrication, but the integrated system will not be completely tested until cold commissioning of the LAW Vitrification Facility.

ILAW Container Finishing Handling System (LFH) -Container Decontamination and Surface Contamination Measurement

The LFH container subsystem uses a solid carbon dioxide (CO_2) abrasive cleaning process to remove loose contamination from the ILAW container. The CO_2 abrasive is applied to localized areas on the ILAW container by a nozzle and shroud system using a remotely operated manipulator system. The shroud collects the CO_2 gas and the loose contamination. This decontamination approach is unique because a wide variety of remotely operated tools is required to clean a complex surface and maintain control of contamination. A portion of the decontamination system will be tested following fabrication and the system will not be completely tested until hot commissioning of the LAW Vitrification Facility.

LAW Melter Feed Process System (LFP)

The LFP prepares the LAW melter feed by blending treated low-activity waste and glass-forming chemicals. The remote, dry addition of glass-forming chemicals is novel (at the Savannah River Defense Waste Processing Facility [DWPF], glass formers were slurried ahead of time). The unique composition of the glass-forming chemicals, comprised mostly of industrial quality minerals, can lead to dusting of the glass formers on the liquid surface leading to potential blockage in the vessel ventilation system and inhomogeneous feed. The LAW melter feed preparation system relies on the integration of custom designed (e.g., vessels) and vendor-designed, commercially available equipment (e.g., mechanical mixer).

LAW Melter Process System (LMP)

The LAW melter design used for the WTP represents the largest capacity (design capacity 15 metric tons glass per day [MT/day]) melter used in the United States for the vitrification of radioactive waste. In addition, some of the equipment components used in the melter, such as the bubblers and multiple feed nozzles, are unique to this process system, and there are some issues with the availability of the materials required for the components of the melter.

LAW Melter Offgas System/LAW Secondary Offgas/Vessel Vent Process Systems (LOP/LVP)

The specific sub-components that comprise the LOP are a combination of unique WTP designs (e.g., film cooler, submerged bed scrubber) and vendor designed, commercially available equipment (e.g., high-efficiency mist eliminator, wet electrostatic precipitator, mercury (Hg) catalyst skid, and organic destruction catalyst skid). The system as proposed for the LAW Vitrification Facility has not been used in the proposed configuration or offgas environment prior to the WTP Project.

Table B.1. Identification of Critical Technology Elements (Systems) in the Analytical Laboratory Facility

System Locators	System Title	Document number	Include in Initial CTE Evaluation?
AHL	Analytical Hotcell Laboratory Equipment	24590-LAB-3YD-AHL-00001	Yes
ARL	Analytical Radiological Laboratory Equipment	24590-LAB-3YD-ARL-00001	Yes
ARV,C1V,C2V, C3V,C5V	Atmospheric Reference Ventilation; Cascade Ventilation System	24590-LAB-3YD-60-00001	No
BAG	Bottled Argon Gas	24590-LAB-3YD-MXG-00001	No
BHG	Bottled Helium Gas	24590-LAB-3YD-MXG-00001	No
BNG	Bottled Nitrogen Gas	24590-LAB-3YD-MXG-00001	No
BSA	Breathing Service Air	24590-LAB-3YD-BSA-00001	No
CHW	Chilled Water	24590-LAB-3YD-CHW-00001	No
DIW	Demineralized Water	24590-LAB-3YD-DIW-00001	No
DOW	Domestic Water	24590-LAB-3YD-DOW-00001	No
LIH	Laboratory In-cell Handling	24590-LAB-3YD-LIH-00001	Yes
LIJ	Laboratory Information Management	24590-LAB-3YD-LIJ-xxxxx	No
LPS,HPS,SCW	Low Pressure Steam	24590-LAB-3YD-LPS-00001	No
MXG	Miscellaneous Gasses	24590-LAB-3YD-MXG-00001	No
PSA	Plant Service Air	24590-LAB-3YD-PSA-00001	No
PTL	Process & Mechanical Handling CCTV	24590-LAB-3YD-PTL-00001	No
PVA	Plant Vacuum Air	24590-LAB-3YD-PVA-00001	No
RLD	Radioactive Liquid Waste	24590-LAB-3YD-RLD-00001	No

Table B.2. Identification of Critical Technology Elements (Systems) in the Balance of Facilities

System Locators	System Title	Document number	Include in Initial CTE Evaluation?
B88-C1V	ITS Switchgear	24590-B88-3YD-C1V-00001	No
CHW	Chilled Water	24590-BOF-3YD-CHW-00001	No
DFO	Diesel Fuel Oil	24590-BOF-3YD-DFO-00001	No
DIW	Demineralized Water	24590-BOF-3YD-DIW-00001	No
DOW	Domestic Water	24590-BOF-3YD-DOW-00001	No
EDX	Emergency Diesel Generator	24590-BOF-3YD-EDX-xxxxx	No
FSW	Fire Water Storage and Distribution	24590-BOF-3YD-FSW-00001	No
GFR	Glass Former Reagent	24590-BOF-3YD-GFR-00001	Yes
HPS	High Pressure Steam	24590-BOF-3YD-HPS-00001	No
NLD	Non-Radioactive Liquid Waste	24590-BOF-3YD-NLD-00001	No
PSA	Plant Service Air	24590-BOF-3YD-PSA-00001	No
RWH	Radioactive Solid Waste Handling	24590-WTP-3YD-RWH-00001	Yes
SCW	Steam Condensate Water	24590-BOF-3YD-SCW-00001	No
SDX	Standby Diesel Generator	24590-BOF-3YD-SDX-xxxxx*	No
TSJ	Training Simulator	24590-BOF-3YD-TSJ-00001	No

Table B.3. Identification of Critical Technology Elements (Systems) in the LAW Waste Vitrification Facility

System Locators	System Title	Document Number	Include in Initial CTE Evaluation?
ARV,C1V,C2V, C3V,C5V	Atmospheric Reference Ventilation; Cascade Ventilation System	24590-LAW-3YD-20-00003	No
BAG	Bottled Argon Gas	24590-LAW-3YD-MXG-00001	No
BNG	Bottled Nitrogen Gas	24590-LAW-3YD-BNG-xxxxx	No
BSA	Breathing Service Air	24590-LAW-3YD-BSA-00001	No
C1V	Cascade Ventilation System	24590-LAW-3YD-C1V-00001	No
C2V	Cascade Ventilation System	24590-LAW-3YD-C2V-00002	No
C5V	Cascade Ventilation System	24590-LAW-3YD-C5V-00002	No
CDG	Carbon Dioxide Gas System	24590-LAW-3YD-CDG-00001	No
CHW	Chilled Water	24590-LAW-3YD-CHW-00001	No
DIW	Demineralized Water System	24590-LAW-3YD-DIW-00001	No
DOW	Domestic Water System	24590-LAW-3YD-DOW-00001	No
HPS; LPS; SCW	High-Pressure Steam; Low-Pressure Steam; Steam Condensate Water	24590-LAW-3YD-HPS-00001	No
ISA	Instrument Service Air	24590-LAW-3YD-ISA-00001	No
LCP	LAW Concentrate Receipt Process	24590-LAW-3YD-LCP-00001	Yes
LEH	LAW Container Export Handling	24590-LAW-3YD-LEH-00001	Yes
LFH	LAW Container Finishing Handling	24590-LAW-3YD-LFH-00001	Yes
LFP	LAW Melter Feed Process	24590-LAW-3YD-LFP-00001	Yes
LMH	LAW Melter Handling	24590-LAW-3YD-LMH-00001	Yes
LMP	LAW Melter Process	24590-LAW-3YD-LMP-00001	Yes
LOP/LVP	Melter Offgas System/LAW Secondary Offgas/Vessel Vent Process	24590-LAW-3YD-LOP-00001	Yes
LPH	LAW Container Pour Handling	24590-LAW-3YD-LPH-00001	Yes
LRH	LAW Container Receipt Handling	24590-LAW-3YD-LRH-00002	Yes
LSH	LAW Melter Equipment Support Handling	24590-LAW-3YD-LSH-00001	Yes
MXG	Miscellaneous Gasses	24590-LAW-3YD-MXG-00001	No
NLD; RLD	Non-radioactive Liquid Waste Disposal; Radioactive Liquid Waste Disposal	24590-LAW-3YD-20-00001	No
PCW	Plant Cooling Water	24590-LAW-3YD-PCW-00002	No
PSA	Plant Service Air	24590-LAW-3YD-PSA-00001	No
RLD	Radioactive Liquid Waste	24590-LAW-3YD-RLD-00001	No
RWH	Radioactive Solid Waste Handling	24590-LAW-3YD-RWH-00002	No

Table B.4. Questions used to determine the Critical Technology Element for the LAB/BOF/LAW Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

Table B.5. Summary of Question Responses for the LAB/BOF/LAW System that were determined to be Critical Technology Elements

System	Analytical Hotcell Laboratory Equipment (AHL)	Analytical Radiological Laboratory Equipment (ARL)	Autosampling System (ASX)	ILAW (LFH) System - Container Sealing	ILAW (LFH) System- Container Decontamina-tion/Surface-Contamination Measurement	LAW Melter Feed Process (LFP)	LAW Melter Process (LMP)	Melter Offgas System/LAW Secondary Offgas/Vessel Vent Process (LOP/LVP)
First Question Set	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1. Does the technology directly impact a functional requirement of the process or facility?	Y	Y	Y	Y	Y	Y	Y	Y
2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required?	N	N	N	N	N	N	N	N
3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	N	N	N	N	N	N	N	N
4. Are there uncertainties in the definition of the end state requirements for this technology?	N	N	N	N	N	N	N	Y
Second Question Set	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1. Is the technology (system) new or novel?	N	N	N	N	N	Y	Y	N
2. Is the technology (system) modified?	N	N	Y	N	N	Y	Y	N
3. Has the technology been repackaged so that a new relevant environment is realized?	Y	Y	N	Y	N	Y	Y	Y
4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?	Y	Y	N	N	Y	N	Y	Y

Appendix C

Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix C

Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix C presents the questions used for assessing the technology maturity of U.S. Department of Energy (DOE) Office of Environmental Management (EM) waste processing and treatment technologies using a modified version of the Air Force Research Laboratory Technology Readiness Level (TRL) Calculator. The following TRL questions were developed for the evaluation of the WTP LAB/BOF/LAW systems in their respective tables as identified below.

- Table C.1 for TRL 1
- Table C.2 for TRL 2
- Table C.3 for TRL 3
- Table C.4 for TRL 4
- Table C.5 for TRL 5
- Table C.6 for TRL 6

The TRL Calculator was used to assess the TRL of the WTP critical technology elements (CTE). The assessment begins by using the top-level questions listed in Figure C.1 to determine the anticipated TRL that will result from the detailed questions. The anticipated TRL was determined from the question with the first "yes" answer from the list in Figure C.1. Evaluation of the detailed questions was started one level below the anticipated TRL. If it was determined from the detailed questions that the technology had not attained the maturity of the starting level, the next levels down were evaluated in turn until the maturity level could be determined.

The Calculator provides a standardized, repeatable process for evaluating the maturity of the hardware or software technology under development. The first columns in Tables C.1 to C.6 identify whether the question applies to Hardware (H), Software (S), or both. The second columns in Tables C.1 to C.6 identify the areas of readiness being evaluated: technical (T), programmatic (P), and manufacturing/ quality requirements (M). A technology is determined to have reached a given TRL if column 3 is judged to be 100% complete for all questions.

Appendix D contains the results of the evaluation of the TRL 6 questions (Table C.6) for the LAB/BOF/LAW CTEs. While questions for TRL 4 and TRL 5 may have been evaluated, only the responses to the hardware questions for TRL 6 are shown in Appendix D.

If Yes, Then Logic		Top Level Question
TRL 9	⟶	Has the actual equipment/process successfully operated in the full operational environment (Hot Operations)?
TRL 8	⟶	Has the actual equipment/process successfully operated in a limited operational environment (Hot Commissioning)?
TRL 7	⟶	Has the actual equipment/process successfully operated in the relevant operational environment (Cold Commissioning)?
TRL 6	⟶	Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?
TRL 5	⟶	Has bench-scale equipment/process testing been demonstrated in a relevant environment?
TRL 4	⟶	Has laboratory scale testing of similar equipment systems been completed in a simulated environment?
TRL 3	⟶	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?
TRL 2	⟶	Has an equipment and process concept been formulated?
TRL 1	⟶	Have the basic process technology process principles been observed and reported?

Figure C.1. Top Level Questions Establish Expected Technology Readiness Level

Table C.1. Technology Readiness Level 1 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		"Back of envelope" environment
B	T		Physical laws and assumptions used in new technologies defined
S	T		Have some concept in mind for software that may be realizable in software
S	T		Know what software needs to do in general terms
B	T		Paper studies confirm basic principles
S	T		Mathematical formulations of concepts that might be realizable in software
S	T		Have an idea that captures the basic principles of a possible algorithm
B	P		Initial scientific observations reported in journals/conference proceedings/technical reports
B	T		Basic scientific principles observed
B	P		Know who cares about the technology; e.g., sponsor, money source
B	T		Research hypothesis formulated
B	P		Know who will perform research and where it will be done

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality

S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table C.2. Technology Readiness Level 2 Questions

H/S/ Both	Cat	% Complete	Criteria
B	P		Customer identified
B	T		Potential system or components have been identified
B	T		Paper studies show that application is feasible
B	P		Know what program the technology will support
B	T		An apparent theoretical or empirical design solution identified
H	T		Basic elements of technology have been identified
B	T		Desktop environment
H	T		Components of technology have been partially characterized
H	T		Performance predictions made for each element
B	P		Customer expresses interest in the application
S	T		Some coding to confirm basic principles
B	T		Initial analysis shows what major functions need to be done
H	T		Modeling & Simulation only used to verify physical principles
B	P		System architecture defined in terms of major functions to be performed
S	T		Experiments performed with synthetic data
B	P		Requirements tracking system defined to manage requirements creep
B	T		Rigorous analytical studies confirm basic principles
B	P		Analytical studies reported in scientific journals/conference proceedings/technical reports.
B	T		Individual parts of the technology work (No real attempt at integration)
S	T		Know what hardware software will be hosted on
B	T		Know what output devices are available
B	P		Preliminary strategy to obtain TRL 6 developed (e.g., scope, schedule, cost)
B	P		Know capabilities and limitations of researchers and research facilities
B	T		Know what experiments are required (research approach)
B	P		Qualitative idea of risk areas (cost, schedule, performance)

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table C.3. Technology Readiness Level 3 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Academic environment
H	T		Predictions of elements of technology capability validated by analytical studies
B	P		The basic science has been validated at the laboratory scale
H	T		Science known to extent that mathematical and/or computer models and simulations are possible
B	P		Preliminary system performance characteristics and measures have been identified and estimated
S	T		Outline of software algorithms available
H	T		Predictions of elements of technology capability validated by Modeling and Simulation (M&S)
S	T		Preliminary coding verifies that software can satisfy an operational need
H	M		No system components, just basic laboratory research equipment to verify physical principles
B	T		Laboratory experiments verify feasibility of application
H	T		Predictions of elements of technology capability validated by laboratory experiments
B	P		Customer representative identified to work with development team
B	P		Customer participates in requirements generation
B	T		Cross technology effects (if any) have begun to be identified
H	M		Design techniques have been identified/developed
B	T		Paper studies indicate that system components ought to work together
B	P		Customer identifies transition window(s) of opportunity
B	T		Performance metrics for the system are established
B	P		Scaling studies have been started
S	T		Experiments carried out with small representative data sets
S	T		Algorithms run on surrogate processor in a laboratory environment
H	M		Current manufacturability concepts assessed
S	T		Know what software is presently available that does similar task (100% = Inventory completed)
S	T		Existing software examined for possible reuse
H	M		Sources of key components for laboratory testing identified
S	T		Know limitations of presently available software (analysis of current software completed)
B	T		Scientific feasibility fully demonstrated
B	T		Analysis of present state of the art shows that technology fills a need
B	P		Risk areas identified in general terms
B	P		Risk mitigation strategies identified
B	P		Rudimentary best value analysis performed for operations
B	P		The individual system components have been tested at the laboratory scale

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table C.4. Technology Readiness Level 4 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology issues (if any) have been fully identified
H	M		Laboratory components tested are surrogates for system components
H	T		Individual components tested in laboratory/by supplier (contractor's component acceptance testing)
B	T		Subsystems composed of multiple components tested at lab scale using simulants
H	T		Modeling and simulation used to simulate some components and interfaces between components
S	T		Formal system architecture development begins
B	P		Overall system requirements for end user's application are documented
B	P		System performance metrics measuring requirements have been established
S	T		Analysis provides detailed knowledge of specific functions software needs to perform
B	P		Laboratory testing requirements derived from system requirements are established
H	M		Available components assembled into laboratory scale system
H	T		Laboratory experiments with available components show that they work together (lab kludge)
S	T		Requirements for each system function established
S	T		Algorithms converted to pseudocode
S	T		Analysis of data requirements and formats completed
S	T		Stand-alone modules follow preliminary system architecture plan
H	T		Analysis completed to establish component compatibility
S	M		Designs verified through formal inspection process
B	P		Science and Technology exit criteria established
B	T		Technology demonstrates basic functionality in simulated environment
S	P		Able to estimate software program size in lines of code and/or function points
H	M		Scalable technology prototypes have been produced
B	P		Draft conceptual designs have been documented
H	M		Equipment scaleup relationships are understood/accounted for in technology development program
B	T		Controlled laboratory environment used in testing
B	P		Initial cost drivers identified
S	T		Experiments with full scale problems and representative data sets
B	M		Integration studies have been started
B	P		Formal risk management program initiated
S	T		Individual functions or modules demonstrated in a laboratory environment
H	M		Key manufacturing processes for equipment systems identified
B	P		Scaling documents and designs of technology have been completed
S	T		Some ad hoc integration of functions or modules demonstrates that they will work together
H	M		Key manufacturing processes assessed in laboratory
B	P		Functional work breakdown structure developed (functions established)
B	T		Low fidelity technology "system" integration and engineering completed in a lab environment
H	M		Mitigation strategies identified to address manufacturability/producibility shortfalls
B	P		Technology availability dates established

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table C.5. Technology Readiness Level 5 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology effects (if any) have been fully identified (e.g., system internally consistent)
B	T		Plant size components available for testing
B	T		System interface requirements known (how will system be integrated into the plant?)
B	P		System requirements flow down through work breakdown structure (design engineering begins)
S	T		System software architecture established
B	T		Requirements for technology verification established
S	T		External process/equipment interfaces described as to source, structure, and requirements
S	T		Analysis of internal system interface requirements completed
B	T		Lab scale similar system tested with limited range of actual wastes, if applicable
B	T		Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)
H	M		Significant engineering and design changes
S	T		Coding of individual functions/modules completed
H	M		Prototypes of equipment system components have been created (know how to make equipment)
H	M		Tooling and machines demonstrated in lab for new manufacturing processes to make component
B	T		High-fidelity lab integration of system completed, ready for test in relevant environments
H	M		Manufacturing techniques have been defined to the point where largest problems defined
H	T		Lab scale similar system tested with range of simulants
H	T		Fidelity of system mock-up improves from laboratory to bench scale testing
B	M		Reliability, Availability, Maintainability Index (RAMI) target levels identified
H	M		Some special purpose components combined with available laboratory components for testing
H	P		Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared
B	T		Laboratory environment for testing modified to approximate operational environment
B	T		Component integration issues and requirements identified
H	P		Detailed design drawings have been completed to support specification of pilot testing system
B	T		Requirements definition with performance thresholds and objectives established for final plant design
S	T		Algorithms run on processor with characteristics representative of target environment
B	P		Preliminary technology feasibility engineering report completed
B	T		Integration of modules/functions demonstrated in a laboratory/bench scale environment
H	T		Formal control of all components to be used in final system
B	P		Configuration management plan in place
B	P		Risk management plan documented
S	T		Functions integrated into modules
S	T		Formal inspection of all modules to be used in the final design
S	T		Individual functions tested to verify that they work
S	T		Individual modules and functions tested for bugs
S	T		Integration of modules/functions demonstrated in a laboratory environment
S	P		Formal inspection of all modules/components completed as part of configuration management
H	P		Individual process and equipment functions tested to verify that they work (e.g., test reports)

H-Hardware element, contains no appreciable amount of software	S-Completely a Software system
B-Some Hardware and Software	T-Technology, technical aspects
M-Manufacturing and quality	P-Programmatic, customer focus, documentation

Table C.6. Technology Readiness Level 6 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Performance and behavior of subcomponent interactions understood (including tradeoffs)
H	M		Reliability, Availability, Maintainability Index (RAMI) levels established
B	M		Frequent design changes occur
H	P		Draft design drawings for final plant system are nearly complete
B	T		Operating environment for final system known
B	P		Collection of actual maintainability, reliability, and supportability data has been started
B	P		Estimated cost of the system design is identified
B	T		Engineering scale similar system tested with a range of simulants
B	P		Plan for demonstration of prototypical equipment and process testing completed, results verify design
B	T		Modeling and simulation used to simulate system performance in an operational environment
H	T		Operating limits for components determined (from design, safety, and environmental compliance)
B	P		Operational requirements document available
B	P		Off-normal operating responses determined for engineering scale system
B	T		System technical interfaces defined
B	T		Component integration demonstrated at an engineering scale
B	P		Scaling issues that remain are identified and supporting analysis is complete
B	P		Analysis of project timing ensures technology will be available when required
S	T		Analysis of database structures and interfaces completed
B	P		Have begun to establish an interface control process
B	P		Acquisition program milestones established for start of final design (CD-2)
H	M		Critical manufacturing processes prototyped
H	M		Most pre-production hardware is available to support fabrication of the system
B	T		Engineering feasibility fully demonstrated (e.g., will it work?)
S	T		Prototype implementation includes functionality to handle large scale realistic problems
S	T		Algorithms partially integrated with existing hardware / software systems
H	M		Materials, process, design, and integration methods have been employed (e.g., can design be produced?)
S	T		Individual modules tested to verify that the module components (functions) work together
B	P		Technology ”system” design specification complete and ready for detailed design
H	M		Components are functionally compatible with operational system
H	T		Engineering scale system is high-fidelity functional prototype of operational system
S	T		Representative software system or prototype demonstrated in a laboratory environment
B	P		Formal configuration management program defined to control change process
B	M		Integration demonstrations have been completed (e.g., construction of testing system)
B	P		Final Technical Report on Technology completed
B	T		Waste processing issues have been identified and major ones have been resolved
S	T		Limited software documentation available
S	P		Verification, Validation, and Accreditation (VV&A) initiated
H	M		Process and tooling are mature to support fabrication of components/system
H	M		Production demonstrations are complete (at least one time)
S	T		"Alpha" version software has been released
S	T		Representative model tested in high-fidelity lab/simulated operational environment

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Appendix D

Technology Readiness Level Summary for WTP Critical Technology Elements for LAB/BOF/LAW

Appendix D

Technology Readiness Level Summary for WTP Critical Technology Elements for LAB/BOF/LAW

Appendix D summarizes the responses to the specific criteria identified in level 6 of the Technology Readiness Level (TRL) Calculator (Appendix C) for all systems identified as critical technology elements (CTE). The ILAW Container Finishing Handling System (LFH) decontamination subsystem was the only CTE determined not to have attained TRL 5. Table D.4 contains the responses for TRL 5 for this system. Responses to questions that reflected the criterion that was not completed are shown in **bold** in the tables below. The following systems were evaluated.

- Table D.1 – Analytical Hot Cell Laboratory Equipment/ Analytical Radiological Laboratory Equipment Systems (AHL/ARL)
- Table D.2 – Autosampling System (ASX)
- Table D.3 – ILAW Container Finishing Handling System (LFH) container sealing subystem
- Table D.4 – ILAW Container Finishing Handling System (LFH) decontamination subsystem (TRL 5)
- Table D.5 – ILAW Container Finishing Handling System (LFH) decontamination subsystem (TRL 6)
- Table D.6 – LAW Melter Feed Process System (LFP)
- Table D.7 – LAW Melter Process System (LMP)
- Table D.8 – LAW Primary Offgas Process and Secondary Offgas Vessel Vent Process Systems (LOP/LVP)

Table D.1. Technology Readiness Level 6 Summary for the Analytical Hot Cell Laboratory Equipment/Analytical Radiological Laboratory Equipment Systems (AHL/ARL)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	Sufficient information is available to specify a prototype and optimize the final design of the Laser Ablation Inductively Coupled Plasma Mass Spectrometry/Laser Ablation Inductively Coupled Plasma Atomic Emission Spectrometry (LA-ICP-MS/LA-ICP-AES) subsystems. Tradeoffs in the major subcomponents were evaluated. The laser was tested for sample preparation included varying laser wavelengths, frequencies, power levels, and length of transfer tubing to get the sample to the ICP-MS/ICP-AES subsystems. The furnace apparatus for glass sample preparations was tested. The results of these tests are documented in two reports from the Savannah River Site (SCT-MOSRLE60-00-216-00001, Rev. 00A; SCT-MOSRLE60-00-216-00002, Rev. 00A), and a Pacific Northwest National Laboratory report (24590-101-TSA-W000-0004-158-00002, Rev. A).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets as identified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) have been achieved for the WTP system based on results of the Operations Research Assessment (24590-WTP-RPT-PO-05-001, Rev. 0). This assessment evaluates rework of analytical samples and considers the turnaround time for samples analysis. Redundancy in the design of the ICP-MS and ICP-AES system is used as a strategy to ensure availability of these analytical systems. The WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) includes budgeted amounts to include redundant ICP-AES & ICP-MS capabilities in Hot Cells 12 & 13.
Y	Frequent design changes occur	The 90% design drawings of the prototype that will be used in the full scale plant are completed (24590-CM-POA-AELE-00009-01-00001 to 00048).
Y	Draft design drawings for final plant system are nearly complete	The 90% design drawings of the prototype that will be used in the full scale plant are completed (24590-CM-POA-AELE-00009-01-00001 to 00048).
Y	Operating environment for final system known	The requirements for the operating environment for the final LA-ICP-AES system are in the engineering specification for the prototype (24590-LAB-3PS-AELE-T0002). Because the prototype test is a full scale test of the plant system, these conditions should be identical to the final system. These requirements include the types of samples that will be analyzed.
Y	Collection of actual maintainability, reliability, and supportability data has been started	AHL systems rely on redundancy to achieve high reliability. If one system fails, a backup is available to support WTP operations.
Y	Estimated cost of the system design is identified	The costs of the AHL and ARL are provided in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0). Although the design has subsequently been modified, it is the best cost estimate available at this time.

Table D.1. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	**Engineering scale similar system tested with a range of simulants**	**Not completed. Engineering scale tests (SCT-MOSRLE60-00-216-00001, Rev. 00A; SCT-M0SRLE60-00-216-00002, Rev. 00A) using a similar system at the Savannah River Site and a Pacific Northwest National Laboratory report (24590-101-TSA-W000-0004-158-00002, Rev. A) helped establish specifications for the final LA-ICP-AES designs. Testing of the LA-ICP-AES planned at Hanford's 222S Laboratory (CCN: 139427) will emulate the full scale plant design.**
Y	Modeling and simulation used to simulate system performance in an operational environment	This is an analytical system not used to treat waste. Preliminary glass formulation algorithm development is underway (24590-HLW-RPT-RT-05-001; 24590-LAW-RPT-04-0003). Execution of these algorithms may require data from the Analytical Laboratory (LAB).
N	**Plan for demonstration of prototypical equipment and process testing completed, results verify design**	**The final design of the LA-ICP-AES subsystem has not been verified. A final design prototype of the LA-ICP-AES is being assembled for testing in Hanford's 222S Laboratory (CCN: 139427). The final design of the LA-ICP-AES system will be completed after prototype testing.**
Y	Operating limits for components determined (from design, safety, environmental compliance)	The requirements for the operating environment and limits for the final LA-ICP-AES system are in the engineering specification for the prototype (24590-LAB-3PS-AELE-T0002). Because the prototype test is a full scale test of the plant system, these conditions should be identical.
Y	Operational requirements document available	Operating requirements are identified in the AHL/ARL system descriptions (24590-LAB-3YD-AHL-00001, Rev. 1; 24590-LAB-3YD-ARL-00001, Rev. 1) and the task plan for testing the prototype with actual hot samples in Hanford's 222S Laboratory (CCN: 139427).
Y	Off-normal operating responses determined for engineering scale system	Off-normal operating responses for the AHL/ARL have been evaluated in Section 7.18 of the AHL/ARL system descriptions (24590-LAB-3YD-AHL-00001, Rev. 1; 24590-LAB-3YD-ARL-00001, Rev. 1).
Y	System technical interfaces defined	The interfaces between the AHL and the balance of the WTP are described in the AHL system description (24590-LAB-3YD-AHL-00001, Rev. 1) and Specification 245990-CM-POA-AELE-00009. The interfaces between the ARL and the balance of the WTP are described in the ARL system description (24590-LAB-3YD-ARL-00001, Rev. 1).
N	**Component integration demonstrated at an engineering scale**	**Component integration will be demonstrated in the prototypic test planned in Hanford's 222S Laboratory (CCN: 139427). This test will compare wet chemistry sample preparation techniques versus laser ablation as a sample preparation technique, and compare the accuracy of the LA-ICP-AES analysis to traditional ICP analysis.**
N	**Engineering scale system is high-fidelity functional prototype of operational system**	**Not completed. Engineering scale tests (SCT-M0SRLE60-00-216-00001, Rev. 00A; SCT-M0SRLE60-00-216-00002, Rev. 00A) using similar systems at the Savannah River Site and a Pacific Northwest National Laboratory report (24590-101-TSA-W000-0004-158-00002, Rev. A) helped establish specifications for the prototype LA-ICP-AES design. Testing planned at Hanford's 222S Laboratory (CCN: 139427). This testing is designed to duplicate the full scale plant design.**

Table D.1. (cont'd)

Criteria Satisfied (Y/N)	**Criteria**	**Basis for Completion**
Y	Scaling issues that remain are identified and supporting analysis is complete	Testing of the LA-ICP-AES system will be done at full scale systems (CCN: 139427). so scaling does not apply.
Y	Analysis of project timing ensures technology will be available when required	The development and availability of the AHL and ARL subsystems is documented in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0). There is a project timing issue for the ARL. The ARL system description (24590-LAB-3YD-ARL-00001, Rev. 1) states that very hot samples will be prepared through the hot cell system. The Tank Farms Contractor needs to address the need for and the ability to handle high-activity samples prior to LAB commissioning.
Y	Have begun to establish an interface control process	The interfaces between the AHL and the balance of the WTP are described in the AHL system description (24590-LAB-3YD-AHL-00001, Rev. 1) and the engineering specification for the prototype (24590-LAB-3PS-AELE-T0002). Because the prototype testing (CCN: 139427) is a full scale test of the plant system, these interfaces should be identical to the final system. The interfaces between the ARL and the balance of the WTP are described in the ARL system description (24590-LAB-3YD-ARL-00001, Rev. 1)
Y	Acquisition program milestones established for start of final design (CD-2)	The schedule for completion of the AHL/ARL systems is defined in the May 2006 WTP Estimate of Completion (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Critical manufacturing processes prototyped	There are no issues identified with the manufacturability of the LA-ICP-MS and LA-ICP-AES system components. Prototype equipment to support testing will be available beginning in April 2007.
Y	Most pre-production hardware is available to support fabrication of the system	There are no issues identified with the manufacturability of the LA-ICP-MS/LA-ICP-AES system components. Prototype equipment to support testing will be available beginning in April 2007.
N	**Engineering feasibility fully demonstrated (e.g., will it work?)**	**Not completed. Engineering feasibility of the LA-ICP-AES system will not be fully demonstrated until the prototypic testing at Hanford's 222S laboratory is complete. A task plan (CCN: 139427) for testing of the prototype at Hanford's 222S Laboratory has been prepared.**
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	The design of the prototype for the LA-ICP-AES system has been completed (24590-QL-MRA-AELE-00009-S0001). The fabrication of the prototype equipment is in process. No significant fabrication issues have been identified.
Y	Technology "system" design specification complete and ready for detailed design	Design of the plant system has been initiated. The final design features will be determined following testing of the prototype at Hanford's 222S Laboratory (CCN: 139427).
Y	Components are functionally compatible with operational system	The compatibility of functional components has been demonstrated based on testing at Savannah River Site (SCT-M0SRLE60-00-216-00001, Rev. 00A; SCT-M0SRLE60-00-216-00002, Rev. 00A) using a similar system and a Pacific Northwest National Laboratory report (24590-101-TSA-W000-0004-158-00002, Rev. A).

Table D.1. (cont'd)

Criteria Satisfied (Y/N)	**Criteria**	**Basis for Completion**
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
N	**Integration demonstrations have been completed (e.g., construction of testing system)**	**Component integration will be demonstrated in the prototypic test planned in Hanford's 222S Laboratory (CCN: 139427). This test will compare wet chemistry sample preparation techniques versus laser ablation as a sample preparation technique, and accuracy of the MS/LA-ICP-AES analysis compared to traditional ICP analysis.**
N	**Final Technical Report on Technology completed**	**The final technical report on the technology will be completed following prototypic testing at Hanford's 222S Laboratory (CCN: 139427).**
N	**Waste processing issues have been identified and major ones have been resolved**	**Not completed. Waste processing issues associated with the LA-ICP-MS and LA-ICP-AES system will be identified and evaluated during prototypic testing at Hanford's 222S Laboratory (CCN: 139427).**
Y	Process and tooling are mature to support fabrication of components/system	No issues have been identified with the manufacturability of the LA-ICP-MS and LA-ICP-AES system components. Prototype equipment to support testing will be available beginning in April 2007.
N	**Production demonstrations are complete (at least one time)**	**Not completed. Production of the prototype for Hanford's 222S Laboratory testing (CCN: 139427) will validate that the system can be produced.**

Table D.2. Technology Readiness Level 6 Summary for the Autosampling System (ASX)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	Subcomponent were identified in the system description for ASX (24590-WTP-3YD-ASX-00001) and the design requirements in the autosampler engineering specification (24590-WTP-3PS-MHSS-T0002, Rev. 0). These specifications provide sufficient information to describe the performance of major system subcomponents including flow through the sample recirculation line, amount of sample material withdrawn, sampler flushing pressure, sampler ventilation requirements, and requirements for the sample bottle-handling robot.
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	A RAMI assessment report was completed by the ASX vendor (24950-QL-HC4-HAHH-00001-12-00001, Rev. 00B). The Autosampling System Operator Manual (24590-QL-HC4-HAHH-0001) was also completed, which determined that the sampler could be decontaminated to contact dose standards.
Y	Frequent design changes occur	The design of the ASX is approximately 90% complete.
Y	Draft design drawings for final plant system are nearly complete	The design of the ASX is approximately 90% complete.
Y	Operating environment for final system known	The operating environment for the ASX is defined in the mechanical datasheets for the system subcomponents, in the autosampler engineering specification (24590-WTP-3PS-MHSS-T0002, Rev. 0), and the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C)
Y	Collection of actual maintainability, reliability, and supportability data has been started	A RAMI assessment report was completed by the ASX vendor (24950-QL-HC4-HAHH-00001-12-00001, Rev. 00B). Reliability in the sample transfer system is achieved by redundancy of the sampler transfer exhausters.
Y	Estimated cost of the system design is identified	The cost of the ASX is identified in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering scale similar system tested with a range of simulants	Engineering scale testing has not been conducted. The design is based on the operation of similar systems used at the Sellafield site, UK. A prototypic ISOLOCK sampler has been tested by BNI using waste feeds with similar characteristics to actual waste.
Y	Modeling and Simulation used to simulate system performance in an operational environment	Not applicable.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	The task plan has been prepared for the integrated testing of the ASX (CCN: 139427). Testing is not yet complete. Criteria are satisfied based on operational performance of similar systems at the Sellafield, UK site.

Table D.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operating limits for components determined (from design, safety, environmental compliance)	The operating limits (temperature, pressure, etc.) are specified in the mechanical datasheets for the ASX components and in the engineering specifications for the system components (24590-WTP-3PS-MHSS-T0002, Rev. 0).
Y	Operational requirements document available	The ASX vendor has prepared draft operating procedures for the ASX plant operation (24950-QL-HC4-HAHH-00001-12-0001).
Y	Off-normal operating responses determined for engineering scale system	Initial identification of off-normal responses is provided in Section 7 of the ASX system description (24590-WTP-3YD-ASX-00001, Rev. A), which is being updated to reflect the current design. The ASX vendor will also provide off-normal operating response information with the completed ASX design.
Y	System technical interfaces defined	The technical interfaces for the ASX are defined in the autosampler engineering specification (24590-WTP-3PS-MHSS-T0002, Rev. 0).
Y	Component integration demonstrated at an engineering scale	The WTP ASX design is based on demonstrated designs at the Sellafield, UK site. Primary components operated at the Sellafield site included the ISOLOCK sampler, pneumatic transfer system, sample bottle-handling robot). Previous operations at Sellafield are discussed in several reports (NHC-8373; NHC-8374; NHC-8375).
Y	Scaling issues that remain are identified and supporting analysis is complete	The system will be designed and tested at full scale systems, so scaling does not apply.
Y	Analysis of project timing ensures technology will be available when required	The schedule for completion of the ASX is consistent with the May 2006 WTP Estimate of Completion (24590-WTP-CE-PC-06-001, Rev. 0) and supports the resequencing of LAB/BOF/LAW with component testing being completed by 2012.
Y	Have begun to establish an interface control process	Interfaces are defined in the ASX piping and instrumentation diagrams (P&ID) (24590-QL-HC4-HAHH-0001-06-00016 through 00030) and the autosampler engineering specification (24590-WTP-3PS-MHSS-T0002, Rev. 0).
Y	Acquisition program milestones established for start of final design (CD-2)	The schedule for completion of the ASX is consistent with the May 2006 WTP Estimate of Completion (24590-WTP-CE-PC-06-001, Rev. 0) and supports the resequencing of LAB/BOF/LAW with component testing being completed by 2012. The design of the ASX is approximately 90% complete.
Y	Critical manufacturing processes prototyped	The ASX is a combination of commercially available (autosamplers) and custom-designed components. Fabrication of the system is envisioned to be routine. No issues with the manufacturability of the equipment have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	Tooling exists to fabricate the ASX equipment components. No issues with the manufacturability of the equipment have been identified.

Table D.2. (cont’d)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Engineering feasibility fully demonstrated (e.g., will it work?)	The WTP ASX design is based on demonstrated designs at the Sellafield, UK site. Primary components operated at the Sellafield site included the ISOLOCK sampler, pneumatic transfer system, and the sample bottle-handling robot. Previous operations at Sellafield are discussed in the design proposal for the ASX.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	Tooling exists to fabricate the ASX equipment components. No issues with the manufacturability of the equipment have been identified
Y	Technology “system” design specification complete and ready for detailed design	The design of the ASX is approximately 90% complete.
Y	Components are functionally compatible with operational system	The WTP ASX design is based on demonstrated designs at the Sellafield, UK site. Primary components operated at the Sellafield site included the ISOLOCK sampler, pneumatic transfer system, sample bottle-handling robot. Previous operations at Sellafield are discussed in several reports (NHC-8373; NHC-8374; NHC-8375).
Y	Engineering scale system is high-fidelity functional prototype of operational system	The WTP ASX design is based on demonstrated designs at the Sellafield, UK site. Primary components operated at the Sellafield site included the ISOLOCK sampler, pneumatic transfer system, sample bottle-handling robot. Previous operations at Sellafield are discussed in several reports (NHC-8373; NHC-8374; NHC-8375).
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	The WTP ASX design is based on demonstrated designs at the Sellafield, UK site. Primary components operated at the Sellafield site included the ISOLOCK sampler, pneumatic transfer system, and the sample bottle-handling robot. Previous operations at Sellafield are discussed in numerous reports (NHC-8373; NHC-8374; NHC-8375).
Y	Final Technical Report on Technology completed	The ASX will be tested by the ASX vendor at the time of mechanical completion and a report prepared. This criterion is closed based upon the previous application of similar system designs at the Sellafield, UK site.
Y	Waste processing issues have been identified and major ones have been resolved	Not applicable.
Y	Process and tooling are mature to support fabrication of components/system	Tooling exists to fabricate the ASX equipment components. No issues with the manufacturability of the equipment have been identified.

Table D.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Production demonstrations are complete (at least one time)	All components that comprise the ASX have been produced at least once for the Sellafield, UK site (NHC-8373; NHC-8374; NHC-8375). Some custom designs are incorporated because of the unique requirements of the WTP. The equipment from these designs should not be difficult to produce.

Table D.3. Technology Readiness Level 6 Summary for the ILAW Container Finishing Handling System (LFH) Container Sealing Subsystem

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The engineering specifications for the LFH components have been defined (24590-LAW-3PS-M000-T0006; 24590-LAW-3PS-HCHH-T0002; 24590-LAW-3PS-HCTH-T0001; 24590-LAW-3PS-HDYR-T0001). These specifications account for the process operating requirements for an appropriately operating container sealing system including factors such as lid placement rates and lid compression pressure to seal the container.
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C). The Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the equipment has been completed. Most drawings and calculations are identified in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Draft design drawings for final plant system are nearly complete	The final design of the equipment has been completed. Most drawings and calculations are identified in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Operating environment for final system known	The operating environment for the LFH container sealing subsystem is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C), the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1), and the LAW PSAR (24590-WTP-PSAR-ESH-01-002-03, Rev. 1).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets have been established in WTP Basis of Design for LAW Vitrification Facility (24590-WTP-DB-ENG-01-001, Rev. 1C). The Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the LFH container sealing subsystem is provided in the May 2005 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).
N	**Engineering scale similar system tested with a range of simulants**	**Integrated testing of the immobilized low-activity waste (ILAW) container sealing subsystem has not been completed. Testing is planned for completion using the actual plant equipment during equipment acceptance and cold commissioning.**
Y	Modeling and Simulation used to simulate system performance in an operational environment	The reliability analysis has been completed in the Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0).

Table D.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	**Plan for demonstration of prototypical equipment and process testing completed, results verify design**	**Process testing is not completed. Actual plant equipment is being fabricated and will be used for equipment testing to support acceptance as defined in the engineering specification (24590-LAW-3PS-HCTH-T0001). Prototypic remote testing is planned for completion during cold commissioning of the LAW Vitrification Facility.**
Y	**Operating limits determined using engineering scale system (from design, safety, environmental compliance)**	**Integrated testing to verify operating limits is not completed. Initial operating limits have been established based on design analyses and are included in the engineering specification (24590-LAW-3PS-HCTH-T0001). These operating parameters will be tested at the vendor's shop following fabrication. The operational parameters will also be verified during cold commissioning of the LAW Vitrification Facility.**
Y	Operational requirements document available	The minimum operating requirements for the LFH are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001, Rev. 2) and the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Off-normal operating responses determined for engineering scale system	A delidding tool has been designed to replace damaged lids. As a secondary measure, an overpack has been designed for the ILAW container. See Section 7.2 of the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	System technical interfaces defined	Interfaces for the LFH are defined the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and Section 9 of the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
N	**Component integration demonstrated at an engineering scale**	**Engineering scale testing has not been completed. Integrated testing of the ILAW container sealing subsystem is planned for completion using the actual plant equipment during equipment acceptance and cold commissioning.**
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified. Equipment will be tested at full scale during cold commissioning.
Y	Analysis of project timing ensures technology will be available when required	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LFH technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the LFH and the balance of the LAW Vitrification Facility are described in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1). This includes both physical and process interfaces with the LAW Vitrification Facility.
Y	Acquisition program milestones established for start of final design (CD-2)	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LFH technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.

Table D.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
N	**Engineering feasibility fully demonstrated (e.g., will it work?)**	**Engineering feasibility is not fully demonstrated. Only engineering analysis has been used to date to demonstrate the feasibility of design concept. The engineering specification (24590-LAW-3PS-HCTH-T0001) requires the vendor to shop test the container sealing equipment; however, this test will not be done to simulate the remote environment in which the system will eventually be operated. The project plans to test the equipment in the LAW Facility at the equipment acceptance/cold commissioning phase of the project.**
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Technology "system" design specification complete and ready for detailed design	The equipment system has been designed and is being fabricated. Vendor drawings will be used to document the final design. The specification to support fabrication of the container sealing system has been completed (24590-LAW-3PS-HCTH-T0001).
Y	Components are functionally compatible with operational system	Functions of the components are defined in the engineering specification for the container sealing system (24590-LAW-3PS-HCTH-T0001). Full-scale testing of a limited number of plant components is planned to validate the equipment design in the vendor's fabrication shop.
N	**Engineering scale system is high-fidelity functional prototype of operational system**	**No engineering scale system testing is planned. Full-scale testing of the plant equipment to validate the technology is planned initially during acceptance testing at the vendor facility. Final testing will be completed at the time of cold commissioning.**
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
N	**Integration demonstrations have been completed (e.g., construction of testing system)**	**Full scale testing of plant equipment to validate the technology was not completed. Integrated testing of the ILAW container sealing subsystem is planned for completion using the actual plant equipment during equipment acceptance and cold commissioning.**
N	**Final Technical Report on Technology completed**	**Not completed. The final technical report will follow full scale tests during cold commissioning.**
Y	Waste processing issues have been identified and major ones have been resolved	Not applicable.

Table D.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
N	**Production demonstrations are complete (at least one time)**	**A prototype or a plant scale container system has not been fabricated. However, this is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.**

Table D.4. Technology Readiness Level 5 Summary for the ILAW Container Finishing Handling System (LFH) Decontamination Subsystem

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Cross technology effects (if any) have been fully identified	The engineering specification for the LFH decontamination subsystem (24590-LAW-3PS-HDYR-T0001) accounts for process operating requirements including factors such CO_2 particle size, CO_2 velocity, and travel rate across the container exterior surface. These have been evaluated and documented in the Research and Technology (R&T) reports (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12, Rev. 00B).
Y	Plant size components available for testing	Actual plant equipment is being fabricated and will be used for integrated testing to support validation of technology concept. This is planned in cold commissioning of the LAW Vitrification Facility.
Y	System interface requirements known (how will system be integrated into the plant?)	Interface requirements are defined in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	System requirements flow down through work breakdown structure (design engineering begins)	System requirements are defined in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
N	Requirements for technology verification established	Laboratory testing was completed only on component pieces. Shroud testing is missing. Integrated testing of all system components is planned prior to cold commissioning testing. Requirements for technology verification will be established as part of cold commissioning activities.
Y	Lab scale similar system tested with limited range of actual wastes	Non-prototypical laboratory scale tests on 2 in. by 4 in., contaminated, flat coupons of the stainless steel that will be used for the ILAW container were performed by the WTP Contractor (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12). Testing involved radioactive cesium (Cs), which had been vapor deposited on the coupon surface followed by a heat treatment cycle to mimic the thermal history of the container surface. Cesium was successfully removed by CO_2 blasting to surface contamination less than 220 dpm/100 cm^2 alpha and less than 2,200 dpm/100cm^2 beta-gamma. However, this testing did not demonstrate the WTP Project requirements of 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma. In addition, the technique was not always successful at removing radioactive Cs that had been deposited on the coupon as a liquid solution. These tests were conducted using contaminated flat-metal plates, and did not employ a shroud system to contain the CO_2 and removed contamination. No engineering scale prototypical tests of the WTP system have been carried out to date.
Y	Interfaces between components/subsystems are realistic (benchtop with realistic interfaces)	The engineering specification for the LFH container decontamination subsystem (24590-LAW-3PS-HDYR-T0001) has been prepared to ensure system components and interfaces are accounted for in design.
Y	Significant engineering and design changes	Equipment is in the final design stage. Most drawings and calculations are completed and identified in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).

Table D.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Prototypes of equipment components have been created (know how to make equipment)	No fabrication issues have been identified in production of full scale plant equipment.
NA	Tooling and machines demonstrated in lab for new manufacturing processes to make component.	Not applicable because full scale prototypes have been designed and will be fabricated to test technology.
N	**High-fidelity lab integration of system completed, ready for test in relevant environments**	**The integrated CO_2 spray and shrouding system has not been tested. Non-prototypical laboratory scale tests on 2 in. by 4 in., contaminated, flat coupons of the stainless steel that will be used for the ILAW container were performed by the WTP Contractor (SCT-M0SRLE60-00-99-07, SCT-M0SRLE60-00-110-12). Testing involved radioactive Cs, which had been vapor deposited on the coupon surface followed by a heat treatment cycle to mimic the thermal history of the container surface. Cesium was successfully removed by CO_2 blasting to surface contamination less than 220 dpm/100 cm^2 alpha and less than 2,200 dpm/100cm^2 beta-gamma. However, this testing did not demonstrate the WTP Project requirements of 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma. In addition, the technique was not always successful at removing radioactive Cs that had been deposited on the coupon as a liquid solution. These tests were conducted using contaminated flat-metal plates, and did not employ a shroud system to contain the CO_2 and removed contamination.**
Y	Manufacturing techniques defined to the point where largest problems identified	No manufacturing issues have been identified to date by vendor in fabrication of plant scale equipment.
Y	Lab scale similar system tested with a range of simulants	Non-prototypical laboratory scale tests on 2 in. by 4 in., contaminated, flat coupons of the stainless steel that will be used for the ILAW container were performed by the WTP Contractor (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12). Testing involved radioactive Cs, which had been vapor deposited on the coupon surface followed by a heat treatment cycle to mimic the thermal history of the container surface. Cesium was successfully removed by CO_2 blasting to surface contamination less than 220 dpm/100 cm^2 alpha and less than 2,200 dpm/100cm^2 beta-gamma. However, this testing did not demonstrate the WTP Project requirements of 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma. In addition, the technique was not always successful at removing radioactive Cs that had been deposited on the coupon as a liquid solution. These tests were conducted using contaminated flat-metal plates, and did not employ a shroud system to contain the CO_2 and removed contamination.
N	**Fidelity of system mock-up improves from laboratory to bench scale testing**	**Bench scale testing was not completed. No integrated laboratory testing of prototypic system components is planned. Requirements for technology verification will be established as part of cold commissioning activities. Test specifications for limited equipment components comprising the system will be completed by the vendor at the factory. These include manipulators and the transfer boggie.**

Table D.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Availability and reliability target levels not yet established	RAMI targets have been established in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C). The Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
N	Some special purpose components combined with available laboratory components	A commercial CO_2 blasting system was used on contaminated metal coupons. This testing program should be supplemented with laboratory scale testing to define the operational parameters for the shrouding system and carbon dioxide (CO_2) decontamination system.
Y	Three dimensional drawings and P&ID have been prepared	Design drawings completed for system and identified in LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Laboratory environment for testing modified to approximate operational environment	The temperatures of the coupons in the lab scale experiments were not prototypic of actual environment; e.g., 350°F.
N	Component integration issues and requirements identified	The engineering specification for the LFH decontamination subsystem (24590-LAW-3PS-HDYR-T0001) accounts for process operating requirements including factors such CO_2 particle size, CO_2 velocity, and travel rate across the container exterior surface. These have been evaluated and documented in the following R&T reports (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12, Rev. 00B). This testing program should be supplemented with laboratory scale testing to define the operational parameters for the shrouding system and carbon dioxide (CO_2) decontamination system.
Y	Detail design drawings have been completed to support specification of pilot testing system	Detailed design drawings have been prepared by vendor(s) to comply with required specifications and support final design of plant scale system.
N	Requirements definition with performance thresholds and objectives established for final plant design	Requirements for system components identified in engineering specification for the container decontamination system (24590-LAW-3PS-HDYR-T0001). This testing program should be supplemented with laboratory scale testing to define the operational parameters for the shrouding system and carbon dioxide (CO_2) decontamination system.
Y	Preliminary technology feasibility engineering report completed	Initial technology testing results show feasibility of concept (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12).
N	**Integration of modules/functions demonstrated in a laboratory/bench scale environment**	**Not completed. Laboratory testing was completed on only pieces of the system. However, no integrated testing of all components of the ILAW decontamination system is planned until the equipment is installed in the LAW Facility. Full-scale decontamination of a ILAW container is not planned until hot commissioning.**

Table D.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan	The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	WTP Project has established *WTP Risk Management Plan* (24590-WTP-RPT-PR-01-006). The Risk Management Plan does not address failure of the LFH decontamination subsystem.
N	**Individual process and equipment functions tested to verify that they work (e.g., test reports)**	**The shroud has not been tested. Non-prototypical laboratory scale tests on 2 in. by 4 in., contaminated, flat coupons of the stainless steel that will be used for the ILAW container were performed by the WTP Contractor (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12). Testing involved radioactive Cs, which had been vapor deposited on the coupon surface followed by a heat treatment cycle to mimic the thermal history of the container surface. Cesium was successfully removed by CO_2 blasting to surface contamination less than 220 dpm/100 cm^2 alpha and less than 2,200 dpm/100cm^2 beta-gamma. However, this testing did not demonstrate the WTP Project requirements of 100 dpm/100 cm^2 alpha and less than 1,000 dpm/100cm^2 beta-gamma. In addition, the technique was not always successful at removing radioactive Cs that had been deposited on the coupon as a liquid solution. These tests were conducted using contaminated flat-metal plates, and did not employ a shroud system to contain the CO_2 and removed contamination.**

Table D.5. Technology Readiness Level 6 Summary for the ILAW Container Finishing Handling System (LFH) Decontamination Subystem

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The engineering specification for the LFH decontamination subsystem (24590-LAW-3PS-HDYR-T0001) accounts for process operating requirements including factors such CO_2 particle size, CO_2 velocity, and travel rate across the container exterior surface. These have been evaluated and documented in the following R&T reports (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12, Rev. 00B). This testing program should be supplemented with laboratory scale testing to define the operational parameters for the shrouding system and carbon dioxide (CO_2) decontamination system.
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C). The Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Frequent design changes occur	Final design of equipment is completed. Most drawings and calculations are identified in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Draft design drawings for final plant system are nearly complete	Vendor drawings are 65% complete. The CO_2 delivery system is still being designed. The shroud and nozzle designs are not complete.
Y	Operating environment for final system known	The operating environment for the LFH decontamination subsystem is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C), the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1), and the LAW PSAR (24590-WTP-PSAR-ESH-01-002-03, Rev. 1).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets have been established in WTP Basis of Design for LAW Vitrification Facility (24590-WTP-DB-ENG-01-001, Rev. 1C). The Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs. Limited data on the CO_2 nozzles is currently available.
Y	Estimated cost of the system design is identified	The cost of the LFH decontamination subsystem is provided in the May 2005 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).
N	**Engineering scale similar system tested with a range of simulants**	**Not completed. The engineering specification (24590-LAW-3PS-HDYR-T0001) requires the vendor to shop-test portions of the equipment system; however, no integrating testing of all components of the LAW decontamination system is planned until the equipment is installed in the LAW Vitrification Facility.**

Table D.5. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Modeling and Simulation used to simulate system performance in an operational environment	The reliability analysis was completed in the Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0).
N	**Plan for and process testing completed, results verify design**	**Demonstration of prototypical equipment was not completed. Actual plant equipment is being fabricated and will be used for integrated testing to support validation of technology concept during cold commissioning. Prior to commissioning, this testing program should be supplemented with laboratory scale testing to define the operational parameters for the shrouding system and carbon dioxide (CO_2) decontamination system.**
Y	Operating limits determined using engineering scale system	Operating limits for process system have been estimated from laboratory scale experiments and design analysis (travel rate, vacuum, offset from the surface, flow rates, and maximum temperature of the container). Operational parameters during full scale will be tested at cold commissioning.
Y	Operational requirements document available	The minimum operating requirements for the LFH are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001, Rev. 2) and the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Off-normal operating responses determined for engineering scale system	A failure in meeting contamination levels will require a repeat of the decontamination process. Following a failure of three decontamination attempts, the ILAW container will be overpacked. See Section 7.2 of the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	System technical interfaces defined	Interfaces for the LFH System are defined in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and Section 9 of the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1).
N	**Component integration demonstrated at an engineering scale**	**Integrated demonstrations were not completed. No integrated testing of all components of the ILAW decontamination system is planned until the equipment is installed in the LAW Facility. Full-scale decontamination of a ILAW container is not planned until hot commissioning.**
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified. Full-scale testing of plant equipment has been planned to validate equipment technology at time of cold commissioning.
Y	Analysis of project timing ensures technology will be available when required	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LFH technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the LFH and the balance of the LAW Vitrification Facility are described in the LFH system description (24590-LAW-3YD-LFH-00001, Rev. 1). This includes both physical and process interfaces with the LAW Vitrification Facility.
Y	Acquisition program milestones established for start of final design (CD-2)	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LFH technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.

Table D.5. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Critical manufacturing processes prototyped	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
N	**Engineering feasibility fully demonstrated (e.g., will it work?)**	**Engineering analysis has been used to demonstrate feasibility of design concept. Initial technology testing results show feasibility of CO_2 decontamination process concept (SCT-M0SRLE60-00-99-07; SCT-M0SRLE60-00-110-12, Rev. 00B). Full-scale testing has not been completed. The engineering specification (24590-LAW-3PS-HDYR-T0001) requires the vendor to shop test portions of the equipment system; however, no integrating testing of all components of the ILAW decontamination system is planned until the equipment is installed in the LAW Vitrification Facility.**
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Technology "system" design specification complete and ready for detailed design	The engineering specification (24590-LAW-3PS-HDYR-T0001) for the equipment systems has been prepared, and the equipment is being fabricated.
N	**Components are functionally compatible with operational system**	**Not completed. Full-scale testing of the plant equipment is planned at time of cold commissioning to validate technology.**
N	**Engineering scale system is high-fidelity functional prototype of operational system**	**Not completed. Full-scale testing of the plant equipment is planned at time of cold commissioning to validate technology.**
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
N	**Integration demonstrations have been completed (e.g., construction of testing system)**	**Not completed. Full-scale testing of plant equipment has been planned to validate equipment technology at time of cold commissioning.**
N	**Final Technical Report on Technology completed**	**Not completed. The final technical report will follow full scale tests during cold commissioning.**

Table D.5. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Waste processing issues have been identified and major ones have been resolved	Not applicable.
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
N	**Production demonstrations are complete (at least one time)**	**Not completed. Actual plant equipment is being fabricated and will be used for integrated testing during cold commissioning to support validation of technology concept.**

Table D.6. Technology Readiness Level 6 Summary for LAW Melter Feed Process System (LFP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The mixing system design has been provided by the vendor. The agitation system design provided by the vendor is based upon vessel design and mixing requirements. The mixing report from the vendor demonstrates the adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001). The R&T testing of mixing system has been completed (SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02 Rev. 00C [cleared]).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C). The Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the equipment has been completed. Most drawings and calculations are identified in the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1). The ILAW concentrate receipt vessels (CRV), melter feed preparation vessels (MFPV), and melter feed vessels (MFV) have been fabricated and are located on the WTP site.
Y	Draft design drawings for final plant system are nearly complete	The final design of the equipment is completed. Most drawings and calculations are identified in the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1). The LAW CRV, MFPV, and MFV have been fabricated and are located on the WTP site.
Y	Operating environment for final system known	The operating environment for the LFP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C), the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1), and the LAW PSAR (24590-WTP-PSAR-ESH-01-002-03, Rev. 1).
Y	Collection of actual maintainability, reliability, and supportability data has been started	The RAMI data is included the RAMI Assessment Report (24590-LAW-RPT-PO-05-0001, Rev. 0) and the Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the LFP is provided in the May 2005 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).

Table D.6. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Engineering scale similar system tested with a range of simulants	The mixing system design has been provided by the vendor. The agitation system design provided by vendor is based upon vessel design and mixing requirements. A mixing report from the vendor demonstrates adequacy of system design (24590-QL-POA-MFAO-00001-10-00001). The R&T testing of the mixing system has been completed (SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02 Rev. 00C [cleared]). Additional testing is planned as part of the R&T Program to test homogeneity of mixed simulated waste and sampling systems. In addition, the melter test reports identified in the response to the first question in Table D.6 for the LAW Melter Process provide additional data on the mixing of simulated wastes.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the LFP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the LFP will support project requirements.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	The mixing system design has been provided by the vendor. The agitation system design provided by the vendor is based upon vessel design and mixing requirements. The mixing report from the vendor demonstrates the adequacy of system design (24590-QL-POA-MFAO-00001-10-00001). The R&T testing of the mixing system has been completed (SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02 Rev. 00C [cleared]).
Y	Operating limits determined using engineering scale system (from design, safety, environmental compliance)	The operating conditions for the LFP have been established based upon engineering analysis presented in the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1) and the testing reports identified in the response to the first question in Table D.6. Key conditions include; solids addition rate, water addition to solids prior to introduction into vessel, and agitation requirements including design. Additional testing is planned to assess the degree of homogenization to support feed make-up sampling requirements.
Y	Operational requirements document available	The minimum operating requirements for the LFP are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001, Rev. 2) and the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1).
Y	Off-normal operating responses determined for engineering scale system	An initial assessment of off-normal operations along with corrective actions is identified in Section 7.2 of the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1).
Y	System technical interfaces defined	The identification of the technical interface requirements is included in Section 9 of the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1).
Y	Component integration demonstrated at an engineering scale	Engineering scale testing has been completed by the vendor and results are documented in reports from the vendor that demonstrate adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001).

Table D.6. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues remain. The mixing system design has been provided by the vendor. The agitation system design provided by the vendor is based upon vessel design and mixing requirements. The mixing report from the vendor demonstrates adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001).
Y	Analysis of project timing ensures technology will be available when required	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LFP technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	An identification of the technical interface requirements is included in Section 9 of the LFP system description (24590-LAW-3YD-LFP-00001, Rev. 1).
Y	Acquisition program milestones established for start of final design (CD-2)	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LFP technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	The LFP design is based upon existing technology and standard industry components.
Y	Most pre-production hardware is available to support fabrication of the system	The LFP design is based upon existing technology and standard industry components.
Y	Engineering feasibility fully demonstrated (e.g., will it work?)	The mixing system design has been provided by the vendor. The agitation system design provided by vendor is based upon vessel design and mixing requirements. The mixing report from the vendor demonstrates adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001, Rev. 00B).
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	The LFP design is based upon existing technology and standard industry components. Vessels for the LFP have been fabricated and are located on the WTP site.
Y	Technology "system" design specification complete and ready for detailed design	The design of the plant scale system has been completed. The vessels have been fabricated and are located on the WTP site.
Y	Components are functionally compatible with operational system	The mixing system design has been provided by the vendor. The agitation system design provided by vendor is based upon vessel design and mixing requirements. A mixing report from Philadelphia Mixers demonstrates adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001, Rev. 00B).
Y	Engineering scale system is high-fidelity functional prototype of operational system	The mixer tests at Philadelphia Mixer demonstrated effective operation in prototypic conditions representative of plant conditions (24590-QL-POA-MFAO-00001-10-00001, Rev. 00B).

Table D.6. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	The mixing system design has been provided by Philadelphia Mixers. The agitation system design is based upon the vessel design and WTP mixing requirements. The mixing test report from Philadelphia Mixer demonstrates that the equipment components are compatible (24590-QL-POA-MFAO-00001-10-00001, Rev. 00B).
Y	Final Technical Report on Technology completed	The mixing test report for the LFP vessels provided by Philadelphia Mixers demonstrate adequacy of system design (24590-QL-POA-MFAO-00001-10-00001, Rev. 00B). The R&T testing of the mixing system has been completed (SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02 Rev. 00C [cleared]).
Y	Waste processing issues have been identified and major ones have been resolved	The only issues were associated with scale-up of the equipment systems, primarily agitation and minimization of dusting of the glass-forming chemicals during addition to the vessel. This issue has been resolved and reporting is completed. Mixing reports from vendor demonstrate adequacy of system design (24590-QL-POA-MFAO-00001-10-00001). The R&T testing of mixing system has been completed (SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02 Rev. 00C [cleared]).
Y	Process and tooling are mature to support fabrication of components/system	A majority of the plant equipment has been fabricated and is on the WTP site.
Y	Production demonstrations are complete (at least one time)	A majority of the plant equipment has been fabricated and is on the WTP site.

Table D.7. Technology Readiness Level 6 Summary for LAW Melter Process System (LMP)

Criteria Satisfied (Y/N)	**Criteria**	**Basis for Completion**
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	R&T was completed on the LMP. A one-third plant scale melter was used to support testing and characterized the performance and behavior of equipment components and different process flowsheets representative of the WTP mission. Equipment components tested include the melter and its specific design features: melter feed nozzle, melter thermowells, melter bubblers, melter pouring system, and representative instrument and control systems. These testing results showed that the LMP will support design requirements as specified in the WTP Contract (DE-AC27-01RL14136). These technology testing results are documented in the following reports: 24590-101-TSA-W000-0009-148-00001, Rev. 00A; 24590-101-TSA-W000-0009-120-09, Rev. 00C; 24590-101-TSA-W000-0009-105-00006, Rev. 00A; 24590-101-TSA-W000-0009-164-00001, Rev. 00A; 24590-101-TSA-W000-0009-162-00001, Rev. 00A; 24590-101-TSA-W000-0009-148-00002, Rev. 00A; 24590-101-TSA-W000-0009-84-02, Rev. 00B; 24590-101-TSA-W000-0009-147-01, Rev. 00B; 24590-101-TSA-W000-0009-49-01, Rev. 00F; 24590-101-TSA-W000-0009-23-10, Rev. 00C; 24590-101-TSA-W000-0009-107-01, Rev. 00C; 24590-101-TSA-W000-0009-96-02, Rev. 00B; 24590-101-TSA-W000-0009-40-00002, Rev. 00A; 24590-101-TSA-W000-0009-148-00003, Rev. 00A; 24590-101-TSA-W000-0009-147-02, Rev. 00A; 24590-101-TSA-W000-0009-32-06, Rev. 00B; 24590-101-TSA-W000-0009-41-02, Rev. 00A; 24590-101-TSA-W000-0009-68-04, Rev. 00B; 24590-101-TSA-W000-0009-32-07, Rev. 00B; 24590-101-TSA-W000-0009-96-03, Rev. 00C; 24590-101-TSA-W000-0009-120-07, Rev. 00C; 24590-101-TSA-W000-0009-120-06, Rev. 00B; 24590-101-TSA-W000-0009-104-02, Rev. 00D (Rev. 1 of report); 24590-101-TSA-W000-0009-106-18, Rev. 00A; 24590-101-TSA-W000-0009-49-04, Rev. 00B; 24590-101-TSA-W000-0009-106-19, Rev. 00B; 24590-101-TSA-W000-0009-101-00007, Rev. 00A; 24590-101-TSA-W000-0009-98-06, Rev. 00A; 24590-101-TSA-W000-0009-53-01, Rev. 00E; 24590-101-TSA-W000-0009-128-02, Rev. 00C; 24590-101-TSA-W000-0009-66-06, Rev. 00B; 24590-101-TSA-W000-0009-106-07, Rev. 00C; 24590-101-TSA-W000-0009-87-09, Rev. 00B; 24590-101-TSA-W000-0009-111-01, Rev. 00B; 24590-101-TSA-W000-0009-111-02, Rev. 00B; 24590-101-TSA-W000-0009-66-05, Rev. 00B; 24590-101-TSA-W000-0009-72-00011, Rev. 00A; 24590-101-TSA-W000-0009-72-00011 Rev. 00B; 24590-101-TSA-W000-0009-144-04, Rev. 00A; 24590-101-TSA-W000-0009-135-04, Rev. 00B; 24590-101-TSA-W000-0009-106-17, Rev. 00B; 24590-101-TSA-W000-0009-102-02, Rev. 00B; 24590-101-TSA-W000-0009-102-00003, Rev. 00A; 24590-101-TSA-W000-0009-69-03, Rev. 00B; 24590-101-TSA-W000-0009-69-04, Rev. 00B; 24590-101-TSA-W000-0009-69-05, Rev. 00B; 24590-101-TSA-W000-0009-72-05, Rev. 00C; 24590-101-TSA-W000-0009-72-05, Rev. 00D; 24590-101-TSA-W000-0009-87-00019, Rev. 00A.

Table D.7. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI levels have been estimated for the LAW Vitrification Facility including the LAW melter. The RAMI targets for the LAW melter system are achieved based on R&T testing results and RAMI modeling for the LAW Vitrification Facility. The basis for the RAMI levels are provided in RAMI data development report (24590-LAW-RPT-PO-05-0001, Rev. 0) and periodic assessments of the Operational Research Assessment Model (24590-WTP-RPT-PO-05-001, Rev. 0).
Y	Frequent design changes occur	The LAW Vitrification Facility, including the LMP, is in a detailed design phase. Fabrication of the LAW Melter is underway. Design changes occur infrequently only to support final construction.
Y	Draft design drawings for final plant system are nearly complete	Section 10 of the LAW Melter system description (24590-LAW-3YD-LMP-00001, Rev. 1) identifies all applicable design documents to support the LMP design. This includes specifications, process, and mechanical system design documents, P&IDs, electrical drawings, control and instrumentation (C&I) specifications, mechanical handling, general arrangement drawings, supplier documents, and authorization basis documents.
Y	Operating environment for final system known	The operating environment for the LMP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and the LMP system description (24590-LAW-3YD-LMP-00001, Rev. 1).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI data is included the RAMI data development report (24590-LAW-RPT-PO-05-0001, Rev. 0) and periodic assessments of the Operational Research Assessment Model (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the LMP is provided in the May 2005 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering scale similar system tested with a range of simulants	See response to the first question of Table D.7.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the LMP has been modeled using the Tank Utilization Assessment (24590-WTP-RPT-PO-05-008, Rev. 0) and the WTP Material Balance (24590-WTP-RPT-PO-05-009, Rev. 0). These modeling activities have characterized the melter performance in terms of capacity the WTP mission.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	The plan for testing the LMP is document in the WTP R&T Program Plan (24590-WTP-PL-RT-01-002, Rev. 2). All testing with the LAW melter pilot plant has been completed. Reports documenting testing results are identified in the response to the first question of Table D.7.
Y	Operating limits for components determined (from design, safety and environmental compliance)	Operating limits for the LMP are identified in the LMP system description (24590-LAW-3YD-LMP-00001, Rev. 1). These operating limits are further evaluated in a series of R&T testing reports, including 24590-101-TSA-W000-0009-162-00001, Rev. 00A; 24590-101-TSA-W000-0009-106-17, Rev. 00B; 24590-101-TSA-W000-0009-157-00001, Rev. 00A; SCT-M0SRLE60-00-135-02, Rev. 00B. Also, see reports in the response to the first question of Table D.7.

Table D.7. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operational requirements document available	The minimum operating requirements for the LMP are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001, Rev. 2) and the LMP system description (24590-LAW-3YD-LMP-00001, Rev. 1).
Y	Off-normal operating responses determined for engineering scale system	Off-normal operating responses for the LMP have been evaluated in a failure modes and effects analysis (24950-QL-HC4-W000-00011-03-00481, Rev. 00A) and included in the LAW Vitrification Facility PSAR (24590-WTP-PSAR-ESH-01-002-03, Rev. 1).
Y	System technical interfaces defined	The interfaces for the LMP are defined the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and the LMP system description (24590-LAW-3YD-LMP-00001, Rev. 1)
Y	Component integration demonstrated at an engineering scale	Integrated testing of all LMP subcomponents have been completed and documented in the R&T testing reports identified in the response to the first question of Table D.7.
Y	Scaling issues that remain are identified and supporting analysis is complete	Testing to validate scaling of the LMP test system and the LMP plant design has been completed. This testing indicates that the LAW melter for the plant design has greater capacity than required to meet minimum design specifications and will exceed design specifications. Test results are provided in the following references: 24590-101-TSA-W000-0009-84-02, Rev. 00B; 24590-101-TSA-W000-0009-147-01, Rev. 00B; 24590-101-TSA-W000-0009-49-01, Rev. 00F; 24590-101-TSA-W000-0009-32-06, Rev. 00B; 24590-101-TSA-W000-0009-41-02, Rev. 00A; 24590-101-TSA-W000-0009-68-04, Rev. 00B; 24590-101-TSA-W000-0009-32-07, Rev. 00B; 24590-101-TSA-W000-0009-96-03, Rev. 00C; 24590-101-TSA-W000-0009-120-07, Rev. 00C.
Y	Analysis of project timing ensures technology will be available when required	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LAW melter technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the LMP and the balance of the LAW Vitrification Facility are described in the LMP system description (24590-LAW-3YD-LMP-00001, Rev. 1). This includes both physical and process interfaces with the LAW Vitrification Facility. These requirements have been factored into the LMP design.
Y	Acquisition program milestones established for start of final design (CD-2)	The acquisition of LMP components is defined in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0). The project has completed CD-2 as identified in DOE O 413.3 and has completed CD-3, Start of Construction.
Y	Critical manufacturing processes prototyped	Engineering and procurement activities for the LMP have been initiated and the equipment systems are being fabricated. Based upon fabrication of the LAW pilot melter, no significant fabrication issues have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	The fabrication of the LAW melter is in process. No significant fabrication issues have been identified. The LAW melter is being fabricated in the United States using several qualified vendors. Final assembly of the melter will occur at the WTP site. All fabrication activities have been awarded.

Table D.7. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Engineering feasibility fully demonstrated (e.g., will it work)	Pilot scale testing of the LAW melter indicates that the plant scale LAW melter will perform as required. Testing to validate scaling of the LMP test system and the LMP plant design has been completed. This testing indicates that the LAW melter for the plant design has greater capacity than required to meet minimum design specifications and will exceed design specifications. Test results are provided in the following references: 24590-101-TSA-W000-0009-84-02, Rev. 00B; 24590-101-TSA-W000-0009-147-01, Rev. 00B; 24590-101-TSA-W000-0009-49-01, Rev. 00F; 24590-101-TSA-W000-0009-32-06, Rev. 00B; 24590-101-TSA-W000-0009-41-02, Rev. 00A; 24590-101-TSA-W000-0009-68-04, Rev. 00B; 24590-101-TSA-W000-0009-32-07, Rev. 00B; 24590-101-TSA-W000-0009-96-03, Rev. 00C; 24590-101-TSA-W000-0009-120-07, Rev. 00C.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	The fabrication of the LAW melter is in process. No significant fabrication issues have been identified. The LAW melter is being fabricated in the United States using several qualified vendors. Final assembly of the melter will occur at the WTP site. All fabrication activities have been awarded. Production problems on the composition of the alloy were identified in the initial MA758 procurement (CCN: 150410). Issues remain with the long-term availability of the MA758, which were identified by the WTP Contractor (CCN: 078791).
Y	Technology "system" design specification complete and ready for detailed design	The design of the LAW melter system is complete. The design concept is described in the LAW Melter System Description (24590-LAW-3YD-LMP-00001, Rev. 1) and supporting design documentation references.
Y	Components are functionally compatible with operational system	The integration of the LMP within the LAW Vitrification Facility is described in the LMP system description (24590-LAW-3YD-LMP-00001, Rev. 1) and the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C). No compatibility issues are identified based on these specifications.
Y	Engineering scale test system is high-fidelity functional prototype of the operation system	Pilot scale testing of the LAW melter indicates that the plant scale LAW melter will perform as required. Testing to validate scaling of the LMP test system and the LMP plant design has been completed. This testing indicates that the LAW melter for the plant design has greater capacity than required to meet minimum design specifications and will exceed design specifications. Test results are provided in the following references: 24590-101-TSA-W000-0009-84-02, Rev. 00B; 24590-101-TSA-W000-0009-147-01, Rev. 00B; 24590-101-TSA-W000-0009-49-01, Rev. 00F; 24590-101-TSA-W000-0009-32-06, Rev. 00B; 24590-101-TSA-W000-0009-41-02, Rev. 00A; 24590-101-TSA-W000-0009-68-04, Rev. 00B; 24590-101-TSA-W000-0009-32-07, Rev. 00B; 24590-101-TSA-W000-0009-96-03, Rev. 00C; 24590-101-TSA-W000-0009-120-07, Rev. 00C.
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).

Table D.7. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Integration demonstrations have been completed (e.g., construction of testing system)	The successful construction and operation of the LAW Vitrification Pilot Plant is documented in selected R&T testing reports. A description of this testing system is provided testing reports included as references in the response to the first question of Table D.7.
Y	Final Technical Report on Technology completed	See response to the first question of Table D.7.
Y	Waste processing issues have been identified and major ones have been resolved	Waste processing issues have been identified, evaluated, and closed. These issues and their resolution are included in the following R&T testing reports: 24590-101-TSA-W000-0009-157-00001, Rev. 00A; 24590-101-TSA-W000-0009-171-00001 Rev. 00A; SCT-M0SRLE60-00-135-02, Rev. 00B; 24590-101-TSA-W000-0004-72-13, Rev. 00B; 24590-101-TSA-W000-0004-173-00001 Rev. 00A.
Y	Process and tooling are mature to support fabrication of components/system	The fabrication of the LAW melter is in process. No significant fabrication issues have been identified. The LAW melter is being fabricated in the United States using several qualified vendors. Final assembly of the melter will occur at the WTP site. All fabrication activities have been awarded. The future availability of melter refractory and MA758 special metal for bubbler assemblies is uncertain. The current MA758 procurement identified quality issues with the alloy composition, which are being resolved. The WTP Project has identified alternative bubble assembly design and materials that can support requirements if necessary (24590-101-TSA-W000-0009-69-04, Rev. 00B, 24590-101-TSA-W000-0009-23-10, Rev. 00C).
Y	Production demonstrations are complete (at least one time)	The design and fabrication of the LAW pilot melter demonstrates that the LAW plant melter can be fabricated.

Table D.8. Technology Readiness Level 6 Summary for LAW Primary Offgas Process and Secondary Offgas Vessel Vent Process System (LOP/LVP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	R&T was completed on a prototype LOP/LVP connected to the DM1200 melter, which is a one-eighth scale of the LAW Vitrification Facility Offgas System. Equipment components tested included all prototypical offgas components (i.e., film cooler, submerged bed scrubber, high efficiency mist eliminator, wet electrostatic precipitator, carbon sulfur bed for mercury removal, and the catalytic oxidizer for NO_x destruction, HEPA filtration, and caustic scrubber). These testing results showed that the LOP/LVP will support design requirements as specified in the WTP contract (DE-AC27-01RL14136). These technology testing results are documented in the following reports: 24590-101-TSA-W000-0009-120-09, Rev. 00C; 24590-101-TSA-W000-0009-107-01, Rev. 00C; 24590-101-TSA-W000-0009-120-06, Rev. 00B; 24590-101-TSA-W000-0009-106-18, Rev. 00A; 24590-101-TSA-W000-0009-54-00001, Rev. 00C; 24590-101-TSA-W000-0009-87-09, Rev. 00B; 24590-101-TSA-W000-0009-111-01 Rev. 00B; 24590-101-TSA-W000-0009-111-02, Rev. 00B; 24590-101-TSA-W000-0009-143-01, Rev. 00B; 24590-101-TSA-W000-0009-87-00019, Rev. 00A; 24590-101-TSA-W000-0009-166-00001, Rev. 00B; 24590-101-TSA-W000-0009-177-00001, Rev. 00A; 24590-101-TSA-W000-0009-174-00001 Rev. 00A. The testing of the LOP/LVP connected to the DM1200 melter did not support 99.99% destruction and removal efficiency (DRE) for naphthalene. The project strategy is to test the LOP/LVP further during cold commissioning (CCN: 128559).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI levels have been estimated for the LAW Vitrification Facility including the LOP/LVP. The RAMI targets for the LOP/LVP are achieved based on R&T testing results and RAMI modeling for the LAW Vitrification Facility. RAMI data is included the RAMI data development report (24590-LAW-RPT-PO-05-0001, Rev. 0) and periodic assessments of the Operational Research Assessment Model (24590-WTP-RPT-PO-05-001, Rev. 0).
Y	Frequent design changes occur	The LAW Vitrification Facility including the LOP/LVP is in a detailed design phase. Fabrication of the LOP/LVP equipment either is underway or will soon be procured. Design changes occur infrequently and only to support final construction.
Y	Draft design drawings for final plant system are nearly complete	Section 10 of the LOP/LVP system description (24590-LAW-3YD-LOP-00001, Rev. 1) identifies all applicable design documents to support the LOP/LVP. This includes specifications, calculations, datasheets, process and mechanical system design documents, P&IDs, electrical drawings, C&I specifications, equipment drawings, general arrangement drawings, supplier documents, and authorization basis documents.

Table D.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operating environment for final system known	The operating environment for the LOP/LVP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and the LOP/LVP system description (24590-LAW-3YD-LOP-00001, Rev. 1). Operating conditions for limited equipment components are also evaluated in the R&T testing report (24590-101-TSA-W000-0009-54-00001, Rev. 00C).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI data is included the RAMI Assessment Report (24590-LAW-RPT-PO-05-0001, Rev. 0) and the Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the LOP/LVP is provided in the May 2005 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering scale similar system tested with a range of simulants	See response to the first question of Table D.8.
Y	Modeling and simulation used to simulate system performance in an operational environment	The performance of the LOP/LVP has been modeled using the Tank Utilization Assessment (24590-WTP-RPT-PO-05-008, Rev. 0) and the WTP Material Balance (24590-WTP-RPT-PO-05-009, Rev. 0). These modeling activities have shown that the melter offgas emissions can be treated to meet stack discharge requirements. The WTP Material Balance (24590-WTP-RPT-PO-05-009, Rev. 0) is also used to estimate the emissions from the facility to support the dangerous waste permit assessments. The results of these assessments show that the LOP/LVP have been adequately designed.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	The plan for testing the LOP/LVP is documented in the WTP R&T Program Plan (24590-WTP-PL-RT-01-002, Rev. 2). Reports documenting testing results are identified in the response the first question of Table D.8.
Y	Operating limits determined using engineering scale system	Operating limits for the LOP/LVP are identified in the LOP/LVP Offgas System Description (24590-LAW-3YD-LOP-00001, Rev. 1). The testing of the LOP/LVP connected to the DM1200 melter did not support 99.99% DRE for naphthalene. The project strategy is to test the LOP/LVP further during cold commissioning (CCN: 128559).
Y	Operational requirements document available	The minimum operating requirements for the LOP/LVP are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001, Rev. 2) and the LOP/LVP Offgas System Description (24590-LAW-3YD-LOP-00001, Rev. 1).
Y	Off-normal operating responses determined for engineering scale system	Off-normal operating responses for the LOP/LVP have been evaluated in the LAW Vitrification Facility PSAR (24590-WTP-PSAR-ESH-01-002-03, Rev. 1). The testing of the LOP/LVP connected to the DM1200 melter did not support 99.99% DRE for naphthalene. The project strategy is to test the LOP/LVP System further during cold commissioning (CCN: 128559).

Table D.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	System technical interfaces defined	Interfaces for the LOP/LVP are defined the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and the LOP/LVP system description (24590-LAW-3YD-LOP-00001, Rev. 1).
Y	Component integration demonstrated at an engineering scale	Integrated testing of the LOP/LVP subcomponents has been completed, and is documented in the R&T testing reports identified in response to the first question of Table D.8.
Y	Scaling issues that remain are identified and supporting analysis is complete	The scaling of the LOP/LVP equipment components has been provided in specific component calculations identified in the LOP/LVP Offgas System Description (24590-LAW-3YD-LOP-00001, Rev. 1). The majority of the equipment components for the LOP/LVP are commercially available and the WTP Contractor is using vendor calculations to support final verification of component sizing. No unique scaling issues have been identified.
Y	Analysis of project timing ensures technology will be available when required	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the LOP/LVP technology will be incorporated into the LAW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the LOP/LVP and the balance of the LAW Vitrification Facility are described in the LOP/LVP Offgas System Description (24590-LAW-3YD-LOP-00001, Rev. 1). This includes both physical and process interfaces with the LAW Vitrification Facility. These requirements have been factored into the design of the LOP/LVP.
Y	Acquisition program milestones established for start of final design (CD-2)	The acquisition of LOP/LVP components is defined in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0). The project has completed CD-2 as identified in DOE O 413.3 and has completed CD-3, Start of Construction.
Y	Critical manufacturing processes prototyped	Engineering and procurement activities for the LOP/LVP have been initiated, and the equipment systems have been or are being fabricated. Based upon fabrication and procurement of the LOP/LVP components, no significant fabrication issues have been identified. Manufacturers are available, but vendors must be certified to quality assurance requirements.
Y	Most pre-production hardware is available to support fabrication of the system	The fabrication of the LOP/LVP is in process. No significant fabrication issues have been identified, but there are some quality concerns with the vendors.
Y	Engineering feasibility fully demonstrated (e.g., will it work)	Scaled testing of the LOP/LVP indicates that the plant design will perform as required. Test results are provided in the R&T reports identified in the response to the first question of Table D.8. The testing of the LOP/LVP connected to the DM1200 melter did not support 99.99% DRE for naphthalene. The project strategy is to test the LOP/LVP further during cold commissioning (CCN: 128559).

Table D.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	The fabrication of the LOP/LVP components is in process. No significant fabrication issues have been identified. Qualification of the carbon sulfur absorbent by testing is still in process. Some issues with vendor qualification to WTP QA requirements for the catalytic oxidizer/reducer system are being resolved.
Y	Technology "system" design specification complete and ready for detailed design	The design of the LOP/LVP is complete. The design concept is described in the LOP/LVP system description (24590-LAW-3YD-LOP-00001, Rev. 1) and supporting design documentation references.
Y	Components are functionally compatible with operational system	The integration of the LOP/LVP with the LAW Vitrification Facility is described in the LOP/LVP system description (24590-LAW-3YD-LOP-00001, Rev. 1) and the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C). No compatibility issues are identified based on these specifications.
Y	Engineering scale system is high-fidelity functional prototype of operational system	The DM1200 offgas system used in testing offgas components is representative of the process system designed for the LAW Vitrification Facility. Testing of this offgas system has provided data that are representative of plant scale operations. See response to the first question of Table D.8. Issues on meeting the DRE are discussed in other question responses.
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	The successful construction and operation of the DM1200 LOP/LVP is documented in selected R&T testing reports identified in the response to the first question. A description of this testing system is provided testing reports included as references in response to the first question of Table D.8.
Y	Final Technical Report on Technology completed	See response to the first question of Table D.8. Testing was completed to demonstrate the function and treatment capability of the LOP/LVP components. .
Y	Waste processing issues have been identified and major ones have been resolved	Carbon beds must be changed out every two years, which will be conducted during a shutdown. Several issues were identified with HEPA filter lifespan, uncertainty with the MACT, and qualification of the carbon sorbant. These waste processing issues have been identified, evaluated, and closed. These issues and their resolution are included in the following R&T testing reports: 24590-101-TSA-W000-0009-166-00001, Rev. 00B; 24590-101-TSA-W000-0009-177-00001, Rev. 00A; 24590-101-TSA-W000-0009-174-00001, Rev. 00A; 24590-101-TSA-W000-0009-171-00001 Rev. 00A.

Table D.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Process and tooling are mature to support fabrication of components/system	The fabrication of the LOP/LVP is in process. No significant fabrication issues have been identified. Qualification of the carbon sulfur absorbent by testing is still in process. Some issues with vendor qualification to WTP QA requirements for the catalytic oxidizer/reducer system are being resolved.
Y	Production demonstrations are complete (at least one time)	The design and fabrication of the DM1200 LOP/LVP demonstrates that the plant scale system can be fabricated. All components have been fabricated.

List of References

1. 06-WTP-105, “Transmittal of U.S. DOE ORP Design Oversight Report Number D-06-Design-027: Review of BNI Radiochemical Analytical Laboratory Pneumatic Autosampling System (ASX) Design,” letter dated September 25, 2006, Bechtel National, Inc., Richland, Washington.

2. 24590-101-TSA-W000-0004-158-00002, Rev. 00A, *Laser Ablation Study for High Level Waste and Melter Feed Characterization, Rev. A,* March 9, 2006, Bechtel National, Inc., Richland, Washington.

3. 24590-101-TSA-W000-0004-173-00001 Rev. 00A, *Waste, Process, and Product Variations and Uncertainties for Waste Treatment Plant IHLW and ILAW*, February 27, 2006, Bechtel National, Inc., Richland, Washington.

4. 24590-101-TSA-W000-0004-72-13, Rev. 00B, *Technical Basis for LAW Vitrification Stream Physical and Rheological Property Bounding Conditions*, February 17, 2004, Bechtel National, Inc., Richland, Washington.

5. 24590-101-TSA-W000-0009-101-00007, Rev. 00A, *RPP-WTP Pilot Melter Prototypic LAW Container and HLW Canister Glass Fill Test Results Report*, May 26, 2004, Bechtel National, Inc., Richland, Washington.

6. 24590-101-TSA-W000-0009-102-00003, Rev. 00A, *LAW Glass Formulation to Support Melter Runs with Simulants*, February 23, 2004, Bechtel National, Inc., Richland, Washington.

7. 24590-101-TSA-W000-0009-102-02, Rev. 00B, *Final Report – Baseline LAW Glass Formulation Testing*, September 30, 2003, Bechtel National, Inc., Richland, Washington.

8. 24590-101-TSA-W000-0009-104-02, Rev. 00D (Rev. 1 of report), *RPP-WTP Pilot Melter – 40% Height LAW Container Pour Test Results Report*, June 13, 2003, Bechtel National, Inc., Richland, Washington.

9. 24590-101-TSA-W000-0009-105-00006, Rev. 00A, *Bubbling Rate and Foaming Tests on the DuraMelter 1200 with LAW C22 and LAW A30 Glasses*, July 15, 2004, Bechtel National, Inc., Richland, Washington.

10. 24590-101-TSA-W000-0009-106-07, Rev. 00C,“*DuraMelter 100 Sub-Envelope Changeover Testing Using LAW Sub-Envelopes A1 and C1 Feeds in Support of the LAW Pilot Melter*, September 30, 2003, Bechtel National, Inc., Richland, Washington.

11. 24590-101-TSA-W000-0009-106-17, Rev. 00B, *DuraMelter 100 Sub-Envelope Changeover Testing Using LAW Sub-Envelope A3 and C2 Feeds in Support of the LAW Pilot Melter*, October 29, 2003, Bechtel National, Inc., Richland, Washington.

12. 24590-101-TSA-W000-0009-106-18, Rev. 00A, *RPP-WTP-Pilot Melter Envelope C Melter Emissions Test Results Report*, September 4, 2003, Bechtel National, Inc., Richland, Washington.

13. 24590-101-TSA-W000-0009-106-19, Rev. 00B, *RPP-WTP Pilot Melter Sub-envelope C2-A3 Changeover Test Results Report*, November 19, 2003, Bechtel National, Inc., Richland, Washington.

14. 24590-101-TSA-W000-0009-107-01, Rev. 00C, *RPP Pilot Melter Envelope A Melter Emissions Test Results Report*, September 23, 2003, Bechtel National, Inc., Richland, Washington.

15. 24590-101-TSA-W000-0009-111-01 Rev. 00B, *Integrated Offgas System Tests on the DM1200 Melter with RPP-WTP LAW Sub-Envelope C1 Simulants*, October 23, 2003, Bechtel National, Inc., Richland, Washington.
16. 24590-101-TSA-W000-0009-111-02, Rev. 00B, *Integrated Offgas System Tests on the DM1200 Melter with RPP-WTP LAW Sub-Envelope A1 Simulants*, November 12, 2003, Bechtel National, Inc., Richland, Washington.
17. 24590-101-TSA-W000-0009-120-06, Rev. 00B, *RPP-WTP Envelope B Melter Emissions Test Results Report*, September 24, 2003, Bechtel National, Inc., Richland, Washington.
18. 24590-101-TSA-W000-0009-120-07, Rev. 00C, *RPP-WTP Pilot Melter Sub-envelope B1 Variation Test Results Report*, September 5, 2003, Bechtel National, Inc., Richland, Washington.
19. 24590-101-TSA-W000-0009-120-09, Rev. 00C, *RPP-WTP Pilot Melter Offgas System Inspection Report*, November 13, 2003, Bechtel National, Inc., Richland, Washington.
20. 24590-101-TSA-W000-0009-128-02, Rev. 00C, *Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A1 Feed (LAWA44 Glass) in Support of the LAW Pilot Melter*, April 17, 2003, Bechtel National, Inc., Richland, Washington.
21. 24590-101-TSA-W000-0009-134-00003, Rev. 00A, *Corrosion Testing of Bubbler Materials for LAW Vitrification*, August 26, 2004, Bechtel National, Inc., Richland, Washington.
22. 24590-101-TSA-W000-0009-135-04, Rev. 00B, *Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope B2 Feed in Support of the LAW Pilot Melter*, October 23, 2003, Bechtel National, Inc., Richland, Washington.
23. 24590-101-TSA-W000-0009-143-01, Rev. 00B, *Integrated Offgas System Tests on the DM1200 Melter with RPP-WTP LAW Sub-Envelope B1 Simulants*, November 19, 2003, Bechtel National, Inc., Richland, Washington.
24. 24590-101-TSA-W000-0009-144-04, Rev. 00A, *DuraMelter 100 Sub-Envelope Changeover Testing Using LAW Sub-Envelope A2 and B1 Feeds in Support of the LAW Pilot Melter*, October 2, 2003, Bechtel National, Inc., Richland, Washington.
25. 24590-101-TSA-W000-0009-147-01, Rev. 00B, *RPP Pilot Melter Sub-envelope C1 Production Verification Test Results Report*, December 8, 2003, Bechtel National, Inc., Richland, Washington.
26. 24590-101-TSA-W000-0009-147-02, Rev. 00A, *RPP-WTP Pilot Melter Metallic Dam Corrosion Test Results Report*, December 31, 2003, Bechtel National, Inc., Richland, Washington.
27. 24590-101-TSA-W000-0009-148-00001, Rev. 00A, *Refractory Corrosion Analysis for the DM-5000A M-Area and DM-3300 LAW Pilot Melters*, January 26, 2004, Bechtel National, Inc., Richland, Washington.
28. 24590-101-TSA-W000-0009-148-00002, Rev. 00A, *RPP Pilot Melter ADS Pump Performance Test Results Report*, January 28, 2004, Bechtel National, Inc., Richland, Washington.
29. 24590-101-TSA-W000-0009-148-00003, Rev. 00A, *RPP-WTP Pilot Melter Lid Hanger Corrosion Test Results Report*, January 23, 2004, Bechtel National, Inc., Richland, Washington.

30. 24590-101-TSA-W000-0009-157-00001, Rev. 00A, *Final Report – DM100 HLW and LAW Tests of the Influence of Technetium on Cesium Volatility Using Rhenium as a Technetium Surrogate*, October 15, 2004, Bechtel National, Inc., Richland, Washington.

31. 24590-101-TSA-W000-0009-162-00001, Rev. 00A, *Investigation of Glass Bubbling and Increased Production Rate (Proprietary Data)*, October 28, 2004, Bechtel National, Inc., Richland, Washington.

32. 24590-101-TSA-W000-0009-166-00001, Rev. 00B, *Regulatory Offgas Emissions Testing on the DM1200 Melter System Using HLW and LAW Simulants,* November 11, 2005, Bechtel National, Inc., Richland, Washington.

33. 24590-101-TSA-W000-0009-171-00001 Rev. 00A, *Summary of DM1200 Operation at VSL*, October 10, 2006, Bechtel National, Inc., Richland, Washington.

34. 24590-101-TSA-W000-0009-174-00001 Rev. 00A, *Summary of DM1200 WESP History and Performance*, August 7, 2006, Bechtel National, Inc., Richland, Washington.

35. 24590-101-TSA-W000-0009-177-00001, Rev. 00A., *Summary of DM1200 SBS History and Performance*, October 10, 2006, Bechtel National, Inc., Richland, Washington.

36. 24590-101-TSA-W000-0009-23-09, Rev. 00C, *RPP-WTP Pilot Melter Bubbler Consumable Changeout Box Test Results Report*, August 20, 2003, Bechtel National, Inc., Richland, Washington.

37. 24590-101-TSA-W000-0009-23-10, Rev. 00C, *RPP-WTP Pilot Melter Bubbler Life Extension Test Results Report*, January 7, 2004, Bechtel National, Inc., Richland, Washington.

38. 24590-101-TSA-W000-0009-32-06, Rev. 00B, *RPP-WTP Pilot Melter Sub--Envelope C1 Variation Test Results Report*, February 10, 2003, Bechtel National, Inc., Richland, Washington.

39. 24590-101-TSA-W000-0009-32-07, Rev. 00B, *RPP-WTP Pilot Melter Sub-envelope C2 Variation Test Results Report*, March 24, 2003, Bechtel National, Inc., Richland, Washington.

40. 24590-101-TSA-W000-0009-40-00002, Rev. 00A, *RPP-WTP Pilot Melter LAW Discharge Heater Corrosion Test Results Report*, February 4, 2004, Bechtel National, Inc., Richland, Washington.

41. 24590-101-TSA-W000-0009-41-02, Rev. 00A, *RPP-WTP Pilot Melter Sub-envelope A2 Variation Test Results Report*, January 21, 2003, Bechtel National, Inc., Richland, Washington.

42. 24590-101-TSA-W000-0009-49-01, Rev. 00F, *RPP-WTP Pilot Melter Sub-Envelope A3 Variation Test Results Report*, November 21, 2002, Bechtel National, Inc., Richland, Washington.

43. 24590-101-TSA-W000-0009-49-04, Rev. 00B, *RPP Pilot Melter Sub-Envelope A2-B1 Changeover Test Results Report*, November 11, 2003, Bechtel National, Inc., Richland, Washington.

44. 24590-101-TSA-W000-0009-53-01, Rev. 00E, *Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAW A88 Glass) in Support of the LAW Pilot Melter*, February 26, 2003, Bechtel National, Inc., Richland, Washington.

45. 24590-101-TSA-W000-0009-54-00001, Rev. 00C, *Final Report – Submerged Bed Scrubber (SBS): Off-line Component Testing of DM1200 SBS Unit*, August 30, 2004, Bechtel National, Inc., Richland, Washington.

46. 24590-101-TSA-W000-0009-66-05, Rev. 00B, *Test Matrix to Support Property-Composition Model Development for RPP-WTP LAW Glasses*, December 16, 2003, Bechtel National, Inc., Richland, Washington.

47. 24590-101-TSA-W000-0009-66-06, Rev. 00B, *Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope B1 Feed in Support of the LAW Pilot Melter,* June 5, 2003, Bechtel National, Inc., Richland, Washington.

48. 24590-101-TSA-W000-0009-68-04, Rev. 00B, *RPP-WTP Pilot Melter Sub-Envelope A-1 Variation Test Results Report*, May 8, 2003, Bechtel National, Inc., Richland, Washington.

49. 24590-101-TSA-W000-0009-69-03, Rev. 00B, *Final Report – LAW Glass formulation to Support AZ-102 Actual Waste Testing*, September 30, 2003, Bechtel National, Inc., Richland, Washington.

50. 24590-101-TSA-W000-0009-69-04, Rev. 00B, *LAW Glass Formulation to Support AP-101 Actual Waste Testing*, September 4, 2003, Bechtel National, Inc., Richland, Washington.

51. 24590-101-TSA-W000-0009-69-05, Rev. 00B, *LAW Glass Formulation to Support AZ-101 Actual Waste Testing*, October 2, 2003, Bechtel National, Inc., Richland, Washington.

52. 24590-101-TSA-W000-0009-72-00011 Rev. 00B, *Letter Report – Summary and Recommendations on Viscosity and Electrical Conductivity Model Forms to Support LAW Vitrification*, October 28, 2004, Bechtel National, Inc., Richland, Washington.

53. 24590-101-TSA-W000-0009-72-05, Rev. 00C, *Final Report – Regulatory Spike Testing for RPP-WTP LAW and HLW Glasses for Compliance with Land Disposal Restrictions*, June 27, 2003, Bechtel National, Inc., Richland, Washington.

54. 24590-101-TSA-W000-0009-72-05, Rev. 00D, *Final Report – Regulatory Spike Testing for RPP-WTP LAW and HLW Glasses for Compliance with Land Disposal Restrictions*, August 8, 2003, Bechtel National, Inc., Richland, Washington.

55. 24590-101-TSA-W000-0009-84-02, Rev. 00B, *RPP-WTP-Pilot Melter Sub-envelope C1-A1 Changeover Test Results Report,* October 1, 2003, Bechtel National, Inc., Richland, Washington.

56. 24590-101-TSA-W000-0009-87-00019, Rev. 00A, *Summary Report – Comparison of Offgas Emissions from Tests with LAW Simulants on the DM100, DM1200, and DM3300 Melters*, April 28, 2004, Bechtel National, Inc., Richland, Washington.

57. 24590-101-TSA-W000-0009-87-09, Rev. 00B, *Off-line Tests of the DM 1200 Thermal Catalytic Oxidation (TCO) Unit*, April 17, 2003, Bechtel National, Inc., Richland, Washington.

58. 24590-101-TSA-W000-0009-96-02, Rev. 00B, *RPP-WTP Pilot Melter Glass Pool Foaming Control Test Results Report*, November 18, 2003, Bechtel National, Inc., Richland, Washington.

59. 24590-101-TSA-W000-0009-96-03, Rev. 00C, *RPP-WTP Pilot Melter Sub-Envelope B2 Variation Test Results Report*, October 31, 2003, Bechtel National, Inc., Richland, Washington.

60. 24590-101-TSA-W000-0009-98-06, Rev. 00A, *Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope C1 Feed (LAWC22 Glass) in Support of the LAW Pilot Melter*, December 13, 2002, Bechtel National, Inc., Richland, Washington.

61. 24590-CM-POA-AELE-00009-01-00001 to 00048, *LA-ICP-AES Prototype Design*, November 2, 2006, Bechtel National, Inc., Richland, Washington.

62. 24590-LAB-3PS-AELE-T0002, Rev. 0, *Engineering Specification for Inductively Coupled Plasma Atomic Emission Spectrometer with Laser Ablation (Prototype)*, October 24, 2005, Bechtel National, Inc., Richland, Washington.

63. 24590-LAB-3YD-AHL-00001, Rev. 1, *System Description for the Analytical Hotcell Laboratory Equipment (AHL)*, August 5, 2005, Bechtel National, Inc., Richland, Washington.

64. 24590-LAB-3YD-ARL-00001, Rev. 1, *System Description for the Analytical Radiological Laboratory Equipment (ARL)*, February 3, 2005, Bechtel National, Inc., Richland, Washington.

65. 24590-LAW-3PS-HCHH-T0002, *Engineering Specification for Special Inert Fill Hoppers – Low Activity Waste Vitrification Facility*, September 18, 2003, Bechtel National, Inc., Richland, Washington.

66. 24590-LAW-3PS-HCTH-T0001, *Engineering Specification for LAW Product Container Lidding Equipment*, February 16, 2006, Bechtel National, Inc., Richland, Washington.

67. 24590-LAW-3PS-HDYR-T0001, *Engineering Specification for Power Manipulators and Turntables – Low Activity Waste Vitrification Facility*, July 11, 2005, Bechtel National, Inc., Richland, Washington.

68. 24590-LAW-3PS-M000-T0006, *Engineering Specification for Shard Sampling System – Low Activity Waste Vitrification Facility*, May 6, 2004, Bechtel National, Inc., Richland, Washington.

69. 24590-LAW-3YD-LFH-00001, Rev. 1, *System Description for System LFH – LAW Container Finishing Handling System*, October 13, 2006, Bechtel National, Inc., Richland, Washington.

70. 24590-LAW-3YD-LFP-00001, Rev. 1, *System Description for the LAW Melter Feed Process (LFP) System*, June 6, 2005, Bechtel National, Inc., Richland, Washington.

71. 24590-LAW-3YD-LMP-00001, Rev. 1, *System Description for the LAW Melter Process System (LMP)*, November 9, 2005, Bechtel National, Inc., Richland, Washington.

72. 24590-LAW-3YD-LOP-00001, Rev. 1, *System Description for the LAW Primary Offgas Process (LOP) and Secondary Offgas Vessel Vent Process (LVP) Systems*, March 23, 2005, Bechtel National, Inc., Richland, Washington.

73. 24590-LAW-RPT-PO-05-0001, Rev. 0, *LAW Reliability, Availability, and Maintainability Data Development Report*, June 8, 2005, Bechtel National, Inc., Richland, Washington.

74. 24590-QL-HC4-HAHH-0001-06-00016 through 00030, *Autosampling System ASX-SMPLR*, November 17, 2004, Bechtel National, Inc., Richland, Washington.

75. 24590-QL-MRA-AELE-00009-S0001, *Materials Requisition Supplement: ICP AES for 222S, LA-ICP-AES Glovebox for 222S, and Laser Ablation System for 222S*, March 23, 2005, Bechtel National, Inc., Richland, Washington.

76. 24590-QL-POA-MFAO-00001-10-00001, Rev. 00B, *Laboratory Test Report: HLW Melter Feed Preparation Vessel and HLW Melter Feed Vessel Agitators*, April 3, 2004, Bechtel National, Inc., Richland, Washington.

77. 24590-WTP-3DP-G04B-00027, Rev. 8, *Design Verification*, September 15, 2006, Bechtel National, Inc., Richland, Washington.

78. 24590-WTP-3DP-G04B-00046, Rev. 16, *Engineering Drawings*, November 7, 2006, Bechtel National, Inc., Richland, Washington.

79. 24590-WTP-3DP-G04T-00901, Rev. 10, *Design Change Control*, April 25, 2006, Bechtel National, Inc., Richland, Washington.

80. 24590-WTP-3DP-G04T-00913, Rev. 5, *Review of Engineering Documents*, August 28, 2006, Bechtel National, Inc., Richland, Washington.

81. 24590-WTP-3PS-MHSS-T0002, Rev. 0, *Engineering Specification for the Autosampling System (ASX)*, June 16, 2004, Bechtel National, Inc., Richland, Washington.

82. 24590-WTP-3YD-ASX-00001, Rev. A, *System Description for the Autosampling System (ASX)*, April 10, 2002, Bechtel National, Inc., Richland, Washington.

83. 24590-WTP-CE-PC-06-001, Rev. 0, *WTP Project Estimate at Completion*, May 31, 2006, Bechtel National, Inc., Richland, Washington.

84. 24590-WTP-DB-ENG-01-001, Rev. 1C, *WTP Basis of Design*, November 1, 2006, Bechtel National, Inc., Richland, Washington.

85. 24590-WTP-PL-MG-01-002, Rev. 4, *WTP Configuration Management Plan*, May 16, 2006, Bechtel National, Inc., Richland, Washington.

86. 24590-WTP-PL-RT-01-002, Rev. 2, *WTP Research and Technology (R&T) Program Plan*, April 20, 2004, Bechtel National, Inc., Richland, Washington.

87. 24590-WTP-PSAR-ESH-01-002-03, Rev. 1, *Preliminary Safety Analysis Report to Support Construction Authorization; LAW Facility Specific Information*, September 30, 2003, Bechtel National, Inc., Richland, Washington.

88. 24590-WTP-RPT-OP-01-001, Rev. 2, *Operations Requirements Document*, May 5, 2003, Bechtel National, Inc., Richland, Washington.

89. 24590-WTP-RPT-PO-05-001, Rev. 0, *2005 WTP Operation Research Assessment* , August 29, 2005, Bechtel National, Inc., Richland, Washington.

90. 24590-WTP-RPT-PO-05-008, Rev. 0, *2005 WTP Tank Utilization Assessment*, August 8, 2005, Bechtel National, Inc., Richland, Washington.

91. 24590-WTP-RPT-PO-05-009, Rev. 0, *2005 WTP Material Balance and Process Flowsheet Assessment*, November 10, 2005, Bechtel National, Inc., Richland, Washington.

92. 24590-WTP-RPT-PR-01-006, Rev. 13, *Risk Assessment Report*, dated May 31, 2006, Bechtel National, Inc., Richland, Washington.

93. 24590-WTP-RPT-PR-01-006, *WTP Risk Management Plan*, dated May 31, 2006, Bechtel National, Inc., Richland, Washington.

94. 24950-QL-HC4-HAHH-00001-12-00001, Rev. 00B, *WTP Autosampling System Reliability Assessment,* December 11, 2004, Bechtel National, Inc., Richland, Washington.

95. 24950-QL-HC4-HAHH-00001-12-0001, *WTP Autosampling System: Autosampling System Operator Manual*, December 20, 2004, Bechtel National, Inc., Richland, Washington.

96. 24950-QL-HC4-W000-00011-03-00481, Rev. 00A, *LAW Melter Failure Modes and Effects Analysis*, May 10, 2004, Bechtel National, Inc., Richland, Washington.

97. CCN: 078791, "Consideration on Melter Materials," letter dated February 24, 2005, Bechtel National, Inc., Richland, Washington. .

98. CCN: 128559, "White Paper on the Analysis of Naphthalene Destruction and Removal Efficiency (DRE) Testing at the Vitreous State Laboratory (VSL)," letter dated December 15, 2005, Bechtel National, Inc., Richland, Washington.

99. CCN: 139427, "Waste Treatment and Immobilization Plant/222-S Laboratory Task Plan," letter dated April 17, 2006, Bechtel National, Inc., Richland, Washington.

100. CCN: 150410, "LAW Melter Bubbler Materials," letter dated January 23, 2007, Bechtel National, Inc., Richland, Washington.

101. DOE O 413.3A, *Program and Project Management for the Acquisition of Capital Assets*, July 28, 2006, U.S. Department of Energy, Washington, D.C.

102. DE-AC27-01RL14136, "Waste Treatment and Immobilization Plant Contract," December 1, 2005, Bechtel National, Inc., Richland, Washington.

103. NHC-8373, *The Interlaboratory Pneumatic Transfer Network for Radioactive Samples Operated in the Analytical Laboratories of the COGEMA La Hague Reprocessing Plants (France), Numatec Hanford Company, Richland, Washington*, June 1, 2001, Bechtel National, Inc., Richland, Washington.

104. NHC-8374, *The Computerized Data Management System Operated in the Analytical Laboratories of the COGEMA La Hague Reprocessing Plants (France), Numatec Hanford Company, Richland, Washington*, June 1, 2001, Bechtel National, Inc., Richland, Washington.

105. NHC-8375, *Analysis Operating Times Observed in the Analytical Laboratories of the COGEMA La Hague Reprocessing Plants (France*), *Numatec Hanford Company, Richland, Washington*, June 1, 2001, Bechtel National, Inc., Richland, Washington.

106. SCT-M0SRLE60-00-110-12, Rev. 00B, *LAW Radioactive Coupon* CO_2 *Decontamination Test*, October 1, 2003, Bechtel National, Inc., Richland, Washington.

107. SCT-M0SRLE60-00-135-02, Rev. 00B, *RPP-WTP LAW Melter Offgas Flammability Assessment*, November 19, 2003, Bechtel National, Inc., Richland, Washington.

108. SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02 Rev. 00C (cleared), *Evaluation of Wetting Agents to Mitigate Dusting of Glass-forming Chemicals During Delivery to the Melter Feed Preparation Vessel (U)*, July 31, 2003, Bechtel National, Inc., Richland, Washington.

109. SCT-M0SRLE60-00-99-07, *LAW Vendor Coupon CO_2 Blasting Tests*, September 5, 2002, Bechtel National, Inc., Richland, Washington.

110. SCT-MOSRLE60-00-216-00001, Rev. A, *The Development of Laser Ablation Inductively Coupled Plasma Atomic Emission Spectroscopy for the Analysis of Hanford High Level Waste: Phase I (U), Rev. A*, September 27, 2005, Bechtel National, Inc., Richland, Washington.

111. SCT-MOSRLE60-00-216-00002, Rev. 0, "*The Development of Laser Ablation Inductively Coupled Plasma Atomic Emission Spectroscopy for the Analysis of Hanford High Level Waste: Phase II (U), Rev. 0*, March 9, 2006, Bechtel National, Inc., Richland, Washington.

Appendix E

Participants in the TRL Assessment

Appendix E
Participants in the TRL Assessment

Table E.1 provides a list of participants in the Technology Readiness Level Assessment for the Analytical Laboratory (LAB), Balance of Facilities (BOF), and LAW Waste Vitrification Facility for each individual critical system evaluated. The participants are divided into the Assessment Team and the Waste Treatment and Immobilization Plant (WTP) Project Technology and Engineering support teams.

The Assessment Team was compromised of staff and consultants representing the U.S. Department of Energy (DOE), Office of River Protection (ORP) (Hanford Site) and Office of Project Recovery (DOE Headquarters). The Assessment Team was also supported by William Nolte of the Air Force Research Laboratory who developed the TRL Calculator used in this assessment.

The Assessment Team was assisted by WTP Project Technology and Engineering teams comprised of subject matter experts associated with the critical technology elements that were being evaluated. These subject matter experts were either responsible for testing the technologies or incorporating the technology design into the WTP. In general, technology testing is managed by staff from Washington Group International (WGI), and engineering of the systems is managed by staff from Bechtel National, Inc. (BNI).

Table E.1. Participants in the Technology Readiness Level Assessment for the WTP Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facility

Name	Affiliation	System Evaluated							
		Analytical Hotcell Laboratory Equipment (AHL)	Analytical Radiological Laboratory Equipment (ARL)	Autosampling System (ASX)	ILAW Container Finishing Handling-Container Sealing (LFH)	ILAW Container Finishing Handling-Container Decontamination (LFH)	LAW Melter Feed Process (LFP)	LAW Melter Process (LMP)	Melter Offgas System/LAW Secondary Offgas/Vessel Vent Process (LOP/LVP)
Assessment Team									
Alexander, Don	DOE/ORP	X	X	X	X	X	X	X	X
Babel, Carol	DOE/ORP	X	X		X	X	X	X	X
Holton, Langdon	ORP-PNNL	X	X	X	X	X	X	X	X
Nolte, William	Air Force Research Laboratory						X	X	
Ryan, Mary	DOE/ORP	X	X	X					
Sutter, Herb	DOE EM Consultant	X	X	X	X	X	X	X	X
Young, Joan	ORP-PNNL	X	X	X	X	X	X	X	X
WTP Project Technology and Engineering									
Damerow, Fred	WGI-Process Technology	X	X	X	X	X	X	X	X
Hall, Mark	BNI-Melter Process Technology							X	X
Hanson, Robert	BNI-LAW Process Systems	X	X	X	X	X	X	X	X
Kunkler, Guy	BNI-Autosampling System			X					
LaBryer, Johnny	BNI-LAW Mechanical Handling				X	X	X	X	X
Perez, Joseph	WGI-Melter Process Technology						X	X	X
Perkins, Doug	WGI-Analytical Laboratory Systems	X	X	X					
Peters, Richard	BNI-Melter Process Technology							X	X
Petkus, Lawrence	WGI-Process Technology	X	X	X	X	X	X	X	X

Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) HLW Waste Vitrification Facility

L. Holton
D. Alexander
C. Babel
H. Sutter
J. Young

August 2007

Prepared by the
U.S. Department of Energy
Office of River Protection
Richland, Washington, 99352

07-DESIGN-046

Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) HLW Waste Vitrification Facility

L. Holton
D. Alexander
C. Babel
H. Sutter
J. Young

August 2007

Prepared by the
U.S. Department of Energy
Office of River Protection
under Contract DE-AC05-76RL01830

Summary

The U.S. Department of Energy (DOE), Office of River Protection (ORP) and the DOE Office of Environmental and Radioactive Waste Management (EM), Office of Project Recovery have completed a Technology Readiness Assessment (TRA) for the Hanford Waste Treatment and Immobilization Plant (WTP) High-Level Waste Vitrification Facility (HLW). The purpose of this assessment was to determine if the maturity of critical technology elements (CTE) is sufficient to be incorporated into the final design of this facility.

The methodology used for this TRA was based upon the detailed guidance for conducting TRAs contained in the Department of Defense (DoD), *Technology Readiness Assessment Deskbook*[1]. The assessment utilized a slightly modified version of the Technology Readiness Level (TRL) Calculator[2] originally developed by Nolte et al. (2003) to determine the TRL for the CTE.

The TRA consists of three parts:

1. Identifying the CTEs

2. Assessing the TRLs of each CTE using the technical readiness scale used by the DoD and National Aeronautics and Space Administration (NASA), and adapted by the Assessment Team for use by DOE (Table S-1)

3. Evaluating, if required, technology testing or engineering work necessary to bring any immature technologies to appropriate maturity levels.

CTEs are those technologies that are essential to successful operation of the facility and are new or are being applied in new or novel ways or environments. The CTE identification process was based upon the definition of WTP systems and the evaluation of 30 systems from the HLW Vitrification Facility. Four of these were identified at CTEs as described below. An identification of systems evaluated and CTEs is presented in Appendix B.

- HLW Melter Feed Process System (HFP) used to prepare the HLW melter feed
- HLW Melter System (HMP), which includes the HLW melter
- HLW Melter Offgas Treatment Process System/Process Vessel Vent Exhaust System (HOP/PVV) used to treat the HLW melter offgas
- Pulse Jet Mixer (PJM) system and Radioactive Liquid Waste Disposal System (RLD), including the submerged bed scrubber (SBS) condensate vessels in the HOP used to store and blend secondary liquid wastes.

The TRL of each CTE was evaluated against a scale developed for this assessment, termed the DOE-EM scale. This is shown in Table 1-1. This scale was developed to support assessment of radioactive waste treatment technologies and is consistent with the scales originally developed by NASA and the DoD. A comparison of the three TRL scales is contained in Appendix A.

---

[1] DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005

[2] Nolte, William L., et al., *Technology Readiness Level Calculator*, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003

The DoD and NASA normally require a TRL 6 for incorporation of a technology into the design process. This is done based upon the recommendations of an influential report[3] by the U.S. General Accounting Office (GAO) that examined the differences in technology transition between the DoD and private industry. It concluded that the DoD takes greater risks and attempts to transition emerging technologies at lesser degrees of maturity than private industry. The GAO also concluded that use of immature technology increased overall program risk and recommended that the DoD adopt the use of NASA's TRLs as a means of assessing technology maturity prior to transition into final design. Based upon the precedence set by DoD, this assessment used TRL 6 as the basis for determining that a technology is sufficiently mature for incorporation into the final design.

A TRL Calculator was used to provide a structured and consistent assessment to determine the TRL of each CTE identified. The TRL Calculator is a standard set of questions addressing hardware, software, program, and manufacturability. The TRL Calculator is implemented in Microsoft Excel™ and produces a graphical display of the TRL achieved. It was adapted for this assessment by adding and modifying existing questions to make it more applicable to DOE waste treatment equipment and processes.
The TRL Calculator is described in Appendix B. Specific responses to each of the TRL questions for the CTEs evaluated in this assessment are presented in Appendix C. The CTEs were not evaluated to determine if they had matured beyond TRL 6. The results of this TRL determination are presented in Table S-1.

The Assessment Team has concluded that the technology status of the HLW Vitrification Facility technologies is sufficiently mature to continue to advance the final design of these facilities. Based upon the results of this assessment, the following recommendations for specific technologies are made:

1. Testing of a prototypical HLW film cooler and film cooler cleaner should be completed to demonstrate the adequacy of the equipment concepts prior to cold commissioning.

    Note: This testing is part of the planned work to resolve the External Flowsheet Review Team (EFRT) issue M-17, "HLW Film Cooler Plugging," dealing with film cooler blockages.

    The use of a film cooler in non-bubbled HLW melters is demonstrated in operations at the West Valley Demonstration Project (WVDP) and the Savannah River Defense Waste Processing Facility. The process conditions that increase film cooler blockages in bubbled melters such as the WTP HLW melter have been evaluated (CCN:144619) but are not completely understood. Consistent delivery of a high-solid feed from ultrafiltration to HLW vitrification, and limiting the melter bubbler air rates are factors that can mitigate film cooler blockage. While testing has shown it is possible to maintain HLW vitrification melt rates with lower concentration feeds, this mode of operation could increase plugging in the film cooler. There may be cold cap conditions and bubbler locations where film cooler plugging is more prevalent, as well as high-bubbling conditions. Understanding these conditions would be useful for optimization of melter design and production rates.

    Because the DM1200 was operated for a limited period of time (approximately 20 days) with the final design configuration, it is not known whether the cited limitations on bubbler rates will prevent excessive film cooler blockages. The film coolers appear to be adequate for a melter capacity of 3 MTG/day without modification. If capacities greater than 3 MTG/day are required, design changes to the melter may be warranted.

---

[3] GAO/NSIAD-99-162, *Best Practices: Better Management of Technologies can Improve Weapon System Outcomes*, U.S. Government Accountability Office, July 1999

Table S.1. Technology Readiness Level Summary for HLW Vitrification Critical Technology Elements

Critical Technology Element/Description	Technology Readiness Level	Rationale
HLW Melter Feed Process System (HFP) The HFP mixes HLW waste and glass formers to provide feed for the HLW melters.	**6**	There has been extensive WTP and vendor testing to demonstrate the adequacy of the mixing systems.
HLW Melter Process System (HMP) The HMP vitrifies the waste feed slurry produced in the HFP.	**6**	The HLW melter has a significant development basis in previous DOE projects and developmental tests for the WTP. Testing of four reference HLW feeds was determined adequate to support initial operations of the WTP. However, extensive evaluation of alternative anticipated HLW glass compositions has not been completed.
HLW Melter Offgas Treatment Process System/Process Vessel Vent Exhaust System (HOP/PVV) The HOP removes hazardous particulates, aerosols, and gases from the HLW melter offgas and vessel ventilation process offgas. The PVV provides a pathway for vessel offgas to the HOP for treatment.	**5**	The HOP/PVV designs have a significant development basis in the WVDP and testing with the DM1200 melter and offgas system. However, the HOP/PVV was determined to be a TRL 5 because risks remain with the HLW melter film coolers, SBS, carbon columns, and the WESP design, the later of which must achieve the lifetime of 40 years.
Pulse Jet Mixer (PJM) System/Radioactive Liquid Waste Disposal System(RLD)/HOP The PJM system mixes waste streams comprised of liquid and solids, blends liquids and solids, and suspends solids for sampling and transport. The RLD receives effluents from contaminated waste treatment processes areas in the HLW Facility, equipment flushes, and facility sumps and flushes. HOP SBS Condensate Vessels - includes all vessels in the HLW Facility that are mixed with PJMs.	**4**	Extensive testing of PJMs to demonstrate adequate mixing of slurries with non-Newtonian rheology characteristics has been completed. The WTP Contractor has recently identified requirement to test PJMs for use in vessels containing slurries with Newtonian rheology characteristics to demonstrate adequacy of design to mix, suspend, and re-suspend solids. No clear requirements exist for PJM mixing requirements. Thus, the PJMs were determined to be TRL 4. See 07-DESIGN-047 for further discussion.

The solutions planned for film cooler blockages (limit bubbling rate, film cooler cleaner, replaceable film cooler) do not include evaluation of design options that might prevent film cooler blockages from forming. For example, there might be design solutions such as splash plates within the plenum below the film cooler, redesign of the melter lid for a more optimum bubbler layout with an increased number of bubblers, or a taller melter plenum that would be more effective in de-entrainment of particulates.

2. Testing and analysis to demonstrate the adequacy of the Wet Electrostatic Precipitator (WESP) design is recommended.

   Further testing of the WESP is recommended to address operational modes. The Vitreous State Laboratory of the Catholic University of America tests indicated difficulties restoring power to the WESP electrodes may be related to the melter feed composition (24590-101-TSA-W000-0009-174-00001). In some cases, the WESP electrodes could not be brought back up to full voltage after significant operation with low-activity waste (LAW) feeds. While no problems were observed with HLW simulants during DM1200 tests, operational information should be confirmed for the HLW feed to understand if feed properties caused the problems.

Further evaluation is also recommended to prove the viability of 6% molybdenum (Mo) stainless steels for WESP internals and vessels in the WTP offgas environment. Selection of a corrosion resistant alloy for WESP vessels and internals is of critical importance, because the WESP vessel is not accessible for maintenance (except for the electrode connectors) or removable for the 40-year life of the HLW Vitrification Facility. The WESP vessel and internals are constructed of 6% Mo stainless steel (24590-HLW-N1D-HOP-00002). The article by Phull (2000) was the basis for the selection of the 6% Mo for the WTP in the WESP corrosion evaluation (24590-HLW-N1D-HOP-00002. Phull showed that even 6% Mo stainless steels exhibited very slight susceptibility to corrosion attack after 656 days of exposure to flue gases. Data from Phull implies that a 6% Mo alloy or greater stainless steel is needed in corrosive environments where long life is mandatory.

3. Activated carbon vendor testing should be completed to confirm the behavior of organics, acids (nitrogen oxide [NO_x], sulfur dioxide [SO_2], and halogen), sulfur, and mercury within the carbon bed.

   Note: Testing on the carbon bed material is scheduled to be completed as part of the WTP baseline within the next 12 months. Any problems identified by vendor testing of the activated carbon bed material may potentially impact the WTP design and the WTP environmental performance test plan (CCN:128559).

4. Testing of the ability of pulse jet mixer (PJM) technology for dissipating gases, blending liquids, and suspending solids should be completed as planned, and a determination made on the adequacy of the PJM designs for the HOP and PLD vessels. Specific requirements for PJM mixing should be established (see 07-DESIGN-047).

   Note: This testing is part of the WTP baseline as part of resolution of the EFRT issue M3, "Inadequate Mixing System."

WTP software and control systems were not included in this TRA because of the limited development on these systems.

This assessment is the second of several TRAs planned for the WTP. An initial TRA was completed on the WTP Analytical Laboratory, Balance of Facilities, and LAW Waste Vitrification Facility (07-DESIGN-042). A third assessment has been completed for the Pretreatment Facility (07-DESIGN-47).

Acknowledgement

The Assessment Team wishes to thank Mr. William Nolte of the Air Force Research Laboratory for consultation, guidance, and direct support in the application of the NASA and DoD Technology Readiness Level (TRL) process to DOE's first use of this process to the Waste Treatment and Immobilization Plant (WTP). Mr. Nolte also provided, and supported, the Assessment Team in the adaptation of a TRL Calculator that he authored, ensuring consistency between the NASA, DoD, and DOE applications of the TRL Assessment process.

The Assessment Team also acknowledges the excellent support and editorial inputs of Ms. Laurie Kraemer, Project Assistance Corporation, in preparing this Technology Readiness Assessment. Ms. Kraemer was able to transform the Assessment Team's input into a professionally prepared document.

Contents

Figures

Tables

Acronyms and Abbreviations

AC	activated carbon
ADS	air displacement slurry
AEA	Atomic Energy Agency
AFRL	U.S. Air Force Research Laboratory
APEL	Advanced Product Evaluation Laboratory
ASX	Autosampling System
BNFL	British Nuclear Fuels Limited
BNI	Bechtel National, Inc.
BOF	Balance of Facilities
CTE	Critical Technology Element
DF	decontamination factor
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DRE	destruction removal efficiency
DWPF	Savannah River Defense Waste Processing Facility
EFRT	External Flowsheet Review Team
EM	Office of Environmental Management
GAO	U.S. Government Accountability Office
GFR	Glass Formers Reagent System
HCP	HLW Concentrate Receipt Process System
HDH	HLW Canister Decontamination Handling System
HEH	HLW Canister Export Handling System
HEME	high-efficiency mist eliminator
HEPA	high-efficiency particulate air
HFP	HLW Melter Feed Process System
HLP	HLW Lag Storage and Feed Blending Process System
HLW	High-Level Waste [Vitrification Facility]
HMP	HLW Melter Process System
HOP	HLW Melter Offgas Treatment Process System
HPH	HLW Canister Pour Handling System
HRH	HLW System Canister Receipt Handling
IHLW	immobilized high-level waste
LAB	Analytical Laboratory
LAW	Low-Activity Waste [Vitrification Facility]
M&S	modeling and simulation
MACT	maximum achievable control technology
MFPV	melter feed preparation vessel
MFV	melter feed vessel
Mo	molybdenum
NASA	National Aeronautics and Space Administration
NLD	Nonradioactive Liquid Waste Disposal System
ORP	Office of River Protection
P&ID	piping and instrumentation diagram
PBS	packed-bed caustic scrubber
PCJ	Process Control System
PJM	pulse jet mixer
PJV	Pulse Jet Ventilation System
PODC	principal organic dangerous constituent

PT	Pretreatment [Facility]
PVV	Process Vessel Vent Exhaust System
PWD	Plant Wash and Disposal System
QARD	Quality Assurance Requirements Document
R&D	research and development
R&T	Research and Technology
RAMI	Reliability, Availability, Maintainability Index
RFD	reverse flow diverter
RLD	System and Radioactive Liquid Waste Disposal System
SBS	submerged bed scrubber
SCR	selective catalytic reducer
SRTC	Savannah River Technical Center
TCO	thermal catalytic oxidizer
TMP	Technology Maturation Plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
VOC	volatile organic compounds
VSL	Vitreous State Laboratory of the Catholic University of America
WESP	Wet Electrostatic Precipitator
WGI	Washington Group International
WTP	Waste Treatment and Immobilization Plant
WVDP	West Valley Demonstration Project

Units of Measure

ft	foot
ft^2	square foot
gpm	gallons per minute
m^2	square meter
m^3	cubic meter
mg/L	milligrams per liter
mg/min	milligrams per minute
MT	metric ton
scfm	standard cubic feet per minute
wt%	weight percentage

Glossary

Critical Technology Element	A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel. Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.
Engineering Scale	A system that is greater than 1/10 of the size of the final application but it is still less than the scale of the final application.
Full Scale	The scale for technology testing or demonstration that matches the scale of the final application.
Identical System	Configuration that matches the final application in all respects.
Laboratory Scale	A system that is a small laboratory model (less than 1/10 of the size of the full-size system
Model	A functional form of a system, generally reduced in scale, near or at operational specification.
Operational Environment (Limited Range)	A real environment that simulates some of the operational requirements and specifications required of the final system (e.g., limited range of actual waste).
Operational Environment (Full Range)	Environment that simulates the operational requirements and specifications required of the final system (e.g., full range of actual waste)
Paper System	System that exists on paper (no hardware).
Pieces System	System that matches a piece or pieces of the final application.
Pilot Scale	The size of a system between the small laboratory model size (bench scale) and a full-size system.
Prototype	A physical or virtual model that represents the final application in almost all respects that is used to evaluate the technical or manufacturing feasibility or utility of a particular technology or process, concept, end item, or system.
Relevant Environment	Testing environment that simulates the key aspects of the operational environment; e.g., range of simulants plus limited range of actual waste.
Similar System	Configuration that matches the final application in almost all respects.
Simulated Operational Environment	Environment that uses a range of waste simulants for testing of a virtual prototype.

1.0 Introduction

1.1 Background

The U.S Department of Energy (DOE), Office of River Protection (ORP) is constructing a Waste Treatment and Immobilization Plant (WTP) for the treatment and vitrification of the underground tank wastes stored at the Hanford Site in Washington State. The WTP is comprised of four major facilities: a Pretreatment (PT) Facility to separate the tank waste into high-level waste (HLW) and low-activity waste (LAW) process streams, a HLW Vitrification Facility to immobilize the HLW fraction, a LAW Vitrification Facility to immobilize the LAW fraction, and an Analytical Laboratory (LAB) to support the operations of all four treatment facilities. Additionally, there are the Balance of Facilities (BOF) operations that provide utilities and other support to the processing facilities. The WTP Project is DOE's largest capital construction project with an estimated cost of $12.263 billion, and a project completion date of November 2019 (DOE 2006).

Issues associated with the maturity of technology in the WTP have been evaluated by independent DOE Review Teams and in DOE's design oversight process. The most notable evaluation was the recently completed "Comprehensive External Review of the Hanford Waste Treatment Plant Flowsheet and Throughput" (CCN:132846) completed in March 2006. This evaluation identified 28 separate technical issues, some of which had not been previously identified by the WTP Contractor or DOE. A number of these issues originated from limited understanding of the technologies that comprise the WTP flowsheet.

As a result of these reviews, and DOE's desire to more effectively manage the technology risks associated with the WTP, the DOE has decided to conduct a Technology Readiness Assessment (TRA) to assess the technical maturity of the WTP design. This TRA is patterned after guidance established by the U.S. Department of Defense (DoD) (DoD 2005) for conducting TRAs.

1.2 Assessment Objectives

The purpose of this TRA is to evaluate the technologies used in the HLW Vitrification Facility. This TRA is intended to:

- Identify critical technology elements (CTE)
- Determine the TRL associated with the CTEs
- Provide recommendations on how to improve the maturity level of technologies that require additional development.

This TRA was performed jointly by ORP and the DOE Office of Environmental Management (EM), Office of Project Recovery, and builds on the initial TRA conducted in January 2007 (07-DESIGN-042), which evaluated the WTP LAB, BOF, and LAW facilities.

1.3 Description of TRA Process

1.3.1 Background

> "A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies [called Critical Technology Elements (CTEs)] used in systems." (DoD 2005)

In 1999, the U.S. General Accounting Office (GAO) produced an influential report (GAO/NSIAD-99-162) that examined the differences in technology transition between the DoD and private industry. The GAO concluded that the DoD took greater risks, and attempted to transition emerging technologies at lesser degrees of maturity compared to private industry, and that the use of immature technology increased overall program risk and led to substantial cost and schedule overruns. The GAO recommended that the DoD adopt the use of the National Aeronautics and Space Administration's (NASA) Technology Readiness Levels (TRL) as a means of assessing technology maturity prior to design transition.

In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed use of TRLs in new major programs. Guidance for assessing technology maturity was incorporated into the *Defense Acquisition Guidebook* (DODI 5000.2). Subsequently, the DoD developed detailed guidance for using TRLs in the 2003 *Department of Defense, Technology Readiness Assessment Deskbook* (updated in May 2005 [DOD 2005]). The DoD Milestone Decision Authority must certify to Congress that the technology has been demonstrated in a relevant environment prior to transition of weapons system technologies to design or justify any waivers. TRL 6 is also used as the level required for technology insertion into design by NASA.

Based upon historical use of the TRA process, the DOE has decided to use the DoD TRA process as a method for assessing technology readiness for the WTP[1].

1.3.2 TRA Process

The TRA process as defined by the DoD consists of three parts: (1) identifying the CTEs; (2) assessing the TRLs of each CTE using an established readiness scale; and (3) preparing the TRA report. As some of the CTEs were judged to be below the desired level of readiness, the TRL assessment was followed by a Technology Maturation Plan (TMP) analysis and report that determines the additional development required to attain the desired level of readiness (see Volume I). Requirements for the TMP analysis are described in the DoD *Technology Readiness Assessment Deskbook* (May 2005) and is usually carried out by a group of experts that are independent of the project under consideration.

The CTE identification process involves breaking the project under evaluation into its component systems and subsystems, and determining which of these are essential to project success and either represent new technologies, combinations of existing technologies in new or novel ways, or will be used in a new environment. Appendix A describes the identification of the CTE process in greater detail.

The TRL scale used in this assessment is shown in Table 1.1. This scale requires that testing of a prototypical design in a relevant environment be completed prior to incorporation of the technology into the final design of the facility.

---

[1] Appendix A of 07-DESIGN-042, *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP), Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities*, March 2007, U.S Department of Energy, provides a detailed description of the NASA and DoD TRL definitions and compares those with the TRL definitions used in the WTP assessments.

Table 1.1. Technology Readiness Levels used in this Assessment

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full-scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot scale, similar (prototypical) system validation in a relevant environment.	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory scale, similar system validation in relevant environment.	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Example might include paper studies of a technology's basic properties.

The testing requirements used in this assessment are compared to the TRLs in Table 1.2.
These definitions provide a convenient means to further understand the relationship between the scale of testing, fidelity of testing system and testing environment, and the TRL. This scale requires that for a TRL 6 testing must be completed at an engineering or pilot scale, with a testing system fidelity that is similar to the actual application and with a range of simulated wastes and/or limited range of actual waste, if applicable.

The assessment of the TRLs was aided by a TRL Calculator that was originally developed by the United States Air Force (USAF) (Nolte et. al. 2003), and modified by the Assessment Team. This tool is a standard set of questions addressing hardware, software, program, and manufacturability questions that is implemented in Microsoft Excel™. The TRL Calculator produces a graphical display of the TRLs achieved. The TRL Calculator used in this assessment is described in more detail in Appendix B.

Table 1.2. Relationship of Testing Requirements to the TRL

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot Scale < Full Scale (Typical)
   Lab Scale < 1/10 Full Scale (Typical)
2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)
3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

2.0 Technology Readiness Level Assessment

2.1 TRL Process Description

An Assessment Team comprised of staff from the DOE ORP, technical consultants to ORP, and DOE EM's Office of Project Recovery completed the TRL assessment with support from the WTP engineering staff (see Appendix D for the identification of the Assessment Team and supporting contractor staff from the WTP). Assessment Team staff have worked on the Hanford WTP project and related nuclear waste treatment and immobilization technologies for more than 30 years, and are independent of the WTP design and construction project.

WTP engineering staff (e.g., WTP Project Team) presented descriptions of the WTP systems that were assessed, participated in the identification of the CTEs, and participated in the completion of responses to individual questions in the TRL Calculator. Each response to a specific Calculator question was recorded along with references to the appropriate WTP Project documents. The Assessment Team also completed independent due-diligence reviews and evaluation of the testing and design information to validate input obtained in the Assessment Team and WTP Project Team working sessions. The Calculator results for each CTE can be found in Appendix C.

This Assessment Team evaluated the process and mechanical systems that are used to treat and immobilize the HLW radioactive waste and prepare the immobilized high-level waste (IHLW) product for disposal. It did not evaluate the software systems used to control the process and mechanical equipment because these software systems have not been sufficiently developed and are not critical to the mechanical design of the facilities. The assessment of the technology readiness of the software systems will be completed at a later date.

2.2 Determination of CTEs

The process for identification of the CTEs for the HLW Vitrification Facility involved two steps:

1. An initial screening by the Assessment Team of the complete list of systems in the HLW Facility for those that have a potential to be a CTE. In this assessment, systems that are directly involved in the processing of the tank waste or handling of the primary products (IHLW and secondary wastes) were initially identified as potential CTEs. The complete list of systems and those identified as potential CTEs are provided in Appendix B.

2. A final screening of the potential CTEs was completed by the Assessment and WTP Project Teams to determine the final set of CTEs for evaluation. The potential CTEs were evaluated against the two sets of questions presented in Table 2.1. A system is determined to be a CTE if a positive response is provided to at least one of the questions in each of the two sets of questions.

The specific responses to each of the questions for each CTE are provided in Table A.3 of Appendix A. In this final assessment, the following systems were identified as CTEs:

- HLW Melter Feed Process System (HFP)
- HLW Melter Process System (HMP)
- HLW Melter Offgas Treatment Process System and Process Vessel Vent Exhaust System (HOP/PVV)
- Pulse Jet Mixer (PJM) system and Radioactive Liquid Waste Disposal System (RLD)

Table 2.1. Questions used to Determine the Critical Technology Element for the HLW Vitrification Facility Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

2.3 Summary of the Technology Readiness Assessment

This section summarizes the results of the TRL assessment completed for each of the CTEs.

The TRL Calculator (Appendix B) employs a two-step process to evaluate TRLs.

1. A top-level set of questions was evaluated to determine the starting point, in terms of readiness level, for the TRL assessment. This evaluation showed that the identified CTEs all had achieved a TRL 5 status.
2. A more detailed assessment was completed using a series of detailed questions starting at TRL 4. This assessment indicated that all CTEs achieved a TRL 4. Next, the assessment evaluated the TRL 5 questions in detail and recorded responses. Finally, the assessment evaluated the TRL 6 questions in detail and recorded responses. The responses to the TRL questions are provided in Appendix C for each CTE.

For each CTE, the discussions below describe the CTE function, description, the relationship to other CTEs, the development history and status, the relevant environment, a comparison of the demonstrated and relevant environments, and the rationale for the TRL determination and any recommendations.

2.3.1 HLW Melter Feed Process System (HFP)

2.3.1.1 Function of the HFP

The function of the HFP is to prepare blended waste feed for the HLW melter by combining HLW concentrate from the PT Facility and glass formers from the Glass Formers Reagent System (GFR).

2.3.1.2 Description of the HFP

The sub-functions of the HFP are described in the HLW Concentrate Receipt Process System (HCP) and HFP systems description (24590-HLW-3YD-HFP-00001), and include:

- Receive HLW concentrate from the PT Facility, glass formers from the GFR and additives such as antifoaming agents that assist the blending and feed process.
- Store the received feed materials.

- Uniformly mix the HLW concentrate, glass formers, and additives. Mixing also suspends the solids for transfer and prevents the buildup of hydrogen gas.
- Remove heat generated by radioactive decay and mixing.
- Transfer the blended feed to the melters; feed is transferred continuously to the melters.
- Confine the HLW melter feed materials. The principal radiological hazard is the HLW concentrate, which is a source of direct radiation and has the potential to generate internal doses if released in respirable form. The system must also prevent hydrogen deflagration by continuous agitation of the waste and purging hydrogen from vessel headspace and associated piping.
- Decontaminate vessels. Demineralized water directed through spray nozzles is used to wash down the vessels. Vessel contents are transferred to the plant wash and drains vessel.
- Sense system operating conditions and report system data to the Process Control System (PCJ). The system senses temperature, pressure, density, and level in the vessels.
- Transfer HLW concentrate and melter feed blend to an autosampler. The HLW concentrate is analyzed to determine the proper glass former addition and the melter feed blend is analyzed to confirm the proper melter feed composition.

A flow diagram of the HFP is shown in Figure 2.1. The HFP contains two identical subsystems each comprised of two vessels, melter feed preparation vessel (MFPV) and melter feed vessel (MFV), along with associated agitators, pumps, and piping. Each subsystem supports a single HLW melter. HLW is transferred from the PT Facility lag storage vessels through a 3-inch diameter transfer line at a rate of 140 gal/min into the MFPV. When a transfer is completed, the line is flushed and flush water is transferred back to the PT Facility. The contents of the MFPV are sampled using the Autosampling System (ASX) to determine the amount of glass former to add to the batch. After the addition of glass formers and mixing, the HLW compliance samples are taken to qualify the batch. The prepared melter feed is transferred to the MFV with a cantilever pump for eventual feeding to the HLW melter.

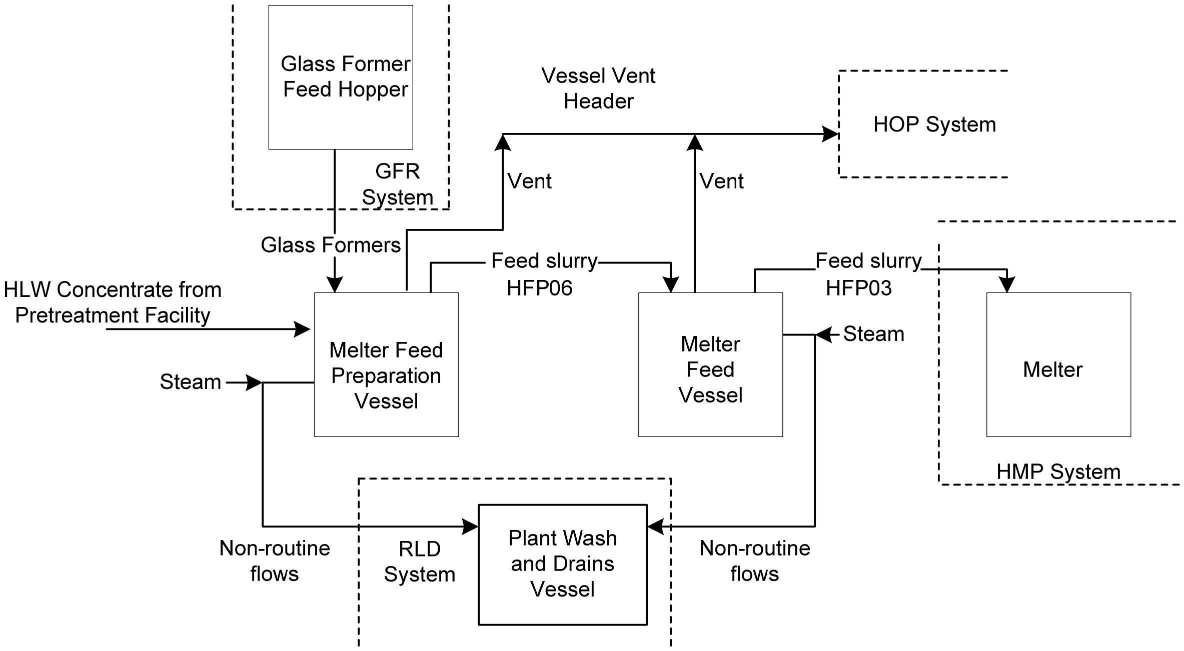


Figure 2.1. Flow Diagram of the HLW Melter Feed Process System (HFP)

The MFPVs and MFVs are 166 inches tall by 132 inches in diameter and hold a maximum batch size of 5,500 gallons; enough blended waste feed for 50 to 70 hours of melter operation. The vessels are manufactured from 316L stainless steel.

The MFPVs are standard designs for mechanically agitated vessels. Each MFPV is equipped with the following:

- Overflow line
- Vessel vent line and demister for de-entrainment
- Instrumentation for level, density, and pressure measurement
- Thermocouple for temperature measurement
- Cooling jacket to remove radioactive decay heat and heat generated by the agitator
- One mechanical agitator
- Air spargers for purging hydrogen from vessel headspace
- Two mechanical pumps to transfer waste to the MFV and to the autosampler (ASX)
- Internal fixed nozzles for periodic wash down
- Steam ejector for transfer to plant wash and drains vessel
- Antifoaming agent capability
- Demister on the vessel vent line for de-entrainment

The mechanical agitator continuously mixes the vessel contents to keep insoluble solids in suspension. The vertical pump discharges at a maximum flow rate of 50 gal/min through a valve bulge to route the concentrate, melter feed, or plant wash to one of the following: corresponding MFV, other MFPV (for melter shutdown or batch shimming), same MFPV (to recirculate for sampling), or a plant wash vessel for recycle to the PT Facility.

Each MFV is equipped with the following:

- Overflow line
- Vessel vent line and demister for de-entrainment
- Instrumentation for level, density, and pressure measurement
- Thermocouple for temperature measurement
- Cooling jacket to remove radioactive decay heat and heat generated by the agitator
- One mechanical agitator
- Two air displacement slurry (ADS) pumps
- Internal fixed nozzles for periodic washdown
- Air spargers for purging hydrogen from vessel headspace and for agitation
- Internal fixed nozzles for periodic washdown
- Steam ejector for transfer to plant wash and drains vessel
- Antifoaming agent capability
- Sample pump to transfer waste to autosampler (ASX)
- Demister on the vessel vent line for de-entrainment

The mechanical agitator continuously mixes the vessel contents to keep insoluble solids in suspension. Each ADS pump feeds one side of the melter. The two ADS pumps alternate on a cycle that semi-continuously feeds the melter at a rate of 1 to 2 gpm through separate feeding nozzles.

2.3.1.3 Relationship to Other Systems

The primary interfacing systems for the HFP are the:

- Autosampling System (ASX), which receives waste samples from the MFPVs and MFVs.
- Glass Formers Reagent System (GFR), which supplies glass formers to MFPVs.
- HLW Lag Storage and Feed Blending Process System (HLP), which supplies HLW concentrate to the MFPVs.
- HLW Melter Process System (HMP), which vitrifies the waste feed slurry produced in the HFP.

None of these interfacing systems adds a new technology to the HFP.

2.3.1.4 Development History and Status

Testing of prototypic component parts of the HFP at the Vitreous State Laboratory of the Catholic University of America (VSL), Savannah River Technical Center (SRTC), and Philadelphia Mixers has provided the primary basis for the design of the HFP. HLW simulants to support mixing system tests were developed by the WTP Project (24590-WTP-RT-04-00027). Research and Technology (R&T) testing of the mixing system at SRTC (SCT-M0SRLE60-00-132-05; SCT-M0SRLE60-00-187-02) was conducted to test blending of glass-forming chemicals and simulated wastes. Bounding physical and rheological conditions of the simulants were determined from characterization of actual tank waste samples (24590-101-TSA-W000-0004-172-00001). The ability to keep glass formers in suspension (24590-101-TSA-W000-0009-171-00001) was demonstrated during testing with the DM1200 melter system. Simulants used for mixer testing are described in WSRC-TR-2003-00220. The ADS pumps were tested at VSL (24590-101-TSA-W000-0009-118-00010) and used for a majority of test runs of the DM1200 and DM3300.

Testing of the proposed prototypic scale mechanical mixing system was completed by Philadelphia Mixers. The mixing report helped the vendor to size the mechanical mixer for the actual HLW MFPV and MFV subsystems (24590-QL-POA-MFAO-00001-10-00001).

A 7/10 (linear) scale version of the MFPV vessel and ASX is also being assembled to use for testing of the MFPV/MFV mixing efficiency (VSL-06T1000-1) to:

- Evaluate the operating parameters (minimum and maximum) for the MFPV mechanical agitator to achieve and maintain the required homogeneity of both the pretreated HLW and HLW melter feed.
- Evaluate operating parameters (minimum and maximum) for the sampling system to provide samples with compositions representative of the MFPV contents, for both pretreated HLW and HLW melter feed.
- Evaluate operating parameters (minimum and maximum) of the mechanical pump for transferring HLW melter feed from the MFPV to the MFV without affecting composition (includes the water flushes of the transfer line and the sampler system).
- Evaluate level measurement for both the bubbler (density) and the radar (level) measurement systems for both pretreated HLW and HLW melter feed at the minimum and maximum operating parameters.
- Document any operational issues associated with mixer, sampler, level indicators, and mechanical pump that may impact the ability of the system to adequately mix, sample, and transfer the MFPV contents, for both pretreated HLW and HLW melter feed.
- Evaluate the blend time requirements for the incorporation of glass-forming chemicals into the pretreated HLW in the MFPV.

2.3.1.5 Relevant Environment

The operating environment for the HFP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001), the HFP system description (24590-HLW-3YD-HFP-00001), and the HLW PSAR (24590-WTP-PSAR-ESH-01-002-04). The relevant operational environment for the HFP is the:

- Remote operation of process fluid equipment to blend and transfer highly radioactive slurries of tank waste concentrate and glass formers.
- Mixing of high solids slurries of glass formers and waste (approximately 50 wt% solids) that have high viscosities and shear strength.
- Transfer of high solids slurries.

All system components including the vessels are designed to be replaceable. The MFPV and MFV are also designed for a 40-year operational life.

2.3.1.6 Comparison of the Relevant Environment and the Demonstrated Environment

Extensive testing of prototypic waste feed slurry mixing systems at an engineering-scale (1/10 to 1/6 of full-scale) has been carried out on a variety of simulants whose properties had been matched to actual waste samples. SRTC (SCT-M03RLE60-132-05; SCT-M03RLE60-00-187-02) and VSL (24590-101-TSA-W000-0009-171-00001) conducted tests with a range of simulants with properties based on actual wastes from several Hanford Site tanks including C-106 and AZ-102. Additional testing is planned as part of the R&T Program that will further demonstrate the mixing concept and the sampling systems.

The mixing system design is to be provided by Philadelphia Mixer having expertise in the design and specification of mixing systems. This vendor has conducted testing of the agitation system based upon vessel design and mixing requirements. The mixing report from the vendor provided evidence of initial feasibility of the system design (24590-QL-POA-MFAO-00001-10-00001).

2.3.1.7 Technology Readiness Level Determination

The HFP was determined to be TRL 6 because of the previous use of the waste and glass former mixing technology on other DOE projects (West Valley Demonstration Project [WVDP] and Savannah River Defense Waste Processing Facility [DWPF]), and the extensive WTP-specific testing activities conducted by VSL (24590-101-TSA-W000-0009-171-00001), SRTC (SCT-M0SRLE60-00-132-05; -187-02), and by Philadelphia Mixers (24590-QL-POA-MFAO-00001-10-00001) to provide the specification for the mechanical agitators for the plant-scale system.

2.3.2 HLW Melter Process System (HMP)

2.3.2.1 Function of the HMP

The function of the HMP is to convert a blended slurry of pretreated high-level liquid waste and glass formers into molten glass and pour the glass into specially designed canisters. The HMP process is designed to produce 6.0 MT of glass per day.

2.3.2.2 Description of the HMP

The HMP is described in the HMP system description (24590-HLW-3YD-HMP-00001). The HMP consists of two melters each with the same design. The melters receive a blend of HLW concentrate and glass former additives from the HLW Melter Feed Process System (HFP), and convert this mixture to a molten glass that is discharged into HLW canisters, which are part of the HLW Canister Pour Handling System (HPH). The IHLW (glass plus canister) product canister will eventually be disposed in a national high-level waste repository.

The HMP system description (24590-HLW-3YD-HMP-00001) lists the following functions of the HMP:

- Receive HLW Concentrates and Additives: The feed systems supply feed to the melters through feed nozzles on the tops of the melters by ADS pumps.
- Vitrify HLW Concentrate and Additives: The system converts glass former additives and HLW concentrate constituents into molten glass in the melt pool.
- Contain Glass Pool: The system contains the molten glass using heat-resisting ceramic (refractory) bricks and a cooled outer metal shell held together with spring-loaded jack bolts.
- Deliver Glass: The system delivers molten glass to stainless steel canisters where it is allowed to cool and form a highly durable borosilicate glass.
- Confine Hazardous Emissions: The system is operated under slight negative pressure that confines emissions and directs them to the HLW Melter Offgas Treatment Process System (HOP) where they are treated to eliminate hazardous constituents.
- Report System Conditions: The system measures melter control variables (e.g., temperature, pressure, melt level) and reports values to monitoring and process control stations.

Each HMP melter (shown in Figure 2.2) consists of a melt chamber and two discharge chambers. The melt chamber consists of a refractory lined tank with two electrodes on opposing walls at each end and a head space volume called the plenum. The discharge chambers are insulated, heated chambers that house troughs that direct molten glass to pour spouts and into the HLW canisters. Each melter is supported by a base structure with transport wheels that allows it to be installed and removed from its melter cave (concrete room that houses the melter) using a rail system. The melter's outer dimensions are approximately 11 ft 1 inch high, by 14 ft 4 inches long by 13 ft 8 inches wide. The melt pool is approximately 8 ft long by 5 ft wide by 4 ft deep.

The melter is fed a slurry from the HFP that is heated, dried, and converted to a glass form. The slurry feed is fed into the melter by two ADS feed pumps and falls from two feed nozzles located in the melter lid onto the surface of the molten glass. The feed material spreads out on the surface of the molten glass forming a layer called the cold cap. As the feed material in the cold cap is heated from ambient to the glass pool temperature, the following processes occur: water in the feed evaporates, gases evolve from the decomposition of salts and inorganic and organic compounds, and the feed is converted to oxides and dissolves into the melt pool. The melter contains approximately 10 MT of glass maintained at a temperature of 1150 ± 25°C.

Refractory bricks with a low corrosion rate potential (e.g., Monofrax K-3 and Monofrax E) line the HLW melt chamber. The refractory that surrounds the molten glass pool is designed to provide electrical insulation from the outer melter shell and prevent glass migration and leakage. The plenum refractory also resists corrosion from gases that evolve from the melt. All refractory must withstand high temperatures, thermal shock, molten oxides, and salts, as well as provide thermal insulation.

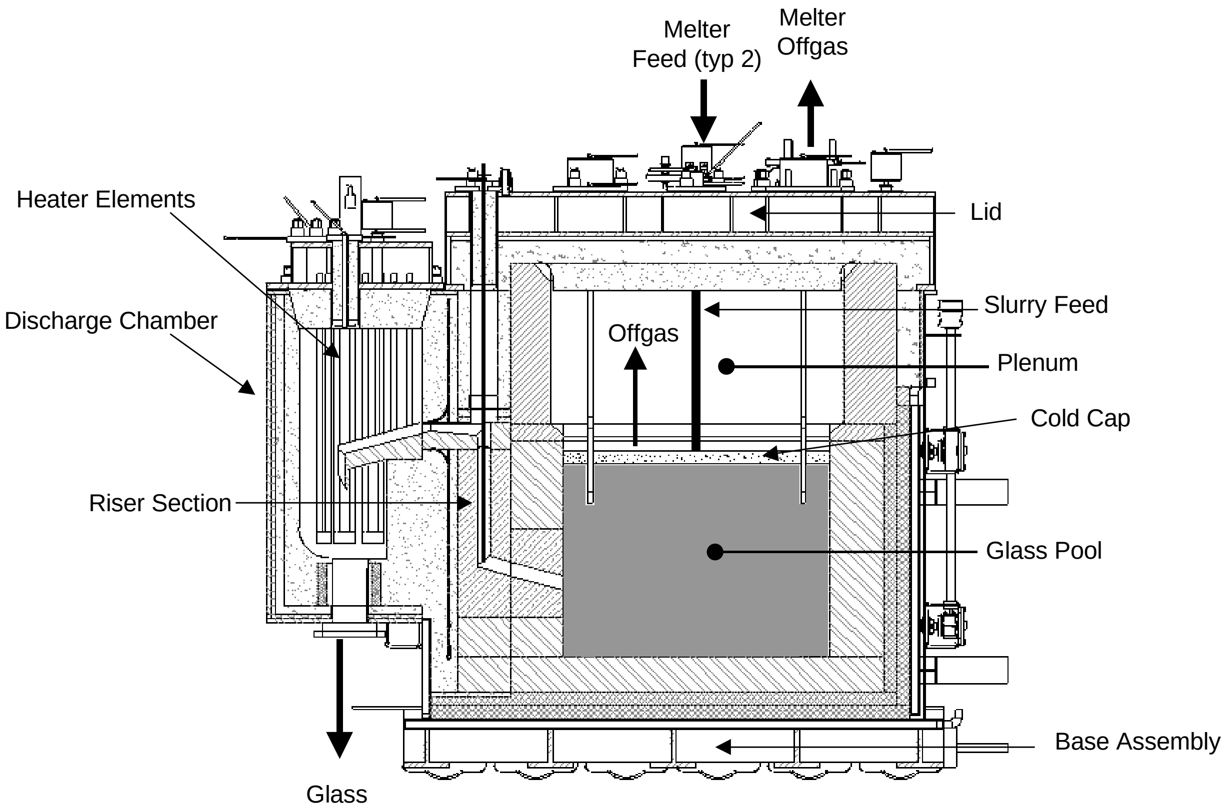


Figure 2.2. Schematic of HLW Melter Section View through Discharge Riser along North-South Axis

The outer melter shell consists of 1/4-inch of corrosion resistant alloy plates stiffened by box section tubular beams. Spring-loaded jackbolts provide constant compression for the melter walls to limit mechanical stress and the formation of gaps between refractory bricks during thermal cycling. Cooling panels attached to the outer shell limit the depth to which molten glass can penetrate melt chamber walls by “freezing” the glass as it moves outward through any gaps in the refractory lining.

The electrodes (not shown in Figure 2.2) are made from 6-inch slabs of Inconel 690 and are mounted horizontally on opposing walls of the melter pool. The electrodes are bored to provide air cooling channels for active cooling of the electrodes. Thermocouples are installed in the electrodes to measure electrode and cooling air temperatures.

The current HLW melter design incorporates five bubbler assemblies that inject air approximately 40 inches below the surface of the melt. (In response to an ORP request to increase glass production rate, Bechtel National, Inc. [BNI] is in the process of submitting a report and trend to increase the number of bubblers to seven). Bubblers are used to gently increase the natural glass circulation within the melt pool. This increases the rate of dissolution of the cold cap and significantly increases the glass production rates by evenly distributing the heat generated by the electric currents passing through the molten glass. The HLW melter bubblers are constructed of Inconel 690 alloy.

If waste glass compositions are found to have compositions that reduce bubbler life, the bubblers will use thick wall pipe and Inconel 690 glass composition for the legs. An Inconel 690 glass dam is designed to prevent molten glass from flowing from the melt chamber through the refractory to the heated discharge chambers. The thin metal diaphragm is contained in the hot wall separating the melt chamber and the discharge chambers. It extends to regions of the discharge wall where temperatures are sufficiently low to freeze the glass and prevent leakage.

The glass is discharged from the melter through the discharge riser into an Inconel 690 trough that routes the molten glass to a pour spout from which it drops into the 2 ft in diameter by 15 ft high stainless steel IHLW canister. The distance from the pour spout tip to the top of the canister is approximately five feet. The discharge riser block contains a channel bored through the refractory. An air lift lance is inserted into the discharge riser channel. During glass pouring, air is bubbled out the tip of the air lift lance causing molten glass to travel up the riser to the discharge trough. Stopping the flow of air stops the flow of glass. Glass will be discharged at rates of 200 to 500 kg/hr in batch fashion. The entire discharge chamber is maintained at a temperature of approximately 1050 to 1100°C by eight silicon carbide discharge heaters.

The HMP includes two subsystems to determine the fill level of glass in the canister. The primary subsystem is an infrared thermal imaging camera that can detect the glass level over the upper 60% of the canister. A secondary subsystem uses gamma radiation detection to determine glass level. WTP specifications require the average canister fill height to be 95% with a minimum of fill height of 87%. The level detection systems are interlocked with the air lift system to stop air flow to the lift if the glass level rises above a preset maximum height.

Offgas consisting of water vapor, air from in-leakage and bubblers, and gases generated by the melt process is discharged to the HLW Melter Offgas Treatment Process System (HOP).

2.3.2.3 Relationship to Other Systems

The major process systems that interface with the HMP are described in Section 6.1 of the HMP system description (24590-HLW-3YD-HMP-00001). Major interfaces include the:

- HLW Melter Feed Process System (HFP) (24590-HLW-3YD-HFP-00001)
- HLW Melter Offgas Treatment Process System (HOP) and secondary offgas Process Vessel Vent Exhaust System (PVV) (24590-HLW-3YD-HOP-00001)
- HLW Canister Pour Handling System (HPH) (24590-HLW-3YD-HPH-00001)

The HMP receives a blend of concentrated HLW and glass former additives from the HLW Melter Feed Process System (HFP). It converts the blend into molten glass that is poured into the HLW canisters that are part of the HLW Canister Pour Handling System (HPH). Melter offgas is fed into the HLW Melter Offgas Treatment Process System (HOP).

The interfacing systems do not add any new technologies to the HMP.

2.3.2.4 Development History and Status

The WTP HLW melter is based on similar design concepts to the DWPF at the Savannah River Site and the WVDP HLW melter at the West Valley Site. The melt pool area of the WTP melter (3.7 m^2) is larger than those of the DWPF (2.6 m^2) and WVDP (2.2 m^2) melters. However, the major technological difference between the WTP melter and the DWPF and WVDP melters is that the WTP melter uses bubblers to gently agitate the melt pool, and thereby substantially increases melter throughput per unit area.

The melters for the WTP were designed by Duratek (now part of Energy*Solutions*). Duratek based its design on lessons from the following:

- West Valley Demonstration Project (WVDP)
- Defense Waste Processing Facility (DWPF)
- Experience with its second generation DM5000 melter used to process Savannah River M-Area low level waste (5.0 m^2)
- DM100 (0.1 m^2), DM1000 (1.0 m^2), and DM1200 (1.2 m^2) melters at the Catholic University of America/Vitreous State Laboratory of the (VSL)
- WTP DM3300 LAW Pilot Melter (3.3 m^2) at Duratek's Columbia, Maryland, site

The VSL and Columbia melters operate only with non-radioactive simulant wastes.

Relevant prototypes of the melter and supporting components (e.g., feed nozzles, thermowells, bubblers) that make up the HMP have been tested in one or more of the above melters (24590-101-TSA-W000-0009-171-00001; 24590-101-TSA-W000-0009-153-00001; 24590-101-TSA-W000-0009-162-00001). The melter tests confirmed the performance and behavior of equipment components and different process flowsheets representative of the initial waste feeds that will be processed in the HLW melter. Equipment components tested included the melter and its specific design features: melter feed nozzle, melter thermowells, melter bubblers, melter pouring system, and representative instrument and control systems.

Most of the development work for the WTP HLW melter has been carried out on the DM1200, which has a melt surface area and melt pool height that are 32% and 57%, respectively, of the WTP HLW melter. Its discharge chamber design is prototypic of the WTP melter. The feed and bubbler assemblies are also prototypic.

The DM1200 has been operated for more than 5 years, melting more than 1.5 million lb of feed, and producing more than 0.5 million lb of glass (24590-101-TSA-W000-0009-171-00001). After 5 years, the DM1200 has shown minimal signs of wear on melter electrodes, thermal insulation, and discharge chamber leading to confidence that the required 5-year melter life will be achieved.

The testing process for HMP has consisted of the following:

- Determination of the physical and chemical properties of the waste as it will be fed to the HMP (24590-101-TSA-W000-004-172-00001; SCT-M0SRLE60-00-83-01A; SCT-M0SRLE60-00-193-00004; 24590-101-TSA-W000-0004-87-09; 24590-101-TSA-W000-009-172-00001). This required small-scale pretreatment of actual waste.
- Development of simulants that match relevant physical and chemical properties of the waste feed (SCT-M0SRLE60-00-211-00001; 24590-101-TSA-W000-009-172-00001).
- Small- and large-scale testing of simulants to determine waste/glass former blend compositions, melter operating conditions and procedures, and waste glass composition and properties (24590-101-TSA-W000-0009-171-00001; 24590-101-TSA-W000-009-48-00001; 24590-101-TSA-W000-009-98-00011; SCT-M0SRLE60-00-110-00023). Engineering-scale tests using simulants lasting 288 days have been carried out using the Duratek DM1200 HLW pilot melter.
- Small-scale confirmatory testing using actual waste (SCT-M0SRLE60-00-195-00001; SCT-M0SRLE60-00-218-00001; SCT-M0SRLE60-00-21-05; 24590-101-TSA-W000-0009-168-00001).

Most of the HLW melter testing has focused on simulants representative of the initial tank waste feeds to be processed in the WTP (e.g., from Hanford Site tanks C-104, C-106, AZ-101, AZ-102), all of which are high-iron feeds.

The original design requirement for the WTP HLW throughput was 1.5 MTG/day per melter. Initial tests at the VSL concluded that this throughput could not be attained without the use of bubblers (24590-HLW-RPT-RT-01-003). In 2002, the specification for WTP HLW throughput was raised to 3.0 MTG/day per melter necessitating extensive testing of bubblers in the DM1200 (24590-101-TSA-W000-0009-171-00001). DM1200 testing was augmented by physical model testing at full WTP HLW melter depth and testing in the DM1200 under idling conditions to determine bubbler air supply requirements; i.e., ability to run double nozzle bubbler with a single air supply (24590-101-TSA-W000-0009-153-00001). All these results were combined with engineering analyses to specify bubbler design and operational requirements for the plant design (24590-101-TSA-W000-0009-162-00001).

Physical modeling and extrapolation of DM1200 results indicate the required throughput of 3.0 MTG/day can be attained for the initial HLW feeds provided feed contains more than 15 wt% undissolved solids at the WTP Contract waste loading requirements. Attempts to achieve the required throughput with solids contents below 15% resulted in unstable melter conditions and frequent blockages of the film cooler.

There were concerns raised in the External Flowsheet Review Team (EFRT) review of the WTP (CCN:132846) that the bubbler air flow rates required to make the required glass production rate in the HLW melter (3.0 MTG/day) may exacerbate entrainment of feed and glass particles from the cold cap. These particles could lead to plugging of the inlet of the offgas system film cooler and deposit solids in the melter to submerged bed scrubber (SBS) transition pipe. Both of these areas of solids buildup could lead to pluggage. In responses to this potential issue, the WTP has evaluated applicable DM1200 testing data to determine the limits of operation of the melter bubblers to prevent pluggage of the film cooler (CCN:144619). The reference HLW melter bubble design is a “J-tube” with two air discharge orifices per assembly. Based upon experimental data, the glass surface bubbling density for the HLW melter will need to be limited to 20 scfm/m^2 of bubbled area (bubbled area is the fractional area of the melter surface bubbling affects). Therefore, a maximum of 1.5 scfm per bubbler assembly assuming five bubbler assemblies per melter is permissible. The HLW feed concentration must also have a minimum glass yields of 325 gram glass per liter. Testing in the DM1200 was conducted within these constraints with acceptable film cooler performance.

The HLW bubbler life requirement is 2 months. Testing in the DM1200 has demonstrated Inconel 690 bubbler life in excess of 2 months with very little corrosion of the bubbler in the cold cap area. The J-bubbler had accumulated over 60 days of feeding without failure and acceptable wear in the bubbler nozzle area (24590-101-TSA-W000-0009-119-00003). These results were obtained with low sulfur wastes. Tests conducted on LAW simulants have shown that high sulfur melts are much more corrosive to Inconel 690 than the HLW simulants that have been tested. If HLW feeds high in sulfur are to be processed in the WTP HLW melter, the more expensive materials used in the fabrication of the LAW bubblers (e.g., alloy MA-758) may be required for the HLW bubblers.

2.3.2.5 Relevant Environment

The HFP will be operating in a high-radiation environment that necessitates remote operation and maintenance. Melter life is projected to be 5 years. Some melter system components will have shorter operating lives (e.g., melter bubblers will have to be replaced every few months). The relevant operational environment for the HMP is identified in the system description (24590-HLW-3YD-HMP-00001) as follows:

- The system shall melt, contain, and pour molten glass at temperatures up to 1200°C.
- The system shall vitrify wastes with a range of physical properties.

- The discharge chamber shall continuously heat the glass using lid mount heaters to avoid becoming clogged.
- An airlift system shall pour glass into the containers using a bubbler lance immersed in the riser glass.
- Maintenance of the HLW melter shall be conducted to periodically replace bubbler assemblies, level detector probes, and thermowells.
- Installing and replacing a melter system shall be conducted for a melter that weights approximately 89 tons (101 tons with a full-glass inventory).

2.3.2.6 Comparison of the Relevant Environment and the Demonstrated Environment

Remote operation and maintenance of similar melters has been demonstrated at the WVDP and DWPF. However, some operational and maintenance features of the HMP are new. For example, although bubbler replacement has been demonstrated on the Duratek nonradioactive pilot melters, regular remote replacement of bubblers has not been demonstrated. However, remote replacement of airlifts and thermowells is an identical operation to bubbler replacement. Approximately 600,000 lb of simulated HLW glass was made in the DM1200 melter during the development and testing program (24590-101-TSA-W000-0009-171- 00001) over 288 run days. During most of that time, operating conditions (e.g., bubbler location, design, and flow rate) were being varied in attempts to optimize melter performance. About 20 days of operation was completed in the final prototypic operating mode.

The HLW melter was operated at the VSL with extensive operator intervention (some HLW melter parameters set and operators frequently looking at the cold cap for "operational cues") to maintain test conditions, per project instructions. In the WTP HLW Facility, the process control will be non-visual based on instrumentation responses (e.g., plenum temperature, bubbler air rate, melt level). Control mechanisms and procedures will relate the measured physical phenomena to process control actions, both operator and automatic. These operational requirements will be established as part of the testing program to support cold commissioning of the HLW melter in the HLW Facility.

The demonstrated environment for the HMP has focused on the initial tank waste compositions to be processed in the HLW Facility and has consisted of the following:

- Determination of the physical and chemical properties of the waste as it will be fed to the HMP.
- Development of simulants that match relevant physical and chemical properties of the waste feed.
- Small- and large-scale testing of simulants to determine waste/glass former blend compositions, melter operating conditions/procedures, and waste glass composition/properties. Engineering-scale tests using the Duratek DM1200 HLW pilot melter.
- Small-scale confirmatory testing using actual waste.

2.3.2.7 Technology Readiness Level Determination

The HMP was determined to be TRL 6 because of the extensive development of the melter concept for previous DOE projects combined with the development and testing of the DM1200 pilot-scale melter for the WTP.

Extensive small-scale and engineering-scale prototypical testing of the melter system has been completed to support the initial waste feeds anticipated at the WTP from Hanford Site tanks (AZ-101, AZ-102, C-104, C-106), which have waste loading limits based on iron. This initial development can support the production of all of the Hanford Site tank wastes. However, to optimize operations at the WTP, a longer-term technology support program is recommended to optimize waste loadings for tank waste compositions containing higher concentrations of aluminum, (Al), phosphorus (P), bismuth (Bi), and chromium (Cr). In addition, alternative HLW feeds compositions such as those higher in sulfur concentrations may require and alternative bubbler design.

2.3.3 HLW Melter Offgas Treatment Process System and Process Vessel Vent Exhaust System (HOP/PVV)

2.3.3.1 Function of the HOP/PVV

The function of HOP is to remove hazardous particulates, aerosols, and gases from the HLW melter offgas and vessel ventilation process offgas. The function of the PVV is to provide a pathway for vessel offgas to the HOP for treatment. Confinement barriers are provided by maintaining a vacuum on vessels and associated piping for the safety of facility staff. The combined primary and vessel ventilation offgas stream is discharged to the secondary offgas system, and then exhausted to the atmosphere from the facility stack. These systems treat the HLW melter offgas so that it conforms to relevant federal, state, and local air emissions requirements at the point of discharge from the facility stack.

2.3.3.2 Description of the HOP/PVV

The HOP and PVV extraction systems are described in the HOP and PVV systems description (24590-HLW-3YD-HOP-00001). The HLW melter offgas stream is discharged from the melter plenum to the primary offgas system. The principal gases generated by the melter are air and steam with small percentages of NO_x and other melter feed decomposition products. Melter offgas treatment calculations referenced in the HOP system description provide estimates of the airborne components emitted from the melter. Melter offgas travels through the film coolers, SBS, and Wet Electrostatic Precipitator (WESP). The PVV air is combined with the WESP offgas discharge, and the combined HOP/PVV offgas is further treated by the primary system high-efficiency mist eliminators (HEME) and high-efficiency particulate air (HEPA) filters. Offgas travels from the primary offgas system to the secondary offgas system.
The secondary offgas system removes mercury, iodine-129, volatile organic compounds (VOC), NO_x, and volatile halides (i.e., chlorine [Cl] and fluorine [F]). Carbon-14 and tritium are not abated.

A block flow diagram of the HOP/PVV is provided in Figure 2.3.

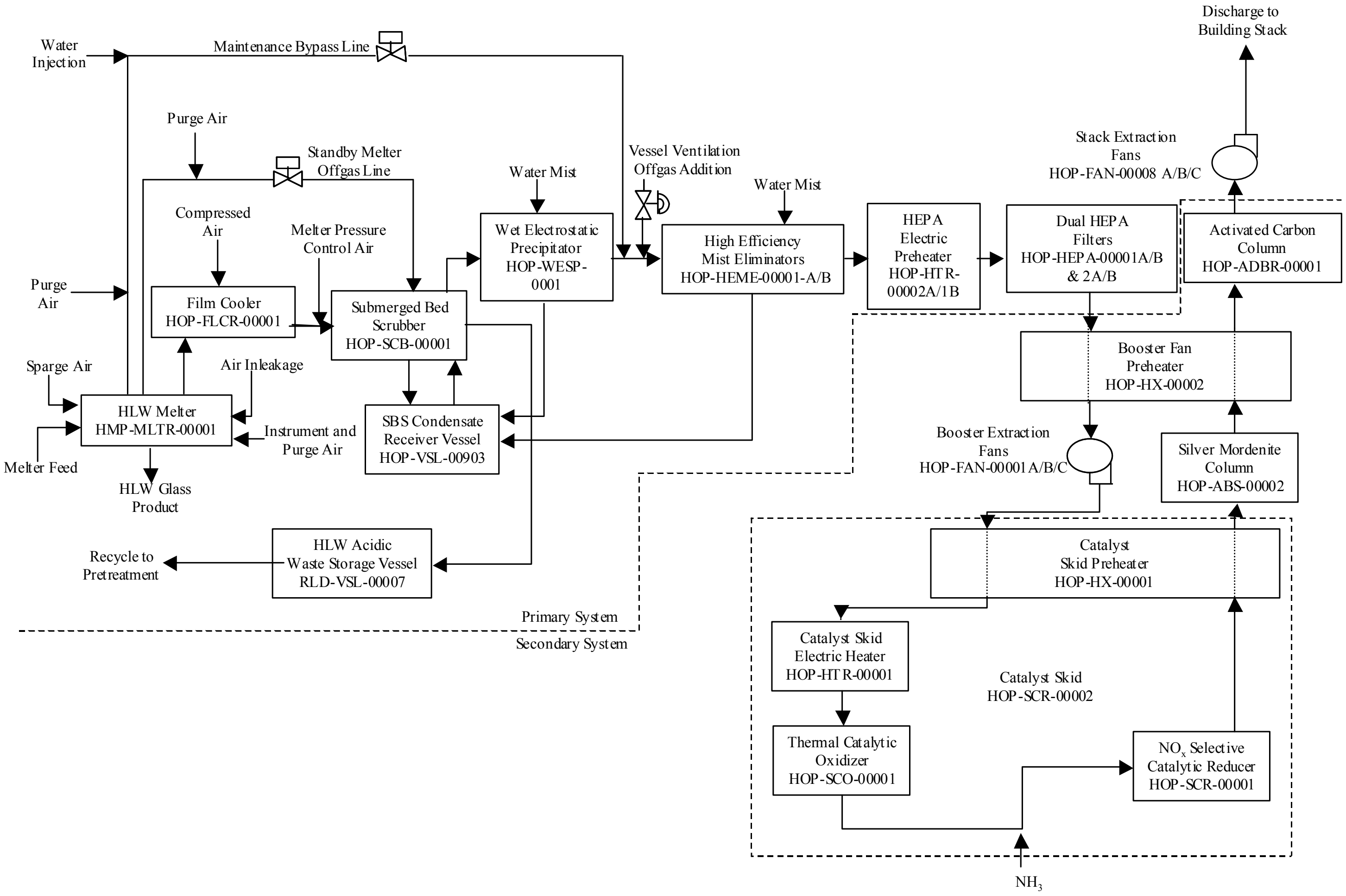


Figure 2.3. Block Flow Diagram for the HOP/PVV

The primary HOP consists of the following major components for each melter:

Offgas Film Coolers and Transition Section. The HLW melter offgas is initially accelerated through the melter film cooler. This film cooler is a double-walled pipe designed to introduce air along the walls through a series of holes or slots in the inner wall. The injection air that flows along the pipe wall mixes with, and cools, the offgas from its melter plenum temperature of about 750°F to a film cooler discharge temperature of about 510°F. The film cooler includes the middle assembly with ten louvers that make up most of the inner film cooler wall. From the film cooler, the exhaust gas flows to a melter offgas jumper transition section that incorporates a mounting flange for a film cooler cleaner.

Offgas Jumper and Melter Pressure Control System. Plant air (in addition to film cooler air) is injected near the outlet of the film cooler to facilitate melter plenum pressure control. The melter offgas jumper and transition line is a piping assembly that routes the melter offgas from the film cooler to the SBS and is connected by flanges. The standby offgas jumper is another line between the melter and submerged bed scrubber (SBS) with a pressure activated control valve. When the melter pressure reaches a pressure set point, -1 inch WC, the valve opens automatically to provide an additional pathway for gas to the SBS, thereby reducing the melter pressure. The offgas maintenance bypass jumper is a piping assembly that periodically routes the melter offgas from the melter to the offgas line between the WESP and the HEME for short periods.

Submerged Bed Scrubbers (SBS). Offgas from the film coolers enters a packed bed submerged in water. The SBS is a passive device designed for steam quenching, scrubbing of entrained particulates and partial removal of aerosols from melter offgas. The SBS normally operates at about 120°F but can operate between 104°F and 140°F. The particulate decontamination factor (DF) (amount of component in/amount of component out) is usually from 5 to 15.

Wet Electrostatic Precipitators (WESP). Offgas from the SBS is routed to a WESP for further removal of particulates and aerosols. The offgas enters the unit and passes through a distribution plate. The evenly distributed saturated gas then flows through the tubes of the WESP. The tubes act as positive electrodes. Each tube has a single negatively charged electrode that runs down the tube's center. A high-voltage transformer rectifier supplies the power to these electrodes so that a strong electric field is generated along the electrode, supplying a negative charge to aerosols as they pass through the tubes.
The negatively charged aerosols move toward the positively charged tube walls where they are attracted to the (grounded) collector plate walls (or the central rods, depending on their charge), where they coalesce and are washed into the WESP sump by a downward water spray. The condensate then drains into a sump collection vessel.

High-Efficiency Mist Eliminator (HEME). The purpose of the HEME is to further remove radioactive aerosols from the HLW melter offgas and the vessel ventilation air, and to reduce the solids loading rate on the HEPA filters. A HEME is a high-efficiency wet filter that has a minimum aerosol removal efficiency of approximately 99% for aerosols less than one micron. There is a water misting nozzle in the HEME gas inlet to wash water soluble solids from the filter element.

High-Efficiency Particulate Air (HEPA) Filters and Preheaters. HEPA filters provide the final removal of radioactive particulates to protect downstream equipment from contamination. The combined offgas stream is passed through a preheater. The electric heaters increase the nominal gas temperature from 131°F to 149°F to avoid condensation in the HEPA filters. The heated offgas passes through HEPA filter housings forming two parallel trains: a main train used in normal operations and an auxiliary train used as an installed backup. The HEPA filter housings in each train are arranged to form primary and secondary stages of filtration.

The Secondary Melter Offgas Treatment System includes the following equipment:

Heaters and Fans. Multiple heaters and fans (booster fan preheater, booster extraction fans, catalyst skid preheater, and catalyst skid electric heater) are employed to move air through and maintain a vacuum on the system. Heaters maintain the offgas temperature above the dewpoint to prevent condensation, which could erode the fans.

Silver Mordenite Column. The purpose of the silver mordenite column is to remove gaseous iodine-129 from the melter offgas stream. The removal efficiency of the column for iodine is 99.9% for temperatures between 300°F to 390°F. Also, the silver mordenite will absorb volatile forms of chlorine and fluorine. Thirty-six cartridges are loaded into a plenum structure similar to that for HEPA filters. Gas flows down through the cartridges to the lower plenum for exhaust. When the cartridge loading capacity is exhausted, the cartridges are replaced. The column has a 40-year life; the cartridges will have to be periodically changed out when loaded (roughly every 5 years).

Activated Carbon (AC) Column. The AC column removes volatile mercury from the offgas. The AC column is made up of two beds housed in two chambers. The offgas normally flows through both beds in series. The AC column is designed to obtain a mercury DF of 1,000 (e.g., 99.9% efficient). The mercury concentration in the offgas is reduced to $\leq 45\ \mu g/m^3$. The spent AC will be removed by gravity and a pneumatic conveyer for collection in containers. The AC will be stabilized in a grout mixture for disposal.

Thermal Catalytic Oxidizer (TCO). The TCO oxidizes organics to carbon dioxide and water and possibly acid gases (depending on the presence of halogenated organics in the gas). The heated offgas is passed through the VOC catalyst to oxidize VOCs and carbon monoxide to carbon dioxide and water vapor. The VOC catalyst is a platinum-based material deposited on a metal monolith, which is held in frames, inserted, and removed through access doors. Pilot-scale testing is in progress to demonstrate the organic removal efficiency.

NO_x Selective Catalytic Reducer (SCR). The offgas has high levels of NO_x because the melter decomposes the parent nitrate/nitrite compounds. Gas from the TCO flows into a chamber where the gas is mixed with ammonia gas injected into the gas stream. Following ammonia injection, the offgas is passed through the SCR catalyst to reduce NO_x to nitrogen and water vapor. The catalyst will likely be vanadium oxide deposited on a substructure that is held in frames inserted and removed through access doors. Catalyst life has not been established. However, catalyst change out should not be more frequent than once every several years.

Stack Extraction Fans. Three variable speed fans provide the motive force for air movement of the melter offgas and the vessel ventilation offgas. The fans also maintain the process offgas system under vacuum relative to the surroundings. Each fan is sized to exhaust 50% of the air flow, such that two fans are required for normal operation. Should one fan fail, the standby fan automatically comes on line. The fans are on emergency backup power.

2.3.3.3 Relationship to Other Systems

Melter process offgas treatment equipment interfaces are provided in Section 9 of the systems description for HOP/PVV (24590-HLW-3YD-HOP-00001). The primary interface with the HOP/PVV is the HLW Melter System (HMP) (24590-HLW-3YD-HMP-00001). The two HLW melters have dedicated primary and secondary offgas treatment systems that are coupled to each other. The exhaust fans are used to ventilate process vessels that connect to both melter systems. The melters and process vessels must be maintained under a slight vacuum at all times to avoid releasing radioactivity to the surroundings. This safety feature must be maintained under normal and off-normal operating conditions.

In case of offgas pipe plugging between the melter and the SBS, the standby offgas system would activate. In the unlikely event that an offgas surge exceeds the capacity of the primary offgas line and standby jumper, a pressure relief device is provided on the standby jumper to vent the melter gases to the melter cave. These gases would be filtered by the C5 filter system prior to environmental release.

2.3.3.4 Development History and Status

The design of the HOP/PVV offgas systems is based upon the use of equipment systems (SBS, film coolers, and HEMEs) for DOE's WVDP. In addition, Savannah River DWPF utilized the HEMEs.

The VSL conducted tests on the DM1200 melter and offgas systems from 2001 through 2005. The DM1200 offgas treatment system consists of SBS, WESP, HEME, HEPA, SCR, packed-bed caustic scrubber (PBS), and a second HEME. A full-flow, sulfur–impregnated, activated-carbon adsorber bed was installed in 2004. The TCO and selective catalytic reduction units were not placed into operation until 2002. Offgas system testing was conducted for several system components: film cooler (24590-101-TSA-W000-0009-171-00001), SBS (24590-101-TSA-W000-0009-54-00001), TCO (24590-101-TSA-W000-0009-87-09), and WESP (24590-101-TSA-W000-0009-174-00001). The HEME, WESP, HEPA filter, and TCO/SCR technologies are commercially available and replaceable within the HLW Facility.

DM1200 and offgas system tests were conducted with high-level waste from Hanford Site tanks C-104, C-106, AZ-101, and AY-102 simulants (24590-101-TSA-W000-0009-172-00001) with adjustments of several toxic metals, nitrogen oxides, and waste organics to bound the concentrations. The tests were designed to determine system destruction removal efficiency (DRE) and DF values for a variety of regulated constituents under WTP normal and challenge melter system conditions. The following issues were observed as summarized in the indicated reports.

<u>Submerged Bed Scrubber (SBS) Blockage</u>. During the initial DM1200 tests (24590-101-TSA-W000-0009-54-00001), solid deposits formed near the base of the downcomer at the bottom of the SBS-packed column. The result was an unwanted pressure drop so that the ventilation system would be unable to pull a vacuum on the melter. This negative pressure is necessary to direct the gases from the melter to the offgas system. SBS modifications (opened the annulus and shortened the submerged portion of the downcomer) eliminated the accumulation of downcomer deposits over the last 51 days of DM1200 testing. These modifications were completed to provide a design concept that more closely match the WVDP and WTP HLW Facility designs.

Throughout DM1200 testing, the SBS was periodically drained and inspected for deposits and unusual wear. The most significant findings were accumulations of deposits in the bottom of the SBS. The accumulation rate of solids showed no evidence of declining with increasing test duration. Solutions were removed from the SBS throughout each test by suction through a wand that extends to the bottom of the SBS bowl. Over the 5-year period of testing, solutions with total solids content as high as 10,000 mg/L were processed through the wand with only one clogging event.

<u>Film Cooler and Transition Line Blockage</u>. Throughout testing on the DM1200 melter, plugging of the film cooler and transition line occurred, particularly in tests with higher melter bubbling rates. At high melter bubbling rates and high temperatures, the film cooler and transition line plugging required that they be cleaned several times per day. The transition line was simple to clean, and required that the line be banged on the side with a hammer. Inspection of film cooler showed 50% blockage at the bottom with

light coating on louvers. The film cooler was flushed with water, which was ineffective. Feeding was interrupted in order to manually rod out the film cooler deposit and, less frequently, a portion of the transition line had to be disassembled for cleaning. R&T staff concluded the transition line blockages could be due to film cooler wash water being entrained into the offgas line. The periodic wetting of solids and the pipe surfaces encouraged solids deposits and accumulation. After instructing VSL to cease the washing operation, transition line accumulations were significantly reduced. Air inlets were added to the underside of the film cooler to prevent blockages at the bottom from bridging over the film cooler opening. Eventually, the film cooler air inlets at the bottom of the film cooler became corroded and blocked with solids that could not be cleaned.

A thorough review of operational data indicated that film cooler plugging could be limited by (a) reducing the bubbling rate (CCN:144619), which had the undesirable effect of reducing the glass production rate; or (b) by increasing the number of bubbling outlets, which permits the use of greater amounts of bubbler air without concentrating the air flow in a limited number of locations. However, with the current WTP melter and film cooler design, testing of a mechanical means to remove blockages was recommended to ensure that it will remove blockages without damaging the delicate film cooler louvers (24590-101-TSA-W000-0009-171-00001).

On March 17, 2006, the EFRT completed their review of melter test data and published their report (CCN:132846). HLW film cooler plugging was identified as an unresolved issue. BNI was directed to prepare a response plan to document the operating conditions required to minimize or avoid film cooler plugging, and to revise design criteria for the film cooler clean-out device (CCN:144619). According to the BNI response plan (CCN:142012), feed will be fed to the DM1200 melter with a high bubbling rate. After the film cooler clogs, a prototype film cooler cleaner will attempt to remove the clog. The results of this testing will indicate if additional modifications to the melter, bubbler, film cooler, or film cooler cleaner system are needed.

Temperature Limits of the Carbon Bed. Per the study *Mercury Abatement Technology Assessment for the WTP* (24590-WTP-RPT-ENG-01-01), the best choice for WTP mercury abatement is sulfur-activated carbon. Sulfur-activated carbon was selected because there is significant commercial experience and because sulfur-activated carbon is the most cost effective alternative. Testing results (CCN:033010; 24590-101-TSA-W000-0009-97-00003; 24590-101-TSA-W000-0009-166-00001) showed that allyl alcohol and LAW levels of nitrate concentrations cause the temperature of the bed to rise. This might result in components bleeding out of the bed and poisoning the downstream catalyst units if the carbon is overheated. Later VSL testing (VSL-05L5290-2) further revealed that if the bed nitrogen oxide (NO), NO_2, and allyl alcohol concentrations are limited, then the temperature rise is reduced to acceptable levels.

Wet Electrostatic Precipitators (WESP) Operational Lifetime. Except for the insulators, the WESP vessels and internals must sustain a 40-year lifetime. Limited access will be available through the metal enclosure for WESP insulator change out (24590-HLW-3YD-HOP-00001). Therefore, the system must have adequate features to address both WESP operational failures and materials failures over the expected operational lifetime. The WESP Corrosion Evaluation (24590-HLW-N1D-HOP-00002) determined that WESP vessels and internals should be fabricated using 6% moly stainless steel.

The WESP Corrosion Evaluation (24590-HLW-N1D-HOP-00002) determined that the internals could accumulate solid deposits that contain halides that cause pitting and crevice corrosion in off-normal situations. An internal memo (CCN:091869) stated that an even water distribution is necessary to efficiently flush solids from the internals and meet the life expectancy of the electrodes. VSL tests of the WESP (24590-101-TSA-W000-0009-174-00001) showed DF degradation over time due to solids buildup and corrosion on the electrode. Flush and deluge systems were added to the WESP to wash the solids from electrodes and removed the solids buildup, but use of the deluge resulted in the shorting of the electrical connections during testing because the top insulators did not drain. It was difficult to restore power to the electrodes after deluge for some LAW feeds.

The final design of the WTP redesigned the WESP to isolate the electrical connections and provided an air purge to avoid wetting the connections from the deluge water. Heated purge air was added to dry water from the internals after the deluge. The new WTP WESP design was flushed during shop tests at the vendor facility using slurry feed of silica dust and water (DMP-4145-FTR-003). The functional test was performed by the vendor where 130 lb of silica dust was injected into the WESP as a slurry. Flush and deluge water were used to clean internals. After flushing and deluge, there were no visible signs of particulate buildup on any internal surfaces. The system was operated with heated purge air for 15 minutes after flushing and deluge. Shop tests confirmed that there was no noticeable dust or water on internal areas where purge air was maintained. Shop tests (DMP-4145-FTR-003) further confirmed that power was restored to the WTP WESP after deluging without shorting electrical connections. Restart time for the end of flush to normal operations varied from 50 minutes to 1 hour and 15 minutes.

<u>Thermal Catalytic Oxidation (TCO) Destruction Removal Efficiency (DRE)</u>. The WTP dangerous waste permit conditions requires the HLW melter offgas systems meet the 99.99% DRE removal efficiency performance standard for principal organic dangerous constituents (PODC). In order to ensure that the required DREs for hazardous organics are met, TCO units were added to the HLW offgas treatment system. Based on agreement between the WTP, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology, the PODCs selected to demonstrate DRE were naphthalene and allyl alcohol (CCN:080128). DRE DM1200 test results (24590-101-TSA-W000-0009-166-00001) exceeded 4-9s DRE in all 12 allyl alcohol test runs and in 10 out of the 12 naphthalene test runs. The naphthalene emission rates for the failed runs were 0.11 and 0.2 mg/min for HLW and LAW, respectively. The passing runs had naphthalene emission rates that ranged from 0.02 to less than 0.002 mg/min.

2.3.3.5 Relevant Environment

The operating environment for the HOP/PVV is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001) and the HOP/PVV systems description (24590-HLW-3YD-HOP-00001). The relevant environment for the HOP/PVV is the:

- Operation of equipment system with high reliability.
- Operation of the primary system for the operating life of the WTP.
- Operation of the primary system in high-contamination/high-radiation areas (C5/R5).
- Operation of the offgas systems with high initial temperatures, high moisture levels, significant particulate loads, and the presence of corrosive acid gasses.
- Use of fixed bed catalyst and absorber beds in the presence of trace poisoning agents.
- Operation of the equipment system at a reduced pressure compared to atmospheric.

The primary offgas treatment system shall remove sufficient radionuclides such that the secondary offgas treatment system can be contact or semi-remotely maintained. The primary offgas system components will be maintained using remote methods.

2.3.3.6 Comparison of the Relevant Environment and the Demonstrated Environment

The HOP/PVV was demonstrated in a relevant environment during DM1200 melter testing. It is projected that the HLW Facility will achieve operational requirements in normal and challenge conditions as a result of the following WTP design characteristics that were demonstrated during DM1200 testing.

Submerged Bed Scrubber (SBS) Blockage

- The annulus of the downcomer for the SBS was opened and the submerged portion of the downcomer was shortened.
- To help minimize the buildup of the solids in the bottom of the SBS, solution jets or spargers were added that agitate the solution at the bottom of the SBS. The solid particulate is guided to the removal point by the swirling flow.
- A siphon line draws slurry from the bottom of the SBS through the suction square to the acidic waste storage vessel.
- The SBS condensate receiving vessel collects condensate and flush solutions from the SBS. The capability exists to flush the SBS and SBS condensate receiver vessel with water or nitric acid (24590-HLW-3YD-HOP-00001). Solution is pumped from the receiving vessel back to the SBS jets. SBS solution then overflows to the receiver.

Wet Electrostatic Precipitators (WESP) Lifetime

- The WESP was designed so that electrical connections are isolated from the water spray.
- A water misting nozzle at the gas inlet facilitates saturating the inlet gas, keeping the collected solids damp (eases washing solids from walls), and providing flush water for washing solids from the collection walls.
- A deluge system at the top of the tube section provides periodic washing capability as necessary to remove solids from the electrodes and maintain the performance of each electrode.
- Water and collected solids drain from the bottom of the WESP into a condensate receiving tank.
- The capability is being included to fill the WESP with nitric acid and allow the WESP internal to soak, thus facilitating solids removal.
- The WESP vessel and internals are manufactured from 6% moly stainless steel for additional corrosion resistance.

Offgas Jumper and Film Cooler Blockage

- Melter offgas jumpers are designed with cleanout access ports, and can be replaced if blockages cannot be removed.
- There are holes in the bottom of the film cooler assembly for air flow to prevent solid accumulation.
- There is the capability to add water to the film cooler inlet air to periodically flush solids buildup from the air distribution slots.
- The film cooler was designed to be replaceable in case clogging is a significant problem.
- A mechanical film cooler cleaner was developed that will be tested at VSL.

- Melting bubbling rates were limited to 1.5 scfm per bubbler, two additional bubblers were added to the HLW melter, and slurry concentrations should be above 325 g-glass/L (CCN:144619; 24590-101-TSA-W000-0009-162-00001).

Temperature Limits of Carbon Bed

- Allyl alcohol and NO_x concentrations in the carbon bed are limited to prevent a temperature rise as result of adsorption and chemical reactions in the activated carbon (AC) bed.
- A water fire suppression system is included as a precaution against AC fires.
- Safety modifications were added to the AC bed.
- Activated carbon vendor tests are planned to obtain efficiency and loading information at the Idaho National Laboratory.

Thermal Catalytic Oxidation (TCO) Destruction Removal Efficiency (DRE) Requirements

The WTP Project evaluated the impact of not achieving the DRE test requirements on the WTP design (CCN:128559; 24590-WTP-RPT-ENV-03-00005) and concluded that the actual WTP offgas system design is more robust compared to the DM1200 offgas system. Based upon analysis, sufficient design contingency exists in the WTP design and it is projected that the HLW Facility will achieve the DRE requirements in normal and challenge conditions. Resolution of issues associated with the offgas system not achieving the DRE test requirements shall be confirmed during cold commissioning of the HLW Facility.

2.3.3.7 Technology Readiness Level Determination

The HOP/PVV was determined to be a TRL 5 because risks remain with the HLW melter film coolers, SBS, carbon columns, and the WESP design. It is recognized that HOP/PVV system designs have a significant development basis in the WVDP and testing with the DM1200 melter and offgas system. However, further development and testing should be completed to reduce the following project risks.

Recommendation 1

Testing of a prototypical HLW film cooler and film cooler cleaner should be completed to demonstrate the adequacy of the equipment concepts prior to cold commissioning.

> *Note: This testing is part of the planned work to resolve the EFRT issue M-17, "HLW Film Cooler Plugging," dealing with film cooler blockages.*

The use of a film cooler in non-bubbled HLW melters is demonstrated in operations at the WVDP and the Savannah River DWPF. The process conditions that increase film cooler blockages in bubbled melters such as the WTP HLW melter have been evaluated (CCN:144619) but are not completely understood. Consistent delivery of a high-solids feed from ultrafiltration to HLW vitrification, and limiting the melter bubbler air rates are factors that can mitigate film cooler blockage. While testing has shown it is possible to maintain HLW vitrification melt rates with lower concentration feeds, this mode of operation could increase plugging in the film cooler. There may be cold cap conditions and bubbler locations where film cooler plugging is more prevalent, as well as high-bubbling conditions. Understanding these conditions would be useful for optimization of melter design and production rates.

Because the DM1200 was operated for a limited period of time (approximately 20 days) with the final design configuration, it is not known whether the cited limitations on bubbler rates will prevent excessive film cooler blockages. The film coolers appear to be adequate for a melter capacity of 3 MTG/day without modification. If capacities greater than 3 MTG/day are required, design changes to the melter may be warranted.

The solutions planned for film cooler blockages (limit bubbling rate, film cooler cleaner, replaceable film cooler) do not include evaluation of design options that might prevent film cooler blockages from forming. For example, there might be design solutions such as splash plates within the plenum below the film cooler, redesign of the melter lid for a more optimum bubbler layout with an increased number of bubblers, or a taller melter plenum that would be more effective in de-entrainment of particulates.

Recommendation 2

Further testing of the WESP is recommended to address operational modes. The VSL tests indicated difficulties restoring power to the WESP electrodes may be related to the melter feed composition (24590-101-TSA-W000-0009-174-00001). In some cases, the WESP electrodes could not be brought back up to full voltage after significant operation with LAW feeds. While no problems were observed with HLW simulants during DM1200 tests, operational information should be confirmed for the HLW feed to understand if feed properties caused the problems.

Further evaluation is also recommended to prove the viability of 6% molybdenum **(**Mo) stainless steels for WESP internals and vessels in the WTP offgas environment. Selection of a corrosion resistant alloy for WESP vessels and internals is of critical importance, because the WESP vessel is not accessible for maintenance (except for the electrode connectors) or removable for the 40-year life of the HLW Vitrification Facility. The WESP vessel and internals are constructed of 6% Mo stainless steel (24590-HLW-N1D-HOP-00002). The article by Phull (2000) was the basis for the selection of the 6% Mo for the WTP in the WESP corrosion evaluation (24590-HLW-N1D-HOP-00002. Phull showed that even 6% Mo stainless steels exhibited very slight susceptibility to corrosion attack after 656 days of exposure to flue gases. Data from Phull implies that a 6% Mo alloy or greater stainless steel is needed in corrosive environments where long life is mandatory.

Recommendation 3

Activated carbon vendor testing should be completed to confirm the behavior of organics, acids (nitrogen oxide [NO_x,] sulfur dioxide [SO_2], and halogen), sulfur, and mercury within the carbon bed.

> *Note: Testing on the carbon bed material is scheduled to be completed as part of the WTP baseline within the next 12 months. Any problems identified by vendor testing of the activated carbon bed material may potentially impact the WTP design and the WTP environmental performance test plan (CCN:128559).*

2.3.4 Pulse Jet Mixer (PJM) System, HLW Melter Offgas Treatment Process System (HOP), and Radioactive Liquid Waste Disposal System (RLD)

2.3.4.1 Function of the PJM System, HOP, and RLD

The function of the PJM system is to mix waste streams comprised of liquid and solids in specially designed vessels to dissipate gases, blend liquids and solids, and suspend solids for sampling and transport. Vessels within the HOP/PVV and RLD use PJMs to support mixing.

The RLD's primary function is to receive effluents from contaminated waste treatment processes areas in the HLW Facility, equipment flushes, and facility sumps and flushes. The RLD vessels provide temporary storage for these liquid effluents before neutralization (if required) and transfer to the PT Facility for treatment.

2.3.4.2 Description of the PJM System, HOP, and RLD

The PJMs are described in the system description for pulse jet mixers and supplemental mixing subsystems (24590-WTP-3YD-50-00003). The HOP/PVV includes two vessels mixed with PJMs. These are the SBS condensate receipt vessels (HOP-VSL-00903; HOP-VSL-00904). The SBS condensate receipt vessels are described in the HOP/PVV systems description (24590-HLW-3YD-HOP-00001).

The RLD contains two vessels that are mixed with PJMs. These are the plant wash and drains vessel (RLD-VSL-00008) and the acidic waste vessel (RLD-VSL-00007). In addition, the RLD includes an offgas drains and collection vessel (RLD-VSL-00002). The RLD vessels are described in the RLD system description (24590-HLW-3YD-RLD-000001).

A schematic that shows the relationship of the HOP and RLD vessels is provided in Figure 2.4.

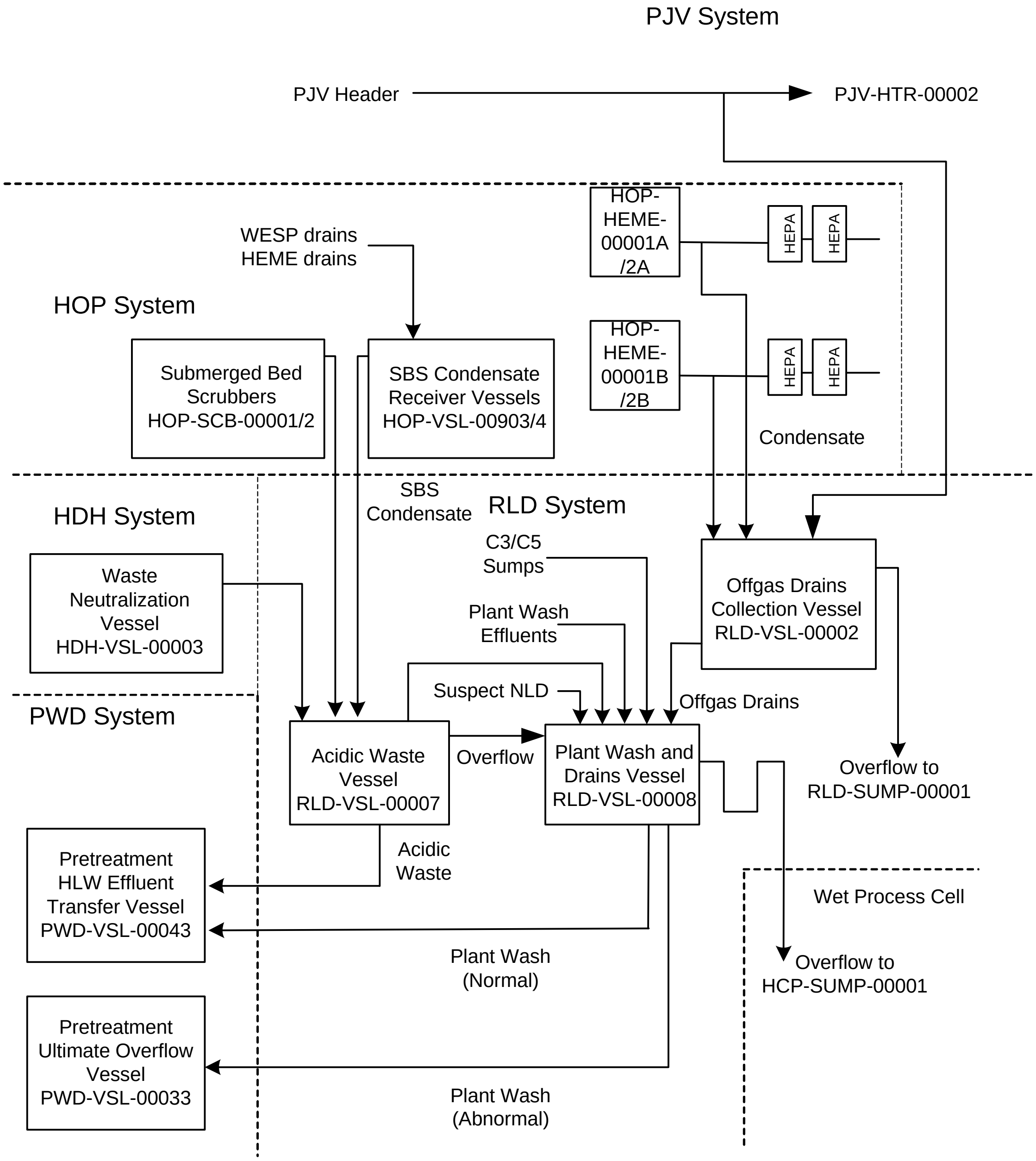


Figure 2.4. Simplified Flow Diagram Showing the HOP and RLD Vessels and their relationship to Interfacing Vessel System

Pulse Jet Mixers (PJM)

PJM devices are long, cylindrical vessels that draw in fluid by a vacuum and then pressurize to eject the fluid to cause mixing; much like a baster draws in and expels fluid. These devices have been shown to be reliable and have no moving parts that require maintenance. Thus, the PJM was selected to be used in vessel systems that were designed to have no maintenance over a 40-year operational design life of the WTP.

The PJMs can be operated either in a continuous pulsing mode, or turned off for a time and restarted in the pulsing mode, depending on process requirements. In vessels that contain particulates, the solids will settle to the bottom between mixing periods. When the PJMs restart, settled solids need to be re-suspended. The PJM design is based on technology developed jointly by AEA Technology and British Nuclear Fuels Limited (BNFL); BNFL was part of the original contractors for the WTP Facility.
A design guide (24590-CM-TSA-HXYG.0008) was prepared to provide the technical basis for the initial design of the PJMs. Later, AEA technology provided the final designs of the WTP PJM mixing systems. Based on waste characteristics, vessel size, and geometry, the number and power (e.g., discharge fluid velocity) of the PJMs were determined.

A PJM system consists of the following components:

- Valves
- Fluidic controller assembly
- Jet pump pair
- Piping
- PJM vessels fitted with nozzles, located in the process vessel

A jet pump is used to pull a vacuum on the PJM and draw process fluids into the PJM vessel from the process vessel. This is the suction phase of the PJM cycle. When the PJM vessel is full, the jet pump is switched from vacuum to pressure mode for the drive cycle. Air pressure applied to the PJM vessel is used to force fluid back out of the PJM vessel and into the process vessel, thereby mixing the process vessel contents.

Melter Offgas Treatment Process System (HOP)

The SBS condensate receiving vessels (BNI Drawing 24590-HLW-MV-HOP-P0001) are used to collect condensate from the SBS, flush solution from the WESP, and flush solution from the HEME. The vessels are 12 ft diameter by 13 ft 9 inches tall. The vessel contains four PJM tubes and four reverse flow diverters (RFD). An RFD is a fluid device used to transfer fluid using air as the motive force.
The vessels are supported on a skirt, and there are two 24-inch inspection ports on the skirt. A system has been supplied to provide ultrasonic measurements to detect vessel erosion on the bottom. Cooling water jackets provide 408 ft^2 heat transfer area and 380,000 Btu/hr duty on the vessel sides and bottom.
The skirt area is vented, and the vessel assembly is electrically grounded. The batch volume is 5,900 gallons. The vessel is constructed of Hastalloy C-22 (24590-HLWN1D-HOP-00009) with 304-L stainless steel being used for the cooling jackets on the vessel exterior. Two RFDs operate at a time for SBS solids suspension, leaving two RFDs as spares. The vessel is vented to the SBS via a vent line.
The SBS overflow lines may also vent the vessel. The SBS condensate receiver vessel has been designed to be maintenance free once the system becomes radioactively contaminated. The vessel contents may be emptied through the SBS, normal route, or can be emptied to the acidic waste collection vessel (RLD-VSL-00007). An installed spray system is used to wash the vessel down with demineralized water for cleaning and to facilitate decontamination and decommissioning.

Radioactive Liquid Waste Disposal System (RLD)

The RLD includes vessels, sumps, piping, pumps, and instrumentation. The vessels include the acidic waste vessel (RLD-VSL-00007), the plant wash and drains vessel (RLD-VSL-00008), and the offgas drains collection vessel (RLD-VSL-00002). It also includes numerous sumps throughout the contaminated areas of the HLW Facility.

The RLD receives effluents from sources throughout the HLW Facility and provides interim storage before transfer to the PT Facility where the waste is recycled to the process. The system is designed to receive effluents, sample them, neutralize them to a pH of 8 or greater, and transfer these effluents to the PT Facility. The acidic waste vessel (RLD-VSL-00007) receives condensate from the SBSs (HOP-SCB-00001/00002), SBS condensate receiver vessels (HOP-VSL-00903/00904), and the waste neutralization vessel (HDH-VSL-00003). The plant wash and drains vessel (RLD-VSL-00008) receives miscellaneous plant wash and vessel wash effluents. The offgas drains collection vessel (RLD-VSL-00002) receives drains from the low points in the offgas system ducts and maintains a hydraulic seal between offgas systems (Pulse Jet Ventilation System [PJV] and Melter Offgas Treatment Process System [HOP]).

The RLD receives the HOP SBS condensate and WESP and HEME drains, the HDH neutralized waste, various plant, vessel, and sump washes, effluents from miscellaneous radioactive drains and the auto sampling drains, and suspect waste from the Nonradioactive Liquid Waste Disposal System (NLD).

When filled, the RLD vessels contents are sampled, neutralized if required, and the contents transferred to the PT Facility.

The RLD-VSL-00007 is fabricated from 6 Mo and RLD-VSL-00008 is fabricated from 316-L stainless steel. Thus, RLD-VSL-00007 was designed in the HLW flowsheet to receive, store, and neutralize corrosive wastes from the SBS condensate receipt vessels and the HLW Canister Decontamination Handling System (HDH). Both vessels have a nominal 5 wt% undissolved solids design limit.

2.3.4.3 Relationship to Other Systems

The major interfaces with the RLD are the SBSs (HOP-SCB-00001/2), the PT/HLW effluent transfer vessel (PWD-VSL-O0043), the waste neutralization vessel (HDH-VSL-00003), and the PT ultimate overflow vessel (PWD-VSL-00033). The system also receives drains from low points in offgas ducting, and various plant wash and vessel wash effluents from throughout the facility. The system boundaries between the RLD vessels and other HLW Facility systems are the nozzles on the RLD vessels.
The system boundary between the RLD vessels and the PT Facility Plant Wash and Disposal System (PWD) is in the transfer piping 5 feet outside of the PT Facility.

2.3.4.4 Development History and Status

Technologies relevant to PJM system, RLD, and HOP are those associated with mixing using PJMs and specification of the materials of construction of the PJMs and vessels.

Extensive nonradioactive simulant testing has been conducted by the WTP Contractor to test the PJM and vessel design concepts for wastes containing high solid concentrations. These studies were focused on establishing the design and operational requirements for the vessels that are nominally referred to as containing non-Newtonian wastes. These vessels are UFP-VSL-00002A/00002B; HLP-VSL-00027A/00027B; and HLP-VSL-00028. Key testing reports are found in the following reports: 24590-101-TSA-W000-0004-124-03, Rev. 00B; 24590-101-TSA-W000-0004-72-08, Rev. 00B; 24590-101-TSA-W000-0004-118-02, Rev. 00B; 24590-101-TSA-W000-0004-114-00019, Rev. 00B;

24590-101-TSA-W000-0004-114-00016, Rev. 00A; 24590-101-TSA-W000-0004-153-00002, Rev. 00A; and 24590-101-TSA-W000-0004-153-00002, Rev. 00B.

The PJM mixed vessels in the HLW Facility are used to blend low-solids (less than 5 wt%) containing process wastes. These wastes are believed to exhibit Newtonian fluid characteristics.

A recent review of the WTP flowsheet (CCN:132846) identified potential design issues with the PJM mixed vessels containing Newtonian process wastes:

> "Issues were identified related to mixing system designs that will result in insufficient mixing and/or extended mixing times. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs."

In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids. This plan has the following objectives related to Newtonian vessels including the vessels in the HOP and RLD.

- Confirm the mixing system design of Newtonian vessels to re-suspend settled waste following a mixing system shutdown.
- Develop testing information that allows accurate prediction of required mixing time for various vessel-mixing functions.
- Demonstrate that normal process mixing successfully meets mixing requirements for each Newtonian processing vessel.

The design basis particle characteristics for Newtonian mixing have not been formally documented by the WTP Contractor. However, a recent report (WTP-RPT-153) presents a revised particulate size and density distribution for the Hanford Site tank wastes. The particle size distribution will be used to develop simulant for testing PJM vessel mixing.

Performance criteria for PJM mixing in the HLW vessels has recently been established (24590-WTP-RPT-PR-07-003) to support definition of a testing program to validate the adequacy of the PJMs in the HLW vessels to blend liquids and solids, maintain solids in suspension, and re-suspend settled solids.

As a precursor to the testing program, the WTP Contractor has conducted an engineering evaluation of the ability of the PJM mixed vessels in the HLW Facility to suspend solids (CCN:150383). The assessment used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. This initial assessment indicates that the mixing capability of the PJMs in the HLW Facility vessels (HOP-VSL-00903; HOP-VSL-00904; RLD-VSL-00007; RLD-VSL-00008) is adequate.

Materials of construction for the HLW Facility vessels have been established through a corrosion evaluation assessment (24590-WTP-GPG-M-047). Corrosion evaluations are based upon a detailed design guide used by the WTP Contractor that considers process chemistry, mechanisms for corrosion, and erosion. The ORP has extensively reviewed and evaluated the vessels design and material of construction to support a conclusion that the vessel design can support a 40-year operational life.

2.3.4.5 Relevant Environment

The operating environment for the PJM system, RLD, and HOP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C), RLD system description (24590-HLW-3YD-RLD-00001), PJM system description (24590-HLW-3YD-PJM-00001), HOP/PVV systems description (24590-HLW-3YD-HOP-00001), and HLW PSAR (24590-WTP-PSAR-ESH-01-002-04). The relevant operational environment for the systems is:

- Remote operation of process fluid mixing equipment to prevent the release of radioactive liquid and solid materials.
- Operation of the equipment systems over a 40-year design life.
- Capability of the mixing systems to mobilize and suspend solids that collect on the bottom of the vessels.

2.3.4.6 Comparison of the Relevant Environment and the Demonstrated Environment

The PJM system, RLD, and HOP vessel systems are based upon design concepts demonstrated in nuclear facilities operated at the Sellafield Site, U.K. (24590-CM-TSA-HXYG.0008). The mixing system design specifications for the WTP were provided by AEA. Testing of the PJM mixing systems for high solids containing slurries has been completed by the WTP Contractor.

The WTP Contractor has identified the need to complete additional testing to demonstrate the ability of the PJMs to mix and re-suspend solids for low solids containing solutions. This work is schedule to be complete in late 2007.

The 40-year design life of the PJMs and vessels has been determined based upon process chemistry, a review of corrosion rates of materials of construction and the preparation of formal corrosion evaluations. The corrosion evaluations are independently reviewed by a BNI chief engineer and a corrosion consultant.

2.3.4.7 Technology Readiness Level Determination

The PJM system supporting the HOP vessels (HOP-VSL-00903; HOP-VSL-00904) and the RLD vessels (PLD-VSL-00007; RLD-VSL-00008) was determined to be a TRL 4 because specific, quantifiable design requirements for the PJM technology have not been established to support testing and design.
The definition of the PJM mixing requirements must consider the functional requirements (i.e., safety, environmental, and process control) of the vessels and the anticipated waste characteristics in the vessel. See 07-DESIGN-047 for further discussion on the PJM technology.

Work associated with the EFRT M-3 IRP (24590-WTP-PL-ENG-013) relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks.
A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

This is based on the use of the PJM technology to suspend and mix the anticipated low solids concentration streams present in these vessels, the corrosion resistant alloys used to fabricate the vessels, and the extensive testing that was completed to verify the operation of non-Newtonian PJM mixed vessels.

Recommendation 4

Testing of the ability of pulse jet mixer (PJM) technology for dissipating gases, blending liquids, and suspending solids should be completed as planned, and a determination made on the adequacy of the PJM designs for the HOP and PLD vessels. Specific requirements for PJM mixing should be established (see 07-DESIGN-047).

> *Note: This testing is part of the WTP baseline as part of resolution of the EFRT issue M3, "Inadequate Mixing System."*

3.0 Findings, Recommendations and Observations

3.1 Findings

The TRA for the HLW facilities identified five systems that were determined to be CTEs:

- HLW Melter Feed Process System (HFP) used to prepare the HLW melter feed
- HLW Melter System (HMP), which includes the HLW melter
- HLW Melter Offgas Treatment Process System/Process Vessel Vent Exhaust System (HOP/PVV) used to treat the HLW melter offgas
- Pulse Jet Mixer (PJM) system and the Radioactive Liquid Waste Disposal System (RLD), including the SBS condensate vessels in the HOP used to store and blend secondary liquid wastes.

The results of the TRL assessment are summarized in Table 3.1. Consistent with NASA and DoD practice, this assessment used TRL 6 as the level that should be attained before the technology is incorporated in the WTP final design. The CTEs were not evaluated to determine if they had matured beyond TRL 6.

3.2 Conclusions and Recommendations

The Assessment Team has concluded that the technology status of HLW facilities is sufficiently mature, except for testing of the following systems, to continue to advance the final design of these facilities. The following recommendations are made based upon the TRA and the information presented in this report.

1. Testing of a prototypical HLW film cooler and film cooler cleaner should be completed to demonstrate the adequacy of the equipment concepts prior to cold commissioning.

   Note: This testing is part of the planned work to resolve the EFRT issue M-17, "HLW Film Cooler Plugging," dealing with film cooler blockages.

   The use of a film cooler in non-bubbled HLW melters is demonstrated in operations at the WVDP and the Savannah River DWPF. The process conditions that increase film cooler blockages in bubbled melters such as the WTP HLW melter have been evaluated (CCN:144619) but are not completely understood. Consistent delivery of a high-solids feed from ultrafiltration to HLW vitrification, and limiting the melter bubbler air rates are factors that can mitigate film cooler blockage. While testing has shown it is possible to maintain HLW vitrification melt rates with lower concentration feeds, this mode of operation could increase plugging in the film cooler. There may be cold cap conditions and bubbler locations where film cooler plugging is more prevalent, as well as high-bubbling conditions. Understanding these conditions would be useful for optimization of melter design and production rates.

   Because the DM1200 was operated for a limited period of time (approximately 20 days) with the final design configuration, it is not known whether the cited limitations on bubbler rates will prevent excessive film cooler blockages. The film coolers appear to be adequate for a melter capacity of 3 MTG/day without modification. If capacities greater than 3 MTG/day are required, design changes to the melter may be warranted.

The solutions planned for film cooler blockages (limit bubbling rate, film cooler cleaner, replaceable film cooler) do not include evaluation of design options that might prevent film cooler blockages from forming. For example, there might be design solutions such as splash plates within the plenum below the film cooler, redesign of the melter lid for a more optimum bubbler layout with an increased number of bubblers, or a taller melter plenum that would be more effective in de-entrainment of particulates.

2. Testing and analysis to demonstrate the adequacy of the Wet Electrostatic Precipitator (WESP) design is recommended.

   Further testing of the WESP is recommended to address operational modes. The VSL tests indicated difficulties restoring power to the WESP electrodes may be related to the melter feed composition (24590-101-TSA-W000-0009-174-00001). In some cases, the WESP electrodes could not be brought back up to full voltage after significant operation with LAW feeds. While no problems were observed with HLW simulants during DM1200 tests, operational information should be confirmed for the HLW feed to understand if feed properties caused the problems.

   Further evaluation is also recommended to prove the viability of 6% Mo stainless steels for WESP internals and vessels in the WTP offgas environment. Selection of a corrosion resistant alloy for WESP vessels and internals is of critical importance, because the WESP vessel is not accessible for maintenance (except for the electrode connectors) or removable for the 40-year life of the HLW Vitrification Facility. The WESP vessel and internals are constructed of 6% Mo stainless steel (24590-HLW-N1D-HOP-00002). The article by Phull (2000) was the basis for the selection of the 6% Mo for the WTP in the WESP corrosion evaluation (24590-HLW-N1D-HOP-00002.
   Phull showed that even 6% Mo stainless steels exhibited very slight susceptibility to corrosion attack after 656 days of exposure to flue gases. Data from Phull implies that a 6% Mo alloy or greater stainless steel is needed in corrosive environments where long life is mandatory.

3. Activated carbon vendor testing should be completed to confirm the behavior of organics, acids (nitrogen oxide [NO_x,] sulfur dioxide [SO_2], and halogen), sulfur, and mercury within the carbon bed.

   Note: Testing on the carbon bed material is scheduled to be completed as part of the WTP baseline within the next 12 months. Any problems identified by vendor testing of the activated carbon bed material may potentially impact the WTP design and the WTP environmental performance test plan (CCN:128559).

4. Testing of the ability of PJM technology for dissipating gases, blending liquids, and suspending solids should be completed as planned, and a determination made on the adequacy of the PJM designs for the HOP and PLD vessels. Specific requirements for PJM mixing should be established (see 07-DESIGN-047).

   Note: This testing is part of the WTP baseline as part of resolution of the EFRT issue M3, "Inadequate Mixing System."

Table 3.1. Technology Readiness Level Summary for the HLW Critical Elements

Critical Technology Element/Description	Technology Readiness Level	Rationale
HLW Melter Feed Process System (HFP) The HFP mixes HLW waste and glass formers to provide feed for the HLW melters.	**6**	There has been extensive WTP and vendor testing to demonstrate the adequacy of the mixing systems.
HLW Melter Process System (HMP) The HMP vitrifies the waste feed slurry produced in the HFP.	**6**	The HLW melter has a significant development basis in previous DOE projects and developmental tests for the WTP. Testing of four reference HLW feeds was determined adequate to support initial operations of the WTP. However, extensive evaluation of alternative anticipated HLW glass compositions has not been completed.
HLW Melter Offgas Treatment Process System/Process Vessel Vent Exhaust System (HOP/PVV) The HOP removes hazardous particulates, aerosols, and gases from the HLW melter offgas and vessel ventilation process offgas. The PVV provides a pathway for vessel offgas to the HOP for treatment.	**5**	The HOP/PVV designs have a significant development basis in the WVDP and testing with the DM1200 melter and offgas system. However, the HOP/PVV was determined to be a TRL5 because risks remain with the HLW melter film coolers, SBS, carbon columns, and the WESP design; the later of which must achieve the lifetime of 40 years.
Pulse Jet Mixer (PJM) System/Radioactive Liquid Waste Disposal System (RLD)/HOP The PJM system mixes waste streams comprised of liquid and solids, blends liquids and solids, and suspends solids for sampling and transport. The RLD receives effluents from contaminated waste treatment processes areas in the HLW Facility, equipment flushes, and facility sumps and flushes. HOP SBS Condensate Vessels - includes all vessels in the HLW Facility that are mixed with PJMs	**4**	Extensive testing of PJMs to demonstrate adequate mixing of slurries with non-Newtonian rheology characteristics has been completed. The WTP Contractor has recently identified requirement to test PJMs for use in vessels containing slurries with Newtonian rheology characteristics to demonstrate adequacy of design to mix, suspend, and re-suspend solids. No clear requirements exist for PJM mixing requirements. Thus, the PJMs were determined to be TRL 4. See 07-DESIGN-047 for further discussion.

4.0 References

1. 07-DESIGN-042, *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities*, February 2007, U.S. Department of Energy, Richland, Washington.
2. 07-DESIGN-047, *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Pretreatment Facility*, June 2007, U.S. Department of Energy, Richland, Washington.
3. 24590-101-TSA-W000-0004-114-00019, Rev. 00B, *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program*, WTP-RPT-127, Rev. 0, January 20, 2006, Bechtel National, Inc., Richland, Washington.
4. 24590-101-TSA-W000-0004-118-02, Rev. 00B, "*Large Tank Experimental Data for Validation for the FLUENT CFD Model of Pulsed Jet Mixers*, July 7, 2003, Bechtel National, Inc., Richland, Washington.
5. 24590-101-TSA-W000-0004-124-03, Rev. 00B, *Demonstration of Ability to Mix in a Small-Scale Pulsed-Jet Mixer Test Facility*, March 13, 2003, Bechtel National, Inc., Richland, Washington.
6. 24590-101-TSA-W000-0004-144-01, Rev. 00B, *Rheological and Physical Properties of AZ-101 HLW Pretreated Sludge and Melter Feed*, WTP-RPT-096, Rev. 0, March 31, 2005, Bechtel National, Inc., Richland, Washington.
7. 24590-101-TSA-W000-0004-172-00001, Rev. 00A, *Final Report: Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*, WTP-RPT-112, Rev. 0, January 5, 2006, Bechtel National, Inc., Richland, Washington.
8. 24590-101-TSA-W000-0004-72-08, Rev. 00B, *Results of Small-Scale Particle Cloud Tests and Non-Newtonian Fluid Cavern Tests*, November 19, 2003, Bechtel National, Inc., Richland, Washington.
9. 24590-101-TSA-W000-0004-87-09, Rev. 00B , *Filtration, Washing and Caustic Leaching of Hanford Tank AZ-101 Sludge*, WTP-RPT-043, Rev. 1, October 2, 2003, Bechtel National, Inc., Richland, Washington.
10. 24590-101-TSA-W000-0004-99-00010, Rev. 00B, *Non-Newtonian Slurry Simulant Development and Selection for Pulse Jet Mixer Testing,* August 17, 2004, Bechtel National, Inc., Richland, Washington.
11. 24590-101-TSA-W000-0009-118-00010, Rev. 00A, *Final Report - ADS Pump Testing as Part of Integrated DM1200 Testing of HLW Compositions Using Bubblers*, VSL-04R4800-2, May 24, 2004, Bechtel National, Inc., Richland, Washington.
12. 24590-101-TSA-W000-0009-119-00003, Rev. B, *Final Report - High-Level Waste Melter System Materials of Construction Testing*, July 22, 2002, Bechtel National, Inc., Richland, Washington.
13. 24590-101-TSA-W000-0009-121-00006, Rev. 00A, *Modeling the Behavior of Noble Metals During HLW Vitrification in the DM1200 Melter*, May 25, 2005, Bechtel National, Inc., Richland, Washington.

14. 24590-101-TSA-W000-0009-144-03, Rev. 00B, *Noble Metals Testing on the DM1200 Pilot Melter System with AZ-101 HLW Simulants*, VSL-03R3740-2, Rev. 0, December 31, 2003, Bechtel National, Inc., Richland, Washington.
15. 24590-101-TSA-W000-0009-153-00001, Rev. 00A, *Final Report - High-Level Waste Melter Alternate Bubbler Configuration Testing*, June 29, 2004. Bechtel National, Inc., Richland, Washington.
16. 24590-101-TSA-W000-0009-162-00001, Rev00A, *Investigation of Glass Bubbling and Increased Production Rate (Proprietary Data)*, October 28, 2004, Bechtel National, Inc., Richland, Washington.
17. 24590-101-TSA-W000-0009-166-00001, Rev. 00B, *Regulatory Offgas Emissions Testing on the DM1200 Melter System Using HLW and LAW Simulants*, VSL-05R5830-1, Rev. 0, November 11, 2005, Bechtel National, Inc., Richland, Washington.
18. 24590-101-TSA-W000-0009-168-00001, Rev. B , *Comparison of HLW Simulant, Actual Waste, and Melter Glasses*, VSL-05R5760-1, Rev. 0, December 2, 2005, Bechtel National, Inc., Richland, Washington.
19. 24590-101-TSA-W000-0009-171-00001, Rev. 00A, *Summary of DM1200 Operation at VSL*, VSL-06R6710-2, Rev. 0, October 10, 2006. Bechtel National, Inc., Richland, Washington.
20. 24590-101-TSA-W000-0009-172-00001, Rev. 00A, *Review of Properties of Simulated Feeds Used for Melter Testing*, VSL-06R6410-1, Rev. 0, September 26, 2006, Bechtel National, Inc., Richland, Washington.
21. 24590-101-TSA-W000-0009-174-00001, Rev. 00A. *Summary of DM1200 WESP History and Performance,* VSL-06R6710-1, Rev. 0, August 7, 2006, Bechtel National, Inc., Richland, Washington.
22. 24590-101-TSA-W000-0009-23-10, Rev. 00C, *RPP-WTP Pilot Melter Bubbler Life Extension Test Results Report*, TRR-PLT-061, Rev. 0, January 7, 2004, Bechtel National, Inc., Richland, Washington.
23. 24590-101-TSA-W000-0009-34-03, Rev. 00C, *Final Report, Tests on the DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants*, July 31, 2003, Bechtel National, Inc., Richland, Washington.
24. 24590-101-TSA-W000-0009-54-00001, Rev. 00C, *Final Report - Submerged Bed Scrubber (SBS): Off-line Component Testing of DM1200 SBS Unit*, VSL-01R2200-1, Rev. 1, August 30, 2004, Bechtel National, Inc., Richland, Washington.
25. 24590-101-TSA-W000-0009-74-01, Rev. 00D, *Final Report, Start-Up and Commissioning Tests on the DuraMelter 1200 HLW Pilot Plant Melter System Using AZ-101 HL Simulants*, Rev. 1, August 29, 2005, Bechtel National, Inc., Richland, Washington.
26. 24590-101-TSA-W000-0009-87-09, Rev. 00B, *Off-line Tests of the DM1200 Thermal Catalytic Oxidation (TCO) Unit*, VSL-02R8200-1, Rev. 0, April 17, 2003, Bechtel National, Inc., Richland, Washington.
27. 24590-101-TSA-W000-0009-97-00003, Rev. 00A. *Regulatory Offgas Emissions Testing on the DM1200 Melter System Using HLW Simulants: Data Summary Report*, VSL05S.5830-1, February 28, 2005, Bechtel National, Inc., Richland, Washington.

28. 24590-101-TSA-W000-004-172-00001, Rev00A, *Technical Basis For HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*, January 2006, Bechtel National, Inc., Richland, Washington.
29. 24590-101-TSA-W000-009-172-00001, Rev. 0, *Review of Properties of Simulated Feeds Used for Melter Testing,* August 16, 2006, Bechtel National, Inc., Richland, Washington.
30. 24590-101-TSA-W000-009-48-00001, *Duramelter 100 Tests with AZ-101 HLW Simulant Using a DuraMelter 100 Vitrification System*. VSL-01R10N0-1, Rev. 1, February 25, 2002, Bechtel National, Inc., Richland, Washington.
31. 24590-101-TSA-W000-009-98-00011, Rev. 00A , *Preparation and Testing of HLW Matrix Glasses to Support Development of WTP Phase 2 Property- Composition Models*, September 26, 2006, Bechtel National, Inc., Richland, Washington.
32. 24590-CM-TSA-HXYG.0008, *Technical Basis for River Protection Project Waste Treatment Plant (RPP-WTP)-Power Fluidics System Design*, August 6, 2001, BNFL.
33. 24590-HLW-3YD-HFP-00001, *System Description for HLW Concentrate Receipt and Melter Feed Process Systems (HCP and HPP)*, December 22, 2004, Bechtel National, Inc., Richland, Washington.
34. 24590-HLW-3YD-HMP-00001, Rev. 2, *System Description For The HLW Melter Process System (HMP)*, May 2006, Bechtel National, Inc., Richland, Washington.
35. 24590-HLW-3YD-HOP-00001, *System Description for HLW Melter Offgas Treatment Process and Process Vessel Vent Extraction (HOP and PVV Systems)*, November 14, 2002, Bechtel National, Inc., Richland, Washington.
36. 24590-HLW-3YD-HPH-00001, *HLW Container Pour Handling System*, February 3, 2005, Bechtel National, Inc., Richland Washington.
37. 24590-HLW-3YD-RLD-00001, Rev. 1.0, *System Description for HLW Radioactive Liquid Waste Disposal (System RLD)*, May 18, 2005, Bechtel National, Inc., Richland, Washington.
38. 24590-HLW-N1D-HOP-00002, Rev. 2, *WESP Corrosion Evaluation*, December 22, 2005, Bechtel National, Inc., Richland, Washington.
39. 24590-HLW-RPT-M-03-004, Rev. 0, *CFD Modeling Report for WTP Vessel; RLD-VSL-00007*, August 22, 2003, Bechtel National, Inc., Richland, Washington.
40. 24590-HLW-RPT-M-03-005, Rev. 0, *CFD Modeling Report for WTP Vessel; RLD-VSL-00008*, August 22, 2003, Bechtel National, Inc., Richland, Washington.
41. 24590-HLW-RPT-RT-01-003, Rev. 0, *Research & Technology Recommendation on the Requirement of Bubblers in the HLW Melter*, March 16, 2002, Bechtel National, Inc., Richland, Washington.
42. 24590-PTF-TSP-RT-06-007, Rev. 0, *Scaled Testing to Determine the Adequacy of the WTP Pulse Jet Mixer Designs*, January 16, 2007, Bechtel National, Inc., Richland, Washington.
43. 24590-QL-POA-MFAO-00001-10-00001, Rev. 00B, *Rotating Mechanical Agitators Test Report*, March 17, 2004, Prepared by Philadelphia Mixers for Bechtel National, Inc., Richland, Washington.
44. 24590-WTP-3YD-50-00003, Rev. A. *System Description for Pulse Jet Mixers and Supplemental Mixing Systems*, May 19, 2004, Bechtel National, Inc., Richland, Washington.
45. 24590-WTP-DB-ENG-01-001, Rev. 1C, *WTP Basis of Design*, November 1, 2006, Bechtel National, Inc., Richland, Washington.

46. 24590-WTP-GPG-M-047, Rev. 2.0, *Preparation of Corrosion Evaluations*, Bechtel National, Inc., Richland, Washington.
47. 24590-WTP-PL-ENG-06-0013, Rev. 000, *Issue Response Plan for Implementation of External Flowsheet Review Team (EFRT) Recommendations-M3, Inadequate Mixing System Design*, August 8, 2006, Bechtel National, Inc., Richland, Washington.
48. 24590-WTP-PSAR-ESH-01-002-04, Rev. 1, *Preliminary Safety Analysis Report to Support Construction Authorization; HLW Facility,* December 22, 2006, Bechtel National, Inc., Richland, Washington.
49. 24590-WTP-PSAR-ESH-01-002-04, Rev. 2b, *Preliminary Safety Analysis Report to Support Construction Authorization; HLW Facility*, February 16, 2007, Bechtel National, Inc., Richland, Washington.
50. 24590-WTP-RPT-ENG-01-013. *Mercury Abatement Technology Assessment for the WTP*, December 14, 2001, Bechtel National, Inc., Richland, Washington.
51. 24590-WTP-RPT-ENV-03-00005, Rev. 0, *4-9s Destruction and Removal Efficiency Assessment*, November 20, 2003, Bechtel National, Inc., Richland, Washington.
52. 24590-WTP-RPT-PR-07-003, Rev. 0, *Pulse Jet Mixer (PJM) Mixing Test Performance Criteria*, February 2, 2007. Bechtel National, Inc., Richland, Washington.
53. 24590-WTP-TSP-RT-01-004, *Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste*, November 12, 2002, Bechtel National, Inc., Richland, Washington.
54. CCN:033010, “Determine Path Forward for Safe Operation of Carbon Absorption Beds,” May 1, 2002, Bechtel National Inc., Richland, Washington.
55. CCN:080128, Letter, from R. J. Schepens, DOE ORP, to M. A. Wilson, Washington Department of Ecology, “Request for Concurrence with Principal Organic Dangerous Constituents (PODCs) for Demonstrating a 99.99 Percent Organic Destruction and Removal Efficiency (DRE), 03-AMWTP-164,” December 17, 2003, Bechtel National, Inc., Richland, Washington.
56. CCN:091869, “HLW-WESP Internals and 40 Year Lifespan.” May 27, 2004, Bechtel National, Inc., Richland, Washington.
57. CCN:119800, “FW:ABAR 24590-WTP-SE-ENS-04-090 Erosion Information,” May 25, 2005, Bechtel National, Inc., Richland, Washington.
58. CCN:128559, “White paper on the Analysis of Naphthalene Destruction and Removal Efficiency (DRE) Testing at the Vitreous State Laboratory (VSL),” December 15, 2005, Bechtel National, Inc., Richland, Washington.
59. CCN:132846, “Report of External Flowsheet Review Team for the Hanford Waste Treatment and Immobilization Plant-Final Report Titled: ‘Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput’,” March 17, 2006, Bechtel National, Inc., Richland, Washington.
60. CCN:142012, “EFRT M17: “HLW Film Cooler Plugging,” July 17, 2006, Bechtel National, Inc., Richland, Washington.
61. CCN:144619, “EFRT M17: Evaluation of HLW Film Cooler Blockage Issues,” December 22, 2006, Bechtel National, Inc., Richland, Washington.

62. CCN:150383, "Path Forward for EFRT Mixing Issue M3," January 11, 2007, Bechtel National, Inc., Richland, Washington.

63. DMP-4145-FTR-003, *HLW WESP Functional Test Report*, June 2006, prepared by DMP for Bechtel National, Inc., Richland, Washington.

64. DoD 2004, *Acquisition System Guidebook*, DODI 5000.2, U.S. Department of Defense, November 17, 2004.

65. DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005.

66. FMP 064, *Jet Solid Suspension Design Guide*, October 2005, BHR Group Limited, Bedfordshire, U.K.

67. GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Can Improve Weapon System Outcomes*, July 1999, United States General Accounting Office.

68. Nolte, William L., et al., *Technology Readiness Level Calculator*, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003.

69. NUREG/CR-6826/ANL-03/22. *Fracture Toughness and Crack Growth Rates of Irradiated Austenitic Stainless Steels*, August 2003, Argonne National Laboratory, Argonne, Illinois.

70. Phull, B.S., W.L. Mathay, and R.W. Ross, 2000, "Corrosion Resistance of Duplex and 4-6% Mo-Containing Stainless Steels in FGD Scrubber Absorber Slurry Environments," presented at Corrosion 2000, Orlando, Florida, March 26-31, 2000, NACE International, Houston, Texas.

71. SCT-M0SRLE60-00-110-00023, Rev. 00A, *Tank 241-AY-102 Simulant Development, Ultrafiltration, and Washing, WSRC-TR-2003-00547*, Rev. 0, March 31, 2004, Bechtel National, Inc., Richland, Washington.

72. SCT-M0SRLE60-00-132-05, Rev. 00C, *Pilot Scale Testing - Transport of HLW Glass Former Chemicals Proof of Principle Test Results (U)*, April 10, 2003, Bechtel National, Inc., Richland, Washington.

73. SCT-M0SRLE60-00-187-02, Rev. 00C (cleared)), *Evaluation of Wetting Agents to Mitigate Dusting of Glass Forming Chemicals During Delivery to the Melter Feed Preparation Vessel (U)*, WSRC-TR-2003-00209, July 31, 2003, Bechtel National, Inc., Richland, Washington.

74. SCT-M0SRLE60-00-193-00004, Rev. 00A, *Hanford HLW AY-102/C106 Pretreated Sludge Physical and Chemical Properties Prior to Melter Feed Processing (U)*, WSRC-TR-2004-00394, Bechtel National, Inc., Richland, Washington.

75. SCT-M0SRLE60-00-195-00001, Rev. 00A, *Interim Report: RPP-WTP Semi-Integrated Pilot Plant – Campaign 1*, WSRC-TR-2004-00201, Rev. 0, May 18, 2004, Bechtel National, Inc., Richland, Washington.

76. SCT-M0SRLE60-00-21-05, Rev. 00B, *Crucible Scale Vitrification of Pretreated C-106 Sludge Mixed with Secondary Wastes*, WSRC-TR-2001-00252, August 8, 2002, Bechtel National, Inc., Richland, Washington.

77. SCT-M0SRLE60-00-211-00001, Rev. 00A, *Physical Characterization of Vitreous State Laboratory AY102/C106 and AZ-102 High Level Waste Melter Feed Simulants (U)*, WSRC-TR-2005-00035, Rev. 0, March 31, 2005, Bechtel National, Inc., Richland, Washington.

78. SCT-M0SRLE60-00-218-00001, Rev. 0A, "*Vitrification and Product Testing of AY-102/C-106 HLW (Env D)*, WSRC-TR-2005-00410, Rev. 0," November 2005, Bechtel National, Inc., Richland, Washington.
79. SCT-M0SRLE60-00-83-01A, *Physical Characterization for Hanford Tank Waste Samples AN-102, AN-103, and AZ-102*, WSRC-TR-2000-00352, June 6, 2002, Bechtel National, Inc., Richland, Washington.
80. VSL-05L5290-2, *Letter Report: Off-Line DM1200 Slipstream Carbon Column Scoping Tests*, Vitreous State Laboratory of the Catholic University of America, Washington, D.C. (This document is included as Appendix III of VSL-05R5830-1).
81. VSL-06T1000-1, *Test Plan Pretreated Waste and Melter Feed Composition Variability Testing Using HLW and LAW Simulants*, September 29, 2006, Vitreous State Laboratory of the Catholic University of America, Washington, D.C.

Appendix A – Determination of Critical Technology Elements

Appendix A – Determination of Critical Technology Elements

The working definition of the Critical Technology Element (CTE) as defined in the *Department of Defense, Technology Readiness Assessment Deskbook*[1] (2005) was used as a basis for identification of CTEs for the Waste Treatment and Immobilization Plant (WTP). The working definition is as follows:

> "A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel.
>
> Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility."

The WTP Project is divided into five project elements:

- Analytical Laboratory (LAB)Facility
- Balance of Facilities (BOF)
- Low-Activity Waste (LAW) Vitrification Facility
- High-Level Waste (HLW) Vitrification Facility
- Pretreatment (PT) Facility

Within each project, the specific design features of the facility are divided into "systems." Thus for convenience, the identification of the CTEs was done on a system basis. Most systems within the WTP Facility are unique to the five project elements identified above. However, the Pulse Jet Mixer (PJM) system is common to several treatment facilities including the Radioactive Liquid Waste Disposal System (RLD). Therefore, the PJM system was allocated to the RLD project element.

Determination of CTEs

The process for identification of the CTEs for the HLW facilities involved two steps:

1. An initial screening of the complete list of systems for HLW for those that have a potential to be a CTE. In this assessment, systems that are directly involved in the processing of the tank waste, or handling of the primary products (immobilized low-activity waste) and secondary wastes, are initially identified as potential CTEs. The complete list of systems and those identified as potential CTEs are listed in Table A.1. This initial assessment was completed by the Assessment Team (see Appendix D).
2. A final screening of the potential CTEs was completed to determine the final set of CTEs for evaluation. This was completed by assessing the initial systems against two set of questions as presented in Table A.2. A CTE is determined if there is a positive response to at least one of the questions, in each of the question sets identified in Table A.2. This final assessment of the CTEs was completed jointly by the Assessment Team and the WTP Project Technology and Engineering staff.

The specific responses to each of the questions for each potential CTE are provided in Table A.3.

The rationale for the selection of each of the systems as a CTE is summarized below.

---

[1] Department of Defense, *Technology Readiness Assessment (TRA) Deskbook*, May 2005, prepared by the Deputy Undersecretary of Defense for Science and Technology (DUSD(S&T))

HLW Melter Feed Process System (HFP)

The purpose of the HFP is to prepare the HLW meter feed by blending treated high-level waste (HLW) and glass-forming chemicals. The components are commercially available but have been repackaged for a remote environment. Application of the final system configuration in a remote environment is unique. Integrated testing has not been completed in a remote environment for the entire range of waste feeds expected at the WTP from pretreatment. During testing with the DM3300 melter, dry glass-forming chemicals were added to a feed simulants. There was no attempt to wet the glass formers. Wetted chemicals are added to the melter, and the addition of glass formers using wetted powders is unique.

HLW Melter Process (HMP)

The WTP melter is most similar to the West Valley Demonstration Project (WVDP) melter in that both melters use similar “air lift” glass discharge systems. However, the WTP melter has a glass pool surface are of 3.7 m^2, which is larger than the WVDP (2.2 m^2) and Savannah River Defense Waste Processing Facility (DWPF) (2.6 m^2) melters. In addition, some of the equipment components used in the melter, such as the bubblers and multiple-feed nozzles, are unique to this process system. Issues have been identified with glass composition, bubbler life, bubbler configuration, and noble metals settling in the melter. Testing at the Vitreous State Laboratory of the Catholic University of America (VSL) is much more limited than what was done with low-activity waste (LAW). VSL testing was augmented by physical modeling to estimate melter requirements. There may be an overestimation of production capability as a result.

HLW Melter Offgas Treatment Process System and Process Vessel Vent Exhaust System (HOP/PVV)

The specific subcomponents that comprise the HLW melter offgas system are a combination of unique WTP designs (e.g., film cooler, submerged bed scrubber [SBS]) and vendor-designed, commercially available equipment (e.g., high-efficiency mist eliminator [HEME], wet electrostatic precipitator [WESP], mercury (Hg) catalyst skid, and organic destruction catalyst skid). Issues were identified during Research and Technology (R&T) testing with film cooler blockage due to splashing of the glass onto the louvers of the film cooler at high bubbling rates and the lack of an effective cleaner for the film cooler. The SBS required design modifications to address solids accumulation leading to an unacceptable pressure drop in the downcomers. The WESP includes design modifications to maintain the decontamination factor (DF) and premature failure of internals. The technology has never been used in a radioactive environment. It is a permanently designed vessel inside the WTP. The electrodes and connectors replaceable, but the remaining components of the WESP have not been designed for routine maintenance. Proof is needed that application of the WESP in the radioactive environment does not exceed the currently demonstrated capability for WESP equipment lifetime.

Pulse Jet Mixers (PJM) and Supplemental Mixing Systems

PJMs are used within the WTP to dissipate gases, blend liquids, and suspend solids for sampling and transport. The PJM system is identical the system used at the Sellafield site, U.K. PJMs have been shown to adequately mix non-Newtonian fluids. For Newtonian fluids, there may not be enough power to suspend the solids and keep them from settling on the bottom.

Radioactive Liquid Waste Disposal System (RLD)

The RLD handles liquid waste for interim storage before being transferred to the effluent system. The RLD is located in the high-contamination/high-radiation zone of the WTP; entry into the zone will not be possible once hot production begins. There are static areas with PJMs when the vessels are full. Furthermore, the RLD has a 40-year design life requirement for the WTP. The system is based on the design at the Sellafield site, but the vessels at Sellafield were replaceable.

The following systems were not considered critical systems, because they do not use new, novel, modified, or repackaged technology: HLW Canister Decontamination Handling System (HDH) and

HLW Canister Export Handling System (HEH) because the processes are similar to those used at WVDP and the Sellafield site. Similarly, the HLW Mechanical Handling System (HMH), HLW System Canister Receipt Handling (HRH), and HLW Canister Pour Handling System (HPH) are almost identical to WVDP.

Table A.1. Identification of Critical Technology Elements (Systems) in the HLW Facility

System Locators	System Title	Document number	Include in Initial CTE Evaluation?
AFR,NAR,SHR,ANR,SPR,STR	HLW Reagents	24590-HLW-3YD-30-00001	No
ARV,C1V,C2V,C3V,C5V	Cascade Ventilation System	24590-HLW-3YD-30-00002	No
BSA	Breathing Service Air	24590-HLW-3YD-BSA-00001	No
C1V	Cascade Ventilation System	24590-HLW-3YD-C1V-00001	No
C2V	Cascade Ventilation System	24590-HLW-3YD-C2V-00001	No
C3V	Cascade Ventilation System	24590-HLW-3YD-C3V-00002	No
C3V	Cascade Ventilation System	24590-HLW-3YD-C3V-00001	No
C5V	Cascade Ventilation System	24590-HLW-3YD-C5V-00001	No
CHW	Chilled Water	24590-HLW-3YD-CHW-00001	No
DOW	Domestic Water System	24590-HLW-3YD-DOW-00001	No
HFP	HLW Melter Feed Process	24590-HLW-3YD-HFP-00001	Yes
HDH	Canister Decontamination Handling	24590-HLW-3YD-HDH-00002	Yes
HEH	HLW Canister Export Handling	24590-HLW-3YD-HEH-00001	Yes
HFH	HLW Melter Feed Process	24590-HLW-3YD-HFH-00002	Yes
HFH	HLW Melter Feed Process	24590-HLW-3YD-HFH-00001	Yes
HMH	HLW Melter Handling	24590-HLW-3YD-HMH-00001	Yes
HMP	HLW Melter Process	24590-HLW-3YD-HMP-00001	Yes
HOP/PVV	Melter Offgas Treatment Process	24590-HLW-3YD-HOP-00001	Yes
HPH	HLW Canister Pour Handling	24590-HLW-3YD-HPH-00001	Yes
HPS	High Pressure Steam	24590-HLW-3YD-HPS-00001	No
HRH	HLW Melter Cave Support Handling	24590-HLW-3YD-HRH-00001	Yes
HSH	HLW Melter Cave Support Handling	24590-HLW-3YD-HSH-00001	Yes
ISA	Instrument Service Air	24590-HLW-3YD-ISA-00001	No
LPS	Low Pressure Steam	24590-HLW-3YD-LPS-xxxxx*	No
LTE	Cave Lighting	24590-HLW-3YD-LTE-00001	No
NLD	Non-radioactive Liquid Waste	24590-HLW-3YD-NLD-00001	No
PJV	Pulse Jet Ventilation	24590-HLW-3YD-PJV-00001	No
PWD	Plant Wash and Disposal	24590-HLW-3YD-PWD-00001	No
RLD	Radioactive Liquid Waste	24590-HLW-3YD-RLD-00001	No
SCW	Steam Condensate Water	24590-HLW-3YD-SCW-xxxxx*	No

Table A.2. Questions used to Determine the Critical Technology Element for the HLW Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

Table A.3. Summary of Question Responses for the LAB/BOF/LAW Systems that were determined to be Critical Technology Elements

Critical Technology Evaluation Questions	HDH	HEH	HFP	HMH	HMP	HOP/ PVV	HPH	HRH	HSH	PJM	PJV	RLD
Critical Technology Element?	No	No	Yes	No	Yes	Yes	No	No	No	Yes	No	Yes
First Set	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Does the technology directly impact a functional requirement?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required?	N	N	N	N	N	N	N	N	N	N	N	N
Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns	N	N	N	N	N	N	N	N	N	N	N	N
Are there uncertainties in the definition of the end state requirements for this technology ?	N	N	N	N	N	N	N	N	N	N	N	N
Second Set	No	No	Yes	No	Yes	Yes	No	No	No	Yes	No	Yes
Is the technology new or novel?	N	N	N	N	N	Y	N	N	N	N	N	N
Is the technology modified?	N	N	N	N	N	Y	N	N	N	N	N	N
Has the technology been repackaged so that a new relevant environment is realized?	N	N	Y	N	Y	Y	N	N	N	N	N	Y
Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?	N	N	Y	N	Y	Y	N	N	N	Y	N	Y

Appendix B – Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix B – Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix B presents the questions used for assessing the technology maturity of U.S. Department of Energy (DOE) Office of Environmental and Radioactive Waste Management (EM) waste processing and treatment technologies using a modified version of the U.S. Air Force Research Laboratory (AFRL) Technology Readiness Level (TRL) Calculator (Nolte et al. 2003). The following TRL questions were developed for the evaluation of the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory (LAB), Balance of Facilities (BOF), and Low-Activity Waste (LAW) Facility, and applied to High-Level Waste (HLW) Facility systems in their respective tables as identified below.

- Table B.1 for TRL 1
- Table B.2 for TRL 2
- Table B.3 for TRL 3
- Table B.4 for TRL 4
- Table B.5 for TRL 5
- Table B.6 for TRL 6

The TRL Calculator developed by the U.S. AFRL is available online by searching at the “Defense Acquisition University.”

The U.S. General Accounting Office (GAO) (1999) recommended that the U.S. Department of Defense (DoD) assess technology readiness prior to entering the next stage of development. The recommended minimum maturity for a technology to be included in an acquisition was TRL 6 (prototype demonstration in a relevant environment). TRL 7 (system prototype demonstration in an operational environment) was preferred. The DoD has developed detailed guidance for using TRLs (DOD *Technology Readiness Assessment Deskbook,* 2005*).*

The DOE EM version of the TRL Calculator includes a standard set of questions at each technology readiness level implemented in Microsoft Excel™. The questions in the original calculator were for DoD weapons systems, so the questions were modified for EM use. The modified questions shown in Tables B.1 to B.6 reflect the technology development for waste processing technologies. The questions were reviewed by Mr. Nolte (developer of the TRL Calculator) to assure that the maturity levels did not change as a result of changing the words.

The goal of using the modified TRL Calculator was to assess whether the critical technology elements (CTE) in the WTP were ready to proceed with design and construction. Prior to initiating the process, the review was initiated using top-level questions. The expected TRL was determined from the question with the first “yes” answer from the list in Figure B.1. Many of the HLW Facility systems did not meet TRL 6. Therefore, the process started using the questions at either TRL 4 or TRL 5 to assure that the prior level of readiness was achieved before evaluating the expected level of technology readiness.

If Yes, Then Logic		Top Level Question
TRL 9	⟶	Has the actual equipment/process successfully operated in the full operational environment (Hot Operations)?
TRL 8	⟶	Has the actual equipment/process successfully operated in a limited operational environment (Hot Commissioning)?
TRL 7	⟶	Has the actual equipment/process successfully operated in the relevant operational environment (Cold Commissioning)?
TRL 6	⟶	Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?
TRL 5	⟶	Has bench scale equipment/process testing been demonstrated in a relevant environment?
TRL 4	⟶	Has laboratory scale testing of similar equipment systems been completed in a simulated environment?
TRL 3	⟶	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?
TRL 2	⟶	Has an equipment and process concept been formulated?
TRL 1	⟶	Have the basic process technology process principles been observed and reported?

Figure B.1. Top Level Questions Establish Expected Technology Readiness Level

By answering the questions in the TRL calculator for the expected TRL, the calculator provided a standardized, repeatable process for evaluating the maturity of any hardware or software technology under development. The first columns of Tables B.1 to B.6 identify whether the question applies to hardware (H), software (S) or both. The second columns of Tables B.1 to B.6 identify the areas of readiness being evaluated: technical (T), programmatic (P), and manufacturing/quality requirements (M). To complete the TRL, column 3 had to be 100% complete for all questions in the table.

Appendix C summarizes expected state of readiness assessed using the TRL Calculator questions in Tables B.5 and B.6 for the HLW Facility systems. While questions for TRL 4 may have been evaluated, only the responses to the hardware questions for TRLs 5 and 6 are shown in Appendix C.

Table B.1. Technology Readiness Level 1 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		"Back of envelope" environment
B	T		Physical laws and assumptions used in new technologies defined
S	T		Have some concept in mind for software that may be realizable in software
S	T		Know what software needs to do in general terms
B	T		Paper studies confirm basic principles
S	T		Mathematical formulations of concepts that might be realizable in software
S	T		Have an idea that captures the basic principles of a possible algorithm
B	P		Initial scientific observations reported in journals/conference proceedings/technical reports
B	T		Basic scientific principles observed
B	P		Know who cares about the technology; e.g., sponsor, money source
B	T		Research hypothesis formulated
B	P		Know who will perform research and where it will be done

H-Hardware element, contains no appreciable amount of software — T-Technology, technical aspects
S-Completely a Software system — M-Manufacturing and quality
B-Some Hardware and Software — P-Programmatic, customer focus, documentation

Table B.2. Technology Readiness Level 2 Questions

H/S/ Both	Cat	% Complete	Criteria
B	P		Customer identified
B	T		Potential system or components have been identified
B	T		Paper studies show that application is feasible
B	P		Know what program the technology will support
B	T		An apparent theoretical or empirical design solution identified
H			Basic elements of technology have been identified
B	T		Desktop environment
H	T		Components of technology have been partially characterized
H	T		Performance predictions made for each element
B	P		Customer expresses interest in the application
S	T		Some coding to confirm basic principles
B	T		Initial analysis shows what major functions need to be done
H	T		Modeling and simulation only used to verify physical principles
B	P		System architecture defined in terms of major functions to be performed
S	T		Experiments performed with synthetic data
B	P		Requirements tracking system defined to manage requirements creep
B	T		Rigorous analytical studies confirm basic principles
B	P		Analytical studies reported in scientific journals/conference proceedings/technical reports
B	T		Individual parts of the technology work (no real attempt at integration)
S	T		Know what hardware software will be hosted on
B	T		Know what output devices are available
B	P		Preliminary strategy to obtain TRL 6 developed (e.g., scope, schedule, cost)
B	P		Know capabilities and limitations of researchers and research facilities
B	T		Know what experiments are required (research approach)
B	P		Qualitative idea of risk areas (cost, schedule, performance)

H-Hardware element, contains no appreciable amount of software — T-Technology, technical aspects
S-Completely a Software system — M-Manufacturing and quality
B-Some Hardware and Software — P-Programmatic, customer focus, documentation

Table B.3. Technology Readiness Level 3 Questions

Both	Cat	% Complete	Criteria
B	T		Academic environment
H	T		Predictions of elements of technology capability validated by analytical studies
B	P		The basic science has been validated at the laboratory scale
H	T		Science known to extent that mathematical and/or computer models and simulations are possible
B	P		Preliminary system performance characteristics and measures have been identified and estimated
S	T		Outline of software algorithms available
H	T		Predictions of elements of technology capability validated by modeling and simulation (M&S)
S	T		Preliminary coding verifies that software can satisfy an operational need
H	M		No system components, just basic laboratory research equipment to verify physical principles
B	T		Laboratory experiments verify feasibility of application
H	T		Predictions of elements of technology capability validated by laboratory experiments
B	P		Customer representative identified to work with development team
B	P		Customer participates in requirements generation
B	T		Cross technology effects (if any) have begun to be identified
H	M		Design techniques have been identified/developed
B	T		Paper studies indicate that system components ought to work together
B	P		Customer identifies transition window(s) of opportunity
B	T		Performance metrics for the system are established
B	P		Scaling studies have been started
S	T		Experiments carried out with small representative data sets
S	T		Algorithms run on surrogate processor in a laboratory environment
H	M		Current manufacturability concepts assessed
S	T		Know what software is presently available that does similar task (100% = inventory completed)
S	T		Existing software examined for possible reuse
H	M		Sources of key components for laboratory testing identified
S	T		Know limitations of presently available software (analysis of current software completed)
B	T		Scientific feasibility fully demonstrated
B	T		Analysis of present state of the art shows that technology fills a need
B	P		Risk areas identified in general terms
B	P		Risk mitigation strategies identified
B	P		Rudimentary best value analysis performed for operations
B	P		Individual system components have been tested at laboratory scale

H-Hardware element, contains no appreciable amount of software	T-Technology, technical aspects
S-Completely a Software system	M-Manufacturing and quality
B-Some Hardware and Software	P-Programmatic, customer focus, documentation

Table B.4. Technology Readiness Level 4 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology issues (if any) have been fully identified
H	M		Laboratory components tested are surrogates for system components
H	T		Individual components tested in laboratory/by supplier (contractor's component acceptance testing)
B	T		Subsystems composed of multiple components tested at lab scale using simulants
H	T		Modeling and simulation used to simulate some components and interfaces between components
S	T		Formal system architecture development begins
B	P		Overall system requirements for end user's application are documented
B	P		System performance metrics measuring requirements have been established
S	T		Analysis provides detailed knowledge of specific functions software needs to perform
B	P		Laboratory testing requirements derived from system requirements are established
H	M		Available components assembled into laboratory scale system
H	T		Laboratory experiments with available components show that they work together (lab kludge)
S	T		Requirements for each system function established
S	T		Algorithms converted to pseudocode
S	T		Analysis of data requirements and formats completed
S	T		Stand-alone modules follow preliminary system architecture plan
H	T		Analysis completed to establish component compatibility
S	M		Designs verified through formal inspection process
B	P		Science and technology exit criteria established
B	T		Technology demonstrates basic functionality in simulated environment
S	P		Able to estimate software program size in lines of code and/or function points
H	M		Scalable technology prototypes have been produced
B	P		Draft conceptual designs have been documented
H	M		Equipment scaleup relationships are understood/accounted for in technology development program
B	T		Controlled laboratory environment used in testing
B	P		Initial cost drivers identified
S	T		Experiments with full scale problems and representative data sets
B	M		Integration studies have been started
B	P		Formal risk management program initiated
S	T		Individual functions or modules demonstrated in a laboratory environment
H	M		Key manufacturing processes for equipment systems identified
B	P		Scaling documents and designs of technology have been completed
S	T		Some ad hoc integration of functions or modules demonstrates that they will work together
H	M		Key manufacturing processes assessed in laboratory
B	P		Functional work breakdown structure developed (functions established)
B	T		Low-fidelity technology “system” integration and engineering completed in a lab environment
H	M		Mitigation strategies identified to address manufacturability/producibility shortfalls
B	P		Technology availability dates established

H-Hardware element, contains no appreciable amount of software
S-Completely a Software system
B-Some Hardware and Software

T-Technology, technical aspects
M-Manufacturing and quality
P-Programmatic, customer focus, documentation

Table B.5. Technology Readiness Level 5 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology effects (if any) have been fully identified (e.g., system internally consistent)
B	T		Plant size components available for testing
B	T		System interface requirements known (how will system be integrated into the plant?)
B	P		System requirements flow down through work breakdown structure (design engineering begins)
S	T		System software architecture established
B	T		Requirements for technology verification established
S	T		External process/equipment interfaces described as to source, structure, and requirements
S	T		Analysis of internal system interface requirements completed
B	T		Lab scale similar system tested with limited range of actual wastes, if applicable
B	T		Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)
H	M		Significant engineering and design changes
S	T		Coding of individual functions/modules completed
H	M		Prototypes of equipment system components have been created (know how to make equipment)
H	M		Tooling and machines demonstrated in lab for new manufacturing processes to make component
B	T		High-fidelity lab integration of system completed, ready for test in relevant environments
H	M		Design techniques have been defined to the point where largest problems defined
H	T		Lab-scale similar system tested with range of simulants
H	T		Fidelity of system mock-up improves from laboratory to benchscale testing
B	M		Reliability, Availability, Maintainability Index (RAMI) target levels identified
H	M		Some special purpose components combined with available laboratory components for testing
H	P		Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared
B	T		Laboratory environment for testing modified to approximate operational environment
B	T		Component integration issues and requirements identified
H	P		Detailed design drawings have been completed to support specification of pilot testing system
B	T		Requirements definition with performance thresholds and objectives established for final plant design
S	T		Algorithms run on processor with characteristics representative of target environment
B	P		Preliminary technology feasibility engineering report completed
B	T		Integration of modules/functions demonstrated in a laboratory/bench-scale environment
H	T		Formal control of all components to be used in final system
B	P		Configuration management plan in place
B	P		Risk management plan documented
S	T		Functions integrated into modules
S	T		Formal inspection of all modules to be used in the final design
S	T		Individual functions tested to verify that they work
S	T		Individual modules and functions tested for bugs
S	T		Integration of modules/functions demonstrated in a laboratory environment
S	P		Formal inspection of all modules/components completed as part of configuration management
H	P		Individual process and equipment functions tested to verify that they work (e.g., test reports)

H-Hardware element, contains no appreciable amount of software	T-Technology, technical aspects
S-Completely a Software system	M-Manufacturing and quality
B-Some Hardware and Software	P-Programmatic, customer focus, documentation

Table B.6. Technology Readiness Level 6 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Performance and behavior of subcomponent interactions understood (including tradeoffs)
H	M		Reliability, Availability, Maintainability Index (RAMI) levels established
B	M		Frequent design changes occur
H	P		Draft design drawings for final plant system are nearly complete
B	T		Operating environment for final system known
B	P		Collection of actual maintainability, reliability, and supportability data has been started
B	P		Estimated cost of the system design is identified
B	T		Engineering scale similar system tested with a range of simulants
B	P		Plan for demonstration of prototypical equipment and process testing completed, results verify design
B	T		Modeling and simulation used to simulate system performance in an operational environment
H	T		Operating limits for components determined (from design, safety and environmental compliance)
B	P		Operational requirements document available
B	P		Off-normal operating responses determined for engineering scale system
B	T		System technical interfaces defined
B	T		Component integration demonstrated at an engineering scale
B	P		Scaling issues that remain are identified and supporting analysis is complete
B	P		Analysis of project timing ensures technology will be available when required
S	T		Analysis of database structures and interfaces completed
B	P		Have begun to establish an interface control process
B	P		Acquisition program milestones established for start of final design (CD-2)
H	M		Critical manufacturing processes prototyped
H	M		Most pre-production hardware is available to support fabrication of the system
B	T		Engineering feasibility fully demonstrated (e.g., will it work?)
S	T		Prototype implementation includes functionality to handle large scale realistic problems
S	T		Algorithms partially integrated with existing hardware/software systems
H	M		Materials, process, design, and integration methods have been employed (e.g., can design be produced?)
S	T		Individual modules tested to verify that the module components (functions) work together
B	P		Technology "system" design specification complete and ready for detailed design
H	M		Components are functionally compatible with operational system
H	T		Engineering scale system is high-fidelity functional prototype of operational system
S	T		Representative software system or prototype demonstrated in a laboratory environment
B	P		Formal configuration management program defined to control change process
B	M		Integration demonstrations have been completed (e.g., construction of testing system)
B	P		Final Technical Report on Technology completed
B	T		Waste processing issues have been identified and major ones have been resolved
S	T		Limited software documentation available
S	P		Verification, Validation, and Accreditation (VV&A) initiated
H	M		Process and tooling are mature to support fabrication of components/system
H	M		Production demonstrations are complete (at least one time)
S	T		"Alpha" version software has been released
S	T		Representative model tested in high-fidelity lab/simulated operational environment

H-Hardware element, contains no appreciable amount of software	T-Technology, technical aspects
S-Completely a Software system	M-Manufacturing and quality
B-Some Hardware and Software	P-Programmatic, customer focus, documentation

References

DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005.

GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Can Improve Weapon System Outcomes*, July 1999, United States General Accounting Office.

Nolte, William L., et al., *Technology Readiness Level Calculator*, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003.

Appendix C – Technology Readiness Level Summary for WTP Critical Technology Elements for HLW Vitrification

Appendix C – Technology Readiness Level Summary for WTP Critical Technology Elements for HLW Vitrification

Appendix C summarizes the responses to the specific criteria identified in levels 5 and 6 of the Technology Readiness Level (TRL) Calculator (Appendix B) for systems identified as critical technology elements (CTE). The following systems were evaluated.

Table C.1 Technology Readiness Level 5 Summary for HLW Melter Feed Process System (HFP)

Table C.2 Technology Readiness Level 6 Summary for HLW Melter Feed Process System (HFP)

Table C.3 Technology Readiness Level 5 Summary for HMP Melter System (HMP)

Table C.4 Technology Readiness Level 6 Summary for HMP Melter System (HMP)

Table C.5 Technology Readiness Level 5 Summary for HLW Melter Offgas Treatment Process System and Process Vessel Vent Exhaust System (HOP/PVV)

Table C.6 Technology Readiness Level 6 Summary for HLW Melter Offgas Treatment Process System and Process Vessel Vent Exhaust System (HOP/PVV)

Table C.7 Technology Readiness Level 5 Summary for HLW Pulse Jet Mixer (PJM) System and Radioactive Liquid Waste Disposal System (RLD)

Table C.8 Technology Readiness Level 6 Summary for HLW Pulse Jet Mixer (PJM) System and Radioactive Liquid Waste Disposal System (RLD)

Table C.1. Technology Readiness Level 5 Summary for HLW Melter Feed Process System (HFP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Cross technology effects (if any) have been fully identified (e.g., system internally consistent)	The mixing system design has been provided by the vendor. The mixing report from the vendor demonstrates the feasibility of the system design (24590-QL-POA-MFAO-00001-10-00001). Research and Technology (R&T) testing of the mixing system at Savannah River Technical Center (SRTC) (SCT-M0SRLE60-00-132-05, -187-02) was completed. The HFP contains two types of vessels (melter feed preparation vessel [MFPV] and melter feed vessel [MFV]).
Y	Plant-size components available for testing	Most of the subcomponents of the system are standard industrial items. Many have been used at other DOE projects (West Valley Demonstration Project [WVDP] and Savannah River Defense Waste Processing Facility [DWPF]). The components can be easily procured or fabricated.
Y	System interface requirements known (how will system be integrated into the plant?)	Section 9 of the HFP system description (24590-HLW-3YD-HFP-00001) defines the interface requirements.
Y	System requirements flow down through work breakdown structure (design engineering begins)	HFP system description (24590-HLW-3YD-HFP-00001) defines the flowdown requirements.
Y	Requirements for technology verification established	Test acceptance criteria are in Appendix C of the HFP system description (24590-HLW-3YD-HFP-00001). The verification requirements will be defined in the requirements verification matrix planned for inclusion in the HFD system description. This is not yet produced as a project document.
Y	Lab-scale similar system tested with limited range of actual wastes, if applicable	There have been tests at the laboratory-scale (24590-101-TSA-W000-0009-48-01). The use of real wastes is not practicable.
Y	Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)	Benchtop testing with realistic interfaces includes the dusting studies (SCT-M0SRLE60-00-187-02) and experience at WVDP and DWPF.
Y	Significant engineering and design changes	The design is completed and small-scale prototypes have been created to feed prototypical melters such as the DM100 (24590-101-TSA-W000-0009-48-01) and DM1200 melters (24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-144-00005; 24590-101-TSA-W000-0009-98-07) at the Vitreous State Laboratory of the Catholic University of America (VSL).
Y	Prototypes of equipment system components have been created (know how to make equipment)	The design is completed and small-scale prototypes have been created to feed prototypical melters the DM100 (24590-101-TSA-W000-0009-48-01) and DM1200 melters (24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-144-00005; 24590-101-TSA-W000-0009-98-07) at VSL.

Table C.1. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	The design is completed and small-scale prototypes have been created for the DM100 (24590-101-TSA-W000-0009-48-01) and DM1200 melters (24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-144-00005; 24590-101-TSA-W000-0009-98-07) at VSL.
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	The design is completed and small-scale prototypes have been created for the DM100 (24590-101-TSA-W000-0009-48-01) and DM1200 melters (24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-144-00005; 24590-101-TSA-W000-0009-98-07) at VSL.
Y	Design techniques have been defined to the point where largest problems defined	Hydrogen gas generation in storage vessels (24590-101-TSA-W000-0004-114-00018) was addressed with head space spargers. Concerns have also been raised about possible corrosion/erosion of the spargers during normal operation.
Y	Lab-scale similar system tested with range of simulants	The design is completed and small-scale prototypes have been created for the DM100 (24590-101-TSA-W000-0009-48-01) and DM1200 melters (24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-144-00005; 24590-101-TSA-W000-0009-98-07) at VSL.
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	The design is completed and small-scale prototypes have been created for the DM100 (24590-101-TSA-W000-0009-48-01) and DM1200 melters (24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-144-00005; 24590-101-TSA-W000-0009-98-07) at VSL. Testing of the proposed plant-scale system was completed by Philadelphia Mixers. The mixing report helped the vendor to size the system (24590-QL-POA-MFAO-00001-10-0001).
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	The HFP is located in the melter cave, which is a high-contamination/high-radiation area (C5/R5); personnel access is not allowed. Maintenance for the HFP performed in the melter cave will be done remotely.
Y	Some special purpose components combined with available laboratory components for testing	Hydrogen gas generation in storage vessels (24590-101-TSA-W000-0004-114-00018) is being addressed with headspace spargers. The technical basis for the spargers is documented in a technical report (24590-101-TSA-W000-0004-160-0000). There has been no engineering-scale, prototypical testing of the sparger system that demonstrates the capability of releasing hydrogen from the blend in the MFPVs and MPVs if the mechanical agitators fail.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	P&IDs are found in Section 10.1.5 of the HFP system description (24590-HLW-3YD-HFP-00001). The jumpers have not been scoped out for fabrication.

Table C.1. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Laboratory environment for testing modified to approximate operational environment	The design is completed and small-scale prototypes have been created for the DM100 (24590-101-TSA-W000-0009-48-01) and DM1200 melters (24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-144-00005; 24590-101-TSA-W000-0009-98-07) at VSL. Testing of the proposed plant-scale system was completed by Philadelphia Mixers. The mixing report helped the vendor to size the system (24590-QL-POA-MFAO-00001-10-00001).
Y	Component integration issues and requirements identified	A final design has been completed. Component integration issues have been addressed in the testing described in response to the first question of Table C.1.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Design documents are found in Section 10 of the HFP system description (24590-HLW-3YD-HFP-00001). The jumpers have not been scoped out for fabrication.
Y	Requirements definition with performance thresholds and objectives established for final plant design	Section 4 of the system description (24590-HLW-3YD-HFP-00001) and the mechanical datasheets for the equipment include requirements.
Y	Preliminary technology feasibility engineering report completed	Feasibility is captured in multiple R&T reports. HLW simulants to support mixing system tests were developed (TEF-24590-WTP-RT-04-00027). R&T testing of the mixing system at SRTC (SCT-M0SRLE60-00-132-05, -187-02, Rev. 00C (cleared)) was conducted to test blending of glass-forming chemicals and simulated wastes. Bounding physical and rheological conditions were determined (24590-101-TSA-W000-0004-172-00001). The ability to keep glass formers in suspension (24590-101-TSA-W000-0009-171-00001) was demonstrated with the DM1200. Simulants used for mixer testing are described in SCT-M0SRLE60-00-193-02, Rev. 0. Testing of the proposed plant-scale system was completed by Philadelphia Mixers. The mixing report helped the vendor to size the system (24590-QL-POA-MFAO-00001-10-00001).
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Integration of modules is demonstrated in the R&T reports listed in response to the first question Table C.1. A final report summarizes integrated testing at the VSL (24590-101-TSA-W000-0009-144-00006).
Y	Formal control of all components to be used in final system	A test specification and test plan are generated by the project. The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).

Table C.1. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Configuration management plan in place	The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002).
Y	Risk management plan documented	WTP Project has established a risk management plan (24590-WTP-RPT-PR-01-006).
Y	Individual process and equipment functions tested to verify that they work (e.g., test reports)	A final report summarizes integrated testing at the VSL (24590-101-TSA-W000-0009-144-00006). The mixing system design has been provided by the vendor. The mixing report from the vendor demonstrates the feasibility of the system design (24590-QL-POA-MFAO-00001-10-00001). R&T testing of the mixing system at SRTC (SCT-M0SRLE60-00-132-05; -187-02) was completed.

Table C.2. Technology Readiness Level 6 Summary for HLW Melter Feed Process System (HFP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The mixing system design has been provided by the vendor. The mixing report from the vendor demonstrates the feasibility of the system design (24590-QL-POA-MFAO-00001-10-00001). R&T testing of the mixing system at SRTC (SCT-M0SRLE60-00-132-05;-187-02, Rev. 00C (cleared)) was completed. HLW simulants to support mixing system tests were developed (TEF-24590-WTP-RT-04-00027; 24590-101-TSA-W000-0004-172-00001). The ability to keep glass formers in suspension (24590-101-TSA-W000-0009-171-00001) was demonstrated with the DM1200 melter. Simulants used for mixer testing are described in SCT-M0SRLE60-00-193-02. Other R&T reports that characterize simulants and testing include SCT-M0SRLE60-00-211-00001; 24590-101-TSA-W000-00009-106-00021; and 24590-101-TSA-W000-0009-144-00006.
Y	Reliability, Availability, Maintainability Index levels established	RAMI targets have been established in WTP Basis of Design for HLW Vitrification Facility (24590-WTP-DB-ENG-01-001). The 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the equipment has been completed. Most drawings and calculations are identified in the HFP system description (24590-HLW-3YD-HFP-00001).
Y	Draft design drawings for final plant system are nearly complete	The final design of the equipment is completed. Most drawings and calculations are identified in the HFP system description (24590-HLW-3YD-HFP-00001). Section 10.1.8 of the HFP system description includes the equipment drawing citations.
Y	Operating environment for final system known	The operating environment for the HFP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001), the HFP system description (24590-HLW-3YD-HFP-00001), and the HLW PSAR (24590-WTP-PSAR-ESH-01-002-04).
Y	Collection of actual maintainability, reliability, and supportability data has been started	The RAMI data is included the RAMI Assessment Report (24590-HLW-RPT-PO-05-0001, Rev. 0) and the 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the HFP is provided in the May 2005 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Engineering-scale similar system tested with a range of simulants	An engineering-scale similar to HFP was system-tested with a range of simulants using the DM1200 melter. See response to the first question for Table C.2. Air spargers had to be added to the design. The technical basis for the spargers is documented in a technical report (24590-101-TSA-W000-0004-160-0000). Additional Quality Assurance Requirements Document (QARD)-based testing (VSL-06T1000-1) is planned as part of the R&T Program to validate the number of samples required.
Y	Modeling and simulation used to simulate system performance in an operational environment	The performance of the HFP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the HFP systems will support project requirements.
N	Plan for demonstration of prototypical equipment and process testing completed, results verify design	Most prototypical equipment has been demonstrated in a relevant environment in the absence of radioactive species. Large-scale testing with actual radioactive waste offgas is not practical. The test reports are listed in response to the first question for Table C.2. The HFP uses mechanical agitators to mix the vessel contents, which did not give adequate mixing for hydrogen. Air spargers had to be added to the design. The technical basis for the spargers is documented in a technical report (24590-101-TSA-W000-0004-160-0000). There has been no engineering-scale, prototypical testing of the sparger systems that demonstrates the capability of releasing hydrogen from the blend in the MFPVs and MPVs if the mechanical agitators fail. Additional QARD testing (VSL-06T1000-1) is planned as part of the R&T Program to validate the number of samples required.
Y	Operating limits determined using engineering-scale system (from design, safety, environmental compliance)	The operating conditions for the HFP have been established based upon engineering analysis presented in the HFP system description (24590-HLW-3YD-HFP-00001), and the testing reports identified in the response to the first question for Table C.2. Additional testing is planned to assess the degree of homogenization to support feed make-up sampling requirements.
Y	Operational requirements document available	The minimum operating requirements for the HFP are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001) and the HFP system description (24590-HLW-3YD-HFP-00001).
Y	Off-normal operating responses determined for engineering-scale system	An initial assessment of off-normal operations along with corrective actions is identified in the specification for the upcoming QARD testing (VSL-06T1000-1). See Section 7.2 of the HFP system description (24590-HLW-3YD-HFP-00001).
Y	System technical interfaces defined	The identification of the technical interface requirements is included in Section 9 of the HFP system description (24590-HLW-3YD-HFP-00001).

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Component integration demonstrated at an engineering scale	Most of the subcomponents of the system are standard industrial items. Many have been used at other DOE projects (WVDP and DWPF). WTP Project-specific testing completed by VSL (24590-101-TSA-W000-0009-171-00001), SRTC (SCT-M0SRLE60-00-132-05; -187-02) and Philadelphia Mixers (24590-QL-POA-MFAO-00001-10-00001) provides the specifications for the plant-scale system. However, the original limits for tests may not address the entire range of properties for waste feeds expected at the WTP from pretreatment, and pilot testing did not test the ability to hold glass formers in suspension with low solids concentration. There has been no engineering- scale, prototypical testing of the sparger system that demonstrates the capability of releasing hydrogen from the blend in the MFPVs and MPVs if the mechanical agitators fail.
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues remain. The mixing system design has been provided by the vendor. The agitation system design provided by the vender is based upon vessel design and mixing requirements. The mixing report from the vendor demonstrates adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001).
Y	Analysis of project timing ensures technology will be available when required	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the HFP technology will be incorporated into the HLW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	An identification of the technical interface requirements is included in Section 9 of the HFP system description (24590-HLW-3YD-HFP-00001).
Y	Acquisition program milestones established for start of final design (CD-2)	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the HFP technology will be incorporated into the HLW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	The HFP design (24590-HLW-3YD-HFP-00001) is based upon existing technology, commonly fabricated equipment, and standard industry components.
Y	Most pre-production hardware is available to support fabrication of the system	The HFP design (24590-HLW-3YD-HFP-00001) is based upon existing technology and standard industry components.
Y	Engineering feasibility fully demonstrated (e.g., will it work?)	The mixing system design has been provided by the vendor based upon vessel design and mixing requirements. The mixing report from the vendor, VSL, and SRTC demonstrates adequacy of the system design (24590-QL-POA-MFAO-00001-10-00001; SCT-M0SRLE60-00-187-02; VSL-00R2590-2; 24590-101-TSA-W000-0009-34-03; 24590-101-TSA-W000-0009-118-00009).
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	The HFP design is based upon existing technology and standard industry components. Vessels for the HFP have been fabricated and are located on the WTP site.
Y	Technology "system" design specification complete and ready for detailed design	The design of the plant-scale system has been completed. The HFP design (24590-HLW-3YD-HFP-00002) is based upon existing technology and standard industry components.

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Components are functionally compatible with operational system	Common components are being used in the design. Operational requirements were defined and incorporated into the stress tests being conducted by the vendor. A mixing report from Philadelphia Mixers demonstrates initial feasibility of the system design (24590-QL-POA-MFAO-00001-10-00001).
Y	Engineering-scale system is high-fidelity functional prototype of operational system	The mixer tests at Philadelphia Mixer demonstrated effective operation in prototypic conditions representative of plant conditions (24590-QL-POA-MFAO-00001-10-00001). There has been no engineering-scale, prototypical testing of the sparger system that demonstrates the capability of releasing hydrogen from the blend in the MFPVs and MPVs if the mechanical agitators fail.
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	The mixing system design has been provided by Philadelphia Mixers. The agitation system design is based upon the vessel design and WTP mixing requirements. The mixing test report from Philadelphia Mixer demonstrates that the equipment components are compatible (24590-QL-POA-MFAO-00001-10-00001, Rev. 00B).
Y	Final Technical Report on Technology completed	The mixing test report for the HFP vessels provided by Philadelphia Mixers demonstrate adequacy of system design (24590-QL-POA-MFAO-00001-10-00001, Rev. 00B). The R&T testing of the mixing system has been completed as described in response to the first question of Table C.2. The HFP uses mechanical agitators to mix the vessel contents, which did not give adequate mixing for hydrogen. Air spargers had to be added to the design. The technical basis for the spargers is documented in a technical report (24590-101-TSA-W000-0004-160-0000). There has been no engineering-scale, prototypical testing of the sparger systems that demonstrates the capability of releasing hydrogen from the blend in the MFPVs and MPVs if the mechanical agitators fail. Additional QARD testing (VSL-06T1000-1) is planned as part of the R&T Program to validate the number of samples required.

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Waste processing issues have been identified and major ones have been resolved	Issues have been resolved associated with scale-up of the equipment systems, interaction of glass formers and waste (offgas-ing and foaming) (SCT-M0SRLE60-00-196-00001) and minimization of dusting (SCT-M0SRLE60-00-187-02) of the glass-forming chemicals during addition to the vessel. The technical basis for predicting mixing and flammable gas behavior (24590-101-TSA-W000-0004-114-00018) is understood. Mixing reports from vendor demonstrate adequacy of system design (24590-QL-POA-MFAO-00001-10-00001).
Y	Process and tooling are mature to support fabrication of components/system	A majority of the plant equipment has been fabricated at least once. Most of the subcomponents of the system are standard industrial items. Many have been used at other DOE projects (WVDP and DWPF).
Y	Production demonstrations are complete (at least one time)	A majority of the plant equipment has been fabricated at least once. Most of the subcomponents of the system are standard industrial items. Many have been used at other DOE projects (WVDP and DWPF).

Table C.3. Technology Readiness Level 5 Summary for HMP Melter System (HMP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Cross technology effects (if any) have been fully identified (e.g., system internally consistent)	R&T was completed on the DM1200 platform. This one third plant-scale melter was used to support testing and characterized the performance and behavior of equipment components and different process flowsheets representative of the WTP mission. Equipment components tested included the melter and its specific design features as documented in the following reports: 24590-101-TSA-W000-0009-164-00001; 4590-101-TSA-W000-0009-162-00001; 24590-101-TSA-W000-0009-74-01; 24590-101-TSA-W000-0009-48-01; 24590-101-TSA-W000-0010-06-04A; 24590-101-TSA-W000-0009-102-01; 24590-101-TSA-W000-0009-34-03; 24590-101-TSA-W000-0009-144-03; 24590-101-TSA-W000-0009-72-05; 24590-101-TSA-W000-0009-82-02; 24590-101-TSA-W000-0009-72-08; 24590-101-TSA-W000-0009-144-01; 24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-98-07; 24590-101-TSA-W000-0009-105-04; 24590-101-TSA-W000-0009-64-00003; 24590-101-TSA-W000-0009-156-00001; 24590-101-TSA-W000-0009-118-00009; 24590-101-TSA-W000-0009-153-00001; 24590-101-TSA-W000-0009-158-00001; 24590-101-TSA-W000-0009-119-00003; 24590-101-TSA-W000-0009-157-00002; 24590-101-TSA-W000-00009-106-00021; 24590-101-TSA-W000-0009-121-00006; 24590-101-TSA-W000-0009-168-00001; 24590-101-TSA-W000-00009-098-00009; 24590-101-TSA-W000-0009-165-00001; 24590-101-TSA-W000-0009-144-00006).
Y	Plant-size components available for testing	Full-scale components have been used at DWPF and WVDP. The components can be easily procured or fabricated.
Y	System interface requirements known (how will system be integrated into the plant?)	Section 9 of the HMP system description (24590-HMP-3YD-HMP-00001) defines the interface requirements.
Y	System requirements flow down through work breakdown structure (design engineering begins)	Section 4 of the HMP system description (24590-HMP-3YD-HMP-00001) defines the flowdown requirements.
Y	Requirements for technology verification established	Test acceptance requirements are in Appendix A of the HMP system description (24590-HMP-3YD-HMP-00001). The verification requirements will be defined in the requirements verification matrix in the system description. This is not yet produced as a project document.
Y	Lab-scale similar system tested with limited range of actual wastes, if applicable	There have been tests at the laboratory-scale with real wastes (24590-101-TSA-W000-0009-168-00001; SCT-M0SRLE60-00-110-17; SCT-M0SRLE60-00-218-00001).
Y	Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)	Benchtop testing with realistic interfaces includes the DM1200 studies and there is past experience at WVDP and DWPF. See response to the first question of Table C.3 for test reports.

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Significant engineering and design changes	The design is completed and components are being fabricated.
Y	Prototypes of equipment system components have been created (know how to make equipment)	Small-scale prototypes have been created at VSL. Full-scale components have been used at DWPF and WVDP. Full-scale components are being fabricated.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	Small-scale prototypes have been created at VSL. Full-scale components have been used at DWPF and WVDP. Full-scale components are being fabricated.
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	Small-scale prototypes have been created at VSL. Full-scale components have been used at DWPF and WVDP. Full-scale components are being fabricated.
Y	Design techniques have been defined to the point where largest problems defined	The design is based on the WVDP, DWPF, Savannah River M-Area, DM100, DM1200, and DM3300 designs and experience.
Y	Lab-scale similar system tested with range of simulants	DM100 tests were conducted for AZ-101 and C-106/AY-102 HLW feeds (24590-101-TSA-W000-00009-106-00021; 24590-101-TSA-W000-0009-48-01; SCT-M0SRLE60-00-21-05, Rev. 00B).
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	The fidelity of the HLW test melters improves as the design capacity of the test platform increases from the DM100 to the DM1200 melter at VSL. Test results for the DM1200 are summarized in 24590-101-TSA-W000-0009-171-00001.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	The RAMI data is included the RAMI Assessment Report (24590-HLW-RPT-PO-05-0001, Rev. 0) and the 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Some special purpose components combined with available laboratory components for testing	Special purpose components in the present melter design include J-Tube bubblers. Beginning in May 2003, multiple outlet bubblers were used in the DM1200 (24590-101-TSA-W000-0009-171-00001). The HLW bubbler life requirement is 2 months. Testing in the DM1200 with a limited number of feed compositions has demonstrated bubbler life in excess of 2 months with very little corrosion of the bubbler in the cold cap area (24590-101-TSA-W000-0009-119-00003). DM1200 testing was augmented by physical model testing at full WTP HLW melter depth and testing in the DM1200 under idling conditions to determine bubbler air supply requirements; i.e., ability to run double nozzle bubbler with a single air supply (24590-101-TSA-W000-0009-153-00001). All these results were combined with engineering analyses to specify bubbler design and operational requirements for the plant design (24590-101-TSA-W000-0009-162-00001).

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	P&IDs are listed in the HMP system description (24590-HMP-3YD-HMP-00001) for the full-scale system. Fabrication drawings have been completed.
Y	Laboratory environment for testing modified to approximate operational environment	The DM100 and DM1200 laboratory environment was prototypic of the operational environment (24590-101-TSA-W000-00009-106-00021; 24590-101-TSA-W000-0009-48-01).
Y	Component integration issues and requirements identified	A final design has been completed. Component integration has been addressed in the HMP system description (24590-HMP-3YD-HMP-00001).
Y	Detailed design drawings have been completed to support specification of pilot testing system	Detailed design drawings have been completed for the DM1200 melter, and it has already been fabricated. Design drawings for the full-scale system are listed Section 10 of the HMP system description (24590-HMP-3YD-HMP-00001).
Y	Requirements definition with performance thresholds and objectives established for final plant design	The HMP system description (24590-HMP-3YD-HMP-00001) and the mechanical datasheets for the equipment include detailed requirements.
Y	Preliminary technology feasibility engineering report completed	The melters were designed by Duratek (now part of Energy*Solutions*). Duratek based its design on DOE technology developments and its own experience with the second generation DM5000 melter used to process Savannah River M-Area low level waste (5.0 m^2), the DM-1000 operated at the VSL, and WTP LAW pilot (3.3 m^2 operated at Duratek's Columbia, Maryland, site) melters. Versions of virtually all the subsystems that make up the HMP have been tested in one or more of the above melters (24590-101-TSA-W000-0009-171-00001; 24590-101-TSA-W000-0009-153-00001; 24590-101-TSA-W000-0009-162-00001).
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Integration of modules is demonstrated in the R&T reports for the DM100 and DM1200 melters. Reports are listed in the response to the first question of Table C.3
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Configuration management plan in place	The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	WTP Project has established a risk management plan (24590-WTP-RPT-PR-01-006).
Y	Individual process and equipment functions tested to verify that they work (e.g., test reports)	Functions were tested on the DM-1200 melter operated at the VSL (24590-101-TSA-W000-0009-171-00001; 24590-101-TSA-W000-0009-153-00001).

Table C.4. Technology Readiness Level 6 Summary for HMP Melter System (HMP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	Duratek design documentation explains the tradeoffs evaluated in the design and operation of the HLW melter. Tradeoffs included how to obtain the surface area, depth of melter, and throughput needed within the space envelope and operating lifetime of the WTP. R&T has completed testing on the HMP on the DM1200 platform. The DM1200, a one-third plant-scale melter, was used to support testing and characterization of the performance and behavior of equipment components and different process flowsheets representative of the WTP mission. Equipment components tested included the melter and its specific design features documented in the following reports: 24590-101-TSA-W000-0009-164-00001; 24590-101-TSA-W000-0009-162-00001; 24590-101-TSA-W000-0009-74-01; 24590-101-TSA-W000-0009-48-01; 24590-101-TSA-W000-0010-06-04A; 24590-101-TSA-W000-0009-102-01; 24590-101-TSA-W000-0009-34-03; 24590-101-TSA-W000-0009-144-03; 24590-101-TSA-W000-0009-72-05; 24590-101-TSA-W000-0009-72-05; 24590-101-TSA-W000-0009-82-02; 24590-101-TSA-W000-0009-72-08; 24590-101-TSA-W000-0009-72-08; 24590-101-TSA-W000-0009-144-01; 24590-101-TSA-W000-0009-144-02; 24590-101-TSA-W000-0009-98-07; 24590-101-TSA-W000-0009-105-04; 24590-101-TSA-W000-0009-64-00003; 24590-101-TSA-W000-0009-156-00001; 24590-101-TSA-W000-0009-118-00009; 24590-101-TSA-W000-0009-118-00010; 24590-101-TSA-W000-0009-153-00001; 24590-101-TSA-W000-0009-158-00001; 24590-101-TSA-W000-0009-119-00003; 24590-101-TSA-W000-0009-157-00002; 24590-101-TSA-W000-00009-106-00021; 24590-101-TSA-W000-0009-121-00006; 24590-101-TSA-W000-0009-168-00001; 24590-101-TSA-W000-00009-098-00009; 24590-101-TSA-W000-0009-165-00001; 24590-101-TSA-W000-0009-144-00006; 24590-101-TSA-W000-0009-0174-00001.
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP Basis of Design for HLW Vitrification Facility (24590-WTP-DB-ENG-01-001, Rev. 1C). The 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the equipment has been completed. Most drawings and calculations are identified in the HMP system description (24590-HMP-3YD-HMP-00001).
Y	Draft design drawings for final plant system are nearly complete	The final design of the equipment is completed. Most drawings and calculations are listed in Section 10 of the HMP system description (24590-HMP-3YD-HMP-00001).
Y	Operating environment for final system known	The operating environment for the HMP is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C), the HMP system description (24590-HMP-3YD-HMP-00001, Rev. 1), and the HLW PSAR (24590-WTP-PSAR-ESH-01-002-04).
Y	Estimated cost of the system design is identified	The cost of the HMP is provided in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Collection of actual maintainability, reliability, and supportability data has been started	The RAMI data is included the RAMI Assessment Report (24590-HMP-RPT-PO-05-0001, Rev. 0) and the 2005 WTP Operations Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results of similar equipment and literature reviews of applicable designs.
N	Engineering-scale similar system tested with a range of simulants	See response to the first question of Table C.4. The demonstrated environment for the HMP has focused on the initial tank waste (waste from tanks AY-102 and C-106) that will be processed in the WTP. Approximately 600,000 lb of glass (based on commissioning waste compositions) was made (24590-101-TSA-W000-0009-171- 00001) during a 288-day continuous test run of the DM1200. However, there has been little testing of feeds that are high in aluminum, chromium, zirconium, sulfur, and bismuth phosphate ($BiPO_4$) and are characteristic of Balance of Mission feeds. .
Y	Modeling and simulation used to simulate system performance in an operational environment	The performance of the HMP has been modeled using the 2005 WTP Operations Research Assessment Report (24590-WTP-RPT-PO-05-001) and the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0). The results of these assessments show that the HMP will support project requirements.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	Approximately 600,000 lbs of glass (based on commissioning waste compositions) was made (24590-101-TSA-W000-0009-171- 00001) during 288 days of testing over a 5-year period. See response to the first question of Table C.4.
Y	Operating limits determined using engineering-scale system (from design, safety, environmental compliance)	The operating conditions for the HMP have been established based upon engineering analysis presented in the HMP system description (24590-HMP-3YD-HMP-00001), and the testing reports identified in the response to the first question of Table C.4. See Section 10 of the system description for the specifications.
Y	Operational requirements document available	The minimum operating requirements for the HMP are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001, Rev. 2) and the HMP system description (24590-HMP-3YD-HMP-00001). Testing in the DM1200 has demonstrated bubbler life in excess of 2 months (24590-101-TSA-W000-0009-119-00003). However, Balance of Mission feed compositions are projected to have higher concentrations of halides and sulfates, which can increase the corrosion rate of the bubbler alloy. Thus a 2 month bubbler life is not been demonstrated. DM1200 testing was augmented by physical model testing (24590-101-TSA-W000-0009-153-00001). All these results were combined with engineering analyses to specify bubbler design and operational requirements for the plant design (24590-101-TSA-W000-0009-162-00001).
Y	Off-normal operating responses determined for engineering-scale system	An initial assessment of off-normal operations along with corrective actions is identified in the specification for the upcoming QARD testing (VSL-06T1000-1). See Section 7.2 of the HMP system description (24590-HMP-3YD-HMP-00001).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	System technical interfaces defined	The identification of the technical interface requirements is included in Section 9 of the HMP system description (24590-HMP-3YD-HMP-00001).
N	Component integration demonstrated at an engineering scale	See response to the first question of Table C.4. Although there has been extensive small-scale and engineering-scale prototypical testing of the melter system, it is has not been demonstrated that the HMP can achieve design melt rates for the full range of wastes in the Hanford Site tanks.
Y	Scaling issues that remain are identified and supporting analysis is complete	DM100, DM1200, and DM3300 tests addressed scaling issues. See response to the first question of Table C.4 for available test reports. No scaling issues remain. 24590-101-TSA-W000-0010-407-679, Rev. 00A, *River Protection Project – Waste Treatment Plant HLW Melter Life Report*, provides the bases for the size and service life of the plant melter components.
Y	Analysis of project timing ensures technology will be available when required	May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the HMP technology will be incorporated into the HLW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	An identification of the technical interface requirements is included in Section 9 of the HMP system description (24590-HMP-3YD-HMP-00001).
Y	Acquisition program milestones established for start of final design (CD-2)	May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the HMP technology will be incorporated into the HLW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	HMP design is based upon existing technology and standard industry components. Duratek based its materials, process, design, and integration methods on its experience with its second generation DM5000 melter used to process Savannah River M-Area low-level waste, the DM1200 operated at the VSL, and WTP DM3300 LAW pilot melter operated at Duratek's Columbia, Maryland, site.
Y	Most pre-production hardware is available to support fabrication of the system	HMP design is based upon existing technology and standard industry components. Duratek based its materials, process, design, and integration methods on its experience with its second generation DM5000 melter used to process Savannah River M-Area low-level waste, the DM1200 operated at the VSL, and WTP 3300 LAW pilot melter operated at Duratek's Columbia, Maryland, site.

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Engineering feasibility fully demonstrated (e.g., will it work?)	The demonstrated environment for the HMP has focused on the initial tank waste (waste from tanks AY-102 and C-106) that will be processed in the WTP. Approximately 600,000 lb of glass (based on commissioning waste compositions) was made (24590-101-TSA-W000-0009-171-00001) during 288 days of operation of the DM1200. However, there has been little testing of feeds that are high in aluminum, chromium, zirconium, sulfur, and bismuth phosphate ($BiPO_4$) and are characteristic of Balance of Mission feeds. HLW simulant tests conducted with the DM1200 relied on visual observation of the cold cap and plenum space to control melter feeding rate. The HMP will be controlled remotely on the basis of instrument (temperature, pressure, etc.) readouts. Melter rates are expected to be lower under instrument control because it is generally less responsive to the varying melt conditions that are routinely observed in HLW melters. Projected melter rates are based on receiving waste that has been concentrated to 15 to 20% solids. The WTP Pretreatment Facility may not be able to supply wastes this concentrated for all types of waste. Melter glass production rates drop as solids concentration in the feed drops.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	The HMP design is based upon existing technology and standard industry components. Duratek based its materials, process, design, and integration methods on its experience with its second generation DM5000 melter used to process Savannah River M-Area low-level waste, the DM1200 operated at the VSL, and WTP DM3300 LAW pilot melter operated at Duratek's Columbia, Maryland, site.
Y	Technology "system" design specification complete and ready for detailed design	The design of the plant-scale system has been completed. The design is described in the HMP system description (24590-HMP-3YD-HMP-00001).
Y	Components are functionally compatible with operational system	Testing conducted at VSL on the DM1200 melter was the basis for the bubbler designs later used for the WTP. Equipment components tested included the melter and its specific design features, melter feed nozzle, melter thermowells, melter bubblers, melter pouring system, and representative instrument and control systems. See response to the first question of Table C.4 for test reports.
Y	Engineering-scale system is high-fidelity functional prototype of operational system	Testing conducted at VSL on the DM1200 melter was the basis for the bubbler designs later used for the WTP. Equipment components tested included the melter and its specific design features, melter feed nozzle, melter thermowells, melter bubblers, melter pouring system, and representative instrument and control systems. See response to the first question of Table C.4 for test reports.

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Formal configuration management program defined to control change process	WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	The successful construction and operation of the HLW Vitrification Pilot Plant is documented in the R&T testing reports listed in response to the first question of Table C.4. A description of this testing system is provided in testing reports included as references to the first question. However, some operational and maintenance features of the HMP are new.
Y	Final Technical Report on Technology completed	See response to the first question for Table C.4. Although there has been extensive small-scale and engineering-scale prototypical testing of the melter system, it is has not been demonstrated that the WTP HLW melter can achieve design melt rates for the full range of wastes in the Hanford Site tanks.
Y	Waste processing issues have been identified and major ones have been resolved	Most waste processing issues have been identified, evaluated, and closed including bubbler requirements. The corrosion effects of mercury and mercury compounds on WTP materials were evaluated in electrochemical tests (24590-101-TSA-W000-0004-125-02, Rev. 00B).
Y	Process and tooling are mature to support fabrication of components/system	The fabrication of the HLW melter is in process. No significant fabrication issues have been identified. Final assembly of the melter will occur at the WTP site. All fabrication activities have been awarded.
Y	Production demonstrations are complete (at least one time)	HMP design is based upon existing technology and standard industry components. Duratek based its materials, process, design, and integration methods on its experience with its second generation DM5000 melter used to process Savannah River M-Area low-level waste, the DM1200 operated at the VSL, and WTP 3300 LAW pilot melter operated at Duratek's Columbia, Maryland, site. The design and fabrication of the HLW pilot melter and M-Area melter as well as the DWPF and WVDP melters demonstrate the HLW Plant melters can be fabricated.

Table C.5. Technology Readiness Level 5 Summary for HLW Melter Offgas Treatment Process System and Process Vessel Vent Exhaust System (HOP/PVV)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Cross technology effects (if any) have been fully identified (e.g., system internally consistent)	R&T has completed testing on a prototype HOP/PVV offgas system components connected to the DM1200 melter (24590-101-TSA-W000-0009-74-01; 24590-101-TSA-W000-0009-48-01; 24590-101-TSA-W000-0009-54-00001; 24590-101-TSA-W000-0009-34-03; 24590-101-TSA-W000-0009-87-09; 24590-101-TSA-W000-0009-166-00001; VSL-06R6410-2, Rev. 0; 24590-101-TSA-W000-0009-174-00001; 24590-101-TSA-W000-0009-171-00001). Equipment components tested included all prototypical offgas components (i.e., film cooler; submerged bed scrubber [SBS]; high-efficiency mist eliminator [HEME]; wet electrostatic precipitator [WESP]; carbon sulfur bed for mercury removal; 1/30-scale silver mordenite column for iodine removal; thermal catalytic oxidizer [TCO] for organic destruction; selective catalytic reduction (SCR) for NO_x destruction; and high-efficiency particulate air [HEPA] filtration). These testing results demonstrate that the HOP/PVV offgas system will support design requirements as specified in the WTP contract (DE-AC27-01RL14136). The main tradeoff is potential clogging of the film cooler versus high bubbling rate (CCN:144619).
Y	Plant-size components available for testing	Full-scale components have been used at DWPF and WVDP. The components can be easily procured from vendors or fabricated.
Y	System interface requirements known (how will system be integrated into the plant?)	HOP/PVV offgas system description (24590-LAW-3YD-HOP-00001) defines the interface requirements.
Y	System requirements flow down through work breakdown structure (design engineering begins)	HOP/PVV offgas system description (24590-LAW-3YD-HOP-00001) defines the flowdown requirements.
Y	Requirements for technology verification established	Testing specifications have been developed. Test acceptance requirements will be detailed in the system description. The verification requirements will be defined in the requirements verification matrix in the HOP/PVV offgas system description (24590-LAW-3YD-HOP-00001). This is not yet produced as a project document.
Y	Lab-scale similar system tested with limited range of actual wastes, if applicable	Pacific Northwest National Laboratory (PNNL) and SRTC have conducted tests at the laboratory-scale (24590-101-TSA-W000-0004-113-02; SCT-M0SRLE60-00-218-00001, Rev. 00A, (WSRC-TR-2005-00410, Rev. 0) and vitrification and product testing of AY-102/C-106 HLW (Env D)).

Table C.5. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)	The VSL conducted offgas tests on the DM1200 melter between 2001 and 2005. The DM1200 offgas treatment system consists of an SBS; a WESP; a HEME (for HLW only), a HEPA filter; a TCO; an SCR for NO_x destruction; a packed-bed caustic scrubber (PBS); and a second HEME. System modifications were completed in 2004 to include addition of a full-flow activated carbon adsorber bed and use of TCO catalyst media to match the WTP design. The sulfur–impregnated, activated-carbon column was installed between the HEPA and the TCO. Limited testing of a ~1/30-scale silver mordenite column occurred; e.g., 24590-101-TSA-W000-0009-144-01, Rev. 00B and 24590-101-TSA-W000-0009-098-07, Rev. 00C. The technology is replaceable inside the HLW Facility.
Y	Significant engineering and design changes	Multiple design changes were implemented (24590-HLW-3YD-HOP-00001) as a result of DM1200 testing. The following design modifications address identified issues: Sparging and suction systems were added to remove solids that accumulate in the bottom of the SBS. The WTP HLW WESP was redesigned to isolate the electrical connections and includes a deluge from the bottom of the WESP. The film cooler was designed to be replaceable in case clogging is a significant problem. A film cooler cleaner was developed that will be tested at VSL. Melter offgas jumpers were designed with cleanout access ports and they can be replaced if blockages cannot be removed (CCN:144619).
Y	Prototypes of equipment system components have been created (know how to make equipment)	Small-scale prototypes have been created. All equipment except the film cooler, film cooler cleaner, and melter offgas jumpers are standard industrial equipment.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	Small-scale prototypes have been created. All equipment except the film cooler, film cooler cleaner, and melter offgas jumpers are standard industrial equipment.
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	Small-scale prototypes have been created. All equipment except the film cooler, film cooler cleaner, and melter offgas jumpers are standard industrial equipment.
N	Design techniques have been defined to the point where largest problems defined	While testing has shown it is possible to maintain HLW vitrification melt rates with lower concentration feeds, this mode of operation could lead to offgas system plugging in the melter film cooler or the transition line to the offgas system. These plugs will be difficult to remove and could constrain glass production (CCN:132846). Film cooler blockage is tied to bubbler rate, which in turn is tied to glass production rate, and the impact of blockage on melter design is not fully understood.

Table C.5. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Lab-scale similar system tested with range of simulants	PNNL has conducted tests at the laboratory-scale (24590-101-TSA-W000-0004-113-02). Offgas system testing was conducted using the DM1200 melter system for several system components: SBS (24590-101-TSA-W000-0009-54-00001), TCO (24590-101-TSA-W000-0009-87-09), and WESP (24590-101-TSA-W000-0009-174-00001). All tests were conducted with HLW C-106/ AY-102 simulants (24590-101-TSA-W000-0009-172-00001) with adjustments of several toxic metals, nitrogen oxides, and waste organics to bound the concentrations.
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	DM1200 offgas test system was prototypical of the plant. Limited testing of a ~1/30-scale silver mordenite column occurred; e.g., 24590-101-TSA-W000-0009-144-01, Rev. 00B and 24590-101-TSA-W000-0009-098-07, Rev. 00C. The silver mordenite column is standard industrial equipment and replaceable inside the HLW Facility.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	RAMI data is included the RAMI Assessment Report (24590-HMP-RPT-PO-05-0001, Rev. 0) and the 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results of similar equipment and literature reviews of applicable designs.
N	Some special purpose components combined with available laboratory components for testing	DM1200 tests included film coolers, which are special purpose components. However, tests have not been completed on the film cooler cleaner. Unfortunately, the HLW deposits are not soluble and may be difficult to remove.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	P&IDs are listed in the HOP/PVV offgas system description (24590-LAW-3YD-HOP-00001).
Y	Laboratory environment for testing modified to approximate operational environment	DM1200 laboratory environment is prototypic of the operational environment.
Y	Component integration issues and requirements identified	A final design has been completed. Component integrations have been addressed in the HOP/PVV offgas system description (24590-LAW-3YD-HOP-00001.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Detailed design drawings were completed for the DM1200 system prior to testing.
Y	Requirements definition with performance thresholds and objectives established for final plant design	HOP/PVV offgas system description (24590-LAW-3YD-HOP-00001) and the mechanical data sheets for the equipment include detailed requirements.
Y	Preliminary technology feasibility engineering report completed	See responses to the first question of Table C.5.
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Integration of modules is demonstrated in the R&T reports. . See response to the first question of Table C.5.

Table C.5. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Formal control of all components to be used in final system	A test specification and test plan are generated by the project. The design process uses a flowsheet under configuration control.
Y	Configuration management plan in place	The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	WTP Project has established a risk management plan (24590-WTP-RPT-PR-01-006).
Y	Individual process and equipment functions tested to verify that they work (e.g., test reports)	See response to the first question of Table C.5.

Table C.6. Technology Readiness Level 6 Summary for HLW Melter Offgas Treatment Process System and Process Vessel Vent Exhaust System (HOP/PVV)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	R&T has completed testing on a prototype HOP/PVV offgas system connected to the DM1200 melter (24590-101-TSA-W000-0009-166-00001). Equipment components tested included all prototypical offgas components (i.e., film cooler; SBS; HEME; WESP; carbon sulfur bed for mercury removal; 1/30-scale silver mordenite column for iodine removal; TCO for organic destruction; SCR for NO_x destruction; HEPA filtration; and caustic scrubber. Offgas system testing was conducted for several system components: SBS (24590-101-TSA-W000-0009-54-00001), TCO (24590-101-TSA-W000-0009-87-09), and WESP (24590-101-TSA-W000-0009-174-00001). Limited testing of a ~1/30-scale silver mordenite column occurred; e.g., 24590-101-TSA-W000-0009-144-01, Rev. 00B and 24590-101-TSA-W000-0009-098-07, Rev. 00C. The technology is replaceable inside the HLW Facility. The HEME technology has been used at DWPF and WVDP. Tests were conducted with high-level wastes AZ-101, AZ-102, C-104/AY-101, and C-106/AY-102 simulants (24590-101-TSA-W000-0009-172-00001) with adjustments of several toxic metals, nitrogen oxides, and waste organics to bound the concentrations. These testing results demonstrated the HOP/PVV offgas system will support design requirements as specified in the WTP contract (DE-AC27-01RL14136).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI levels have been estimated for HLW Vitrification Facility including the HOP/PVV offgas system. RAMI targets have been established in WTP Basis of Design for HLW Vitrification Facility (24590-WTP-DB-ENG-01-001, Rev. 1C). The 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	HLW Vitrification Facility including the HOP/PVV is in a detailed design phase. Project and vendor P&IDs have been completed. Design changes occur infrequently and only to support final construction.
Y	Draft design drawings for final plant system are nearly complete	Section 10 of the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001, Rev. 0) identifies all applicable design documents to support the LMP system design. This includes specifications, calculations, datasheets, process and mechanical system design documents, P&IDs, electrical drawings, control and instrumentation (C&I) specifications, equipment drawings, general arrangement drawings, supplier documents, and authorization basis documents. Vendor design drawings are in progress.

Table C.6. (cont’d)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operating environment for final system known	The operating environment for the HOP/PVV offgas system is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and the HOP/PVV offgas system description (24590-LAW-3YD-HOP-00001). Operating conditions for limited equipment components are also evaluated in the R&T testing reports (24590-101-TSA-W000-0009-54-00001, Rev. 00C). Mechanical datasheets are prepared as part of the final engineering specification.
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI data is included the RAMI Assessment Report (24590-LAW-RPT-PO-05-0001, Rev. 0) and the 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results, vendor information, and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the HOP/PVV offgas system is provided in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering-scale similar system tested with a range of simulants	Equipment components tested on the DM1200 melter system (24590-101-TSA-W000-0009-166-00001) included most prototypical offgas components (i.e., film cooler; SBS; HEME; WESP; carbon sulfur bed for mercury removal; the 1/30-scale silver mordenite column for iodine removal; TCO for organic destruction; SCR for NO_x destruction; and HEPA filtration.
Y	Modeling and simulation used to simulate system performance in an operational environment	The performance of the HOP/PVV offgas system has been modeled using the Tank Utilization Assessment (24590-WTP-RPT-PO-05-008, Rev. 0), the 2005 WTP Operations Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0), and the WTP Material Balance (24590-WTP-RPT-PO-05-009, Rev. 0). These modeling activities have shown that the melter offgas emissions can be treated to meet stack discharge requirements. The WTP Material Balance (24590-WTP-RPT-PO-05-009, Rev. 0) is also used to estimate the emissions from the facility to support the dangerous waste permit assessments. The results of these assessments show that the HOP/PVV have been adequately designed.

Table C.6. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Plan for demonstration of prototypical equipment and process testing completed, results verify design	The plan for testing the HOP/PVV offgas system is documented in the WTP R&T Program Plan (24590-WTP-PL-RT-01-002,). Reports documenting test results are identified in the response to the first question of Table C.6. While design modifications were incorporated into the final design to address the problems encountered during DM1200 testing, further testing is needed to verify the operational limits of the final design. Problems observed include WESP decontamination factor (DF) and power supply problems (24590-101-TSA-W000-0009-174-00001) Page: 26 [This was DM1200-specific due to the electrical leads being in the process offgas stream (no isolation or purging), inadequate materials for the service intended (grounding strap made of copper and also exposed to the process gases.]; occlusion of the SBS downcomer (24590-101-TSA-W000-0009-54-00001) [This was "solved" using the reference design of the downcomer]; film cooler and transition line blockage (CCN:144619); and failure to meet 99.99% Destruction Removal Efficiency (DRE) for naphthalene (CCN:128559).
N	Operating limits determined using engineering-scale system	Operating limits for the HOP/PVV offgas system are identified in the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001, Rev. 0). Several problems with operations were identified during DM1200 testing with a limited range of feeds. While design modifications were incorporated into the final design to address the problems, further testing is needed to verify the operational limits of the final design. Problems observed include WESP DF and power supply problems (24590-101-TSA-W000-0009-174-00001); occlusion of the SBS downcomer (24590-101-TSA-W000-0009-54-00001); film cooler and transition line blockage (CCN:144619); and failure to meet 99.99% DRE for naphthalene (CCN:128559). (See previous discussion for an explanation of the WESP and SBS issues.)
Y	Operational requirements document available	The minimum operating requirements for the HOP/PVV offgas system are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001) and the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001).
Y	Off-normal operating responses determined for engineering-scale system	Off-normal operating responses for the HOP/PVV offgas system have been evaluated in the HLW Vitrification Facility PSAR (24590-WTP-PSAR-ESH-01-002-04). Off-normal conditions are described in RPT-W375SH-TE0000.
Y	System technical interfaces defined	Interfaces for the HOP/PVV offgas system are defined the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C) and Section 9 of the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001, Rev. 0).

Table C.6. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Component integration demonstrated at an engineering scale	Integrated testing of the HOP/PVV subcomponents has been completed, and is documented in the R&T testing reports identified in response to the first question of Table C.6. Several problems with operations were identified during DM1200 testing with a limited range of feeds. While design modifications were incorporated into the final design to address the problems, further testing is needed to verify the operational limits of the final design. Problems observed include WESP DF and power supply problems (24590-101-TSA-W000-0009-174-00001); occlusion of the SBS downcomer (24590-101-TSA-W000-0009-54-00001); film cooler and transition line blockage (CCN:144619); and failure to meet 99.99% DRE for naphthalene (CCN:128559). (See previous discussion for an explanation of the WESP and SBS issues.)
N	Scaling issues that remain are identified and supporting analysis is complete	The scaling of the HOP/PVV equipment components has been provided in specific component calculations identified in the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001). The majority of the equipment components for the HOP/PVV are commercially available and the WTP Contractor is using vendor calculations to support final verification of component sizing. A report was completed that demonstrated the impact of increased glass bubbling on higher melter production rate (24590-101-TSA-W000-0009-162-00001). High glass bubbling rates contribute to film cooler blockage (CCN:144619), which may result in limitations on the melter production rate as a result of excess downtime and/or restrictions on the glass bubbling rate.
Y	Analysis of project timing ensures technology will be available when required	May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the HOP/PVV technology will be incorporated into the HLW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the HOP/PVV and the balance of the HLW Vitrification Facility are described in the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001, Rev. 0). This includes both physical and process interfaces with the HLW Vitrification Facility. These requirements have been factored into the design of the HOP/PVV.
Y	Acquisition program milestones established for start of final design (CD-2)	The acquisition of HOP/PVV offgas system components is defined in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0). The project has completed CD-2 as identified in DOE O 413.3A and has completed CD-3, Start of Construction.
Y	Critical manufacturing processes prototyped	Engineering and procurement activities for the HOP/PVV have been initiated. Based upon fabrication and procurement of the HOP/PVV components, no significant fabrication issues have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	The fabrication of the HOP/PVV is in process. The SBS, film coolers, and HEMEs were used for DOE's WVDP.

Table C.6. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Engineering feasibility fully demonstrated (e.g., will it work?)	Engineering-scale testing of the HOP/PVV indicates that the plant design will perform as required. Test results are provided in the R&T reports identified in the response to the first question of Table C.6. Problems observed include WESP DF and power supply problems (24590-101-TSA-W000-0009-174-00001); occlusion of the SBS downcomer (24590-101-TSA-W000-0009-54-00001); film cooler and transition line blockage (CCN:144619); and failure to meet 99.99% DRE for naphthalene (CCN:128559). (See previous discussion for an explanation of the WESP and SBS issues.)
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	The fabrication of the HOP/PVV components is in process. No significant fabrication issues have been identified. Qualification of the carbon sulfur absorbent by testing is still in process.
Y	Technology "system" design specification complete and ready for detailed design	The design of the HOP/PVV offgas system is complete. The design concept is described in the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001) and supporting design documentation references.
Y	Components are functionally compatible with operational system	The integration of the HOP/PVV with the HLW Vitrification Facility is described in the HOP/PVV offgas system description (24590-HLW-3YD-HOP-00001, Rev. 1) and the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C). No compatibility issues are identified based on these specifications.
N	Engineering-scale system is high-fidelity functional prototype of operational system	DM1200 offgas system used in testing offgas components is representative of the process system designed for the HLW Vitrification Facility. Testing of this offgas system has provided data that is representative of plant-scale operations. See response to the first question of Table C.6. Design modifications were incorporated into the final design to address the problems, so that further testing is needed to the final design. Problems observed include WESP DF and power supply problems (24590-101-TSA-W000-0009-174-00001); occlusion of the SBS downcomer (24590-101-TSA-W000-0009-54-00001); film cooler and transition line blockage (CCN:144619); and failure to meet 99.99% DRE for naphthalene (CCN:128559). (See previous discussion for an explanation of the WESP and SBS issues.)
Y	Formal configuration management program defined to control change process	WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).

Table C.6. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Integration demonstrations have been completed (e.g., construction of testing system)	The successful construction and operation of the DM1200 HOP/PVV offgas system is documented in select R&T testing reports identified in the first question of Table C.6. A description of this testing system is provided in test reports included as response to the first question. While design modifications were incorporated into the final design to address the problems, further testing is needed to verify the operational limits of the final design. Problems observed include WESP DF and power supply problems (24590-101-TSA-W000-0009-174-00001); occlusion of the SBS downcomer (24590-101-TSA-W000-0009-54-00001); film cooler and transition line blockage (CCN:144619); and failure to meet 99.99% DRE for naphthalene (CCN:128559).
N	Final Technical Report on Technology completed	Problems observed during DM1200 testing include WESP DF and power supply problems (24590-101-TSA-W000-0009-174-00001); occlusion of the SBS downcomer (24590-101-TSA-W000-0009-54-00001); film cooler and transition line blockage (CCN:144619); and failure to meet 99.99% DRE for naphthalene (CCN:128559). Testing did not demonstrate feasibility of the film cooler cleaner or compliance with maximum achievable control technology (MACT) standards; therefore, the final technology testing is not completed.
Y	Waste processing issues have been identified and major ones have been resolved	Carbon beds must be changed out every 2 years, which will be conducted during a shutdown. Several issues were identified with HEPA filter lifespan, uncertainty with the MACT, and qualification of the carbon sorbant. These waste processing issues have been identified, evaluated, and closed. These issues and their resolution are included in the response to the first question of this table.
Y	Process and tooling are mature to support fabrication of components/system	The fabrication of the HOP/PVV is in process. No significant fabrication issues have been identified. Qualification of the carbon sulfur absorbent by testing is in process.
Y	Production demonstrations are complete (at least one time)	The design and fabrication of the DM1200 HOP/PVV offgas system demonstrates that the plant-scale system can be fabricated.

Table C.7. Technology Readiness Level 5 Summary for HLW Pulse Jet Mixer (PJM) System and Radioactive Liquid Waste Disposal System (RLD)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Cross technology effects (if any) have been fully identified (e.g., system internally consistent)	Cross technology effects are analyzed in the CFD model reports listed in Section 10.2.4 of the PJM system description (24590-HLW-3YD-50-00003). A recent review of the WTP flowsheet (CCN:132846) identified potential design issues with the PJM mixed vessels containing Newtonian process wastes. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs. In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids.
Y	Plant-size components available for testing at required scale	Full-scale components have been used at Sellafield, U.K. (24590-CM-TSA-HXYG.0008). The components can be easily procured or fabricated from AEA Technology. The project has done operational analysis to understand the scale of vessels required for the WTP.
Y	System interface requirements known (how will system be integrated into the plant?)	Section 9 of the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001) define the interface requirements.
Y	System requirements flow down through work breakdown structure (design engineering begins)	RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001) define the flowdown requirements.
N	Requirements for technology verification established	Test acceptance requirements are in the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001). The verification requirements will be defined in the requirements verification matrix in the system descriptions. This is not yet produced as a project document.
Y	Lab-scale similar system tested with limited range of actual wastes, if applicable	The project made the decision that they did not need to test at the laboratory-scale because AEA had done significant testing (24590-QL-POA-MFAO-00001-10-00001).
Y	Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)	Benchtop testing with realistic interfaces includes past experience at 336 Advanced Product Evaluation Laboratory (APEL) testing (24590-101-TSA-W000-0004-99-00010; 24590-101-TSA-W000-0004-114-00016; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-150-00003; 24590-101-TSA-W000-0004-114-00019; 24590-101-TSA-W000-0004-165-00001). The PJM, RLD, and HOP vessel systems are based upon design concepts demonstrated in nuclear facilities operated at the Sellafield site (24590-CM-TSA-HXYG.0008).

Table C.7. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Significant engineering and design changes	The project is in the detailed design phase. Design documentation is provided in the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001).
Y	Prototypes of equipment system components have been created (know how to make equipment)	Small-scale prototypes have been created. The PJM, RLD, and HOP vessel system are based upon design concepts demonstrated in nuclear facilities operated at the Sellafield site (24590-CM-TSA-HXYG.0008).
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	Small-scale prototypes have been created. The PJM, RLD, and HOP vessel system are based upon design concepts demonstrated in nuclear facilities operated at the Sellafield site (24590-CM-TSA-HXYG.0008).
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	Small-scale prototypes have been created for the purposes of PJM testing. The PJM, RLD, and HOP vessel systems are based upon design concepts demonstrated in nuclear facilities operated at the Sellafield site (24590-CM-TSA-HXYG.0008).
Y	Design techniques have been defined to the point where largest problems defined	The WTP Contractor has conducted an engineering evaluation of the ability of the PJM mixed vessels in the HLW Facility to suspend solids (CCN:150383). The assessment used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. This initial assessment indicates that the mixing capability of the PJMs in the HLW Facility vessels (HOP-VSL-00903; HOP-VSL-00904; RLD-VSL-00007; RLD-VSL-00008) is adequate.
Y	Lab-scale similar system tested with range of simulants	The mixing report from the vendor with simulants demonstrates the feasibility of the system design (24590-QL-POA-MFAO-00001-10-00001). R&T testing of the mixing system was conducted at SRTC (SCT-M0SRLE60-00-132-05; -187-02, Rev. 00C (cleared)).
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	The mixing report from the vendor demonstrates the feasibility of the system design (24590-QL-POA-MFAO-00001-10-00001). R&T testing of the mixing system at SRTC (SCT-M0SRLE60-00-132-05; -187-02).
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	RAMI targets have been established in WTP Basis of Design for HLW Vitrification Facility (24590-WTP-DB-ENG-01-001, Rev. 1C). The 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. For the black cells, there are redundant systems and the systems have a 40-year lifetime. If there is a seismic event, all systems will be shut down. The failures are assumed to be minimal. There are very few parts that require maintenance.
Y	Some special purpose components combined with available laboratory components for testing	Small-scale tests were done for purposes of establishing the 336 APEL test setup (24590-101-TSA-W000-0004-124-03; 24590-101-TSA-W000-0004-72-08).

Table C.7. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	P&IDs are done and listed in the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001).
Y	Laboratory environment for testing modified to approximate operational environment	The project made the decision that they did not need to test at the laboratory-scale because AEA had done significant testing (24590-QL-POA-MFAO-00001-10-00001). The bench-scale testing environment is prototypic of the operational environment.
Y	Component integration issues and requirements identified	Component integrations have been addressed in Section 9 of the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001).
Y	Detailed design drawings have been completed to support specification of pilot testing system	The project is in the detailed design phase. Design documentation is provided in the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001).
Y	Requirements definition with performance thresholds and objectives established for final plant design	Requirements have been addressed in Section 9 of the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001). Performance criteria for PJM mixing in the HLW vessels has recently been established (24590-WTP-RPT-PR-07-003) to support definition of a testing program to validate the adequacy of the PJMs in the HLW vessels to: blend liquids and solids, maintain solids in suspension and re-suspend settled solids.
Y	Preliminary technology feasibility engineering report completed	The preliminary feasibility is documented by the body of knowledge of PJM testing (24590-101-TSA-W000-0004-99-00010; 24590-101-TSA-W000-0004-114-00016; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-150-00003; 24590-101-TSA-W000-0004-114-00019; 24590-101-TSA-W000-0004-165-00001).
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Integration of modules is demonstrated in the R&T reports (24590-101-TSA-W000-0004-99-00010; 24590-101-TSA-W000-0004-114-00016; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-150-00003; 24590-101-TSA-W000-0004-114-00019; 24590-101-TSA-W000-0004-165-00001).
Y	Formal control of all components to be used in final system	A test specification and test plan was generated by the project (24590-101-TSA-W000-0004-114-00019). The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002).

Table C.7. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Configuration management plan in place	The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002).
Y	Risk management plan documented	WTP Project has established a risk management plan (24590-WTP-RPT-PR-01-006).
Y	Individual process and equipment functions tested to verify that they work (e.g., test reports)	Testing of modules is demonstrated in the R&T reports (24590-101-TSA-W000-0004-99-00010; 24590-101-TSA-W000-0004-114-00016; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-150-00003; 24590-101-TSA-W000-0004-114-00019; 24590-101-TSA-W000-0004-165-00001).

Table C.8. Technology Readiness Level 6 Summary for HLW Pulse Jet Mixer (PJM) System and Radioactive Liquid Waste Disposal System (RLD)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The PJM is a standard design based on the PJM system at Sellafield (24590-CM-TSA-HXYG.0008). An experimental program was initiated by BNI to look at non Newtonian vessels (24590-101-TSA-W000-0004-124-03; 24590-101-TSA-W000-0004-72-08; 24590-101-TSA-W000-0004-118-02; 24590-101-TSA-W000-0004-149-00001; 24590-101-TSA-W000-0004-99-00011; 24590-101-TSA-W000-0004-99-00010; -99-00010; 24590-101-TSA-W000-0004-172-00001; 24590-101-TSA-W000-0004-114-00016). In 2003, both RLD vessels were modeled, and the models concluded that all solids could be suspended (24590-HLW-RPT-M-03-005; 294950-HLW-RPT-M-03-004). Additional computation fluid dynamic reports are listed in Section 10.2.4 of the PJM system description (24590-WTP-3YD-50-00003). Simulants used for mixer testing are described in SCT-M0SRLE60-00-193-02.
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP Basis of Design for HLW Vitrification Facility (24590-WTP-DB-ENG-01-001). The 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001) documents acceptability of the design concept. For the black cells, there are redundant systems and the systems have a 40-year lifetime. If there is a seismic event, all systems will be shut down.
Y	Frequent design changes occur	The final design of the equipment has been completed. Most drawings and calculations are identified in the PJM system description (24590-HLW-3YD-50-00003).
Y	Draft design drawings for final plant system are nearly complete	The final design of the equipment is completed by the vendor. Most preliminary drawings and calculations are identified in the PJM system description (24590-HLW-3YD-50-00003).
Y	Operating environment for final system known	The operating environment for the HFP system is specified in the WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1C), the PJM system description (24590-HLW-3YD-50-00003), and the HLW PSAR (24590-WTP-PSAR-ESH-01-002-03).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI data is included the RAMI Assessment Report (24590-HLW-RPT-PO-05-0001, Rev. 0) and the 2005 WTP Operational Research Assessment Report (24590-WTP-RPT-PO-05-001, Rev. 0). This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the PJM system and RLD is provided in the May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0).

Table C.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Engineering-scale similar system tested with a range of simulants	The preliminary feasibility is documented by the body of knowledge of PJM testing (24590-101-TSA-W000-0004-99-00010; 24590-101-TSA-W000-0004-114-00016; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-153-00002; 24590-101-TSA-W000-0004-150-00003; 24590-101-TSA-W000-0004-114-00019; 24590-101-TSA-W000-0004-165-00001). A mixing report from the vendor demonstrates adequacy of system design (24590-QL-POA-MFAO-00001-10-00001). The R&T testing of the mixing system has been completed. A recent review of the WTP flowsheet (CCN:132846) identified potential design issues with the PJM mixed vessels containing Newtonian process wastes. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs. In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids.
Y	Modeling and simulation used to simulate system performance in an operational environment	The performance of the PJM system has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The WTP Contractor has conducted an engineering evaluation of the ability of the PJM mixed vessels in the HLW Facility to suspend solids (CCN:150383). The assessment used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. This initial assessment indicates that the mixing capability of the PJMs in the HLW Facility vessels (HOP-VSL-00903; HOP-VSL-00904; RLD-VSL-00007; RLD-VSL-00008) is adequate.
N	Plan for demonstration of prototypical equipment and process testing completed, results verify design	Testing of the PJMs to mixed Newtonian fluids is planned as part of the resolution of the EFRT issue M3, "Inadequate Mixing System." Testing is scheduled for completion in fiscal year (FY) 2007 (24590-WTP-PL-ENG-06-0013).
N	Operating limits determined using engineering-scale system (from design, safety, environmental compliance)	The operating conditions for the PJM system have been established based upon engineering analysis presented in the PJM system description (24590-HLW-3YD-50-00003), and the testing reports identified in the response to the first question of Table C.8. A recent review of the WTP flowsheet (CCN:132846) identified potential design issues with the PJM mixed vessels containing Newtonian process wastes. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs. In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids.

Table C.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operational requirements document available	The minimum operating requirements for the PJM system are defined in the WTP Operations Requirements Document (24590-WTP-RPT-OP-01-001), and the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001).
Y	Off-normal operating responses determined for engineering-scale system	An initial assessment of off-normal operations along with corrective actions is identified in the specification for the upcoming QARD testing (VSL-06T1000-1). Off-normal operating responses are discussed in the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001).
Y	System technical interfaces defined	The identification of the technical interface requirements is included in Section 9 of the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001)
N	Component integration demonstrated at an engineering scale	Engineering-scale testing has been document in the 336 APEL testing reports in the response to the first question of Table C.8 for non-Newtonian fluids. Component integration is demonstrated in reports from the vendor (24590-QL-POA-MFAO-00001-10-00001). A recent review of the WTP flowsheet (CCN:132846) identified potential design issues with the PJM mixed vessels containing Newtonian process wastes. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs. In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids.
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues remain for the vessels and PJMs.
Y	Analysis of project timing ensures technology will be available when required	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the PJM technology will be incorporated into the HLW Vitrification Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	Identification of the technical interface requirements is included in Section 9 of the RLD, HOP, PJM, and PJV system descriptions (24590-HLW-3YD-HOP-00001; 24590-HLW-3YD-HPH-00001; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-50-00003; 24590-HLW-3YD-RLD-00001).
Y	Acquisition program milestones established for start of final design (CD-2)	The May 2006 WTP Estimate at Completion (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the PJM technology will be incorporated into the HLW Vitrification Facility. Technology availability does not constrain this schedule.

Table C.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Critical manufacturing processes prototyped	RLD and PJM system design is based upon existing technology, commonly fabricated equipment. Some vessels (HOP-VSL-00903; HOP-VSL-00904; RLD-VSL-00007; RLD-VSL-00008) are already fabricated.
Y	Most pre-production hardware is available to support fabrication of the system	RLD and PJM system design is based upon existing technology, commonly fabricated equipment. Some vessels (HOP-VSL-00903; HOP-VSL-00904; RLD-VSL-00007; RLD-VSL-00008) are already fabricated.
N	Engineering feasibility fully demonstrated (e.g., will it work?)	Engineering-scale testing has been document in the 336 APEL testing reports in the response to the first question of Table C.8 for non-Newtonian fluids. Component integration is demonstrated in reports from the vendor (24590-QL-POA-MFAO-00001-10-00001). A recent review of the WTP flowsheet (CCN:132846) identified potential design issues with the PJM mixed vessels containing Newtonian process wastes. These issues include a design basis that discounts the effects of large particles and of rapidly settling Newtonian slurries. There is also insufficient testing of the selected designs. In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	PJM system design is based upon existing technology and standard industry components. Vessels for the RLD have been fabricated.
Y	Technology "system" design specification complete and ready for detailed design	The design of the plant-scale system has been completed (design drawings).
Y	Components are functionally compatible with operational system	PJMs and supporting systems for process air and ventilation air have been integrated with the HLW Facility design.
N	Engineering-scale system is high-fidelity functional prototype of operational system	In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids.
Y	Formal configuration management program defined to control change process	WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046); review of engineering documents (24590-WTP-3DP-G04T-00913; Rev. 5); design change control (24590-WTP-3DP-G04T-00901; Rev. 10); design verification (24590-WTP-3DP-G04B-00027; Rev. 8); and other engineering department procedures. WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).

Table C.8. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	Integration demonstrations have been completed (e.g., construction of testing system)	Test reports for the PJM vessels are identified in the response to the first question for Table C.8. There is also insufficient testing of the selected designs. The WTP Contractor has identified the need to complete additional testing to demonstrate the ability of the PJMs to mix and re-suspend solids for low solids containing solutions. This work is scheduled to be complete in late 2007.
Y	Final Technical Report on Technology completed	Test reports for the PJM vessels are identified in the response to the first question for Table C.8. There is also insufficient testing of the selected designs. The WTP Contractor has identified the need to complete additional testing to demonstrate the ability of the PJMs to mix and re-suspend solids for low solids containing solutions. This work is scheduled to be complete in late 2007. In response to this issue, the WTP Contractor has established a plan (24590-WTP-PL-ENG-06-0013) for testing to evaluate the mixing behavior of vessels that are anticipated to contain Newtonian fluids.
N	Waste processing issues have been identified and major ones have been resolved	The WTP Contractor has identified the need to complete additional testing to demonstrate the ability of the PJMs to mix and re-suspend solids for low solids containing solutions. This work is scheduled to be complete in late 2007.
Y	Process and tooling are mature to support fabrication of components/system	The PJM is a standard design based on the PJM system at Sellafield (24590-CM-TSA-HXYG.0008). A majority of the plant equipment has been fabricated at least once.
Y	Production demonstrations are complete (at least one time)	The PJM is a standard design based on the PJM system at Sellafield (24590-CM-TSA-HXYG.0008). A majority of the plant equipment has been fabricated at least once.

References

1. 24590-101-TSA-W000-00009-098-00009, *Final Report - Development of Phase 1 IHLW Models for PCT Response and One-Percent Crystal Fraction Temperature (T1%)*, April 21, 2005, Bechtel National, Inc., Richland, Washington.
2. 24590-101-TSA-W000-00009-106-00021, Rev. 00A, *Final Report - DM100 HLW Simulant Validation Tests with C-106/AY-102 Feeds*, June 14, 2005, Bechtel National, Inc., Richland, Washington.
3. 24590-101-TSA-W000-0004-113-02, Rev. 00B, *Evaluation of Corona Oxidation as Back-up Technology for Organic Destruction in the Secondary Offgas Treatment System*, May 8, 2003, Bechtel National, Inc., Richland, Washington.
4. 24590-101-TSA-W000-0004-114-00016, Rev. 00A, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, March 15, 2005, Bechtel National, Inc., Richland, Washington.
5. 24590-101-TSA-W000-0004-114-00018, Rev. 00B, *Technical Basis for Predicting Mixing and Flammable Gas Behavior in the Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels with Non-Newtonian Slurries*, January 20, 2006, Bechtel National, Inc., Richland, Washington.
6. 24590-101-TSA-W000-0004-114-00019, Rev. 00B, *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program*, January 20, 2006, Bechtel National, Inc., Richland, Washington.
7. 24590-101-TSA-W000-0004-118-02, Rev. 00B, *Large Tank Experimental Data for Validation for the FLUENT CFD Model of Pulsed Jet Mixers*, July 7, 2003, Bechtel National, Inc., Richland, Washington.
8. 24590-101-TSA-W000-0004-124-03, Rev. 00B, *Demonstration of Ability to Mix in a Small-Scale Pulsed-Jet Mixer Test Facility*, March 13, 2003, Bechtel National, Inc., Richland, Washington.
9. 24590-101-TSA-W000-0004-125-02, Rev. 00B, *The Corrosion Effects of Mercury and Mercury Compounds on WTP Materials: Electrochemical Tests*, March 24, 2003, Bechtel National, Inc., Richland, Washington.
10. 24590-101-TSA-W000-0004-139-01, Rev. 00B, *Chemical Analysis and Physical Property Testing of 241-AP-104 Tank Waste*, October 2, 2003, Bechtel National, Inc., Richland, Washington.
11. 24590-101-TSA-W000-0004-144-01, Rev. 00B, *Rheological and Physical Properties of AZ-101 HLW Pretreated Sludge and Melter Feed,* January 8, 2004, Bechtel National, Inc., Richland, Washington.
12. 24590-101-TSA-W000-0004-150-00003, Rev. 00A, *Gas Generation Testing and Support for the Hanford Waste Treatment and Immobilization Plant*, June 24, 2004, Bechtel National, Inc., Richland, Washington.
13. 24590-101-TSA-W000-0004-153-00002, Rev. 00A, *Interim Report: Gas Retention and Release in Pulse Jet Mixed Tanks Containing Non-Newtonian Waste Simulants*, August 31, 2004, Bechtel National, Inc., Richland, Washington.
14. 24590-101-TSA-W000-0004-153-00002, Rev. 00B, *Final Report: Gas Retention and Release in Hybrid Pulse Jet Mixed Tanks Containing Non-Newtonian Waste Simulants*, March 22, 2005, Bechtel National, Inc., Richland, Washington.

15. 24590-101-TSA-W000-0004-160-00001, Rev. 00A, *Technical Basis for Scaling of Air Sparging Systems for Mixing in Non-Newtonian Slurries*, March 4, 2005, Bechtel National, Inc., Richland, Washington.

16. 24590-101-TSA-W000-0004-165-00001, Rev. 00B, *Hybrid Mixing System Test Results for Prototype Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels,* April 21, 2005, Bechtel National, Inc., Richland, Washington.

17. 24590-101-TSA-W000-0004-172-00001, Rev. 00A, *Final Report: Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions*, January 5, 2006, Bechtel National, Inc., Richland, Washington.

18. 24590-101-TSA-W000-0004-72-08, Rev. 00B, *Results of Small-Scale Particle Cloud Tests and Non-Newtonian Fluid Cavern Tests*, November 19, 2003, Bechtel National, Inc., Richland, Washington.

19. 24590-101-TSA-W000-0004-99-00010, Rev. 00A; -99-00010, Rev. 00B (published), *Non-Newtonian Slurry Simulant Development and Selection for Pulse Jet Mixer Testing*, August 17, 2004, Bechtel National, Inc., Richland, Washington.

20. 24590-101-TSA-W000-0004-99-00011, Rev. 00A, *Test Results for Pulse Jet Mixers in Prototypic Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, August 17, 2004, Bechtel National, Inc., Richland, Washington.

21. 24590-101-TSA-W000-0009-101-00007, *RPP-WTP Pilot Melter Prototypic LAW Container and HLW Canister Glass Fill Test Results Report*, May 26, 2004, Bechtel National, Inc., Richland, Washington.

22. 24590-101-TSA-W000-0009-102-01, *Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A3 Feed in Support of the LAW Pilot Melter*, March 7, 2003, Bechtel National, Inc., Richland, Washington.

23. 24590-101-TSA-W000-0009-105-04, *Summary Report - Augmentation Test Matrix to Support TCLP Model Development for RPP-WTP HLW Glasses*, December 9, 2003, Bechtel National, Inc., Richland, Washington.

24. 24590-101-TSA-W000-0009-118-00009, Rev. 00A, *Final Report: Integrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C 106/AY-102 Simulants*, May 6, 2004, Bechtel National, Inc., Richland, Washington.

25. 24590-101-TSA-W000-0009-118-00010, *Final Report - ADS Pump Testing as Part of Integrated DM1200 Testing of HLW Compositions Using Bubblers*, May 24, 2004, Bechtel National, Inc., Richland, Washington.

26. 24590-101-TSA-W000-0009-119-00003, Rev. B, *Final Report - High-Level Waste Melter System Materials of Construction Testing,* July 22, 2002, Bechtel National, Inc., Richland, Washington.

27. 24590-101-TSA-W000-0009-121-00006, Rev. 00A, *Modeling the Behavior of Noble Metals During HLW Vitrification in the DM1200 Melter*, May 25, 2005, Bechtel National, Inc., Richland, Washington.

28. 24590-101-TSA-W000-0009-144-00005, Rev. 00A, *Final Report - DM1200 Tests with AZ-101 HLW Simulants*, February 26, 2004, Bechtel National, Inc., Richland, Washington.

29. 24590-101-TSA-W000-0009-144-00006, Rev. 00A, *Final Report - Integrated DM1200 Melter Testing Using AZ-102 and C-106/AY-102 HLW Simulants: HLW Simulant Verification*, July 27, 2005, Bechtel National, Inc., Richland, Washington.

30. 24590-101-TSA-W000-0009-144-01, *Integrated DM1200 Melter Testing of HLW C-106/AY-102 Composition Using Bubblers,* October 17, 2003, Bechtel National, Inc., Richland, Washington.

31. 24590-101-TSA-W000-0009-144-02, Rev. 00B, *Final Report - Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers*, October 17, 2003, Bechtel National, Inc., Richland, Washington.

32. 24590-101-TSA-W000-0009-144-03, Rev. 00B, *Noble Metals Testing on the DM1200 Pilot Melter System with AZ-101 HLW Simulants*, December 31, 2003, Bechtel National, Inc., Richland, Washington.

33. 24590-101-TSA-W000-0009-153-00001, Rev. 00A, *Final Report - High-Level Waste Melter Alternate Bubbler Configuration Testing*, June 29, 2004, Bechtel National, Inc., Richland, Washington.

34. 24590-101-TSA-W000-0009-156-00001, *Final Report - Regulatory Testing of RPP-WTP HLW Glasses to Support Delisting Compliance (plus CD with Appendices)*, October 14, 2004, Bechtel National, Inc., Richland, Washington.

35. 24590-101-TSA-W000-0009-157-00002, *Final Report - DM100 HLW and LAW Tests of the Influence of Technetium on Cesium Volatility Using Rhenium as a Technetium Surrogate*, October 15, 2004, Bechtel National, Inc., Richland, Washington.

36. 24590-101-TSA-W000-0009-158-00001, *Final Report - Integrated DM1200 Melter Testing of Bubbler Configurations Using HLW AZ-101 Simulants*, October 15, 2004, Bechtel National, Inc., Richland, Washington.

37. 24590-101-TSA-W000-0009-162-00001, Rev. 00A, *Investigation of Glass Bubbling and Increased Production Rate (Proprietary Data)*, October 28, 2004, Bechtel National, Inc., Richland, Washington.

38. 24590-101-TSA-W000-0009-164-00001, M*odeling of HLW Melter with Revised Bubbler Design and Noble Metals*, October 12, 2005, Bechtel National, Inc., Richland, Washington.

39. 24590-101-TSA-W000-0009-165-00001, *Preparation and Testing of HLW Matrix Glasses to Support WTP Property-Composition Model Development Final Report,* October 24, 2005, Bechtel National, Inc., Richland, Washington.

40. 24590-101-TSA-W000-0009-166-00001, Rev. 00B, *Regulatory Offgas Emissions Testing on the DM1200 Melter System Using HLW and LAW Simulants,* November 11, 2005, Bechtel National, Inc., Richland, Washington.

41. 24590-101-TSA-W000-0009-168-00001, Rev. B, *Comparison of HLW Simulant, Actual Waste, and Melter Glasses*, December 7, 2005, Bechtel National, Inc., Richland, Washington.

42. 24590-101-TSA-W000-0009-171-00001, Rev. 00A, *Summary of DM1200 Operation at VSL*, October 10, 2006, Bechtel National, Inc., Richland, Washington.

43. 24590-101-TSA-W000-0009-172-00001, Rev. 00A, *Review of Properties of Simulated Feeds Used for Melter Testing*, September 26, 2006, Bechtel National, Inc., Richland, Washington.

44. 24590-101-TSA-W000-0009-174-00001, Rev. 00A, *Summary of DM1200 WESP History and Performance*, August 7, 2006, Bechtel National, Inc., Richland, Washington.

45. 24590-101-TSA-W000-0009-23-09, Rev. 00C, *RPP-WTP Pilot Melter Bubbler Consumable Changeout Box Test Results Report*, August 20, 2003, Bechtel National, Inc., Richland, Washington.

46. 24590-101-TSA-W000-0009-23-10, Rev. 00C, *RPP-WTP Pilot Melter Bubbler Life Extension Test Results Report*, January 7, 2004, Bechtel National, Inc., Richland, Washington.

47. 24590-101-TSA-W000-0009-34-03, Rev. 00C, *Final Report: Tests on the DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants*, June 11, 2002, Bechtel National, Inc., Richland, Washington.

48. 24590-101-TSA-W000-0009-48-01, Rev. 00C, *Final Report - Melter Tests with AZ-101 HLW Simulant Using a DuraMelter 100 Vitrification System*, July 31, 2003, Bechtel National, Inc., Richland, Washington.

49. 24590-101-TSA-W000-0009-54-00001, Rev. 00C, *Final Report - Submerged Bed Scrubber (SBS): Off-line Component Testing of DM1200 SBS Unit*, August 30, 2004, Bechtel National, Inc., Richland, Washington.

50. 24590-101-TSA-W000-0009-64-00003, *Final Report - HLW Glass Formulation to Support C-106/AY-102 Actual Waste Testing*, August 17, 2004, Bechtel National, Inc., Richland, Washington.

51. 24590-101-TSA-W000-0009-72-05, *Final Report - Regulatory Spike Testing for RPP-WTP LAW and HLW Glasses for Compliance with Land Disposal Restrictions*, August 8, 2003, Bechtel National, Inc., Richland, Washington.

52. 24590-101-TSA-W000-0009-72-08, *Final Report - Regulatory Testing of WTP HLW Glasses for Compliance with Delisting Requirements*, October 28, 2004, Bechtel National, Inc., Richland, Washington.

53. 24590-101-TSA-W000-0009-74-01, *Start-up and Commissioning Tests on the DuraMelter 1200 HLW Pilot Melter System Using AZ-101 HLW Simulants,* August 29, 2005, Bechtel National, Inc., Richland, Washington.

54. 24590-101-TSA-W000-0009-82-02, *Glass Formulation to support Melter Runs with HLW Simulants*, October 6, 2003, Bechtel National, Inc., Richland, Washington.

55. 24590-101-TSA-W000-0009-87-09, Rev. 00B, *Off-line Tests of the DM1200 Thermal Catalytic Oxidation (TCO) Unit*, April 17, 2003, Bechtel National, Inc., Richland, Washington.

56. 24590-101-TSA-W000-0009-98-07, Rev. 00C, *Final Report: DM1200 Tests with C-104/AY-101 HLW Simulants*, December 4, 2003, Bechtel National, Inc., Richland, Washington.

57. 24590-101-TSA-W000-0010-06-04A, *Glass Formulation and Testing With RPP-WTP HLW Simulants*, July 26, 2002, Bechtel National, Inc., Richland, Washington.

58. 24590-CM-TSA-HXYG.0008, *Technical Basis for River Protection Project Waste Treatment Plant (RPP-WTP)-Power Fluidics System Design*, September 6, 2001, Bechtel National, Inc., Richland, Washington.

59. 24590-HLW-3YD-HDH-00002, *System Description of HLW System HDH Canister Decontamination Handling*, February 17, 2005, Bechtel National, Inc., Richland, Washington.

60. 24590-HLW-3YD-HEH-00001, *System Description for HLW System HEH Canister Export Handling*, January 19, 2005, Bechtel National, Inc., Richland, Washington.

61. 24590-HLW-3YD-HFP-00002, *System Description for HLW Concentrate Receipt and Melter Feed Process Systems (HCP and HPP)*, December 22, 2004, Bechtel National, Inc., Richland, Washington.

62. 24590-HLW-3YD-HMH-00001, *System Description for System HMH HLW Melter Transport,* January 9, 2007, Bechtel National, Inc., Richland, Washington.

63. 24590-HLW-3YD-HMP-00001, *System Description for HLW Melter Process System (HMP)*, May 22, 2006, Bechtel National, Inc., Richland, Washington.

64. 24590-HLW-3YD-HOP-00001, *Systems Description for HLW Melter Offgas Treatment Process and Process Vessel Vent Extraction (HOP and PVV Systems)*, November 14, 2002, Bechtel National, Inc., Richland, Washington.

65. 24590-HLW-3YD-HPH-00001, *System Description for HLW System HPH Canister Pour Handling*, February 1, 2005, Bechtel National, Inc., Richland, Washington.

66. 24590-HLW-3YD-PJV-00001, *System Description for the HLW Pulse Jet Ventilation System,* May 18, 2005, Bechtel National, Inc., Richland, Washington.

67. 24590-HLW-3YD-RLD-00001, *System Description for HLW Radioactive Liquid Waste Disposal (System RLD)*, May 18, 2005, Bechtel National, Inc., Richland, Washington.

68. 24590-HLW-MV-HOP-P0001, *Equipment Assembly SBS Condensate Receiver Vessel HOP-VSL-00903*, December 2004, Bechtel National, Inc., Richland, Washington.

69. 24590-QL-POA-MFAO-00001-10-00001, Rev. 00B, *Rotating Mechanical Agitators Test Report*, March 17, 2004, Bechtel National, Inc., Richland, Washington.

70. 24590-WTP-3DP-G04B-00027, Rev. 8, *Design Verification*, September 15, 2006, Bechtel National, Inc., Richland, Washington.

71. 24590-WTP-3DP-G04B-00046, Rev. 16, *Engineering Drawings*, November 7, 2006, Bechtel National, Inc., Richland, Washington.

72. 24590-WTP-3DP-G04T-00901, Rev. 10, *Design Change Control*, April 25, 2006, Bechtel National, Inc., Richland, Washington.

73. 24590-WTP-3DP-G04T-00913, Rev. 5, *Review of Engineering Documents*, August 28, 2006, Bechtel National, Inc., Richland, Washington.

74. 24590-WTP-3PS-MHSS-T0002, Rev. 0, *Engineering Specification for the Autosampling System (ASX)*, June 16, 2004, Bechtel National, Inc., Richland, Washington.

75. 24590-WTP-3YD-50-00003, Rev. A, *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems,* May 19, 2004, Bechtel National, Inc., Richland, Washington.

76. 24590-WTP-CE-PC-06-001, Rev. 0, *WTP Project Estimate at Completion*, May 31, 2006, Bechtel National, Inc., Richland, Washington.

77. 24590-WTP-DB-ENG-01-001, Rev. 1C, *WTP Basis of Design,* November 1, 2006, Bechtel National, Inc., Richland, Washington.

78. 24590-WTP-GPG-RTD-001, Rev. 0, *Guidelines for Performing Chemical, Physical, and Rheological Properties Measurements*, May 20, 2002, Bechtel National, Inc., Richland, Washington.

79. 24590-WTP-PL-ENG-06-0013, Rev. 000, *Issue Response Plan for Implementation of External Flowsheet Review Team (EFRT) recommendations-M3, Inadequate Mixing System Design*, September 8, 2006, Bechtel National, Inc., Richland, Washington.

80. 24590-WTP-PL-MG-01-002, Rev. 4, *WTP Configuration Management Plan*, May 16, 2006, Bechtel National, Inc., Richland, Washington.

81. 24590-WTP-PL-RT-01-002, Rev. 2, *WTP Research and Technology (R&T) Program Plan*, April 20, 2004, Bechtel National, Inc., Richland, Washington.

82. 24590-WTP-PSAR-ESH-01-002-04, Rev. 1, *Preliminary Safety Analysis Report to Support Construction Authorization; HLW Facility,* December 22, 2006, Bechtel National, Inc., Richland, Washington.

83. 24590-WTP-RPT-ENV-03-00005, Rev. 0, *4-9s Destruction and Removal Efficiency Assessment* , November 20, 2003, Bechtel National, Inc., Richland, Washington.

84. 24590-WTP-RPT-OP-01-001, Rev. 2, *Operations Requirements Document*, May 5, 2003, Bechtel National, Inc., Richland, Washington.

85. 24590-WTP-RPT-PO-05-001, Rev. 0, 2*005 WTP Operation Research Assessment*, August 29, 2005, Bechtel National, Inc., Richland, Washington.

86. 24590-WTP-RPT-PO-05-008, Rev. 0, *2005 WTP Tank Utilization Assessment*, August 8, 2005, Bechtel National, Inc., Richland, Washington.

87. 24590-WTP-RPT-PO-05-009, Rev. 0, *2005 WTP Material Balance and Process Flowsheet Assessment,* November 10, 2005, Bechtel National, Inc., Richland, Washington.

88. 24590-WTP-RPT-PR-01-006, Rev. 13, *WTP Risk Assessment Report,* May 31, 2006, Bechtel National, Inc., Richland, Washington.

89. 294950-HLW-RPT-M-03-004, Rev. 0, *CFD Modeling Report for WTP Vessel; RLD-VSL-00008*, August 22, 2003, Bechtel National, Inc., Richland, Washington.

90. 294950-HLW-RPT-M-03-005, Rev. 0, *CFD Modeling Report for WTP Vessel; RLD-VSL-00007*, August 22, 2003, Bechtel National, Inc., Richland, Washington.

91. CCN:078791, "Consideration on Melter Materials," February 24, 2005.

92. CCN:080128, Letter, from R. J. Schepens, DOE OW, to M. A. Wilson, Washington Department of Ecology, "Request for Concurrence with Principal Organic Dangerous Constituents (PODCs) for Demonstrating a 99.99 Percent Organic Destruction and Removal Efficiency (DRE)," 03-AMWTP-164, , December 17, 2003.

93. CCN:128559, "White Paper on the Analysis of Naphthalene Destruction and Removal Efficiency (DRE) Testing at the Vitreous State Laboratory (VSL)," December 15, 2005.

94. CCN:132846, "Report of External Flowsheet Review Team for the Hanford Waste Treatment and Immobilization Plant-Final Report Titled: 'Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput'," March 17, 2006.

95. CCN:144619, "EFRT M17: Evaluation of HLW Film Cooler Blockage Issues," December 22, 2006, Bechtel National, Inc., Richland, Washington..

96. CCN:150383, "Path Forward for EFRT Mixing Issue M3," January 11, 2007.

97. DE-AC27-01RL14136, *Waste Treatment and Immobilization Plant Contract*, December 1, 2005.

98. DOE O 413.3A, 2006, *Program and Project Management for the Acquisition of Capital Assets,* Change No. 1, U.S. Department of Energy, Office of Management, Budget and Evaluation, Washington, D.C..

99. FMP 064, *Jet Solid Suspension Design Guide*, November 1, 2005.

100. *Determination of Processing Rate of RPP-WTP HLW Simulants using a DuraMelter™ 1000 Vitrification System*, August 21, 2000.

101. *Test Plan: Pretreated Waste and Melter Feed Composition Variability Testing Using HLW and LAW Simulants*, September 29, 2006.

102. PNNL-13359, *Rheological Studies on Pretreated Feed and Melter Feed from C-104 and AZ-102*, January 1, 2001.

103. RPT-W375SH-TE00005, *Evaluation of Alternatives for Maintaining HLW/LAW Melter Offgas Systems Function Under Off-normal Conditions*, September 14, 1999.

104. SCT-M0SRLE60-00-110-17, Rev. 00B, *Compositing and Characterization of Samples from Hanford Tank 241-AY-102/C-106*, October 7, 2003.

105. SCT-M0SRLE60-00-132-05, Rev. 00C, *Pilot Scale Testing - Transport of HLW Glass Former Chemicals Proof of Principle Test Results (U)*, April 10, 2003.

106. SCT-M0SRLE60-00-187-02, Rev. 00B; -187-02, Rev. 00C (cleared), *Evaluation of Wetting Agents to Mitigate Dusting of Glass Forming Chemicals During Delivery to the Melter Feed Preparation Vessel (U)*, July 31, 2003.

107. SCT-M0SRLE60-00-187-02, Rev. 00C (cleared)), *Evaluation of Wetting Agents to Mitigate Dusting of Glass Forming Chemicals During Delivery to the Melter Feed Preparation Vessel (U)*, July 31, 2003.

108. SCT-M0SRLE60-00-193-02, Rev. 00A, *Development of Simulants to Support Mixing Tests for High Level Waste and Low Activity Waste*, December 31, 2003.

109. SCT-M0SRLE60-00-196-00001, Rev. 00B, *Foaming/Antifoaming in WTP Tanks Equipped with Pulse Jet Mixers and Air Spargers*, October 12, 2005.

110. SCT-M0SRLE60-00-21-05, Rev. 00B, *Crucible Scale Vitrification of Pretreated C-106 Sludge Mixed with Secondary Wastes*, August 8, 2002.

111. SCT-M0SRLE60-00-211-00001, Rev. 00A, *Physical Characterization of Vitreous State Laboratory AY102/C106 and AZ102 High Level Waste Melter Feed Simulants*, March 31, 2005.

112. SCT-M0SRLE60-00-218-00001, Rev. 00A, *Vitrification and Product Testing of AY-102/C-106 HLW (Env D) [U]*, November 16, 2005.

113. VSL-06T1000-1, *Test Plan Pretreated Waste and Melter Feed Composition Variability Testing Using HLW and LAW Simulants*, December 11, 2006.

Appendix D – Participants in the TRL Assessment

Appendix D – Participants in the TRL Assessment

Participants in the Technology Readiness Level (TRL) Assessment for the Waste Treatment and Immobilization Plant (WTP) High-Level Waste (HLW) Vitrification Facility for each individual critical system evaluated are identified in Table D.1.

The participants are divided into the Assessment Team and the WTP Project Technology and Engineering support teams.

The Assessment Team was compromised of staff and consultants representing the U.S. Department of Energy (DOE), Office of River Protection (ORP) (Hanford) and DOE Office of Environmental and Radioactive Waste Management (EM) Office of Project Recovery (Headquarters). The Assessment Team was also supported by William Nolte of the Air Force Research Laboratory, who developed the TRL Calculator used in this assessment.

The Assessment Team was assisted by WTP Project Technology and Engineering teams comprised of subject matter experts associated with the critical technology elements that were being evaluated. These subject matter experts were either responsible for testing the technologies or the incorporation of the technology design into the WTP. In general, technology testing is managed by staff from Washington Group International (WGI) and engineering of the systems is managed by staff from Bechtel National, Inc. (BNI).

Table D.1. Participants in the Technology Readiness Level Assessment for the HLW Waste Vitrification Facility

Name	Affiliation	Systems Evaluated			
		HLW Melter Feed Process System (HFP)	**HLW Melter System (HMP)**	**HLW Melter Offgas Treatment Process System/Process Vessel Vent Exhaust System (HOP/PVV)**	**Pulse Jet Mixer (PJM) System/ Radioactive Liquid Waste System (RLD)**
Assessment Team					
Alexander, Don	DOE/ORP	X	X	X	X
Babel, Carol	DOE/ORP	X	X		
Holton, Langdon	ORP-PNNL	X	X	X	X
Sutter, Herb	DOE EM Consultant	X	X	X	X
Young, Joan	ORP-PNNL	X	X	X	X
WTP Project Technology and Engineering					
Damerow, Fred	WGI-Process Technology	X	X	X	X
Hall, Mark	BNI-Melter Process Technology		X		
Perez, Joseph	WGI-Melter Process Technology	X			
Peters, Richard	BNI-Melter Process Engineering		X		
Petkus, Lawrence	WGI-Process Technology	X	X	X	
Rouse, Jim	BNI-HLW Process Engineering	X		X	X

Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Pretreatment Facility

L. Holton
D. Alexander
M. Johnson
H. Sutter

August 2007

Prepared by the
U.S. Department of Energy
Office of River Protection
Richland, Washington, 99352

07-DESIGN-047

Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Pretreatment Facilities

L. Holton
D. Alexander
M. Johnson
H. Sutter

August 2007

Prepared by the
U.S. Department of Energy
Office of River Protection
under Contract DE-AC05-76RL01830

Summary

The U.S. Department of Energy (DOE), Office of River Protection (ORP) and the DOE Office of Environmental Management (EM), Office of Project Recovery has completed a Technology Readiness Assessment (TRA) for the Hanford Waste Treatment and Immobilization Plant (WTP) Pretreatment (PT) Facility. The purpose of this assessment was to determine if the maturity of critical technology elements (CTE) in the PT Facility is sufficient for these CTEs to be incorporated into the final design of this facility.

The methodology used for this TRA was based upon detailed guidance for conducting TRAs contained in the Department of Defense (DoD), *Technology Readiness Assessment Deskbook*[1]. The assessment utilized a slightly modified version of the Technology Readiness Level (TRL) Calculator[2] originally developed by Nolte et al. (2003) to determine the TRL for the CTEs. See Section 1.1, Table 1.1 for a discussion on the TRL scale used.

The TRA consisted of three parts:

1. Identifying the CTEs
2. Assessing the TRLs of each CTE using the technical readiness scale used by DoD and the National Aeronautics and Space Administration (NASA) and adapted by the Assessment Team for use by DOE
3. Evaluating, if required, technology testing or engineering work necessary to bring immature technologies to appropriate maturity levels.

CTEs are those technologies that are essential to successful operation of the facility, and are new or are being applied in new or novel ways or environments. The CTE identification process was based upon the definition of WTP systems, and 33 systems were considered from the PT Facility. A determination of the CTEs is presented in Appendix A. The nine PT Facility systems identified as CTEs are:

- Cesium Nitric Acid Recovery Process System (CNP)
- Cesium Ion Exchange Process System (CXP)
- Waste Feed Evaporation Process System (FEP)
- Treated LAW Evaporation Process System (TLP)
- Ultrafiltration Process System (UFP)
- Pulse Jet Mixer (PJM) system
- Waste Feed Receipt Process System (FRP)
- HLW Lag Storage and Feed Blending Process System (HLP)
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

The Assessment Team evaluated the TRL of each CTE against a scale developed for this assessment that is consistent with the scales originally developed by NASA and the DoD. The DoD and NASA normally

---

[1] DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005

[2] Nolte, William L., et al., *Technology Readiness Level Calculator*, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003

require TRL 6 for incorporation of a technology into the design process. This is done based on the recommendations of an influential report[3] by the U.S. Government Accountability Office (GAO) that examined the differences in technology transition between the DoD and private industry. It concluded that the DoD takes greater risks and attempts to transition emerging technologies at lesser degrees of maturity than private industry. The GAO also concluded that use of immature technology increased the overall program risk and recommended that the DoD adopt the use of NASA's TRLs as a means of assessing technology maturity prior to transition into final design. Based on the precedence set by the DoD, this assessment used TRL 6 as the basis for determining that a technology is sufficiently mature for incorporation into the final design.

The Assessment Team used a TRL Calculator, which is a software program, to provide a structured, consistent assessment to determine the TRL of each identified CTE. The TRL Calculator tabulates the responses to a standard set of questions addressing the hardware, software program, and manufacturability. The TRL Calculator is implemented in Microsoft Excel™ and produces a graphical display of the TRL achieved. It was adapted for this assessment by adding to and modifying the existing questions to make them more applicable to DOE waste treatment equipment and processes. The TRL Calculator is described in Appendix B. The specific responses to each of the TRL questions for each CTE evaluated in this TRA are presented in Appendix C. The CTEs were not evaluated to determine if they had matured beyond TRL 6.

The TRL for each of the nine CTEs evaluated is presented in Section 3, Table 3.1. This table presents the CTE and description; TRL rating based on the TRL scale presented in Section 1, Table 1.1; and the rationale for the TRL rating.

Based on the results of this TRA, the assessment team concluded the following:

- Cesium Nitric Acid Recovery Process System (CNP). The CNP is used for the recovery of nitric acid generated from the elution of the Cesium Ion Exchange Process System (CXP). The recovered nitric acid is recycled back to the CXP. The CNP was determined to be immature (e.g., TRL 3) due to the design concept which requires a unique process control system. The CNP has not been demonstrated by testing or analysis. The CNP concept may not be viable based on the changing process conditions (e.g., neutralization of the CNP separator product, change to resorcinol formaldehyde [RF] ion exchange [IX] resin.)
- Cesium Ion Exchange Process System (CXP). The CXP is used to recover cesium-137 from filtered low-activity waste (LAW). The CXP was determined to be mature (e.g., TRL 5) due to the advanced development of the CXP engineering concept and technology testing. The CXP can be fully matured (e.g., TRL 6) following completion of resorcinol formaldehyde testing and documentation, and testing of the ion exchange column functional requirements (e.g., resin removal, hydrogen gas venting). Redesign of vessel CXP-VSL-00001 to include mixing, chemical addition, and heating/ cooling capability is also required to effectively process solids generated from precipitation reactions in the filtered LAW.
- Waste Feed Evaporation Process System (FEP). The FEP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site and is based on extensive lab-scale and pilot-scale prototypic testing has been completed to demonstrate this technology. The FEP evaporator is a mature technology. Vessels in the FEP (FEP-VSL-00017A/17B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs

---

[3] GAO/NSIAD-99-162, *Best Practices: Better Management of Technologies can Improve Weapon System Outcomes*, U.S. Government Accountability Office, July 1999

of these vessels, and the FEP, are determined to be immature (e.g., TRL 4) until these mixing issues on the pulse jet mixers (PJM) are resolved.

- Treated LAW Evaporation Process System (TLP). The TLP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site, and is based on extensive lab-scale and pilot-scale prototypic testing that has been completed to demonstrate this technology. The TLP evaporator is a mature technology. Vessels in the TLP (TLP-VSL-00009A/9B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the TLP, are determined to be immature (e.g., TRL 4) until these mixing issues on the PJMs are resolved.
- Ultrafiltration Process System (UFP). The UFP is used to separate high-level waste (HLW) solids from liquids, and wash and leach the HLW solids to reduce their mass. The UFP is determined to be an immature technology (e.g., TRL 3) because the proposed process flowsheet has not been tested on a laboratory scale in an integrated test, and the design of the UFP process flowsheet and equipment system is still being completed. Plans are in place to test, evaluate, and select a final process flowsheet and equipment configuration to demonstrate the UFP.
- Pulse Jet Mixer (PJM) System. The PJM is a fluidic device used to mix process fluids in selected process vessels located in PT and HLW Facilities black cells. The PJM concept was based on previous applications at the Sellafield site in the United Kingdom. The PJM was determined to be immature (e.g., TRL 4) because the design requirements for the PJM technology have not been clearly and completely documented. Extensive testing has been completed to support final PJM design requirements on vessels that are anticipated to contain high solids concentrations (e.g., UFP-VSL-00002A/2B, HLP-VSL-000027A/27B, HLP-VSL-000028). No testing has been completed to support the final design of vessels anticipated to contain low solids concentrations. However, testing is planned. The Contractor has also identified vessels in which the PJM design will not meet basic mixing requirements (e.g., FRP-VSL-00002A/2B/2C/2D, HLP-VSL-00028, PWD-VSL-00044). Other vessels will not meet basic mixing requirements when 50% of the PJMs are operated as in a post-design basis event (e.g., FEP-VSL-00017A/17B, PWD-VSL-00033, PWD-VSL-00043, UFP-VSL-00001A/1B, CXP-VSL-00004, PWB-000015, PWD-VSL-000016, RDP-VSL-00002A/2B/2C, TCP-VSL-00001, TLP-VSL-00009A/9B).
- Waste Feed Receipt Process System (FRP). The FRP is used to receive low solids containing wastes (e.g., less than 3.8 wt%) from the tank farm into the PT Facility. The FRP is mixed using PJMs. The PJMs in the FRP were determined to be an immature technology (e.g., TRL 4) due to the inadequate design of the PJMs as determined by the Contractor based on engineering analysis. No testing has been completed to support the final design of vessels anticipated to contain low solids concentrations. However, testing is planned.
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD). The PWD and RLD are used to collect and manage process cycles, process line flushes, equipment flushes, and sump drains fluids in the PT. The PJMs in the PWD and RLD were determined to be an immature technology (e.g., TRL 4) due to the inadequate design of the PJMs as determined by the Contractor based on engineering analysis. No testing has been completed to support the final design of vessels anticipated to contain low solids concentrations. However, testing is planned.

Based upon the results of this assessment, the following recommendations for specific technologies are made:

Recommendation 1

Design activities associated with the CNP should be discontinued until: (1) a reassessment of the design and operational requirements for the CNP is completed; (2) the engineering specification for the CNP is revised to reflect operational conditions; and (3) the technology concept, which includes the process equipment and control system, is demonstrated through integrated prototypic testing.

> *Rationale*
>
> The design concept for the CNP evaporator has not been previously used in radioactive operations for the recovery of nitric acid, or proven by the Contractor in testing. Engineering calculations for the system design do not represent the variable feed compositions from the CXP and resultant product composition anticipated in the CNP. The CNP nitric acid product will likely require compositional adjustment to support subsequent reuse as an elution agent. The proposed continuous operation of the CNP will not accommodate this required chemical adjustment. Thus, the system as conceptualized appears to be undersized and may not support the waste treatment rate requirements of the PT Facility. This process design deficiency appears to be the result of the "Pretreatment Reconfiguration" studies that removed two CNP feed vessels and two CNP acid product vessels from the plant flowsheet.

Recommendation 2

The CNP should be functionally tested prior to installation in the black cell. The testing should include: testing with representative process feed compositions; verifying the process control system concept; verifying the ability to control and monitor the composition of the nitric acid product; demonstrating the cesium decontamination factor of 5 million; and demonstrating the ability to adequately decontaminate the demister pads using the sprays installed in the separator vessel.

> *Rationale*
>
> The CNP is not planned to be tested until cold commissioning. The CNP will be installed in a black cell and will be very difficult to modify after installation because of accessibility. Testing prior to installation will demonstrate the adequacy of the design and minimize post-installation modifications.

Recommendation 3

Prototypic equipment testing should be completed prior to continuing design of the hydrogen venting subsystem (nitrogen inerting and hydrogen gas collection piping system, and control system) for removing hydrogen and other gases from the cesium IX columns to demonstrate this design feature over the range of anticipated operating conditions.

> *Rationale*
>
> Integrated testing of all CXP technology components has not been completed. Major components not tested include the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns, and the capability to remove 99% by volume of the spherical RF resin from a prototypic IX column. The hydrogen venting system is a first-of-a-kind engineered design that is essential to safe operations of the CXP. Without proper functioning of this system, the CXP may not meet its required waste treatment rate performance objectives.

Alternatively, the project should consider re-designing (and testing) the hydrogen venting subsystem for the IX columns in order to simplify the system. For example, a small recycle stream from the IX columns to the feed vessel (CXP-VSL-00001) could be used to vent gases from the columns. The recycle stream could be controlled through the use of orifice plates and stop valves for isolation.

Recommendation 4

The adequacy of the design concept for CXP-VSL-00001 should be reevaluated and a determination made if this vessel should be modified to include mixing, chemical addition, and heating/cooling to mitigate anticipated process flowsheet issues with precipitation of solids in the CXP feeds.

Rationale

Bechtel National, Inc. engineering studies conducted in 2005 and 2007 indicate that precipitation of sodium oxalate and gibbsite solids will occur following filtration. The capability of the CXP to effectively treat feeds that contain freshly precipitated sodium oxalate and gibbsite solids is not known. Understanding of the dissolution and precipitation kinetics for sodium oxalate and gibbsite is lacking. The morphology of freshly precipitated sodium oxalate is not completely understood. The CXP-VSL-00001 has no capability for blending solutions or suspending solids. Flowsheet modeling indicates that solids are likely to precipitate if chemical adjustments are not made to the vessel. The CXP-VSL-00001 has no capability for chemical adjustments to reduce/mitigate the solids concentration in cesium IX feed or dissolve/remove solids. It is not clear that the CXP-VSL-00001 vessel design is adequate to perform its required function and support the waste treatment capacity requirements of the PT Facility.

Recommendation 5

Development and testing at a laboratory-scale with actual wastes, and at an engineering-scale with simulants, should be completed in prototypical process and equipment testing systems to demonstrate all detailed flowsheets for the UFP prior to final design. The testing should validate the scaling methodology for mixing, chemical reactions, and filter surface area sizing; determination of process limits; and recovery from off-normal operating events.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-12, "Undemonstrated Leaching Process," and WTP Baseline testing of the Oxidative Leaching Process.

Rationale

Previous DOE evaluations (D-03-DESIGN-05) have been completed on the adequacy of the UFP process chemistry and ultrafilter sizing. This assessment concluded that the WTP flowsheet was not adding sufficient sodium hydroxide to support the dissolution of aluminum in the HLW sludge and the ultrafilter surface area was undersized by a factor of about 2.6. Partial planning is in place by the Contractor to conduct technology testing to provide the technical basis for the ultrafiltration flowsheet and equipment design.

Recommendation 6

Evaluation of a vertical modular equipment arrangement for the UFP filter elements for increasing the filter surface area should be continued. The design configuration (currently proposed horizontal or vertical orientation of the filters) that has the highest probability of successfully achieving performance requirements should be thoroughly tested in high fidelity, prototypical engineering-scale tests using simulants that represent a range of tank waste compositions. Testing scope should include all filtration system operations, process flowsheets (caustic and oxidative leaching and strontium/transuranic precipitation), high-temperature filtration, and filter back pulsing, cleaning, draining, and replacement. Based on the results of this testing, a design concept (either the horizontal arrangement proposed by the Contractor or the vertical arrangement conceptualized by Energy*Solutions*) should be selected for final design.

Rationale

A review and assessment of a proposed modified ultrafiltration system design was conducted by the Contractor. This design concept was based on deploying five filter elements (two 10 ft sections and three 8 ft sections) in a nominally horizontal arrangement as a single fabricated unit. The expert review team advised that:

- The proposed new arrangement for the ultrafilter with five modules connected in series may not provide sufficient drainage, and may cause problems with residual slurry solids buildup in the lower tubes of each module.
- The need to remove and discard a complete five-module filter system because of a blockage or partial blockage, and its replacement with a new unit, may be both lengthy and costly.
- An alternate vertical arrangement of filter modules was strongly recommended by the reviewers. Such an arrangement would trap residual solids within the tubes themselves and have the potential to allow the removal of individual modules or tube bundles.

Recommendation 7

Clear, quantitative, and documented mixing performance requirements for all PJM mixed vessels in the PT Facility and HLW Vitrification Facility should be established. The requirements should be established for all vessel systems even though only those associated with FRP, HLP, PWD, TLP, and FEP were discussed in this assessment.

These requirements should include requirements from criticality safety, environmental compliance, hydrogen management and mitigation, process control, process operations, and immobilized low-activity waste and immobilized high-activity waste form production. These requirements should be used to assess the adequacy of the design and operation of each of the PJM mixed vessels and provide a basis for the completion of the planned testing work on PJMs planned as part of Issue Response Plan M-3, “Inadequate Mixing System Design.” These requirements should be established jointly with project personnel representing safety, environmental compliance, and process operations, with DOE as owner and operator of the WTP.

Rationale

The lack of requirements for mixing performance of each PJM mixed vessels does not provide a basis for:

- The Contractor’s mixing design for the vessels and PJMs.
- DOE’s assessment, as owner and operator of the WTP, of the adequacy of the WTP to achieve safety and operational requirements.
- The Contractor’s planning and conduct of a technology testing program to generate PJM mixing test information to support design decisions (see Recommendation 8).

Recommendation 8

PJM demonstration testing should be completed. The testing information, supplemented with analysis, should be used to determine the design capability of each PJM mixed vessel and identify any required design changes.

> *Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-3, "Inadequate Mixing System Design."*
>
> Rationale
>
> The Contractor has developed a testing program on the PJMs to assess the adequacy of the design and operation of each of the PJM mixed vessels.

The following supporting recommendations are made by the Assessment Team. These recommendations supplement the major recommendations presented in the previous section.

1. The specific gravity operating limit for controlling the concentrated cesium eluate in the CNP separator to a maximum of 80% saturation should be re-evaluated. Based on the WTP Contractor's plan to neutralize cesium concentrate in the separator, and thereby create solids, this operating constraint may not be required.
2. The engineering specification for the CNP should be modified to include (1) the estimated variable feed composition and (2) factory acceptance testing to demonstrate removal and installation of the demister pads from the separator vessel.
3. The Contractor should reassess the corrosion evaluations for the CNP vessels and piping based on the operating conditions of the system.
4. Testing of spherical RF resin should be conducted to: (1) assess physical degradation for irradiated resin samples; (2) assess effects from anti-foaming agent and separate organics present in the feed to the CXP; and (3) assess the impact of particulates on IX column performance.
5. All currently planned testing and documentation of test results for spherical RF resin should be completed. (*Note: This planned work is in the WTP Baseline.*)
6. Additional research should be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate.
7. The engineering specification for the IX columns should be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the External Flowsheet Review Team recommendations for the CXP.
8. The engineering specification for the CXP should be modified to include factory acceptance testing of the IX column to demonstrate that the system is capable of removing greater than 99% by volume of resin from the IX column, upon completion of the resin removal mode, using a maximum volume of 7,500 gallons of water to displace the resin.
9. The strategy and method to scale the ultrafiltration processes (mixing, chemical reaction, and filter surface area) to predict performance of the ultrafiltration system should be established to ensure a high-fidelity UFP engineering-scale test platform and support useful interpretation of the testing results.

10. Process modeling to project the performance of the WTP and confirm design capability should use realistic assumptions on the effectiveness of mixing (both time and efficiency of mixing).

11. An evaluation of the fluids to be received and mixed in the feed receipt vessels (FRP-VSL-00002A/ B/C/D) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

12. An evaluation of the fluids to be received and mixed in the HLW feed receipt vessel (HLP-VSL-00022) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

Acknowledgement

The Assessment Team wishes to thank Mr. William Nolte of the Air Force Research Laboratory for consultation, guidance, and direct support in the application of the NASA and DoD Technology Readiness Level (TRL) process to DOE's first use of this process to the Waste Treatment and Immobilization Plant (WTP). Mr. Nolte also provided, and supported, the Assessment Team in the adaptation of a TRL Calculator that he authored, ensuring consistency between the NASA, DoD, and DOE applications of the TRL Assessment process.

The Assessment Team also acknowledges the excellent support and editorial inputs of Ms. Laurie Kraemer, Project Assistance Corporation, in preparing this Technology Readiness Assessment. Ms. Kraemer was able to transform the Assessment Team's input into a professionally prepared document.

Contents

Figures

Tables

Acronyms and Abbreviations

Al	aluminum
APEL	Applied Process Engineering Laboratory
BNFL	British Nuclear Fuels Limited, Inc.
BNI	Bechtel National, Inc.
BV	bed volume
Ca	calcium
CBT	cone-bottom tank
CFD	Computational Fluid Dynamic
CNP	Cesium Nitric Acid Recovery Process System
Cr	chromium
CRP	Cesium Resin Addition Process System
CRV	concentrate receipt vessel
Cs	cesium
CTE	critical technology element
CUF	cells unit filter
CXP	Cesium Ion Exchange Process System
DBE	design basis event
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EARP	Enhanced Actinide Removal Plant
EFRT	External Flowsheet Review Team
EM	Office of Environmental Management
ESP	Environmental Simulation Program
ETF	Effluent Treatment Facility
FEP	Waste Feed Evaporation Process System
FRP	Waste Feed Receipt Process System
GAO	U.S. Government Accountability Office
GR&R	gas retention and release
HLP	HLW Lag Storage and Feed Blending Process System
HLW	High-Level Waste [Facility]
HNO_3	nitric acid
ID	inner diameter
ILAW	immobilized low-activity waste
IRP	Issue Response Plan
IX	ion exchange
K	potassium
LAW	Low Activity Waste [Facility]
LERF	Liquid Effluent Retention Facility
LS	Large-Scale
MnO_4	permanganate
Na	sodium
$NaMnO_4$	sodium permanganate
$NaNO_3$	sodium nitrate
NaOH	sodium hydroxide
NAS	sodium alumino-silicate
NASA	National Aeronautics and Space Administration
NO_3	nitrate
NPH	normal paraffin hydrocarbon

OD	outer diameter
OH	hydroxide
ORP	Office of River Protection
PJM	pulse jet mixer
PNWD	Pacific Northwest Division
PT	Pretreatment [Facility]
Pu	plutonium
PUREX	Plutonium-Uranium Extraction (Plant)
PWD	Plant Wash and Disposal System
RDP	Spent Resin Collection/Dewatering Process System
RF	resorcinol formaldehyde
RLD	Radioactive Liquid Waste Disposal System
SBS	submerged bed scrubber
SIPP	Semi-Integrated Pilot Plant
Sr	strontium
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SS-PJM	small-scale-pulsed jet mixer
TBP	tri-butyl phosphate
TCP	Treated LAW Concentrate Storage Process System
TFC	Tank Farm Contractor
TLP	Treated LAW Evaporation Process System
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TRU	transuranic
U	uranium
UFP	Ultrafiltration Process System
UKAEA	United Kingdom Atomic Energy Agency
WTP	Waste Treatment and Immobilization Plant
ZOI	zone of influence

Units of Measure

acfm	actual cubic feet per minute
bar	metric unit of atmospheric pressure [barometric]
cP	centipoise
ft	foot
ft^2	square foot
g	gram
gpm	gallons per minute
Kgal	thousand gallon
L	liter
m	meter
m^2	square meter
m^3	cubic meter
ml	milliliter
M	molar
Mgal	million gallon
MT	metric ton
Pa	pascal
ppm	parts per million
psi	pounds per square inch
psia	means pound per square inch *absolute*
psig	pounds per square inch gauge
sec	second
vol%	volume percentage
wt%	weight percentage

Glossary

Critical Technology Element	A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel. Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.
Engineering-Scale	A system that is greater than 1/10 of the size of the final application, but it is still less than the scale of the final application.
Full-Scale	The scale for technology testing or demonstration that matches the scale of the final application.
Identical System	Configuration that matches the final application in all respects.
Laboratory-Scale	A system that is a small laboratory model (less than 1/10 of the size of the full-size system.
Model	A functional form of a system generally reduced in scale, near or at operational specification.
Off-Bottom Suspension	A condition in which the solids that settle to the bottom of the vessel in the suction phase are re-suspended in the drive phase.
Operational Environment (Limited Range)	A real environment that simulates some of the operational requirements and specifications required of the final system (e.g., limited range of actual waste).
Operational Environment (Full Range)	Environment that simulates the operational requirements and specifications required of the final system (e.g., full range of actual waste).
Paper System	System that exists on paper (no hardware).
Pieces System	System that matches a piece or pieces of the final application.
Pilot-Scale	The size of a system between the small laboratory model size (bench-scale) and a full-size system.
Prototype	A physical or virtual model that represents the final application in almost all respects that is used to evaluate the technical or manufacturing feasibility or utility of a particular technology or process, concept, end item, or system.
Relevant Environment	Testing environment that simulates the key aspects of the operational environment; e.g., range of simulants plus limited range of actual waste.
Similar System	Configuration that matches the final application in almost all respects.
Simulated Operational Environment	Environment that uses a range of waste simulants for testing of a virtual prototype.
50/50	Designation of the percentage of the number of pulse jet mixers that will be in operation at any one time following a design basis event for selected vessels. This currently applies to the vessels that contain low solid concentrations (e.g., below 16.7 wt% solids).

1.0 Introduction

1.1 Background

The U.S. Department of Energy (DOE), Office of River Protection (ORP) is constructing a Waste Treatment and Immobilization Plant (WTP) for the treatment and vitrification of the underground tank wastes stored at the Hanford Site in Washington State. The WTP Project is comprised of four major facilities: a Pretreatment (PT) Facility to separate the tank waste into high-level waste (HLW) and low-activity waste (LAW) process streams; a HLW Vitrification Facility to immobilize the HLW fraction; a LAW Vitrification Facility to immobilize the LAW fraction; and an Analytical Laboratory to support the operations of all four treatment facilities. Additionally, there are the Balance of Facilities operations that provide utilities and other support to the processing facilities. The WTP Project is DOE's largest capital construction project with an estimated cost of $12.263 billion, and a project completion date of November 2019 (DOE 2006).

Issues associated with the maturity of technology in the WTP have been evaluated by independent DOE Review Teams and in DOE's design oversight process. The most notable evaluation was the recently completed "Comprehensive External Review of the Hanford Waste Treatment Plant Flowsheet and Throughput" (CCN:132846) completed in March 2006. This evaluation identified 28 separate technical issues, some of which had not been previously identified by the WTP Contractor (Bechtel National Inc. [BNI]) or DOE. A number of these issues originated from limited understanding of the technologies that comprise the WTP flowsheet.

As a result of these reviews, and DOE's desire to more effectively manage the technology risks associated with the WTP, DOE decided to conduct a Technology Readiness Assessment (TRA) to assess the technical maturity of the WTP design. This TRA is patterned after guidance established by the U.S. Department of Defense (DoD) (DoD 2005) for conducting TRAs.

1.2 Assessment Objectives

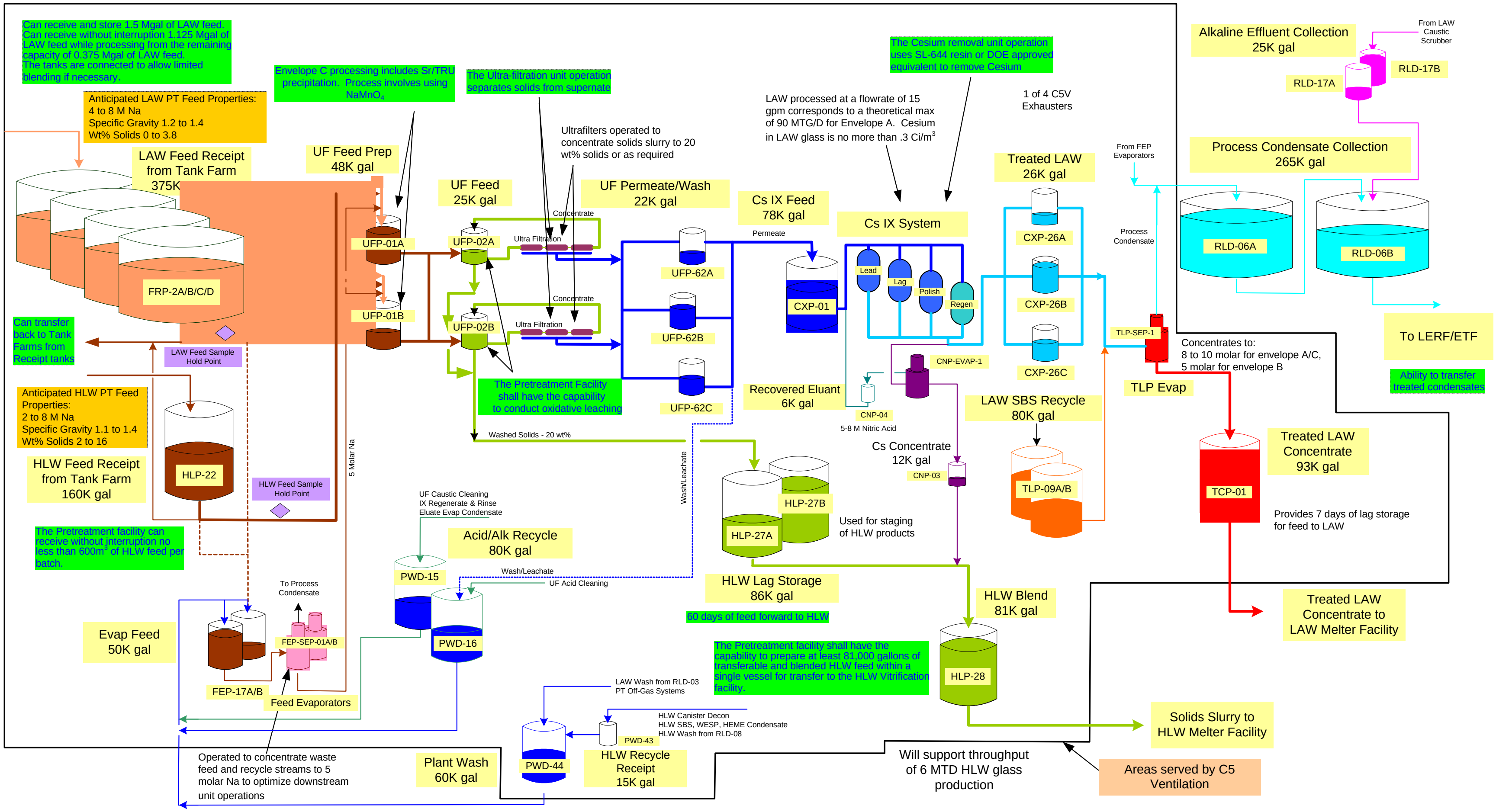
The purpose of this TRA is to evaluate the technologies used in PT Facility. This TRA:

- Identifies critical technology elements (CTE)
- Determines the TRL associated with the CTEs
- Provides recommendations on how to improve the maturity level of technologies that require additional development.

The TRA was performed jointly by DOE ORP and the DOE Office of Environmental Management (EM), Office of Project Recovery.

1.3 Pretreatment Facility Flowsheet

The PT Facility flowsheet is shown in Figure 1.1. This flowsheet provides the relationship of the systems that were evaluated in this TRA. Essentially all process systems were evaluated. The vessel batch capacities and selected process design conditions are indicated on the flowsheet. Additional detail on these systems is presented in Section 2.3.



Can receive and store 1.5 Mgal of LAW feed. Can receive without interruption 1.125 Mgal of LAW feed while processing from the remaining capacity of 0.375 Mgal of LAW feed. The tanks are connected to allow limited blending if necessary.

Envelope C processing includes Sr/TRU precipitation. Process involves using $NaMnO_4$

The Ultra-filtration unit operation separates solids from supernate

The Cesium removal unit operation uses SL-644 resin or DOE approved equivalent to remove Cesium

Can transfer back to Tank Farms from Receipt tanks

The Pretreatment Facility shall have the capability to conduct oxidative leaching

The Pretreatment facility can receive without interruption no less than 600m^3 of HLW feed per batch.

60 days of feed forward to HLW

The Pretreatment facility shall have the capability to prepare at least 81,000 gallons of transferable and blended HLW feed within a single vessel for transfer to the HLW Vitrification facility.

Ability to transfer treated condensates

Figure 1.1. WTP Pretreatment Facility Flowsheet

1.4 Description of TRA Process

1.4.1 Background

> "A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies [called Critical Technology Elements (CTEs)] used in systems." (DoD 2005)

In 1999, the U.S. General Accounting Office (GAO) produced an influential report (GAO/NSIAD-99-162) that examined the differences in technology transition between the DoD and private industry. The GAO concluded that the DoD took greater risks, and attempted to transition emerging technologies at lesser degrees of maturity compared to private industry, and that the use of immature technology increased overall program risk and led to substantial cost and schedule overruns. The GAO recommended that the DoD adopt the use of National Aeronautics and Space Administration's (NASA) Technology Readiness Levels (TRL) as a means of assessing technology maturity prior to design transition (see Appendix A for further discussion).

In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major programs. Guidance for assessing technology maturity was incorporated into the *Defense Acquisition Guidebook* (DODI 5000.2). Subsequently, the DoD developed detailed guidance for using TRLs in the 2003 *DoD Technology Readiness Assessment Deskbook* (updated in May 2005 [DOD 2005]). The DoD Milestone Decision Authority must certify to Congress that the technology has been demonstrated in a relevant environment prior to transition of weapons system technologies to design or justify any waivers. TRL 6 is also used as the level required for technology insertion into design by NASA.

Based upon historical use of the TRA process, the DOE has decided to use the DoD TRA process as a method for assessing technology readiness for the WTP.

1.4.2 TRA Process

The TRA process as defined by the DoD consists of three parts: (1) identifying the CTEs; (2) assessing the TRLs of each CTE using an established readiness scale; and (3) preparing the TRA report. As some of the CTEs were judged to be below the desired level of readiness, the TRA was followed by a Technology Maturation Plan (TMP) analysis and report that determines the additional development required to attain the desired level of readiness (see Volume I). Requirements for the TMP analysis are described in the DoD *Technology Readiness Assessment Deskbook* (May 2005) and is usually carried out by a group of experts that are independent of the project under consideration.

The CTE identification process involves breaking the project under evaluation into its component systems and subsystems, and determining which of these are essential to project success and either represent new technologies, combinations of existing technologies in new or novel ways, or will be used in a new environment. Appendix B describes the CTE process in detail.

The TRL scale used in this assessment is shown in Table 1.1. The scale is based on the DoD and NASA scales. Minor modifications have been made to reflect the chemical processing nature of the WTP. The scale requires that testing of a prototypical design in a relevant environment be completed prior to incorporation of the technology into the final design of the facility.

Table 1.1. Technology Readiness Levels used in this Assessment

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full-scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in a relevant environment.	Representative engineering-scale model or prototype system, which is well beyond the lab-scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory-scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

The testing requirements used in this assessment are compared to the TRLs in Table 1.2.
These definitions provide a convenient means to understand further the relationship between the scale of testing, fidelity of testing system, and testing environment and the TRL. This scale requires that for a TRL 6, testing must be completed at an engineering- or pilot-scale, with a testing system fidelity that is similar to the actual application and with a range of simulated wastes and/or limited range of actual waste, if applicable.

The assessment of the TRLs was aided by a TRL Calculator that was originally developed by the U.S. Air Force (Nolte et al. 2003), and modified by the Assessment Team. This tool is a standard set of questions addressing hardware, software, program, and manufacturability questions that is implemented in Microsoft Excel™. The TRL Calculator produces a graphical display of the TRLs achieved. The TRL Calculator used in this assessment is described in more detail in Appendix B.

Table 1.2. Relationship of Testing Requirements to the TRL

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full-Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot-Scale < Full-Scale (Typical)
   Lab-Scale < 1/10 Full-Scale (Typical)

2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)

3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

2.0 TRL Assessment

2.1 TRL Process Description

An Assessment Team comprised of staff from the DOE ORP, technical consultants to ORP, and DOE EM's Office of Project Recovery completed the TRL assessment with support from the WTP engineering staff (see Appendix D for the identification of the Assessment Team and supporting contractor staff from the WTP). Assessment Team staff have worked on the Hanford WTP project and related nuclear waste treatment and immobilization technologies for more than 30 years, and are independent of the WTP design and construction project.

The WTP engineering staff (e.g., WTP Project Team) presented descriptions of the WTP systems that were assessed, participated in the identification of the CTEs, and participated in the completion of responses to individual questions in the TRL Calculator. Each response to a specific Calculator question was recorded along with references to the appropriate WTP Project documents. The Assessment Team also completed independent due-diligence reviews and evaluation of the testing and design information to validate input obtained in the Assessment Team and WTP Project Team working sessions. The Calculator results for each CTE can be found in Appendix C.

This Assessment Team evaluated the process and mechanical systems that are planned for use in the WTP PT Facility. This assessment was focused on the adequacy of the equipment technologies that comprise the design. A detailed assessment of the process flowsheet chemistry was not completed as part of this assessment. The Assessment Team did not evaluate the software systems used to control the process and mechanical equipment because these software systems have not been sufficiently developed and are not critical to the mechanical design of the facilities. The assessment of the technology readiness of the software systems will be completed at a later date.

2.2 Determination of CTEs

The process for identification of the CTEs for the PT Facility involved two steps:

1. An initial screening by the Assessment Team of the complete list of systems in the PT Facility for those that have a potential to be a CTE. In this assessment, systems that are directly involved in the processing of the tank waste or and secondary wastes were initially identified as potential CTEs. The complete list of systems and those identified as potential CTEs are provided in Appendix A, Tables A.1.
2. A final screening of the potential CTEs was completed by the Assessment and WTP Project Teams to determine the final set of CTEs for evaluation. The potential CTEs were evaluated against the two sets of questions presented in Table 2.1. A system is determined to be a CTE if a positive response is provided to at least one of the questions in each of the two sets of questions.

Table 2.1. Questions used to Determine the CTEs for the Pretreatment Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

The specific responses to each of the questions for each CTE are provided in Table B.5 of Appendix B. In this final assessment, the following systems were identified as CTEs:

- Cesium Nitric Acid Recovery Process System (CNP)
- Cesium Ion Exchange Process System (CXP)
- Ultrafiltration Process System (UFP)
- Treated LAW Evaporation Process System (TLP)
- Waste Feed Evaporation Process System (FEP)
- Pulse Jet Mixer (PJM) system
- Waste Feed Receipt Process System (FRP)
- HLW Lag Storage and Feed Blending Process System (HLP)
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

2.3 Summary of the Technology Readiness Assessment

A TRL assessment was completed for each CTE, and the results are summarized in this section.

The Calculator (Appendix B) employs a two-step process to evaluate TRLs:

1. A top-level set of questions is evaluated to determine the starting point, in terms of readiness level, for the TRL assessment.
2. A more detailed assessment was completed using a series of detailed questions starting at a TRL level one level below the expected outcome. The responses to the TRL criteria are provided in Appendix C for the highest level evaluated for each CTE.

For each CTE, the discussions below describe the CTE function, CTE description, the relationship to other CTEs, the development history and status, the relevant environment, a comparison of the demonstrated and relevant environments, and the rationale for the TRL determination and any recommendations.

2.3.1 Cesium Nitric Acid Recovery Process System (CNP)

2.3.1.1 Function of the CNP

The primary functions of the CNP are to: receive eluate from the Cesium Ion Exchange Process System (CXP); concentrate the eluate; transfer eluate concentrate to the HLW Lag Storage and Feed Blending Process System (HLP); and recover the evaporator overheads stream as nitric acid (HNO_3) eluent for reuse in the CXP.

2.3.1.2 Description of the CNP

The CNP is described in the *System Description for the Pretreatment Facility Cs Nitric Acid Recovery Process (CNP) System* (24590-PTF-3YD-CNP-00001). A block flow diagram of the CNP is provided in Figure 2.1.

Cesium (Cs) eluate and rinse water are sent from the Cs ion exchange (IX) process on a periodic basis to the Cs evaporator breakpot (CNPBRKPT-00002). The eluate received from the IX column is, on average, more dilute than the 0.5 M HNO_3 used for elution. In addition, the concentration of nitric acid will vary throughout the elution cycle starting with a more dilute concentration, reaching a maximum concentration, and ending with a more dilute concentration. This occurs because hydrogen ions are exchanged with eluted cations (aluminum [Al], calcium [Ca], Cs, potassium [K], sodium [Na], etc.) on the IX resin during the elution process and because some wash water (used for displacing residual caustic and nitric acid from the IX column) will precede and follow the eluate transfers to the evaporator. The breakpot may also receive infrequent transfers of eluate or concentrate from the eluate contingency storage vessel, CNP-VSL-00003.

The breakpot gravity feeds down to the Cs evaporator eluate lute pot, CNP-VSL-00001, which provides a vacuum seal between the breakpot and the Cs evaporator separator vessel, CNP-EVAP-00001. The separator vessel is initially charged with nominally 7.2 M HNO_3 (a range of 5 M to 8 M HNO_3 can be used). Cs eluate is fed at 6.9 to 10 gpm into the separator vessel and evaporated, leaving the salts contained in the eluate to concentrate in the separator vessel. The Cs evaporator concentrate reboiler, CNP-HX-00001, provides the heat transfer area required to transfer adequate heat to the process fluid to evaporate eluate at the same rate it is received in the separator vessel. The separator vessel contains built-in demister pads to remove aerosols formed during evaporation. The Cs evaporator separator vessel operates under vacuum at approximately 40 inches water (H_2O) absolute to reduce the boiling temperature of the liquor to approximately 122° to 140°F.

The CXP/CNP will operate at constant flow rates during elution/evaporation modes. The system is designed to operate from a flow rate of 6.9 to 10 gpm, but during the actual processing the flow rate is maintained constant, thus the evaporation rate/duty is constant throughout an IX column elution. There will be variation in the feed stream as far as the nitric acid concentration received in the evaporator; however, this is buffered first by the charge in the evaporator, and secondly by the large volume of 0.5 M nitric acid in CNP-VSL-00004. The system is controlled to recover nitric acid at 0.5 M, and a variation in the operating pressure allows for manipulation of the vapor equilibrium curve to obtain the desired concentration. In the event that adjustment to the nitric acid concentration is required, fresh nitric or water may be added to CNP-VSL-00004 at any time, and CNP-VSL-00004 may be discharged at anytime as long as a heel is maintained to provide the hydraulic seal necessary for the evaporator vacuum.

The system as designed will provide an unlimited elution supply, as the evaporator recovers nitric acid at the same rate the IX column is eluted. In the event that the evaporator is unavailable and the 6200 gallons is not adequate, fresh nitric acid from BOF may be supplied, and the eluate is sent to CNP-VSL-00003.

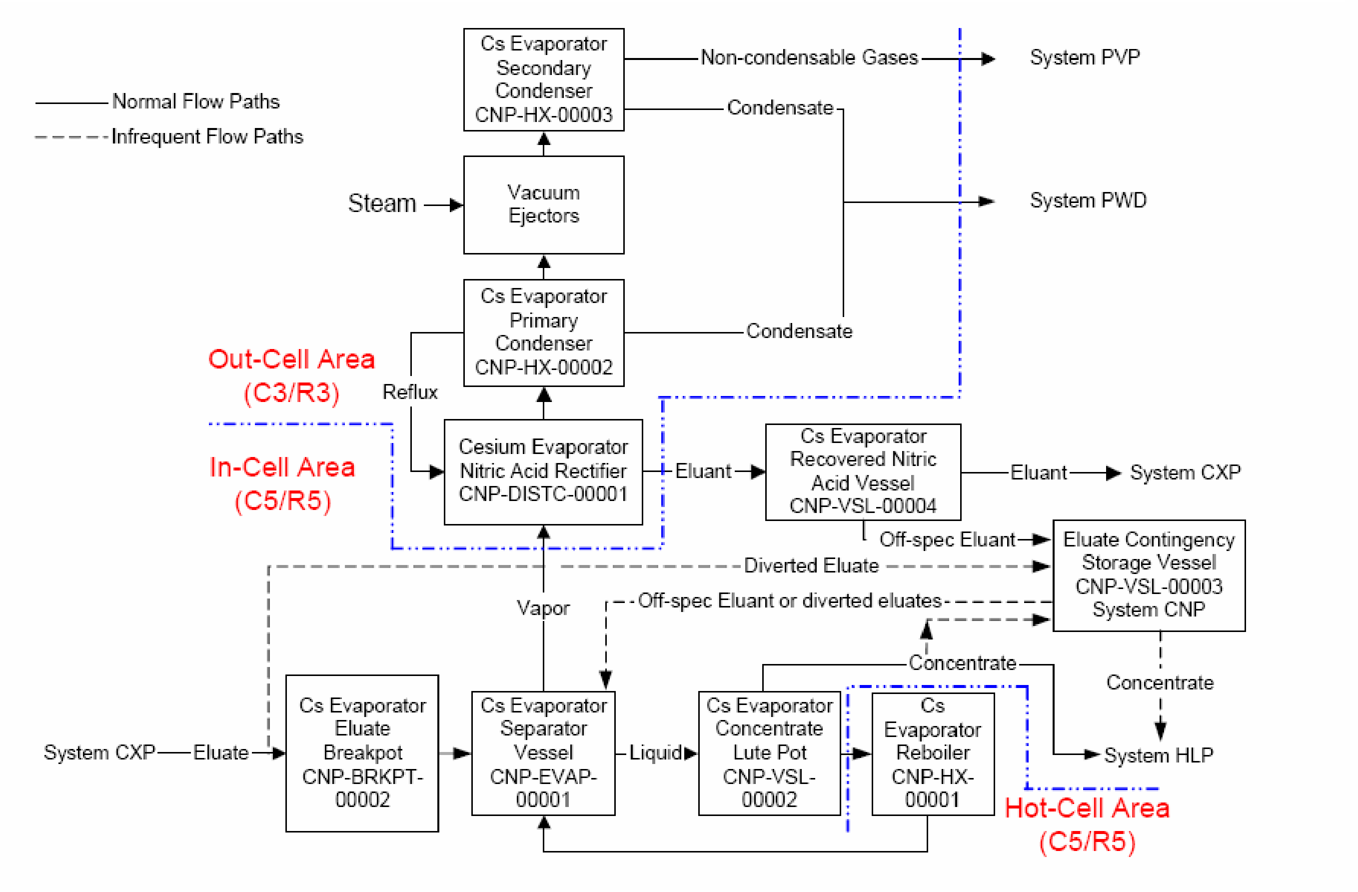


Figure 2.1. Block Flow Diagram for the Cesium Nitric Acid Recovery Process System

The following is a summary of the approach to be taken for operation and control of the CNP to continuously provide elution acid at or near 0.5 M nitric acid for elution of the IX columns:

- CNP-VSL-00004 is the elution acid feed vessel. This 10,000-gallon vessel (6,300 gallon batch volume) may be adjusted to 0.5 M by addition of 2 M HNO_3 after each elution cycle. The acid adjustment is confirmed by sampling the vessel contents. This would ensure that the correct acid strength is used at the start of each elution cycle. If required adjustments may be made after each elution cycle; however, the elution of an IX column may be successfully done with a range of acid concentrations (WTP-RPT-143, Rev 1) and operation of the CNP will allow for a range of concentration for efficient operations.
- At the beginning of the elution cycle, the column effluent is displaced rinse water and for the first 5 to 6 bed volumes there will be no acid fed to the CNP evaporator because the H^+ ions are loading on the resin as the sodium, Cs, and other cations are displaced (24590-101-TSA-W000-00004-99-00013 Rev. 00B; WTP-RPT-143, pg. 11.15).
- The elution column effluent is fed directly to the evaporator at 7 to 10 gpm and the concentration of the acid that is recovered in the acid recovery tower (CNP-DISTC-00001) is controlled as follows:
  - The evaporator is charged with about 1,800 gallons of 5 to 8 M HNO_3

- For every bottoms acid concentration, there will be a corresponding vapor acid concentration at the boiling point at constant pressure. This well-known equilibrium data is readily available and will be used to aid in control of the process. The equilibrium curve shifts as the evaporator pressure is changed and the equilibrium values can be derived for each pressure, giving a series of curves that relate the known bottoms concentration to the vapor concentration. Based on modeling, the overheads product will remain at a constant average for each concentration cycle, as the salts in the evaporator increase, the acid concentration decreases. However, the overheads product remains nearly constant at a set operating pressure.
- By changing the evaporator operating pressure, the acid concentration in the vapor can be controlled over a range for any given bottoms concentration.
- By vendor calculation 24590-QL-POA-MEVV-00002, *Hanford Evaporator Project #2-Evaporator Mass and Energy Balance Calculation*, pg. 7), CNP-DISTC-00001 will conservatively recover 98.5% of the acid from the vapor fed to the bottom of the tower.
- The recovered acid stream flows through a conductivity cell enroute to CNP-VSL-00004. This provides a continuous check on the recovered acid concentration. Earlier lab tests performed at Savannah River Site (SRS) showed the validity of using conductivity measurement to determine the nitric acid concentration around 0.5 M (WSRC-TR-2003-00135, Rev. 0, pg. 24).
- If the conductivity indicates low acid in the recovered acid stream, the evaporator operating pressure can be changed to shift the equilibrium in favor of recovering more acid. In this way, the recovered acid concentration can be maintained at or very near to 0.5 M. Modeling of the system indicates that minimal control will be required if initial conditions are set and maintained.
- In the event the evaporator pressure cannot be changed sufficiently and the recovered acid concentration drops slightly below 0.5 M, the acid routed to the IX column will still be near 0.5 M for more than the first 5 to 6 bed volumes due to the small dilution of the initial 6,000 to 8,000 gallons of 0.5 M acid in CNP-VSL-00004.
- As the salt content of the evaporator bottoms increases from elution to elution, the vapor/liquid equilibrium will be affected by the non-volatile solute and this will be taken into consideration along with the pressure variation.

Several batches of Cs eluate (up 10 to 13) are concentrated until the dissolved salt concentration reaches 80% of saturation when cooled to 25°C. Alternatively, the concentrate can be transferred to the HLP after each eluent recovery and concentration operation in smaller batches if required. The Cs concentrate is extracted from the Cs evaporator separator vessel by gravity feeding to the eluate lute pot, CNP-VSL-00002, where transfer ejectors send it to vessels HLP-VSL-00028 or HLP-VSL-00027B. If the HLP cannot accept additional volume at the time of a required transfer, vessel CNP VSL-00003 (batch capacity of 12,500 gallons) will receive the transfer. When the evaporator is shut down, purge air will be used to dilute any evolved hydrogen to maintain a concentration below the lower flammability limit.

The vapor leaving the Cs evaporator separator vessel contains water and nitric acid and entrained salts. The salts (including Cs, K, Ca, Na, Al, and nitrate [NO_3]) dissolved in the feed are non-volatile at the Cs evaporator separator vessel operating conditions and accumulate in the bottom of the Cs evaporator separator vessel. Passing the vapor stream from the Cs evaporator separator vessel and demister, through the Cs evaporator nitric acid rectifier (CNP-DISTC-00001) increases the concentration of the recovered acid. The column operates with a high top reflux flow from the Cs evaporator primary condenser (CNP-HX-00002). Recovered acid flows from the bottom of the rectifier to the Cs evaporator recovered nitric acid vessel, CNP-VSL-00004. A conductivity probe is used to monitor the nitric acid concentration in the rectifier bottoms (i.e., recovered nitric acid solution). The recovered nitric acid collected in vessel

CNP-VSL-00004 can be sampled; this vessel is not equipped with a conductivity probe for real-time monitoring of recovered nitric acid solution acidity.

The rectifier bottoms product is predicted to be nominally 0.5 M HNO_3, and the overheads product is water (H_2O). The rectifier will have the ability to reflux 100% of the vapor received from the Cs evaporator separator vessel back to the Cs evaporator separator vessel. This allows for continuous operation of the evaporator system in a standby state when eluate is not being fed to the Cs evaporator separator vessel. This minimizes the startup and shutdown of the system when elution of a Cs IX column is not required. The rectifier is also under vacuum conditions, being coupled with the Cs evaporator separator vessel and condensers, and is sealed by a barometric leg down to the Cs evaporator recovered nitric acid vessel (CNP-VSL-00004), which has a batch capacity of 6,200 gallons.

2.3.1.3 Relationship to Other Systems

Cs eluate is transferred from the Cs IX column (CXP-IXC-00001, -00002, -00003, or -00004) to the Cs evaporator breakpot (CNPBRKPT-00002).

Recovered nitric acid eluent is transferred from the Cs evaporator recovered nitric acid vessel (CNP-VSL-00004) to the Cs IX reagent vessel (CXP-VSL-00005).

The Cs evaporator separator vessel is operated at reduced pressure to lower the boiling temperature of the liquids. The system uses a two-stage steam ejector system to create reduced pressure in the separator vessel. Exhaust vapors from the ejectors are condensed in the Cs evaporator secondary condensers (CNP-HX-00003 and CNP HX-00004) prior to venting to the ventilation system scrubbing equipment. Process condensate from the Cs evaporator primary condenser and Cs evaporator secondary condenser drains to the acidic/alkaline effluent vessels, PWD-VSL-00015 and PWD-VSL-00016, located in the PWD.

Concentrated Cs eluate solution is transferred from the Cs evaporator separator vessel (CNP-EVAP-00001) to the HLW blend vessel (HLP-VSL-00028 or HLP-VSL-00027B) via a breakpot. During discussions with WTP Engineering staff, it was noted that the Cs concentrate would be neutralized prior to transfer to the HLP.

2.3.1.4 Development History and Status

The WTP Project has conducted laboratory-scale testing to characterize actual Cs eluate solutions, prepare simulants, and conduct vacuum evaporation of simulated Cs eluate solutions. The physical and chemical properties of the Cs eluate and concentrate solutions are understood based on laboratory-scale experiments and analytical models having been developed to predict physical properties of these solutions (SCT-M0SRLE60-00-183-02). The actual Cs eluate solutions were derived from laboratory-scale IX column testing using SuperLig® 644 resin. The project has subsequently decided to use spherical resorcinol formaldehyde (RF) resin in the CXP.

The laboratory-scale components tested were surrogates for the following system components: reboiler (CNP-HX-0001), separator vessel and demister pads (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004). However, the laboratory-scale components tested did not include a surrogate for the acid rectifier column (CNP-DISTC-00001) present in the CNP (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).

2.3.1.5 Relevant Environment

The relevant environment for the CNP, as identified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001), the *System Description for the Pretreatment Facility Cs Nitric Acid Recovery Process (CNP) System* (24590-PTF-3YD-CNP-00001), and as modified by the *Engineering Specification for Cesium Nitric Acid Recovery Forced Circulation Vacuum Evaporator System* (24590-PTF-3PS-MEVV-T0002, Rev. 4), is:

- The system shall concentrate Cs eluate and post-elution rinse solutions from the CXP at operating pressure of approximately 0.10 bar (1.5 psia) results in an operating temperature of 50°C to 55°C.
- The system shall operate batchwise continuously with a non-constant feed rate of 6.9 to 10 gpm at 25°C.
- The system shall produce a vapor with condensed acid concentration of approximately 0.5 M HNO_3.
- The system shall maintain a constant volume of 0.5 M HNO_3 solution, with excess nitric acid and water purged from the system.
- At steady state operation, the concentration of Cs in the evaporator bottoms shall be at least 5,000,000 times greater than that in the recovered eluent (Cs decontamination factor of 5,000,000).
- The system shall produce a concentrated Cs eluate solution with a maximum specific gravity of 1.37 g/ml (for sodium hydroxide [NaOH] at 80% of its solubility limit), which is exclusive of any solids present.
- All system components within the R5/C5 black cell (except for the demister pads) shall be non-replaceable components with a design life of 40 years. The reboiler and recirculation pump in the R5/C5 hot cell shall be remotely replaceable. The demister pads are contact maintained and replaceable.

2.3.1.6 Comparison of the Relevant Environment and the Demonstrated Environment

The CNP process and equipment technology concept has not been prototypically demonstrated in a relevant environment. The capability of the system to produce a concentrated Cs eluate solution with a maximum specific gravity of 1.37 g/ml (for sodium nitrate [$NaNO_3$] at 80% of its solubility limit) has not been demonstrated. The functions of the CNP, and in particular the rectifier column and demister pads, have not been fully demonstrated in the laboratory or a simulated environment. These issues are discussed further below.

A comparison of the CNP lab-scale testing system, CNP design as proposed by the Contractor, Hanford's B-Plant application, and Hanford's Plutonium-Uranium Extraction (PUREX) Plant application for the recovery on nitric acid is provided in Table 2.2. The information in this table illustrates that the CNP design by the Contractor:

- Modifies the historic use of the technology at Hanford, and
- Repackages the nitric acid recovery technology, into a new environment, that requires operation of the technology beyond its demonstrated capability.

Table 2.2. Comparison of Nitric Acid Evaporation Systems

System	Components and Operating Volume	Mode of Operation	Function	Operating Range	Control Concept	Other Special Requirements	Testing / Operating Basis
Lab-Scale	Evaporator vessel: 5-in. diameter; 2.2-L Two Condensers	Semi-batch using constant feed composition throughout operation	Determine relationships for solubility and physical properties for Cs eluate concentrate	Evaporator vessel initially charged with 7.5 M HNO_3 Four separate evaporator tests with feed at 0.24, 0.28, 0.29, and 0.36 M HNO_3	Vacuum used to control boiling temperature in evaporator vessel All vapors condensed	None	Testing conducted to provide information for modeling plant system
CNP Design Concept	Separator Vessel (CNP-EVAP-00001): 1,500-gallons Reboiler (CNP-HX-00001) Nitric Acid Rectifier (CNP-DISTC-00001) Two Condensers (CNP-HX-00002 and CNP-HX-00003) Recovered Nitric Acid Vessel (CNP-VSL-00004): ~6,200-gallons	Fed directly from CXP column Continuous during CXP elution cycle	Concentrate Cs eluate to 80% of solubility limit of dissolved salts Recover 0.5 M HNO_3 at high purity	Evaporator vessel initially charged with 7.2M HNO_3, but can range from 5 to 8 M HNO_3 6.9 to 10 gpm feed varies from water to 0.5 M HNO_3 during evaporator operation	Vacuum used to control boiling temperature in evaporator vessel Conductivity probe in rectifier drain line used to control rectifier operation and concentration of HNO_3 in recovered HNO_3 product	Achieve Cs decontamination factor [DF] of 5 million (must be suitable for re-use in CXP)	Limited, lab-scale tests, calculations and modeling Plan to demonstrate Cs DF during WTP PT Facility cold commissioning

Table 2.2. Comparison of Nitric Acid Evaporation Systems

System	Components and Operating Volume	Mode of Operation	Function	Operating Range	Control Concept	Other Special Requirements	Testing / Operating Basis
Previous Application							
B Plant Cell 5 (ARH-CD-691, pp. 600 – 603)	Feed vessel: 1,800 gallons Integrated Evaporator / Separator vessel: 260 gallons Condenser	Fed from 1,800-gallon vessel Continuous during Solvent Extraction processing	Concentrate Strontium nitrate solution to 0.05 to 0.2 M	Evaporator vessel initially charged with 1.0 M HNO_3. Feed adjusted to 0.3 M HNO_3 in feed vessel	Vacuum used to control boiling temperature in evaporator vessel Nitric acid recovery/re-use not intended	Condensed nitric acid solution neutralized and processed in separator evaporator along with other low-level waste solutions. Low strontium (Sr) DF (<100,000) required	Plant operations
PUREX Plant (HW-31000, pp. 1001 – 1014)	Integrated Evaporator / Separator vessel with bubble-cap tray and packed section: 3,200 gallons Condenser Bubble-cap tray absorber tower Two 30wt% HNO_3 intermediate product vessels: 5,00 gallons each Vacuum fractionator column Two 60 wt% HNO_3 product vessels: 15,00 gallons each	Semi-batch	Concentrate mixed fission product waste solution and recover HNO_3 for re-use in solvent extraction process	~1.6 M HNO_3 feed to evaporator ~4.5 M HNO_3 produced from absorber tower, which collected in intermediate product vessels and fed to vacuum fractionator	Vacuum used to control boiling temperature in evaporator vessel Two-step process to decontaminate nitric acid and produce concentrated HNO_3	Mixed fission product DF ~100,000	Plant operations

The discussions below address each of the aspects of this technology and the technical challenges that exist in the application of this technology.

<u>Cesium Eluate Concentration/Evaporator</u>: The Contractor has estimated that the Cs eluate solution has a maximum specific gravity of 1.37 g/ml and a corresponding $NaNO_3$ concentration of 2.6 M at 80% $NaNO_3$ saturation (24590-PTF-3PS-MEVV-T0002, Rev. 4, pg. C-1; 24590-WTP-RPT-PT-02-019, Rev. 1). The laboratory evaporator tests demonstrated at 100% $NaNO_3$ saturation, the specific gravity varied from 1.312 to 1.372 g/ml (SCT-M0SRLE60-00-183-02, Rev. 00A, pg. 13). This indicated that if the CNP were operated at a specific gravity of 1.37, then solids would form in the evaporator. The evaporator was not designed to operate with solids. During discussions with WTP Engineering staff, it was noted that the Cs concentrate would be neutralized prior to transfer to the HLP. This will result in the formation of solids from the precipitation of salts. *The Contractor should re-evaluate the specific gravity operating limit for controlling the concentrated Cs eluate to a maximum of 80% saturation and the ability of the evaporator to manage solids. If required, design changes should be specified.*

The WTP Contractor completes corrosion evaluations to support the specification of materials of construction for the WTP vessels and piping. The corrosion evaluation for the CNP-EVAP-00001 (24590-PTF-N1D-CNP-00005) indicates that the pH range for evaporator operations will be 0.3 to 14. The lower end of this pH range is based on an assumed 0.5 M HNO_3 concentration in the Cs eluate. However, the evaporator is charged with nitric acid up to 8 M. The engineering material balance (24590-WTP-MVC-V11T-00005) referenced in the corrosion evaluation correctly states the lower end of the pH range at -0.9. *The Contractor should reassess the corrosion evaluations for the CNP vessels and piping.*

<u>Rectifier Column</u>: Laboratory demonstration of the acid rectifier column (CNP-DISTC-00001) has not been conducted.

Rectifier (also referred to as distillation or fractionator) columns are commonly used in commercial industry to recover nitric acid and other distillates. The PUREX Plant at the Hanford Site recovered nitric acid from a vacuum evaporator system that processed mixed fission product wastes (HW-31000, pp. 1001 – 1061) during plant operations from 1956 to 1995. The PUREX Plant acid recovery system was designed for remote maintenance/replacement and operation. The CNP rectifier column is not designed for remote replacement. While the nitric acid absorption and fractionation technology is similar between PUREX and the CNP design, the equipment used in the PUREX Plant and the CNP differ significantly.

The PUREX Plant acid recovery system included a vacuum evaporator, a nitric acid absorber tower and condenser, two 30 wt% concentrated nitric acid receiver vessels, a vacuum fractionator column, and two 60 wt% concentrated nitric acid receiver vessels. The distilled nitric acid was passed through the absorber tower and condenser, which resulted in the collection of 30 wt% nitric acid in one of the two 30 wt% concentrated nitric acid receiver vessels. One of the 30 wt% concentrated nitric acid receiver vessels was used to receive 30 wt% acid from the absorber tower while the other vessel contents were feed to the fractionator column, thus providing a uniform concentration of nitric acid as the feed to fractionator column. While the PUREX Plant fractionator column is similar to the CNP rectifier column, the CNP does not include intermediate vessels to collect the nitric acid solution distilled from the separator vessel (CNP-EVP-0001).

The concentration of nitric acid in the Cs eluate solution will vary based on the composition of the waste being processed by the CXP. The CNP engineering specification used for procuring this equipment system states the nitric acid concentration in the Cs eluate will be a minimum of 0.4 M and a maximum of 0.5 M (24590-PTF-3PS-MEVV-T0002, Rev. 4, Appendix C). However, the pre-elution and post-elution rinse sequences for the Cs IX column results in dilute (less than 0.4 M) nitric acid and water being processed in the CNP (24590-PTF-3YD-CXP-00001, Rev. 0, pp. 6-10 and 6-11). The project has prepared mass and energy balance calculations for the CNP components including the rectifier column (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B). The mass and energy balance calculations assumed the nitric acid concentration in the feed to the CNP is 0.5 M and calculated that the recovered nitric concentration is 0.57 M (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B, pp. 29-30). The mass and energy balance calculation did not evaluate feeding a lower and variable nitric acid concentration to the CNP. In addition, this variable nitric acid concentration was not estimated or included in the engineering procurement specification (24590-PTF-3PS-MEVV-T0002) for the CNP. *The functional requirements of the CNP to treat a variable Cs eluate composition while the evaporator concentration varies have not been evaluated through engineering analysis or through testing. In particular, the performance and controls of the rectifier column have not been fully demonstrated in the laboratory or a simulated environment.*

The project plans to use RF resin instead of SuperLig® 644 resin in the CXP. The project has evaluated increasing the resin contained in the Cs IX columns from 415 to 600 gallons (24590-WTP-RPT-RT-06-001, pg. 13), while still eluting the resin with 15 bed volumes (BV) of 0.5 M HNO_3. Therefore, the required volume of 0.5 M HNO_3 solution to elute an IX column is 9,000 gallons (15 BVs x 600 gallons per BV = 9,000 gallons). The batch capacity of the recovered nitric acid vessel (CNP-VSL-00004) is approximately 6,200 gallons, which is not sufficient to contain the entire volume of eluent needed to complete the elution of a 600-gallon column. Regardless of whether the project increases the volume of resin used in an IX column, the need may arise to use more than 15 BVs to completely elute an IX column. For conditions where more than 6,200 gallons of 0.5 M HNO_3 solution are required to eluate an IX column, the project plans to operate the CNP in a continuous mode: evaporating Cs eluate, recovering nitric acid solution in vessel CNP-VSL-00004, and transferring recovered nitric acid solution to the Cs IX reagent vessel (CXP-VSL-00005). Critical to the operation of the CNP coupled to the CXP is the use of an in-line conductivity probe to control the composition of the rectifier product. *This continuous mode of operation for the CNP has not been demonstrated in the laboratory or in a simulated environment. In particular, the performance and controls of the rectifier column has not been fully demonstrated in the laboratory or a simulated environment.*

As part of the Contractor's Pretreatment Reconfiguration studies in 2001, two CNP eluate (CNP feed) receipt vessels with a volume of 10,000 gallons each and two eluant (CNP acid product) vessels with a volume of 9,000 gallons each were removed from the conceptual design provided by DOE (CCN:020148). Preserving these vessels in the CNP flowsheet would have allowed operation of the CNP to have been decoupled from the CXP, and likely simplified process operations and control.

<u>Demister Pads</u>: The demister pads remove entrained droplets from the vapor phase leaving the evaporator vessel and in combination with the rectifier column are intended to achieve the design basis Cs decontamination factor of 5,000,000 (concentration of Cs in the evaporator bottoms relative to the recovered nitric acid solution). The demister pads are located in the top of the separator vessel, which includes sprays to wash the pads during normal operation and for maintenance. Hands-on maintenance is planned for replacement of the demister pads. The ability to adequately decontaminate the demister pads for hands-on replacement has not been demonstrated in previous DOE radiochemical processing plant operations. The basis for the proposed contact (e.g., hands-on) changeout of the CNP separator vessel demister pads has not been established from experimentation or analysis.

The Cs concentration was not measured in the recovered nitric acid solution from laboratory simulations of the evaporator system. Additionally, the vapor flux rate in the laboratory simulations of the evaporator system was not prototypic of that for the CNP (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B). *The functionality of the*

CNP has not been demonstrated to achieve a Cs decontamination factor of 5,000,000 for concentration of Cs in the evaporator bottoms relative to the recovered nitric acid solution.

2.3.1.7 Technology Readiness Level Determination

The CNP was determined to be a TRL 3 because laboratory-scale testing has only simulated the reboiler, separator vessel, and condenser components of the system; the demister pads and rectifier column were not simulated. Simulation of the CNP components has not included the full composition range of feed solutions to the evaporator (reboiler and separator vessel) from the CNP. Proposed changes to the CNP including the neutralization of the Cs concentrate product and impacts of the change to the use of RF resin have not been evaluated.

A subcontractor is completing the detailed design and fabrication of the evaporator components for the CNP: reboiler (CNP-HX-0001); separator vessel and demister pads (CNP-EVP-0001); condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004); rectifier column (CNP-DISTC-00001); steam condensate skid; and associated instrumentation, pumps and ejectors. The Cs evaporator breakpot (CNPBRKPT-00002), recovered nitric acid vessel (CNP-VSL-00004), and the eluate contingency storage vessel (CNP-VSL-00003) are being separately designed and procured. The WTP Contractor is independently developing the software to control this system. The subcontractor is required to conduct a functional test of the evaporator equipment and skids (24590-PTF-3PS-MEVV-T0002, Rev. 4, Section 7.1.4). The subcontractor is also required to demonstrate removal of the demister pad (24590-PTF-3PS-MEVV-T0002, Rev. 4, Section 7.1.5); however, demonstrating installation of a new demister pad is not required. The project is relying upon the verification of the design concept and in particular the Cs decontamination factor after installation in the PT Facility and during cold commissioning (24590-PTF-3PS-MEVV-T0002, Rev. 4, Section 7.2). Modification of the system during or after commissioning would be expensive and time-consuming and could result in delays to hot commissioning.

Because of the risks associated with CNP technology, it is recommended that:

Recommendation 1

Design activities associated with the CNP should be discontinued until: (1) a reassessment of the design and operational requirements for the CNP is completed; (2) the engineering specification for the CNP is revised to reflect operational conditions; and (3) the technology concept, which includes the process equipment and control system, is demonstrated through integrated prototypic testing.

Recommendation 2

The CNP should be functionally tested prior to installation in the black cell. The testing should include: testing with representative process feed compositions; verifying the process control system concept; verifying the ability to control and monitor the composition of the nitric acid product; demonstrating the cesium decontamination factor of 5 million; and demonstrating the ability to adequately decontaminate the demister pads using the sprays installed in the separator vessel.

Supporting Recommendations

- The specific gravity operating limit for controlling the concentrated Cs eluate in the CNP separator to a maximum of 80% saturation should be re-evaluated. Based on the WTP Contractor's plan to neutralize Cs concentrate in the separator, and thereby create solids, this operating constraint may not be required.

- The engineering specification for the CNP should be modified to include (1) the estimated variable feed composition and (2) factory acceptance testing to demonstrate removal and installation of the demister pads from the separator vessel.
- The Contractor should reassess the corrosion evaluations for the CNP vessels and piping based the operating conditions of the system.

2.3.2 Cesium Ion Exchange Process System (CXP)

2.3.2.1 Function of the CXP

The primary functions of the CXP are to receive ultrafiltration permeate from the Ultrafiltration Process System (UFP), remove Cs from the UFP permeate using IX, transfer the Cs-treated LAW (e.g., eluate) to the Treated LAW Evaporation Process System (TLP), and maintain hydrogen to a concentration below the lower flammability limit. Because the IX media has a limited capacity for Cs, the CXP must also perform IX media elution and regeneration, as well as spent media removal and fresh media addition. The Cs eluate from IX media elution is transferred to the CNP, as discussed in Section 2.3.1.

2.3.2.2 Description of the CXP

The CXP is described in the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001). A block flow diagram of the CXP is provided in Figure 2.2. The nitrogen inerting collection piping to vent hydrogen (and other gases) from the Cs IX columns has been modified since issuance of the CXP system description, as described in *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i, Section 3.4.1.8.4).

The CXP utilizes four IX columns (CXP-IXC-00001, -00002, -00003, and -00004) to separate Cs from the UFP permeate. Three columns in series are in service while one is in standby mode. The UFP permeate is transferred from the Cs IX feed vessel (CXP-VSL-00001) through heat exchangers into three IX columns that are operated in series. The first column is designated as the lead column. The second column is designated as the lag column. The third column is designated as the polishing column. Cs is exchanged with sodium (Na) ions on the IX resin as the UFP permeate passes through the three IX columns. The Cs depleted solution exiting the polishing column is referred to as Cs treated LAW, which is collected in one of three vessels (CXP-VSL-00026 A/B/C).

At some point in processing, the removal efficiency of the lead column is reduced. Eventually, the Cs concentration in the effluent streams exiting the columns will increase to a level approaching the predetermined maximum. The point at which the Cs concentration in the effluent from the IX column reaches a predetermined maximum (which is relative to the sodium concentration) is called the breakthrough point. The Cs-137 monitors located on the effluent from each column will determine when the Cs concentration in one of the effluents reaches its setpoint. When this breakthrough point is reached, the valving will be changed so that the freshly regenerated column is placed in the polishing position and the column previously in the lead position is valved off for elution and regeneration. The column previously in the lag position is now the lead column, and the polishing column is now the lag column.

The column previously in the lead position is flushed with 0.1 M NaOH (dilute caustic) solution (from vessel CXP-VSL-00004) and rinsed with demineralized water. The solution displaced from the column during the dilute caustic flush is collected in one of the three Cs-treated LAW collection vessels (CXP-VSL-00026 A/B/C). The rinse water passes through the column to one of the acidic/alkaline effluent vessels (PWD-VSL-00015 or -00016). Nominally, 0.5 M HNO_3 at 25°C from the Cs evaporator recovered nitric acid vessel (CNP-VSL-00004) is used to elute Cs (and other cations) from the column. The eluent passes through the column to the Cs evaporator separator vessel (CNP-EVAP-00001) via breakpot CNP-BRKPT-00002. Following completion of the elution step, nitric acid is displaced from the column to the Cs evaporator separator vessel using demineralized water. Then, the column is regenerated using six BVs (a BV is the volume of resin in the column) of 0.25 M NaOH solution. The first three BVs of caustic solution are routed to the acidic/alkaline effluent vessels (PWD-VSL-00015 or -00016). The remaining three BVs are routed to the Cs IX caustic rinse collection vessel (CXP-VSL-00004).

After elution and regeneration, the column will be in standby until it can be returned to the train as the polishing column. LAW, eluant, other reagent solutions, and rinses are transferred into the column via the Cs IX reagent vessel (CXP-VSL-00005), and enter the column through the top distributor.

After several loading, elution, and regeneration cycles, the resin is expected to lose performance and is termed “spent.” The spent IX resin is slurried with recycled IX resin flush solution (primarily water), flushed out of the column, and collected in the spent resin slurry vessels (RDP-VSL-00002-A, -B, or -C), which are part of the Spent Resin Collection/Dewatering Process System (RDP). Fresh resin from the Cesium Resin Addition Process System (CRP) is slurry fed by gravity from the Cs resin addition air gap vessel (CRP-VSL-00002) to the appropriate column.

Hydrogen gas is produced in the Cs IX columns due to radiolytic decay of the resin and LAW solution in the Cs IX column. Soluble hydrogen and any hydrogen bubbles produced due to solution saturation are normally be expected to be entrained and swept out of the Cs IX column in the flowing liquid stream. There is concern that the velocity of rising hydrogen bubble may exceed the velocity of liquid downflow through the Cs IX column. In this case, hydrogen would accumulate in the Cs IX column, where it would be collected in the nitrogen inerting collection piping. The nitrogen inerting collection piping uses four level control sensors to automatically regulate the liquid and nitrogen gas volumes in the piping and vent gases to the process vessel ventilation system via a vented breakpot (24590-WTP-SED-ENS-03-002-02, Rev. 1i, pg. 3.4.1.8.12).

2.3.2.3 Relationship to Other Systems

UFP permeate solution is transferred from the three UFP permeate vessels (UFP-VSL-00062A, -B, -C) to the Cs IX feed vessel (CXP-VSL-00001).

Three collection vessels (CXP-VSL-00026 A/B/C), each with a batch volume of 26,000 gallons, receive the Cs treated LAW solution.

The Cs eluate solution is sent to the Cs evaporator separator vessel (CNP-EVAP-00001) via breakpot CNP-BRKPT-00002 in the CNP for further processing to recover the nitric acid eluent and concentrate the Cs product.

Post-loading step water rinse and dilute NaOH regeneration solution are transferred to the acidic/alkaline effluent vessels (PWD-VSL-00015 or -00016).

Fresh resin is slurried and fed by gravity from the Cs resin addition air gap vessel (CRP-VSL-00002) in the CRP to the appropriate column. Spent resin is extracted from a column to the spent resin slurry vessels (RDP-VSL-00002-A, -B, or -C), which as part of the RDP.

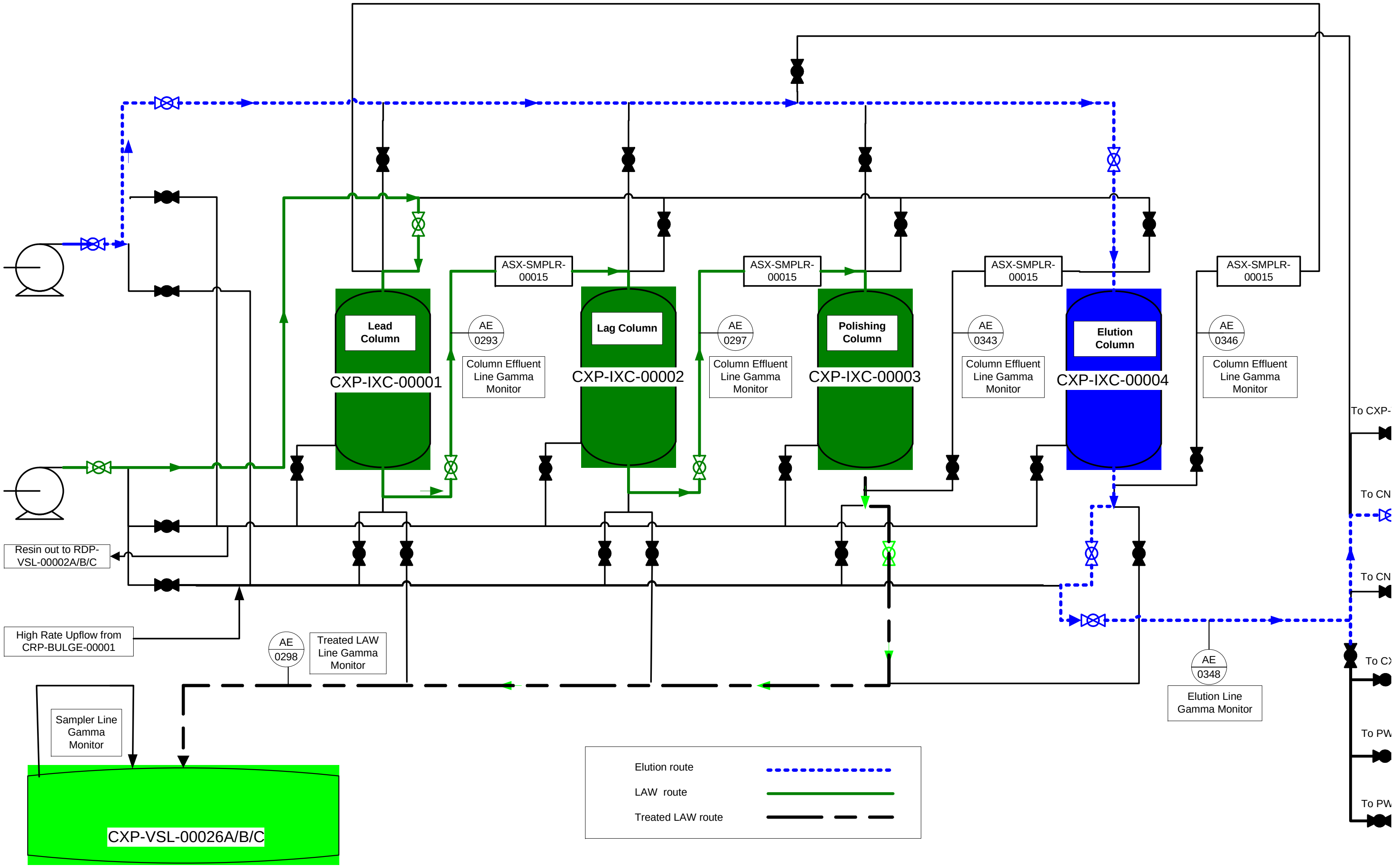


Figure 2.2. Block Flow Diagram for the Cesium Ion Exchange Process System

2.3.2.4 Development History and Status

The WTP Project has conducted laboratory-scale testing of the Cs IX process using radioactive waste samples and simulants. Early testing was conducted using SuperLig® 644 resin, while later testing used an alternative resin, spherical RF. A summary of the status of development for both IX materials is provided in *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644®* (24590-WTP-RPT-RT-06-001). Since the project is planning to use spherical RF resin, this assessment addresses only spherical RF resin in the CXP.

The physical properties of spherical RF resin and the chemical and radiological degradation mechanisms have been determined through laboratory testing in a relevant environment (SCT-MOSRL60-00-221-00001, Rev. 00A; 24590-WTP-RPT-RT-06-001, Sections 5.3 and 5.4). Hydraulic testing of scaled columns using flow rates representative of planned CXP operating conditions was conducted to determine bed flow permeability, pressure drop and fluidization velocity for spherical RF resin (24590-WTP-RPT-RT-06-001, Section 4). Testing of spherical RF resin degradation during storage is ongoing and is expected to be complete by September 2007 (24590-WTP-RPT-RT-06-001, Section 5.2). Gas generation and resin nitration from radiation and chemical (nitric acid [HNO_3] and permanganate [MnO_4]) exposure of spherical RF resin has been determined (24590-WTP-RPT-RT-06-001, Section 8).

The project has demonstrated manufacturing scale-up and reproducibility of spherical RF resin (24590-WTP-RPT-RT-06-001, Section 8.5). Six 100-gallon batches of spherical RF resin were manufactured by two different vendors. These batches of resin were tested and shown to have acceptable mean particle diameter, density, and Cs capacity.

The project has conducted laboratory scale testing of IX columns containing spherical RF resin using AP-101 (SCT-M0SRLE60-00-110-00029, Rev. 00A), AZ-102 (24590-101-TSA-W000-0004-99-00013, Rev. 00A), AN-105 (24590-101-TSA-W000-0004-91-00003, Rev. 00A), and AN-107 (SCT-M0SRLE60-00-110-00029, Rev. 00A) simulants and actual tank AP-101 and pretreated AN-102 (24590-101-TSA-W000-0004-1742-00001, Rev. 00A) waste samples. These laboratory-scale column tests were conducted using flow rates, operating modes, and temperatures that mimic the planned CXP operating conditions. The simulants used in these tests contained simple organic compounds (i.e., oxalate, glycolic acid, acetate, and formate), but did not contain anti-foaming agent (used in various PT Facility systems) or other organic compounds (e.g., chelating agents, tri-butyl phosphate [TBP], and normal paraffin hydrocarbon [NPH]) known to be present in Hanford Site tank wastes. The project plans to use data from these tests to update by September 2007 a computer model for the spherical RF resin IX system (SCT-M0SRLE60-00-05-00003, Rev. 00A).

2.3.2.5 Relevant Environment

The relevant environment for the CXP, as identified in the *Basis of Design* (24590-WTP-DB-ENG-01-001), the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001), and as modified by the *Engineering Specification for the Cesium Ion Exchange Columns* (2459O-PTF-3PS-MWDO-TOOO5, Rev. 1), is:

- The CXP shall remove Cs-137 from the ultrafiltration system permeate to allow for production of an immobilized low-activity waste (ILAW) form that meets contract specifications and facilitate the maintenance concept established for the ILAW melter system.
- The CXP shall process ultrafiltration permeate at a volumetric flow rate between 5 to 22 gpm. *(Note the Contractor is evaluating an increase in the flow rate to 30 gpm).*

- The CXP time cycle for the LAW loading and feed solution displacement processing steps shall exceed the combined time cycle for the elution, post-elution rinse, and regeneration processing steps in order to support continuous semi-batch mode processing of LAW solution.
- The CXP shall be capable of removing greater than 99% by volume of resin from the IX columns upon completion of the resin removal mode using a maximum volume of 7,500 gallons of water to displace the resin.
- The IX columns shall be designed for 10-year life and remote removal and replacement using remote jumper techniques, closed-caption television (CCTV), hot cell crane, and crane-mounted impact wrench.

2.3.2.6 Comparison of the Relevant Environment and the Demonstrated Environment

The chemistry and physical properties of the spherical RF resin has been demonstrated in laboratory- and pilot-scale tests with similar process conditions and in a relevant environment. However, the project has not completed all planned testing of spherical RF resin. Ongoing planned testing includes resin degradation during storage, spent resin analysis after contacting with high concentrations of organic compounds and metals (needed for spent resin disposal evaluation), and update of the IX process computer model. These tasks are scheduled to be completed by September 2007 (24590-WTP-RPT-RT-06-001, Section 9).

Physical degradation testing, such as osmotic shock and crushing, for irradiated, spherical RF resin samples was not conducted (SCT-MOSRLE60-00-10-00005, Rev. 00A, pg. 4). The project has not evaluated the effect of anti-foaming agent and separable organics (such as tri-butyl phosphate [TBP]) present in the feed on the CXP. Evaluation of the effect of separable organics on the CXP is required by the WTP Contract, Standard 2, “Research, Technology, and Modeling,” item (3) (viii), “Effect of Separable Organics” (Contract No. DE-AC27-01RV14136).

The project has not demonstrated the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns. The PT Facility Safety Envelope Document states “For flammable gas to exceed the nitrogen inerting gas volume within the Cs IX column collection piping, a loss of the level control would be required. A loss of level control would require failure of the credited CXP collection piping liquid low-low level LS-4 sensor. The functionality of the CXP collection piping liquid low-low LS-4 sensor (which is not required to meet the single failure criterion in accordance with the revised safety criteria defined in the SRD) will be verified” (24590-WTP-SED-ENS-03-002-02, Rev. 1i, pg. 3.4.1.8.12). The Assessment Team found no evidence of verification of the functionality of these liquid level sensors.

Hydraulic testing of spherical RF resin was conducted using relevant process conditions (e.g., superficial velocity and flow direction), but did not use a prototypic IX column; the column internals such as resin retention screen and flow distributor were not prototypic of the current design. Therefore, the capability was not demonstrated to remove greater than 99% by volume of the resin from the column. The project has prepared a specification for a vendor to prepare the detailed design and fabrication of the IX columns (24590-PTF-3PS-MWD0-T0005, Rev. 1). Although this specification requires the columns to be designed to achieve greater than 99% by volume removal of resin from the IX columns upon completion of the resin removal mode, no factory testing is required to demonstrate compliance with this requirement.

The WTP contractor recognizes that the engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1) for the IX columns needs to be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the External Flowsheet Review Team (EFRT) recommendations for the CXP. The project plans to update this specification before resuming procurement of the IX columns (24590-WTP-PL-ENG-06-0026, Rev. 000).

The consequences of solids in the feed stream to the IX columns are not understood. Almost all testing performed to date with the new "mono-sized" (i.e., narrow resin partial size distribution) spherical RF resin has been performed with feeds free of solids. It is expected that the spherical RF resin paths for any solids to pass by the resin, greatly reduce the risk of plugging the column. Issues with the possible negative impacts of solids present in the CXP feed as identified by the WTP Contractor include:

- Column or areas in the column becoming plugged with solids.
- Solids remaining on the resin, depending on solids makeup, may not be easily dissolved.
- Cs may be occluded into the precipitating solid matrix that becomes a carrier for Cs bypassing resin.
- Precipitating solids coating resin IX sites preventing ion exchange from occurring, resulting in early Cs breakthrough.

Recent analysis of the PT Facility flowsheet (24590-WTP-RPT-PO-07-002) estimates the concentration of solids (gibbsite and sodium oxalate) in the stream entering the Cs IX columns and indicates that undissolved solids are almost always present. Concentrations range from up to 7,000 ppm, assuming that sludge leaching occurs in the UFP-VSL-00002A/2B vessels, to approximately 800 ppm, assuming that sludge leaching occurs in the UFP-VSL-00001A/1B. Additional results provided in these analyses are:

- For caustic leached in UFP-VSL-00002A/B, about 4% of the aluminum entering the CXP feed system precipitated, and about 75% of the solids, are sodium oxalate; about 25% of the solids are gibbsite.
- For caustic leaching in UFP-VSL-00001A/B, about 2% of the aluminum entering the CXP feed system precipitated, and about 1% of the solids, are sodium oxalate; about 99% of the solids are gibbsite.

Based on these results of the flowsheet study (24590-WTP-RPT-PO-07-002), the WTP Contractor recommended the following:

- Additional studies be performed using the preferred CXP resin to determine column performance and operating issues with CXP feeds that contain freshly precipitated sodium oxalate and gibbsite solids. The study must be comprehensive enough to determine CXP feed limits for sodium oxalate solids and gibbsite solids.
- Additional research be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate. It is also important to understand the morphology of freshly precipitated sodium oxalate.
- An engineering assessment be undertaken to determine how to accomplish mixing in CXP-VSL-00001. This vessel has no provisions for blending solutions or suspending solids. However, flowsheet modeling indicates that solids are likely to precipitate if chemical adjustments are not made to the vessel.
- Capability to add NaOH and process condensate to the Cs IX feed vessel, CXP-VSL-00001, should be added. If it becomes necessary to reduce the solids concentration in Cs IX feed, then the capability will be available.

A previous analyses by BNI (24590-WTP-RPT-PR-01-006), which was reviewed by DOE in 2005 (06-WED-009), identified the post-filtration precipitation of solids in the CXP feed as a process issue.

2.3.2.7 Technology Readiness Level Determination

The CXP was determined to be a TRL 5 due to incomplete demonstration of the process and equipment technology for the CXP and the incomplete testing/documentation of spherical RF resin. The project has not demonstrated the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns. The project has not demonstrated the capability to remove 99% by volume of the spherical RF resin from a prototypic IX column. Delaying testing of these design features until cold commissioning of the PT Facility would result in potentially expensive and time-consuming delays to hot commissioning.

Flowsheet analysis indicates that solids will always be present in the Cs IX column feed. The data on the impact of these solids on the operation of the Cs IX columns does not exist. Complete understanding of the chemical stability of the CXP feed does not exist. The equipment capability of the CXP to manage feeds containing solids does not exist.

The EFRT identified issues for the stability of the baseline IX material (SuperLig® 644), column design expertise, inadequate process development, complexity of process valving, cross contamination potential, and effectiveness of the Cs-137 breakthrough monitors. The project is addressing these issues through issue response plans (IRP) with closure of these issues anticipated by September 2007 (24590-WTP-PL-ENG-06-0026, Rev. 000). The adequacy of these IRPs was not evaluated as part of this assessment.

Because of the risks associated with the CXP, it is recommended that:

Recommendation 3

Prototypic equipment testing should be completed prior to continuing design of the hydrogen venting subsystem (nitrogen inerting and hydrogen gas collection piping system, and control system) for removing hydrogen and other gases from the cesium IX columns to demonstrate this design feature over the range of anticipated operating conditions.

> *Alternatively, the project should consider re-designing (and testing) the hydrogen venting subsystem for the IX columns in order to simplify the system. For example, a small recycle stream from the IX columns to the feed vessel (CXP-VSL-00001) could be used to vent gases from the columns. The recycle stream could be controlled through the use of orifice plates and stop valves for isolation.*

Recommendation 4

The adequacy of the design concept for CXP-VSL-00001 should be reevaluated and a determination made if this vessel should be modified to include mixing, chemical addition, and heating/cooling to mitigate anticipated process flowsheet issues with precipitation of solids in the CXP feeds.

Supporting Recommendations

- Testing of spherical RF resin should be conducted to: (1) assess physical degradation for irradiated resin samples; (2) assess effects from anti-foaming agent and separate organics present in the feed to the CXP; and (3) assess the impact of particulates on IX column performance.
- All currently planned testing and documentation of test results for spherical RF resin should be completed. (*Note: This planned work is in the WTP Baseline.*)

- Additional research should be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate.
- The engineering specification for the IX columns should be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the EFRT recommendations for the CXP.
- The engineering specification for the CXP should be modified to include factory acceptance testing of the IX column to demonstrate that the system is capable of removing greater than 99% by volume of resin from the IX column, upon completion of the resin removal mode, using a maximum volume of 7,500 gallons of water to displace the resin.

2.3.3 Treated LAW Feed Evaporation Process System (TLP)

2.3.3.1 Function of the TLP

The primary function of the TLP is to minimize the volume of water that must be processed in the LAW melter. The treated LAW feed is mixed with the scrub solution recycled from the LAW offgas treatment system just before it enters the evaporator.

2.3.3.2 Description of the TLP

The TLP is described in the *System Description for Treated LAW Process*, (24590-PTF-3YD-TLP-00001). The TLP evaporator's purpose is to increase the treated LAW concentration up to the solids crystallization point (expected range from 8 to 10 M Na) such that the vitrification efficiency is maximized without solids buildup in transfer lines. A single evaporator train in the TLP is employed to fulfill all concentration requirements. Some suspended solids are anticipated in the recycle streams to the TLP evaporator.

The WTP TLP evaporator is based on the design concept of the Hanford's 242-A Evaporator (Van Der Cook and Ogren 1976) and is a continuous, forced-circulation, vacuum evaporation system. The major components of the TLP include:

- Feed pumps
- Reboiler
- Vapor liquid separator
- Recirculation pump and pipe loop
- Slurry product pump
- Primary condenser
- Jet vacuum system
- Vessel vent system
- Condensate collection vessel

The waste processing operations in the TLP differs from the 242-A Evaporator in that the TLP is not intended to concentrate to achieve dissolved solids saturation (i.e., crystallization).

The TLP is used to concentrate treated LAW prior to transfer to LAW vitrification and reduce LAW submerged bed scrubber (SBS) condensate recycles. The concentrated LAW product is sent to the treated LAW concentrate storage vessel (TCP-VSL-00001), which stores the concentrate pending its transfer to the LAW Vitrification Facility. The LAW SBS receipt vessels are designed to operate sequentially to maintain continuous operation of the TLP evaporator. One vessel is available for receipt, sampling, and any adjustments (i.e., pH), while the second vessel is discharging to the separator vessel.

A simplified flow diagram of the TLP is provided in Figure 2.3.

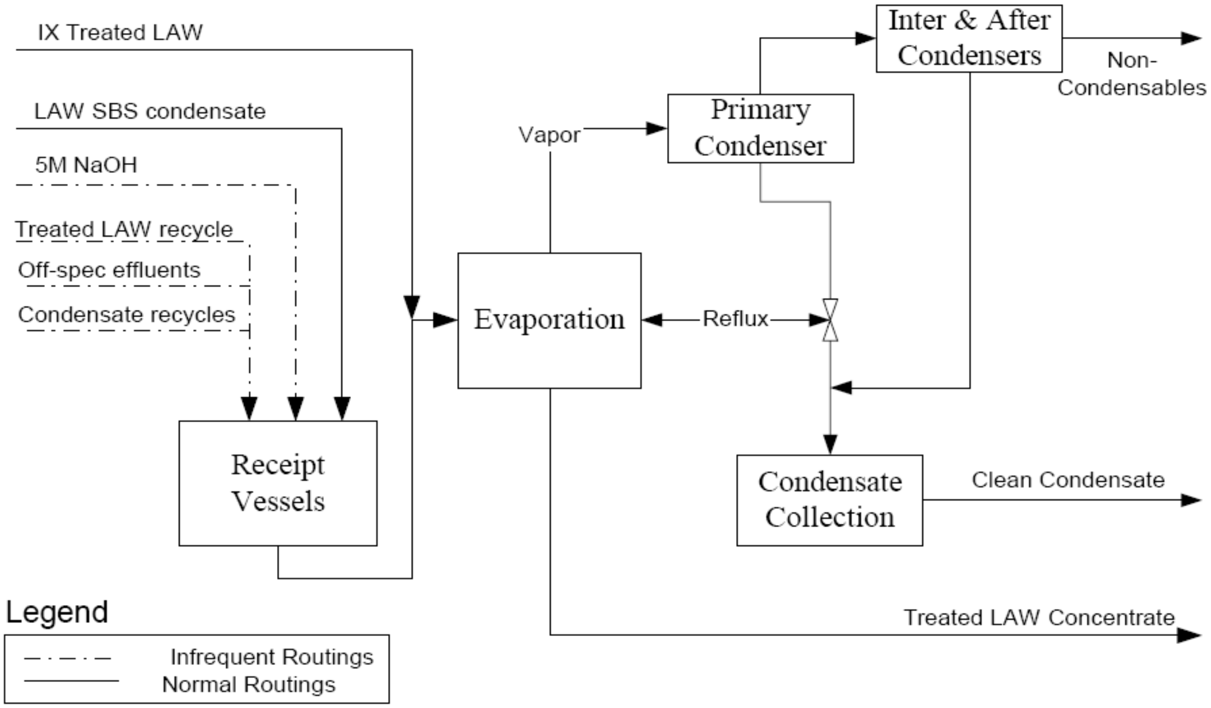


Figure 2.3. Treated LAW Feed Evaporation Process System Simplified Flow Diagram

The LAW SBS receipt vessels require continuous mixing to maintain solid suspension, for chemical blending, and homogeneity of vessel contents before sampling. The mixing is dependant on the liquid level in the vessel. The pulse jet mixers (PJM) will turn on when the vessel level is above the PJM setpoint, and turn off when the vessel level is below the PJM setpoint. The PJM setpoint is determined by the submergence requirements of the mixers (to be determined).

The recirculation pump moves the liquor through the evaporator recirculation loop maintaining a high flow rate through the reboiler. Low-pressure steam, modulated via a flow controller, is used to heat the feed liquor to the selected system boil-off rate. Low-pressure steam is available at 40 psig and 286°F (24590-WTP-DB-ENG-01-001). The heated waste is then discharged to the TLP separator vessel.

The vapors from each separator vessel are sent to a dedicated overhead system that is comprised of primary condensers, vacuum ejectors, intercondenser, aftercondenser, and demisters. Water vapor generated by evaporation of waste is condensed in the primary condenser. The ejector uses steam to discharge the noncondensable gases to the aftercondenser, where the steam condenses. The vessel vent system draws noncondensable gases from the aftercondenser through the demister to remove any liquid entrained in the noncondensable gases. Liquids from each of these unit operations drain to the condensate vessel, where condensate vessel routing valves enable transfer to the RLD.

High-maintenance equipment exposed to highly contaminated fluids (reboilers, recirculation pumps, concentrate transfer pumps, and feed pumps) are located in a hot cell, and the equipment must be remotely maintained. The waste feed evaporator feed vessels (FEP-VSL-00017 A/B) and the separator vessels (excluding de-entrainment section) (FEP-SEP-00001 A/B) are located in a black cell.
The condensers, vacuum ejectors, and condensate collection vessel are contact maintained. The TLP separator vessel has a removable plug to allow access to, and contact replacement of, the demister assembly.

The TLP has a design capacity of greater than 30 gpm. The nominal operating pressure of the evaporator is approximately 1 psia (~27.7 inches water) and the nominal operating temperature is 122°F (50°C).

2.3.3.3 Relationship to Other Systems

The two LAW SBS condensate receipt vessels (TLP-VSL-00009A/B), each with a batch volume of 80,000 gallons, receive LAW SBS vitrification effluent and effluents recycled from pretreatment. These streams include the following:

- LAW SBS condensate from the vitrification SBS condensate vessel (RLD-VSL-00005)
- Off-spec effluent from the process condensate vessels (RLD-VSL-00006A/B)
- Off-spec effluent from the alkaline effluent vessels (RLD-VSL-00017A/B)
- Treated LAW concentrate recycle from the treated LAW concentrate storage vessel (TCP-VSL-00001)
- Treated LAW input from IX vessels (CXP-VSL-00026A/B/C), which is fed directly into the recirculation loop of the evaporator system
- Off-spec effluents from radioactive liquid disposal/recycle vessels (RLD-VSL-00006A/B and RLD-VSL-00017A/B).
- Concentrated fluids from the TLP separator vessel sent to the treated LAW concentrate storage vessel (TCP-VSL-00001).

2.3.3.4 Development History and Status

The WTP *Research and Technology Plan* (24590-WTP-PL-RT-01-002) for testing of the TLP evaporator concept was aimed at addressing nine issues, stated below:

- Evaluate the ability of the TLP to meet design basis operating and throughput requirements.
- Evaluate the affect of trace organics on the evaporator operations.
- Determine the operating impacts from recycle streams.
- Determine the offgas compositions for regulatory purposes.
- Demonstrate process scale-up.
- Evaluate waste foaming in the evaporator.
- Evaluate alumino-silicate plate-out in the evaporator.
- Evaluate if SBS condensate returns produce uranium precipitates.
- Evaluate if dimethyl mercury forms in evaporator operations.

Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001). The results of the technology testing program are briefly described.

Evaluate the Affects of Trace Organics on Evaporator Operations: Separable organics, such as TBP and NPH may impact evaporator operations and thereby impact the propensity of the evaporator to foam. Therefore, testing was completed to examine to impacts of TBP/NPH on the anti-foam agent (WSRC-TR-2003-00216). Concentration levels of up to 10,000 ppm of 50% TBP/50% NPH were tested with simulated feeds with no significant increase in foaminess observed. The presence of TBP/NPH in the TLP is considered unlikely because ultrafiltration studies completed in the Semi-Integrated Pilot Plant (SIPP) showed that the filters would only allow the passage of soluble TBP/NPH. The solubility limit of TBP/NPH is < 1 ppm. Thus, no significant concentrations of TBP/NPH are expected to be processing in the TLP.

Impacts from Process Recycle Streams: Condensate from the LAW Vitrification Facility SBS is recycled into the TLP. Several tests were conducted at lab- and pilot-scale to evaluate the impact of process recycle streams.

The evaporator test program is summarized in the *Final Report: RPP-WTP Semi-Integrated Pilot Plant* (WSRC-TR-2005-00105). Glass production testing has indicated that target endpoints for the treated feed must vary depending on the waste envelope being treated. This variation in endpoint concentration requirement affects the amount of offgas scrub solution recycled back to the evaporator—the higher the concentration, the lower the recycle quantity. The ability of the system to accommodate variations in waste envelopes was examined and found to be adaptable to the system requirements.

Determine the Offgas Compositions for Regulatory Purposes: Testing was completed to characterize the partitioning of volatile and semi-volatile organic across the evaporator and confirm that the evaporator effectively destroyed or recovered the organic materials. Prior to the initiation of pilot-scale evaporator tests, 54 10-ml ampoules, each containing 0.1 gram total of a variety of organic compounds were added to the 100 gallons in the evaporator pot. After the initial charge, the same type of organics in the 10-ml ampoules was added to every 10 gallons of feed. During the operational period, liquid and offgas samples were obtained and analyzed, with liquid samples taken from the feed, concentrate, and primary and secondary condensates. Offgas samples were taken coming off the primary condenser using U.S. Environmental Protection Agency method 0010. Details of how the spiked organics partitioned across the evaporator are reported in WSRC-TR-2003-00561, *WTP Pilot Scale Evaporation Tests*.

Meet Design Basis Operating and Throughput Requirements/Demonstrate Process Scale-Up: Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76 scale in terms of cross-sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system was operated at conditions comparable to the actual process at ~ 1 psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40° to 60°C).

The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.

Waste Foaming: Control of foaming was one of the first issues recognized in the evaporation technology development program. Foam can create two operational problems: (1) Foam can expand throughout the separation volume of the evaporator and carry particulate into the mist eliminator thereby creating a potential plug; and (2) Foam carrying liquid and solids into the demister section can cause carry-over into the offgas system that could require rework of the evaporator overhead stream.

Waste foaming was observed in the evaporator system that was integrated in the RPP-WTP SIPP (WSRC-TR-2005-00105) and has been observed in the Hanford 242-A Evaporator. The 242-A Evaporator uses DOW Chemical 1520 US anti-foam reagent (WSRC-TR-2000-00469). This reagent and several other anti-foam reagents including Q2-3138A were evaluated in the SIPP, and a recommendation to use DOW Q2-3138A was made for both the TLP and FEP evaporation systems.

Sodium Alumino-Silicate (NAS) Plate-Out in the Evaporator: Tests indicated that NAS is present in the waste and will be present in the evaporator concentrate streams. Other compounds that precipitate can be as troublesome as NAS. The formation of solids in the pilot-scale evaporator was examined due to concerns with line plugging and scaling of the heat transfer tubes. Scaling of the evaporator tubes was not found to be significant during the operation of the pilot-scale evaporator. However, during a second 100-hour test, a concentrate loop became plugged. The plug material resembled bayerite, kograrkite, natrophosphate, nitratine, thermonatrite, trona, and lithium aluminum carbonate hydroxide hydrate. The plug did not contain any NAS. The plug was attributed to a low velocity/dead zone. The line was reconfigured and no additional pluggage occurred.

Evaluate Impact of Uranium Precipitates: The operation of the 2H evaporator at the Savannah River Site (SRS) was curtailed due to the accumulation of NAS deposits that contained sodium diuranate ($Na_2U_2O_7 \cdot 6H_2O$) (containing uranium [U]-235) on the heat transfer surfaces. In the WTP, LAW SBS condensate returns, which also contain NAS, could mix in the TLP evaporator to produce similar deposits potentially leading to a criticality event. Thermodynamic modeling of the TLP evaporator was conducted to determine the likelihood of precipitation. Confirmatory laboratory tests with simulants were also conducted and a criticality safety evaluation was completed to resolve this issue. The criticality evaluation has not been evaluated by the DOE.

The criticality analysis showed that a similar event due to the build up of U-235 in the FEP evaporator is extremely unlikely.

Dimethyl Mercury Formation: The formation of dimethyl mercury is not expected at the operating temperatures of the TLP evaporator. However, the use of anti-foam in the TLP evaporator at temperatures greater that 50°C can lead to the formation of diethyl mercury if mercury is also present.

2.3.3.5 Relevant Environment

The operating environment for the TLP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001) and the TLP system description (24590-PTF-3YD-TLP-00001). The relevant operational environment for the TLP is:

- Receive and concentrate a process stream comprised of treated LAW from the CXP and SBS recycle from the LAW Vitrification Facility.
- Concentrate a high solids stream at approximately 1 psia pressure and a boiling temperature (40 to 60°C).
- Transfer evaporator concentrate at 8 to 10 M Na.

2.3.3.6 Comparison of the Relevant Environment and the Demonstrated Environment

The TLP evaporator system is based on existent, proven designs, and demonstrated in a relevant environment in SIPP testing. Operation of the PJMs in the supporting evaporator feed vessels TLP-VSL-00009A/9B has not been demonstrated. Testing and analysis is planned to verify the mixing performance of these vessels.

The technology requirements for the supporting vessel, TCP-VSL-00001, used to store concentrated LAW may not meet functional requirements to effectively mix solids generated from precipitation reactions in the filtered and concentrated LAW. The precipitation of carbonates in this waste stream was identified in 2005 by the Contactor (24590-WTP-RPT-PO-05-009).

2.3.3.7 Technology Readiness Level Determination

The TLP was determined to be TRL 4 because vessels in the TLP (TLP-VSL-00009A/9B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the TLP, is determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved.

The TLP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site and is based on extensive lab-scale and pilot-scale prototypic testing completed to demonstrate this technology. The TLP evaporator is a mature technology. Technology issues evaluated included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of salts of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.

2.3.4 Waste Feed Evaporation Process System (FEP)

2.3.4.1 Function of the FEP

The purpose of the FEP is to receive, blend, and concentrate waste feed and plant recycles. The FEP includes feed vessels, reboilers, separator vessels, and condensers for waste feed evaporation.

2.3.4.2 Description of the FEP

The FEP is described in the *Systems Description for Waste Feed Evaporation Process (FEP)* (24590-PTF-3YD-FEP-00001). The FEP treats low-activity waste and process concentrates waste using a conventional forced-circulation, vacuum evaporation-crystallization system. System FEP employs one evaporator train in normal operation with a secondary train in standby. Two ejectors (per evaporator train) generate the vacuum requirements that enable boiling at approximately 122°F (50°C).

A block flow diagram of the FEP is provided in Figure 2.3.

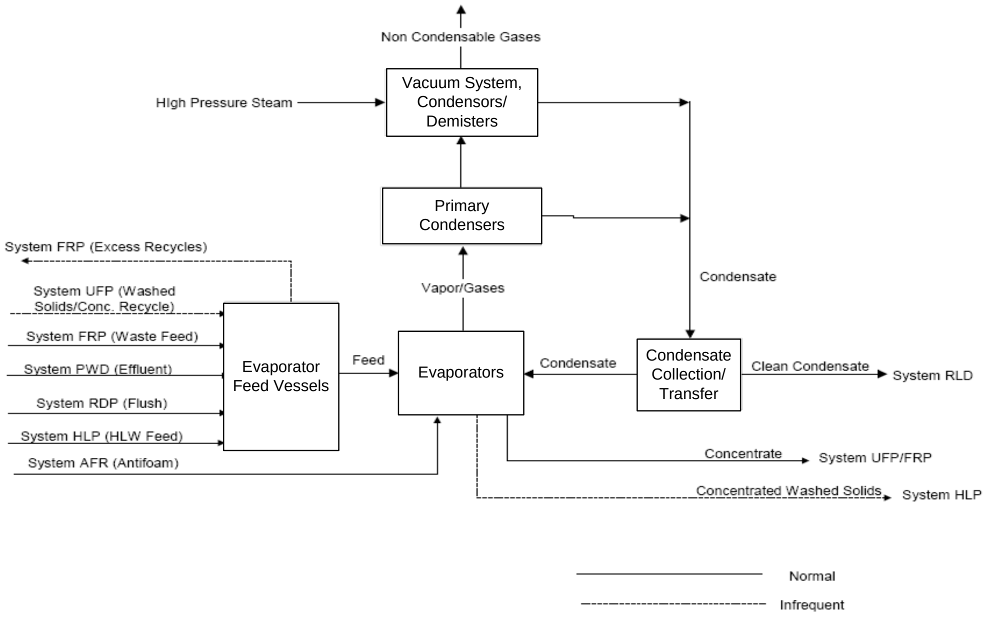


Figure 2.3. Block Flow Diagram for the Waste Feed Evaporation Process System

The FEP contains two waste feed evaporator feed vessels that receive waste feed and recycles. The evaporator feed vessels require continuous mixing with PJMs that turn off if the vessel level is below the PJM setpoint. Sampling ability in the feed vessels, although not required for production, is available to provide analytical information regarding evaporator feed properties. In the event the feed vessels require solids cleanout or decontamination (i.e., during decommissioning), the feed vessels will be washed down with vessel wash rings.

Evaporator feed is pumped from the feed vessels (FEP-VSL-00017 A/B) to the evaporator system. The evaporator system contains two evaporator trains of the same capacity (reboilers, separator vessels, and condensers). Although the evaporator trains can operate simultaneously (each contains independent control logic), a single evaporator train has sufficient capacity to support the maximum vitrification facility production requirements. The evaporators use conditioned steam (the steam system is operated under a vacuum to provide lower temperatures, which will prevent tube fouling) as a source of heat for the reboilers. The maximum boil-off rate per evaporator train is estimated to produce 30 gpm of condensate. Foaming tendencies in the separator vessel will be minimized by the addition of an anti-foam agent.

The vapors from each separator vessel are sent to a dedicated overhead system that is comprised of a primary condenser, vacuum ejectors, intercondenser, aftercondenser, and demisters. Water vapor generated by evaporation of waste is condensed in the primary condenser. The ejector uses steam to discharge the noncondensable gases to the aftercondenser, where the steam condenses. The vessel vent system draws noncondensable gases from the aftercondenser through the demister to remove any liquid entrained in the noncondensable gases. Liquids from each of these unit operations drain to the condensate vessel, where condensate vessel routing valves enable transfer to the RLD.

The condensate draining from the primary condenser is monitored for radioactivity by an area radiation monitor located close to the condenser. In the event the area radiation monitor detects high activity, the contaminated condensate is automatically redirected back to the separator vessel.

The evaporator bottoms are sent through the UFP process using the concentrate pumps. The concentrate pumps receive a permissive signal to run when density instrumentation indicates the evaporator bottoms have a liquid specific gravity of approximately 1.27 (1.27 is estimated to correlate with a Na concentration of 5 M).

Solids within the evaporator recirculation loop are maintained in a suspended state by the waste feed evaporator recirculation pump. If solids build up on the separator vessel wall above the liquid level, the walls will be washed with intermittent sprays. Purge air can be injected into the vapor space of the separator vessels to maintain the hydrogen concentration below the lower flammability limit.

Due to the dissolved salt content of the evaporator feed, there is the potential for solids deposition on vessel and reboiler tube surfaces; however, the potential for fouling has been minimized by employing a high vacuum design (to lower evaporation temperature), conditioned steam, and high recirculation rates. Crystallization is likely to occur at the liquid/vapor interface because of evaporation at the liquid surface. In order to remove solids deposits from the equipment, periodic washdowns will be carried out after transferring the entire separator vessel and recirculation loop contents to the UFP via the evaporator concentrate pumps. The vessel can then be filled with flush solution from the feed and concentrate flush lines, or dilute acid via the demister spray header. The flush solution would be used to dissolve crystallized salts and remove solids deposits. Following a routine vessel wash-down, the wash liquor will be boiled down. The resulting concentrate will be sent to the UFP for processing.

High-maintenance equipment exposed to highly contaminated fluids (reboilers, recirculation pumps, concentrate pumps, and feed pumps) are located in a hot cell, and the equipment must be remotely maintained. The waste feed evaporator feed vessels (FEP-VSL-00017 A/B) and the separator vessels (excluding de-entrainment section) (FEP-SEP-00001 A/B) are located in the black cell and will not be maintained over the life of the plant: The condensers, vacuum ejectors, and condensate collection vessel are contact maintained. The de-entrainment equipment can be accessed via shielding plug from 56-ft level for contact maintenance.

2.3.4.3 Relationship to Other Systems

Recycles are routed to the FEP feed vessels (FEP-VSL-00017 A/B) from the following systems:

- Effluents from the PWD vessel (PWD-VSL-00044) and acidic/alkaline effluent vessels (PWD-VSL-00015 and PWD-VSL-00016)
- Flush from the RDP vessels (RDP-VSL-00002 A/B/C)
- Recycle concentrate from the UFP (UFP-VSL-00001 A/B)
- Waste feed from the FRP (FRP-VSL-00002A/2B/2C/2B)
- HLW feed from the HLP (HLP-VSL-00022)
- Anti-foam from the Anti-Foam Regent System

In the event the ultrafiltration operation yields low solids concentrations (i.e., 10 wt % or less), the evaporator can provide a contingency operation to further increase the washed solids concentrations (up to 20 wt%).

2.3.4.4 Development History and Status

The FEP evaporator trains are similar to the Hanford 242-A Evaporator. Waste inventories that are dilute are concentrated in the Hanford 242-A Evaporator to a maximum specific gravity of approximately 1.44 (or 10 M Na). However, the 242-A Evaporator does not process waste solutions containing high solids content. The FEP evaporators are designed to produce a concentrate of 5 M Na, which is not intended to concentrate beyond the point of crystallization. The solids within the FEP evaporators primarily originate from suspended solids present in the feeds and recycles. It is anticipated that the suspended solids concentration in the evaporator product will not exceed 15 wt%. The system is not expected to perform beyond the demonstrated capability, but the evaporator includes more bubble trays than is typically used. The evaporator tower decontamination factor is not greater than what vendor data supports.

SRS personnel conducted modeling (SCT-M0SRLE60-00-154-05) of waste feed evaporator offgas and recommended more studies to address concerns over the partitioning of organics between the evaporator overhead and bottoms. The organic partitioning was significantly impacted by the amount of water being fed into the system from SBS recycle and ultrafiltration caustic wash. SRS personnel also identified the possibility of a hazardous mercury compound forming in the WTP evaporator overhead and service room (or other locations where sampling or maintenance is performed) (CCN:074276) after dimethyl mercury was found in the 3H evaporator process condensate and in the 3H evaporator overheads and service room (WSRC-TR-2003-00238).

The mechanical integrity of the demisting section due to erosion/corrosion effects over a 40-year operating life was identified as a primary concern (CCN:050417). WTP Plant Design personnel suggested that a single, large demister pad assembly could be first lifted up above 56-ft floor through the existing plug. The assembly could then be moved by crane north (for FEP demister pads) and positioned above a new plug leading into the hot cell. The assembly could then be lowered through the new opening on the 56-ft floor down to the hot cell floor for replacement and disposal of the old demister pads assembly once it is in the hot cell.

SRS personnel summarized testing for resolution of the project evaporation issues in the closure report (24590-PTF-RPT-RT-03-001) for the Research and Technology evaporator test program. Four issues were closed: (1) waste foams in the evaporator; (2) excessive aluminum silicate scale in the treated LAW evaporator; (3) LAW SBS condensate returns that produce uranium precipitates, and (4) dimethyl mercury in WTP evaporator overheads. These are discussed in more detail in Section 2.3.3.4. Foaming in the FEP was not considered significant and anti-foam agents were effective. Equipment will need to be periodically inspected for scale buildup during operations and cleaning performed as required.
The criticality calculation showed that criticality issues for uranium precipitates were extremely unlikely. The formation of dimethyl mercury would not be expected at the mild operating temperature of the WTP evaporators. The effects of potential waste recycle streams from HLW, LAW, and the Analytical Laboratory on the evaporation process was not investigated.

During the bench-scale tests SRS conducted with non-radioactive simulants, it was discovered that additional solids precipitated during addition of the acid cleaning solution to the UFP recycle.
The blended UFP recycle solution formed gels when the pH is reduced below 12 by the acid content of the cleaning solution. NaOH was therefore used to adjust the pH of the blended UFP recycle (WSRC-TR-2003-00238). The EFRT (CCN:132846) identified unresolved issues with chemical and physical plugging because some of the waste feeds have not been characterized. The Contractor's Mechanical Systems Process Technology and Engineering group is capturing approaches to reverse or mitigate line plugging in a design guide titled, *Avoiding Chemical Line Plugging - Plant Design Considerations* (24590-WTP-GPG-M-0059, Rev. 0 draft).

Other technology issues evaluated in the SIPP test are common to both the FEP and TLP. Results of this testing is described in Section 2.3.3.4.

2.3.4.5 Relevant Operational Environment

The operating environment for the FEP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001) and the FEP system description (24590-HLW-3YD-FEP-00001). The relevant environment for the FEP is the:

- The feed vessels (FEP-VSL-00017 A/B) shall operate by both filling and discharging at the same time or by alternating with one vessel filling and the other discharging.
- Operations shall vary cycle time according to equipment availability, operator preferences for recycle management, and throughput requirements.
- The vessel vent system shall maintain the hydrogen concentration to below the lower flammability limit.
- Black cell vessels shall retain their integrity under worst case service conditions (pressure, temperature, corrosion, erosion, mechanical loading, and seismic loading) for the lifetime of the PT Facility.

2.3.4.6 Comparison of the Relevant Environment and the Demonstrated Environment

The FEP was demonstrated in a relevant environment. It is projected that the FEP will achieve operational requirements in normal and challenge conditions because of the following design features that were added to the final WTP design to address identified issues.

Feed Vessels: Common to all operations is the principal requirement that if a feed vessel is receiving from a source vessel, no other source vessel outside of the FEP can discharge to that feed vessel.

Evaporators: Although the evaporator trains can operate simultaneously (each contains independent control logic), a single evaporator train has sufficient capacity to support the maximum production requirements (60 MT/day LAW glass and 6 MT/day HLW glass production).

2.3.4.7 Technology Readiness Level Determination

The FEP was determined to be TRL 4 because vessels in the FEP (FEP-VSL-00017A/18B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the FEP, is determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved.

The FEP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site and is based on extensive lab-scale and pilot-scale prototypic testing that has been completed to demonstrate this technology. The FEP evaporator is a mature technology. Technology issues evaluated included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of salts of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.

2.3.5 Ultrafiltration Process System (UFP)

2.3.5.1 Function of the UFP

The primary functions of the UFP are to: (1) receive waste feed and WTP recycles; filter and concentrate solids, wash solids, and leach solids; and (2) transfer permeate and solids for further treatment and immobilization. The UFP may also be used to carry out the precipitation process used to remove strontium (Sr) and transuranic (TRU) elements from complexed waste.

2.3.5.2 Description of the UFP Process

The UFP performs the initial process steps in the separation of Hanford tank waste into HLW and LAW fractions. The principal process steps include filtration that separates solids from liquids and washing/ leaching that dissolves non-radioactive species from the solids. The liquids and dissolved solids that pass through the ultrafilters (permeate) are sent to the CXP and the solids are sent to the HLW Vitrification Facility.

The UFP is presently undergoing redesign. The most recent version of the *System Description for Ultrafiltration Process System (UFP)* (24590-PTF-3YD-UFP-00001, Rev. 0) was issued September 11, 2002. Figure 2.4, taken from the system description, provides a basis for describing the UFP hardware and process flow. Modifications being considered during the current redesign efforts will be noted later in this section.

UFP Components: There are two parallel UFP processing trains: Two 48,000 gallon (batch volume) ultrafiltration feed preparation vessels, UFP-VSL-00001A and B, receive LAW feed from the FRP, high-level waste from the HLP, and/or evaporator concentrate from the FEP. They are also used for precipitation of Sr-90 and TRU from complexed wastes. PJMs are used to agitate vessel contents. The chemicals used for the precipitation of Sr-90 and TRU can be added to the top of UFP-VSL-00001A and B.

The 25,000 gallon (batch volume) ultrafiltration feed vessels, UFP-VSL-00002A and B, are used to perform solids washing and caustic and oxidative leaching on waste received from the UFP-VSL-00001A/1B vessels. The current design adds caustic, wash water and oxidative leaching reagents (sodium permanganate [$NaMnO_4$] and NaOH) to the top of vessels UFP-VSL -00002A/2B. PJMs and spargers are used to mix caustic with vessel contents. PJMs and pump recirculation are used to mix wash water and oxidative leaching chemicals. The Contractor is examining the possibility of using in-line mixing of chemicals in the recirculation line to shorten blend times. Mixing technology, including the PJMs, is evaluated separately in Section 2.3.6.

The ultrafilters receive waste from UFP-VSL-00002A/2B and separate the slurry into HLW solids and permeate liquid. The HLW solids are sent to HLP vessels (HLP-VSL-00027A/27B) and eventually to the HLW Vitrification Facility, and permeate liquids containing approximately 5 M Na are sent to two 22,000 gallon ultrafilter permeate collection vessels UFP-VSL-00062A and 62B and on to the CXP. Dilute wash/leachate permeate liquids are collected in UFP-VSL-00062C and sent to the PWD for eventual recycle to the waste feed evaporator for concentration. Each of the two cross-flow ultrafilter trains consists of three modules connected in series and laid out horizontally. Each module consists of a bundle of 241 porous stainless steel tubes. Each tube is 8 ft long, 1/2-inch inner diameter (ID) x 5/8-inch outer diameter (OD), and has a nominal filter pore rating of 0.1 micron.

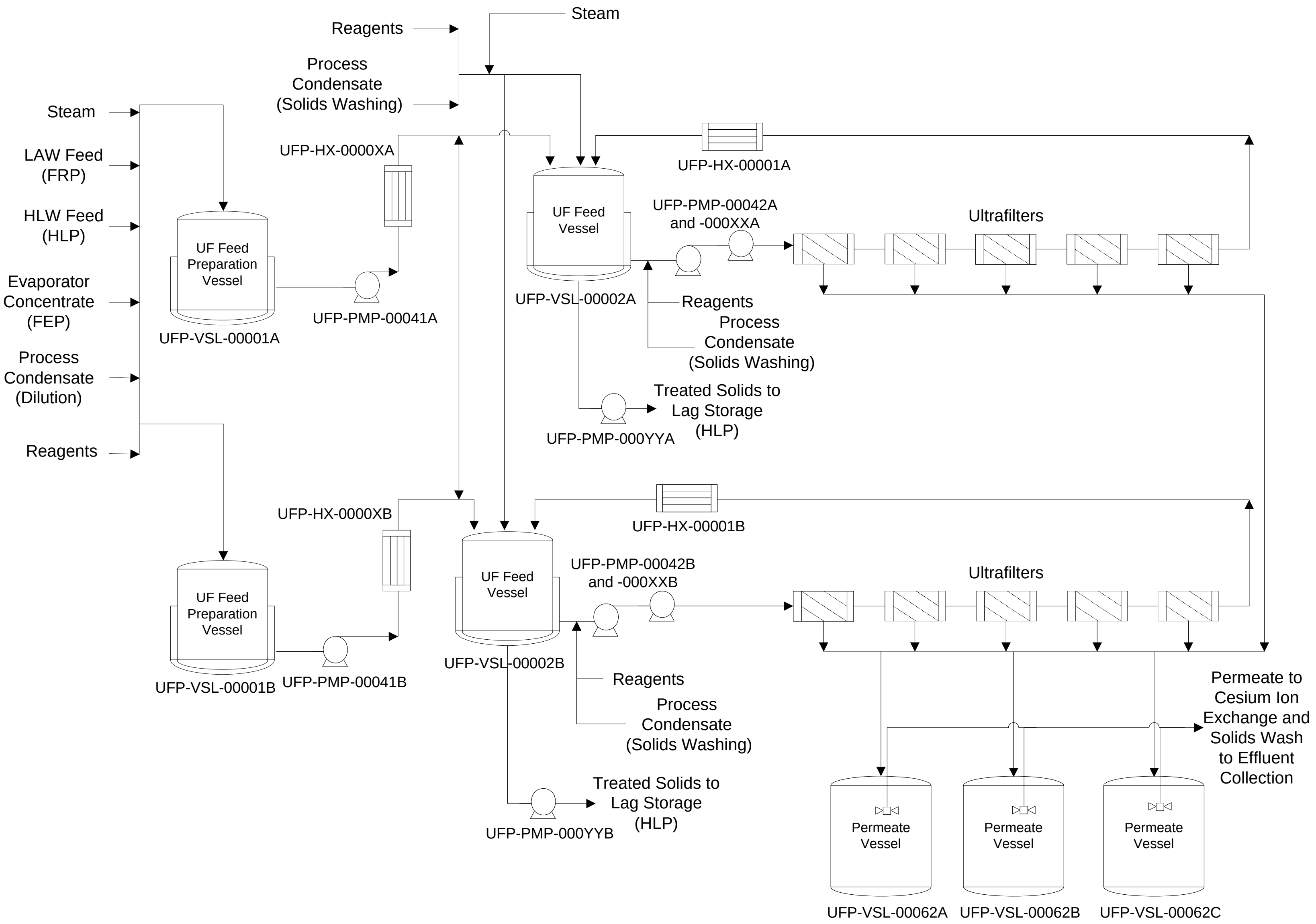


Figure 2.4. Ultrafiltration Process System Simplified Flow Diagram

The ultrafilters can be periodically backpulsed (a short pulse of permeate in the reverse direction) to flush solids from the filter surface. They can also be cleaned by soaking in process condensate, dilute nitric acid, or caustic. The goal of both backpulsing and cleaning is to restore filter flux levels.

The Contractor is examining a modification that would increase the number of modules in each ultrafilter train to five and lengthen the tubes in three of the modules to 10 ft. Filter units would be laid out horizontally. This modification would increase filter surface area by 92% to (from 602 ft^2 to 1,162 ft^2). This design change would also require placing a second pump in series with UFP-PMP-00042A and B in order to generate a required 70% increase in pump head.

UFP Process Description: The UFP is used for the following processes, each of which has its own process flow: concentration, washing, caustic leaching, oxidative leaching, and Sr/TRU precipitation. The two filter trains (A and B) operate independently. The following process flow descriptions are written for filter train A.

1. Solids Concentration (Filtration): Waste is received in vessel UFP-1A from HLP-VSL-00022, the FRP, and FEP. The volumes of the waste feed sources are adjusted to achieve a target concentration in vessel UFP-VSL-00001A of 4 wt% solids and 5 M Na. When vessel UFP-1A is full, and cooled if necessary, the waste is blended by PJMs, and transferred to vessel UFP-VSL-00002A using pump UFP-PMP-00041A. When vessel UFP-VSL-00002A is full, the waste is mixed using PJMs, the variable speed recirculation pump, UFP-PMP-00042A, is turned on and the waste slurry is pumped through the filters at the design velocity (12 to 15 ft/sec). Filter permeate is routed to permeate vessel UFP-VSL-00062A or B. The solids fraction is recirculated back to vessel UFP-VSL-00002A. Additional waste is continually transferred into UFP-VSL-0000A from UFP-VSL-0000A to make up for the loss of volume as permeate. Concentration of solids continues until the desired wt% solids are generated in vessel UFP-VSL-00002A. The present design target endpoint for solids concentration is 20%. Once concentrated, the waste will be washed with process condensate.

2. Caustic Leaching: Caustic leaching is only performed if warranted. If not warranted, then this step is skipped and the solids are washed. After solids concentration is complete, the recirculation pump, UFP-PMP-00042A, is turned off and enough 19 M NaOH added to make the liquid 3 M in hydroxide (OH). The resulting caustic solution in vessel UFP-VSL-00002A is then mixed, heated to 80° to 90°C, and digested until as much Al and other caustic soluble components as possible enter the liquid phase. The Contractor is investigating raising the leaching temperature to 100°C.

   After caustic leaching is complete (8 hours), the vessel contents are cooled to 25°C and the solids re-concentrated to approximately 20 wt%. The Contractor is investigating raising the filtration temperature to 45°C in order to improve flux rates limit the amount of NaOH that must be added and increase batch size. The caustic permeate is sent to vessel UFP-VSL-00062A/B/C and eventually on to the CXP.

   The Contractor is examining the possibility of carrying out caustic leaching in vessels UFP-VSL-00001A and 1B. This option would eliminate the time dedicated to leaching in vessels UFP-VSL-00002A and 2B.

3. Washing: The concentrated solids are washed with process concentrate to remove dissolved components such as Na and Al. The process concentrate is added while the concentrated waste is re-circulated through the ultrafilters. The wash permeate is routed to vessel UFP-VSL-00062A, B, or C (usually C) where it is collected and eventually sent on to the PWD for concentration by evaporation and eventual recycle to the waste feed. The washed solids may be sent directly to the HLW vitrification system (vessels HLP-VSL-00027A/B) or retained for oxidative leaching.

4. Oxidative Leaching: Some waste solids contain concentrations of chromium (Cr) that will severely limit HLW glass loading. Oxidative leaching studies are still in exploratory laboratory stages. However, present plans are to treat high Cr sludges with NaOH and $NaMnO_4$ in vessel UFP-VSL-00002A to remove as much Cr as possible. It is anticipated that the process will be carried out in UFP-VSL-00002A in recirculation mode. Process is performed at ambient temperatures (25°C) and the reaction time is nominally 6 hours. The leached solids will then be washed and concentrated. Leach and wash solutions will be sent to UFP-VSL-00062C and then to the PWD and processed in the FEP. Solids will be sent to the HLW Vitrification Facility.

5. Sr/TRU Precipitation and Removal: Some wastes contain complexants that keep HLW Sr-90 and TRU in the liquid phase. These wastes will be received from FEP at 6 M Na in vessel UFP-VSL-00001A, agitated, and heated to maintain the temperature at 50°C (normal operating temperature of FEP evaporator). NaOH, non-radioactive strontium nitrate ($Sr(NO_3)_2$), and $NaMnO_4$ will then be added and the vessel contents thoroughly mixed. After radioactive Sr-90 and TRU solids precipitate from solution (about a 4-hour reaction time), the vessel contents are cooled and transferred to vessel UFP-VSL-00002A where they are concentrated to approximately 15 wt% using the ultrafilters, washed with process condensate, and sent to the HLW Vitrification Facility. Ultrafilter permeate is sent to the PWD and processed in the FEP. The caustic and oxidative leaching steps are not performed on the Envelope C precipitate.

2.3.5.3 Relationship to Other Systems

UFP is the initial pretreatment system. It receives LAW feed from FRP, HLW feed from the HLP, and plant recycles and process condensate from the FEP. It also receives process chemicals from the Nitric Acid Reagent System, Sodium Hydroxide Reagent System, Sodium Permanganate Reagent System, and Strontium Nitrate Reagent System. It separates the soluble waste fraction from the solids fraction and sends the former to the CXP and the latter to the HLP. Wash liquids are sent to the PWD for eventual recycle.

2.3.5.4 Development History and Status

The development history and status of the UFP is best approached in terms of the physical system and the individual processes. This section will outline the development work that has been completed for the equipment and for each process.

The current baseline ultrafiltration design consists of two cross-flow ultrafilter trains each consisting of three filtration modules connected in series. Each module consists of a bundle of 241 porous stainless steel tubes. Each tube is 8 ft long, 1/2 inch ID x 5/8 inch OD and has a nominal filter cutoff of 0.1 micron. The trains are laid out horizontally. They are hard-piped so that the entire train must be lifted out and replaced as a unit.

The EFRT (CCN 132846) judged that the baseline filtration capacity was inadequate to allow for processing uncertainties and filter degradation over time and recommended that it be increased by a factor 2 to 3 to improve the margin and flexibility. The Contractor is examining a modification that would increase the number of modules in each train to five and lengthen the tubes in three of the modules to 10 ft, the two other filter modules would have 8 ft long filter tubes. Filter module units would still be laid out with a slight slope to horizontal. This proposed modification would increase filter surface area by 92%. It would also require placing a second pump in series with UFP-PMP-00042A and B in order to generate a required 70% increase in pump head.

The EFRT reviewed the proposed modification in January 2007 and issued two documents (*Review of Process Design Changes*, January 28, 2007, and *Review of Issue Closure Plans*, February 2, 2007) that expressed concerns about the drainage and flushing of the horizontal filter arrangement and the high pressure pumps. The latter review stated:

> "The proposed new arrangement for the ultrafilter with five modules connected in series may not provide sufficient drainage and may cause problems with residual slurry solids buildup in the lower tubes of each module.
>
> The need to remove and discard a complete five-module filter system because of a blockage or partial blockage, and its replacement with a new unit, may be both lengthy and costly.
>
> An alternate vertical arrangement of filter modules was strongly recommended by the reviewers. Such an arrangement would trap residual solids within the tubes themselves and have the potential to allow the removal of individual modules or tube bundles."

The Contractor enlisted Energy*Solutions* to develop a design concept for a vertical arrangement of filter modules. Preliminary Energy*Solutions* designs (ES-5501-G-0001) have incorporated the EFRT recommendations and increased filter surface area beyond that of the horizontal filter bundle arrangement. The vertical arrangement provides approximately 2.4 times the baseline filter area, and the horizontal filter arrangement as conceptualized by the Contractor provides about 1.9 times the surface area.

To fit more filter area in the confined hot cell space, the Energy*Solutions* concept eliminated one pulsepot, lowered the level of the pulsepots below the level of the filters, and eliminated the pressure transmitters between each filter bundle that allowed independent transmembrane pressure control on each bundle. These changes from the current design have not been thoroughly evaluated for impact on system operability. Impacts on hydrogen in piping and ancillary vessel requirements have also not been completed.

Hanford Site tank wastes are highly variable. They include liquids with small amounts (<1 wt%) of entrained solids and sludges from a variety of extraction and recovery processes. Confidence in the UFP and the associated processes will require substantial lab- and engineering-scale testing with real and simulated wastes.

Summary of Test Results

1. Concentration (Filtration): Ultrafiltration has been used in a variety of industries and the DOE. However, the EFRT (CCN:132846) concluded that "…the use of ultrafiltration in the WTP is a challenging application of this technology because of the high solids concentration target, which is beyond the typical application of this technology."

   Laboratory-scale filtration testing has been carried out on wastes from a limited number of tanks. The information gained from these tests has been used to estimate filter flux rates and their variation with filtration time and concentration and to develop simulants for laboratory- and engineering-scale testing.

   Table 2.3 summarizes the dimensions of the ultrafiltration test systems and the WTP baseline system and a proposed WTP modified system. Table 2.4 summarizes the ultrafiltration tests on Hanford Site wastes and simulants that have been carried out.

Table 2.3. Summary of Filtration Test Apparatus

	Lab-Scale	**Bench-Scale (CUF)**	**Pilot-Scale (SIPP)**	**WTP Baseline**	**WTP Plant Modification**
Material pore size	316 SS 0.1 and 0.5 micron	316 SS 0.1 micron	316 SS 0.1 micron	316 SS 0.1 micron	316 SS 0.1 micron
Tube Length	6 inch	24 inch	96 inch	96 inch	96 and 120 inch
Tube ID OD	0.5 inch 0.625 inch	0.375 inch 0.5 inch	0.5 inch 0.625 inch	0.5 inch 0.625 inch	0.5 inch 0.625 inch
Tube Arrangement	single tube	single tube	bundle of 7 tubes	3 bundles of 241 tubes in series	5 bundles of 241 tubes in series 1st, 3rd, 5th bundles 120 inch long 2nd, 4th bundles 96 inch long
Tube Orientation	horizontal	horizontal	vertical	horizontal	horizontal
Pump	low shear	low shear	centrifugal	centrifugal	2 centrifugal in series

CUF - cells unit filter
SIPP - Semi-Integrated Pilot Plant
SS - stainless Steel

Table 2.4. Summary of Filtration Tests[1]

Tank	Type of Waste	Test Apparatus	Final Wt. % Solids	Notable Results	Ref
AN-102	entrained solids <0.1 wt%	cells unit filter (CUF)		filter fouled quickly	WTP-RPT-151
	precipitated strontium (Sr)/transuranic (TRU)		13.9		WSRC-TR-2003-00204 WSRC-MS-2005-00756
	simulant	Semi-Integrated Pilot Plant (SIPP)	25	pilot flux 10-87% below CUF PJM mixing during precipitation led to low flux	
AN-102/ C-104	precipitated Sr/TRU	CUF			WTP-RPT-151
AN-104	dissolved saltcake and entrained solids	CUF	1	filter could not be cleaned to original state	WSRC-TR-2003-00295
AN-105	simulant	bundle of 7 tubes, 40 inch long 0.375 ID x 0.5 OD, .1 micron	8		WSRC-MS-99-00467
AN-107	entrained solids <0.1 wt%	CUF		filter fouled quickly	WTP-RPT-151
	precipitated Sr/TRU		4		WTP-RPT-151
AW-101	entrained solids <0.1 wt%	CUF		filter fouled quickly	WTP-RPT-151
AY-102/ C-106	sludge	CUF	15	nitric acid (HNO_3) cleaning "ineffective"	WSRC-TR-2003-00240
	sludge simulant		16		
	sludge simulant	SIPP	24	SIPP flux 30-50% below CUF	WSRC-TR-2005-00105
AZ-101	neutralized current acid waste (NCAW) sludge	CUF	17.9	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
	leached NCAW		22		
AZ-102	NCAW sludge	CUF	20	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
	leached NCAW		20		
B-110	Bismuth phosphate ($BiPO_4$) sludge in dilute sodium hydroxide (NaOH)	lab-scale	8	Test used 0.1 micron pore size Graver filter. Graver filter is an anisotropic filter with a titanium oxide (TiO_2) coating on a 2 micron pore size sintered metal filter substrate	WTP-RPT-151
C-104	sludge, washed sludge, and leached sludge	CUF	20-23	Test used 0.1 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151

Table 2.4. Summary of Filtration Tests[1]

Tank	Type of Waste	Test Apparatus	Final Wt. % Solids	Notable Results	Ref
C-106	sludge in dilute NaOH	lab-scale	8	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
C-107	sludge in dilute NaOH	lab-scale	8	One test used 0.1 micron pore size Graver filter. Second test used 0.5 micron pore size Mott isotropic, sintered metal filter.	WTP-RPT-151
	combination of supernatant and leach and wash solutions			no solids visible in feed no solids on filter	
S-107	sludge in dilute NaOH	lab-scale	8	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
U-110	sludge in dilute NaOH	lab-scale	7.5	Test used 0.1 micron pore size Graver filter.	WTP-RPT-151

[1] Except as noted, 0.1μm Mott filter used for all tests.

Examination of existing technology testing data contained in the references of Table 2.4 leads to the following conclusions:

- There is cells unit filter (CUF)-scale and lab-scale filtration data for 15 of 177 tanks.
- Waste from only four tanks has been concentrated to > 15%.
- Whole, major groups of tank waste compositions have not been tested at any scale.
- Large-scale (SIPP) tests have been conducted on only two simulants, which is only approximately 5% of the total volume of tank waste planned for processing.
- SIPP tests on simulants yield fluxes substantially below CUF results for the same simulants.
- CUF tests on entrained solids in four tanks show rapid dropoff in filter flux as the solids concentrate. Dilute wastes seem to be more difficult to filter. This suggests that low solids LAW should not be processed by itself and the Sr/TRU constituents in Envelope C tanks should be precipitated prior to filtration. [*Note: The WTP does not plan to process the dilute waste from tanks AN-104, AN-105, and AW-101 in the UFP. These wastes will be mixed with HLW feeds and processed in the UFP*.]
- Backpulsing tests were generally inconclusive with regard to restoring filter flux. The SIPP backpulsing (not entirely prototypic) showed some improvement in flux but it was not sustained. Backpulsing may be more useful in off-normal conditions such as restoring a fouled filter. Nitric acid cleaning is often ineffective and generally unable to return filters to original state.
- There is almost no filtration data on caustic and oxidatively leached waste.

WTP-RPT-151, *Review of Caustic Leaching Testing With Hanford Tank Waste Sludges*, draws the following additional conclusions for the filtration data it examined:

- Solids are recycled much more in CUF tests than is prototypical. [It appears that this plus the CUF pump alters the particle size.]

- Some of the simulants tested have not mimicked the waste chemistry and physics.
- Waste chemistry can change significantly with blending of waste types, resulting in precipitation of new and different solids that can have a major, catastrophic impact on filter behavior.
- Waste concentration by evaporation can form new solids that are more difficult to filter. Specifically, calcium carbonate ($CaCO_3$) and sodium oxalate solids may form, which are more difficult to filter.
- A used filter, cleaned with a clean 1 M HNO_3, exhibits a water flux of approximately half a new filter.
- Nitric acid alone is not always effective in cleaning a filter: oxalic and nitric/oxalic acid mixes [and NaOH] have been used in some cases.
- Envelope C [complexed] waste could not be filtered without first treating it with strontium carbonate ($SrCO_3$) and $NaMnO_4$ [to precipitate Sr/TRU]. The waste appears to contain polymer-colloidal solids that blind the filter.

2. <u>Washing and Caustic Leaching</u>: WTP-RPT-151 has summarized washing and caustic leaching data. Table 2.5 lists the wastes that have been tested and gives removal efficiencies for phosphorus (P), Al, and Cr. Tests have been carried out on a laboratory-scale with small quantities (<100 grams) of waste, under a variety of leaching and washing conditions. Most of the wastes have been washed and leached at several temperatures and NaOH concentrations, with 95° to 100°C and approximately 3 M NaOH, respectively, being the most common. Wash solutions, leachate, and washed/leached solids were analyzed for a variety of elements to determine removal of non-radioactive and radioactive species from the solid phase. Rheology and crystalline phases were also analyzed for most samples. Parametric studies were carried out on a number of wastes to determine the effect of time on leaching efficiency.

   As Table 2.5 illustrates, caustic leaching on a laboratory-scale has been carried out on waste from a relatively large number of tanks. The results for Al and P removal are variable but generally >50 to 90%. Cr removal is very variable. Caustic leaching, by itself, is unlikely to be adequate to remove Cr to acceptable levels. However, it is also clear that there is limited information for several waste classifications. Recent work (WTP-RPT-137, *Oxidative Alkaline Leaching of SX-101 and SY-102 and Its Impact on Immobilized High-Level Waste*) concludes that caustic leaching will probably remove 70 to 80% of sulfate from tank solids; however, WTP-RPT-137 also recommends this value should be verified by caustic leach testing on selected high-sulfate sludges.

   Extensive work has been done on characterizing the physical and chemical properties of the leached sludges including their morphology and rheology (WTP-RPT-151). However, there is very little information on the filterability of the leached sludges.

Table 2.5. Summary of Washing and Caustic Leaching Information from WTP-RPT-151

Group ID	Major Waste Type	Tanks Tested	Results Removal Efficiency
1	Bismuth phosphate ($BiPO_4$) sludge	B-104[1], -107[1], -110, -111 BX-107, -112 T-104, -107, -110, -111 B-201, B-202	P generally >90% Al generally <70% Cr generally <70%
2	saltcake (BY, T)	BX-110[2] BY-104, -108, -110	P variable 22 to 90% Al generally >90% Cr generally <50%
3	PUREX cladding sludge	BX-103,-105[3] C-102, -103[4], -104, -105	P minor element Al generally >90% except C-103 (52%), C-107 (22%) Cr variable
4	Reduction oxidation (S Plant) (REDOX) cladding sludge	U-108, -109	P not reported Al 54-81% Cr 5-13%
5	REDOX sludge	S-101, -104, -107[5], 110, -111 SX-108	P generally 65-99% Al variable 30-90% Cr generally >80%
6	S-saltcake (S) most tanks have low amounts of entrained solids	SY-103	P 98% Al 90% Cr 10%
7	tri-butyl phosphate (TBP) sludge	B-106 BX-109	P >90% Al >80% Cr 60-80%
8	FeCN sludge	TY-104	P 98% Al 63% Cr 86%
9	neutralized current acid waste (NCAW) sludge	AZ-101, -102	P 60% Al 80% Cr 60%
10	tanks containing a mixture of wastes	B-101 C-106, -107 -108, -109, -112 SX-113 SY-102 U-110	highly variable
11	a saltcake	AN-104	

[1] Tank also contains BY saltcake waste
[2] Tank also contains $BiPO_4$ sludge
[3] Tank also contains TBP and PUREX cladding sludges
[4] Tank contents transferred to a double-shell tank
[5] Tank also contains REDOX cladding sludge

A recent report (WTP-RPT-137, pg. 5.2) has concluded that “it would difficult to produce Hanford tank sludge simulants that would accurately mimic the partitioning behavior of the actual waste sludge solids in the caustic leaching and washing process.” If this is correct, engineering-scale testing of caustic leaching and filterability of the resulting product using simulants would not be useful.

Given the limited amounts of waste sludges that can be handled due to the radioactivity levels and the difficulty of obtaining samples, it is unlikely that engineering-scale testing using actual waste will be possible.

It is clear that the variable nature of the sludges will require that each batch of sludge sent to the WTP be tested in the lab before optimal plant conditions can be specified.

3. Oxidative Leaching: Early work at Pacific Northwest National Laboratory investigated the efficacy of various oxidants, caustic concentrations, temperature, and leaching times. Exploratory laboratory tests were carried out on wastes from eight tanks. Oxidants investigated included $NaMnO_4$, oxide (O_3), air, and sodium ferrite (Na_2FeO_4). MnO_4^- was determined to be effective and compatible with WTP processing. The leach conditions tested were not chosen to represent potential WTP processes. WTP-RPT-117, *Oxidative Alkaline Leaching of Washed 241-SY-102 and 241-SX-101 Tank Sludges*, contains a review of the work done to date, and WTP-RPT-117 and WTP-RPT-137 contain the latest detailed investigations of the oxidative leaching of tanks SX-101 and SY-102 and its effects on glass loading. These later investigations used test procedures that more closely resemble potential WTP processes. Potential reagents were evaluated by the Contractor, and a recommendation was made to use $NaMnO_4$ (24590-PTF-ES-PR-05-001; 24590-WTP-RPT-ENG-05-006).

   The oxidative leaching process is in the early laboratory stage of development. The combination of caustic leaching and MnO_4^- has been determined to be an effective means to solubilize Cr. The small-scale laboratory tests on tanks SX-101 and SY-102 sludges have shown that it is possible to remove >95% of the Cr, more than enough to eliminate Cr as the limiting factor on HLW glass loading. The earlier work seems to indicate that leaching effectiveness may be substantially less than 90% for some sludges. However, the earlier work did not optimize reaction conditions. Additional work is needed to optimize the concentrations of NaOH and MnO_4^-, the sequence of chemical addition, and the time and temperature of operation. No work has been done on the filterability of oxidatively leached sludges.

   Besides optimizing the conditions for Cr removal, attention will have to be given to the possibility of solubilizing plutonium (Pu) during the process. Solubilized Pu will pass through the ultrafilters and enter the LAW stream where it would be a concern if it concentrates during subsequent processing (e.g., on the ion exchanger), reaches levels in the LAW glass that would cause the glass to be classified as TRU, or affects the performance assessment for the LAW burial site. The work contained in WTP-RPT-117 and WTP-RPT-137 indicates that it is possible to adjust the oxidative leach process to limit Pu solubility to levels considerably below those that would cause LAW glass to become TRU waste or, if necessary, to precipitate and remove soluble Pu in a subsequent processing step. However, more laboratory work is needed

4. Sr/TRU Precipitation and Removal: This process will be required for two waste tanks. Tests of the process have been carried out on tank AN-102, a mixture of AN-102/C-104 sludge leachate, and AN-107 wastes (WTP-RPT-151). The process appears to be effective, and the resulting solids have been shown to be filterable (WTP-RPT-151; WSRC-TR-2003-00204; WSRC-MS-2005-00756). The untreated waste rapidly clogs ultrafilters, and the process seems to require efficient mixing of reagents and sludge to produce filterable products (WSRC-TR-2003-00204).

2.3.5.5 Relevant Environment

The UFP will be required to process waste from a majority of Hanford's 177 underground storage tanks. The waste is chemically and physically variable, and limited physical and chemical characterization data is currently available. Although most tanks have been sampled, available waste samples are limited in size (a few liters at most) and number. Solid waste samples may not be representative of the tank contents or of the waste as it will be fed to UFP for the following reasons:

- Waste solids in any given tank may vary horizontally and vertically. Different wastes were often deposited during multiple transfers and most likely did not settle in uniform layers. Vertical core samples of tank solids taken from different locations in the tank often bear little resemblance to each other.
- Core samples may not be representative. Most tanks are 75 ft in diameter. Core samples are 1 inch in diameter. Few tanks have had more than two core samples taken.
- Waste from a number of tanks will most likely be blended intentionally or inadvertently as it is staged for delivery to the WTP.

Consequently, the UFP will process a wide variety of wastes; the precise processing behavior of which will not be determined prior to staging for the WTP. Efficient processing of the waste will depend on having robust processing capability that has been determined by as comprehensive a set of waste and simulant testing as possible. Each batch of waste will have to be tested as it is staged in the tank farms and received at the WTP in order to determine efficient operating parameters.

2.3.5.6 Comparison of the Relevant Environment and the Demonstrated Environment

1. Ultrafiltration: Laboratory-scale filtration testing has been carried out on wastes from fewer than one tenth of the Hanford Site tanks. Waste from only four tanks has been concentrated to more than 15% due to limitation on sample volume. Pilot-scale testing is limited to simulants derived from two tanks; it is not known if the wastes tested are bounding. Major groups of wastes have not been tested.

   There is almost no ultrafiltration data on sludge that has been caustic leached. There is no ultrafiltration data on sludge that has been oxidatively leached. Laboratory-scale filtration data exists for Sr/TRU precipitated from both of the tanks containing wastes identified as requiring this processing step and engineering-scale data from simulant based on one tank.
2. Washing and Caustic Leaching: Washing and caustic leaching has been carried out at laboratory-scale on wastes from approximately one third of the tanks; however, the waste types in these tanks represent approximately 80% by volume of the sludge in the single-shell tanks and approximately 60% by volume of the sludge in double-shell tanks.
3. Oxidative Leaching: The final oxidative leaching process has not been experimentally determined. Exploratory laboratory-scale testing, not representative of anticipated WTP processes, has been carried out on wastes from eight tanks. Laboratory-scale testing that is more representational of possible WTP processes has been carried out on waste from two tanks.
4. Sr/TRU Precipitation and Removal: There are two tanks that contain complexed waste, AN-102 and AN-107. Laboratory-scale Sr/TRU precipitation and removal testing has been carried out on waste from both tanks and a simulant based on the wastes from AN-102.

The following provides a summary of commercial usage of ultrafiltration technology relevant to the design of the UFP:

Filters:

- Nuclear waste treatment – The Enhanced Actinide Removal Plant (EARP) (Sellafield) uses three filters in series for primary dewatering of ferric-based sludge (conc to 1-1.5 wt%), single filter for secondary dewatering to 10 wt% (consistency of toothpaste). This plant started hot operations in

1993 and has run continuously without any major problems. Reliability data from EARP between 1995 and 1999 shows a failure rate on the 13 filters of 0.08/year. This was based on the original CARBOSEP® and Ceraver ceramic filters, which relied on an elastomeric gasket to seal the tubes at the tubesheets. All failures were attributable to organic attach of this material causing it to soften and flow. Since 1999, the filters in EARP have been changed out for an all-welded, all-stainless steel design, and although reliability data is not available, it is likely to be significantly less than for the ceramic units. Since commencement of operations, there have been no problems or failure of the harness seal between the cartridge plug and the housing. The WTP design is all-welded construction and there are no seals subject to failure.

- Nuclear waste treatment – Oak Ridge National Laboratory Melton Valley, two in series for waste sludge, concentrated to 15 wt%. No performance details are available for this operation.
- Nuclear power stations – Four projects in wastewater treatment, 4 to 6 filters in series, 20 to 40 gpm permeate, low solids endpoint.
- Non-nuclear – Series filters are commonly applied in ultrafiltration and reverse osmosis.

Pumps:

- Weir Slurry identifies – Approximately 60 projects, mostly in the mining industry, with up to 8 pumps in series for slurry pipelines up to 35,000 gpm and very high heads with slurry particles up to 900 microns average size.
- Nuclear waste processing – No specific examples identified.

Pulsepots:

- Independent ultrafilter expert (Dr. Klaus Julkowski) suggested the UFP could be designed with a single pulsepot supporting three filters (CCN:032059) for space considerations and wall penetrations. This configuration has been utilized in full-scale operations (no references available). The WTP Project elected to use three instead of one to reduce backpulse line length. Current studies by Energy*Solutions* in the vertical filter study are revisiting the backpulse concepts for optimization of space considerations.

Ancillary Components:

- Spiral heat exchangers used for slurry service industrially. No known applications to nuclear waste processing.
- Filter cleaning strategies are consistent with industry practice. Avoiding overconcentration is the first line of defense. Flexibility is provided in the WTP design for alternate cleaning methods. Testing is planned to evaluate filter draining.

2.3.5.7 Technology Readiness Level Determination

The WTP ultrafiltration technology design is supported by a history of successful design and operation of relevant systems in both radioactive and non-radioactive service. However, specific pilot testing in a prototypical configuration on relevant waste simulants has not yet been performed to confirm efficiency of the UFP system for meeting throughput requirements.

The UFP was determined to be a TRL 3 because:

- The WTP ultrafiltration technology design has only been conceptualized on paper. There is no representative testing platform available for technology evaluation. However, the WTP Contractor is completing the design of an engineering-scale testing system for testing and evaluation.

- The oxidative leaching process is limited to proof of principle tests, and the final process has not been determined. Additional work is required to optimize the concentrations of NaOH and MnO_4^-, the sequence of chemical addition, and the time and temperature of operation.
- There is very little data on the filtration of caustic leached waste and no filtration data on oxidatively leached waste.
- Hot bench-scale testing will be used to evaluate the effectiveness of the UFP components; optimize NaOH and $NaMnO_4$ concentrations, sequencing, and timing; and demonstrate filtration of treated sludge wastes.
- Pilot-scale testing using simulants to demonstrate efficacy of flowsheet design concepts.
- Demonstration of integrated system will be performed at engineering-scale. Larger scale testing may be required pending evaluation of the results generated in the engineering-scale tests (24590-PTF-TSP-RT-07-001, Rev. A).

Based upon the low technology maturity of the UFP, it is recommended that:

Recommendation 5

Development and testing at a laboratory-scale with actual wastes, and at an engineering-scale with simulants, should be completed in prototypical process and equipment testing systems to demonstrate all detailed flowsheets for the UFP prior to final design. The testing should validate the scaling methodology for mixing, chemical reactions, and filter surface area sizing; determination of process limits; and recovery from off-normal operating events.

> *Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-12, "Undemonstrated Leaching Process," and WTP Baseline testing of the Oxidative Leaching Process.*

Recommendation 6

Evaluation of a vertical modular equipment arrangement for the UFP filter elements for increasing the filter surface area should be continued. The design configuration (currently proposed horizontal or vertical orientation of the filters) that has the highest probability of successfully achieving performance requirements should be thoroughly tested in high fidelity, prototypical engineering-scale tests using simulants that represent a range of tank waste compositions. Testing scope should include all filtration system operations, process flowsheets (caustic and oxidative leaching and strontium/transuranic precipitation), high-temperature filtration, and filter back pulsing, cleaning, draining, and replacement. Based on the results of this testing, a design concept (either the horizontal arrangement proposed by the Contractor or the vertical arrangement conceptualized by Energy*Solutions*) should be selected for final design.

Supporting Recommendations

- The strategy and method to scale the ultrafiltration processes (mixing, chemical reaction and filter surface area) to predict performance of the ultrafiltration system should be established to ensure a high-fidelity UFP engineering-scale test platform and support useful interpretation of the testing results.

2.3.6 Pulse Jet Mixer (PJM) System

2.3.6.1 Function of the PJM System, Pulse Jet Ventilation System, and Pretreatment Vessel Vent Process System

The function of the PJM system is to mix waste streams comprised of liquid and solids in specially designed vessels to dissipate gases, blend liquids and solids, and suspend solids for sampling and transport.

2.3.6.2 Description of the PJM System

The PJM and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003).

PJM devices are long cylindrical vessels that draw in fluid by a vacuum and then pressurize to partially eject the fluid to cause mixing; much like a syringe draws in and expels fluid. These devices have been shown to be reliable and have no moving parts that require maintenance. Thus, the PJM was selected to be used in vessel systems that were designed to have no maintenance over the 40-year operational design life of the WTP.

The PJMs can be operated either in a continuous pulsing mode, or turned off for a time and restarted in the pulsing mode, depending on process requirements. In vessels that contain particulates, the solids will settle to the bottom between mixing periods. When the PJMs restart, settled solids must be re-suspended.

A PJM system consists of the following components:

- Valves
- Fluidic controller assembly
- Jet pump pair
- Piping
- PJM vessels fitted with nozzles, located in the process vessel

The operating concept for the PJMs is presented in Figure 2.5.

A jet pump is used to pull a vacuum on the PJM and draw process fluids into the PJM vessel from the process vessel. This is the suction phase of the PJM cycle. When the PJM vessel is full, the jet pump is switched from vacuum to pressure mode. This is called the drive phase. Air pressure applied to the PJM vessel is used to force fluid back out of the PJM vessel and into the process vessel, thereby mixing the process vessel contents. The application of pressure is halted prior to the complete discharge of fluids from the PJM such that no air is discharged into the process vessel (a condition called overblow). The PJM is then vented to depressurize the PJM. This is the vent phase of the cycle.

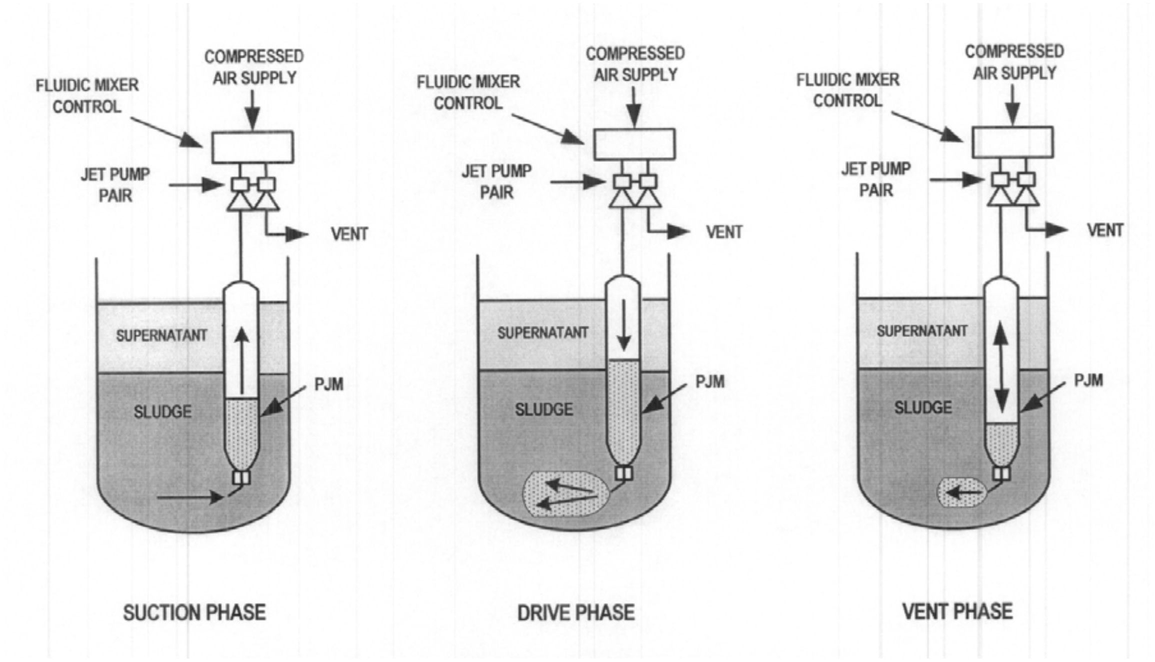


Figure 2.5. Operating Principles of a Pulse Jet Mixer

2.3.6.3 Relationship to Other Systems

The WTP vessels that contain PJMs are summarized in Table 2.6. This table presents the vessel number, common name, material of construction, number of PJMs in each vessel and vessel capacity. The primary interfaces with the PJM system are the vessels; the air supply to the PJMs is provided by the Plant Service Air System. The offgas treatment for the PJM is the *Pulse Jet Ventilation System* (24590-PTF-3YD-PJV-00001).

Table 2.6. Summary of PJMs in WTP Pretreatment and HLW Vitrification Facilities

Vessel Number	Common Name	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
CNP-VSL-00004	Cesium Nitric Acid Recovery Vessel	304L	4	6
CXP-VSL-00004	Cesium IX Caustic Rinse Collection Vessel	304L	1	6
CXP-VSL-00026A/26B/26C	Cesium Ion Exchange Vessels (3)	316L	6	26
FEP-VSL-00017A/17B	Waste Feed Evaporator Feed Vessels (2)	316L	8	50
FRP-VSL-00002A/2B/2C/2B	Waste Feed Receipt Vessels (4)	316L	12	375
PWD-VSL-00015	Acidic/Alkaline Effluent Vessels	316L	8	80
PWD-VSL-00016	Acidic/Alkaline Effluent Vessels	316L	8	80
PWD-VSL-00033	Ultimate Plant Overflow Vessels	316L	8	15
PWD-VSL-00043	Ultimate Plant Overflow Vessels	316L	8	15
PWD-VSL-00044	Plant Wash and Disposal Vessel	316L	8	60
RDP-VSL-00002A/2B/2C	Ion Exchange Spent Resin Collection and Dewatering Vessels (3)	316L	4	8
RLD-VSL-00007	HLW Radioactive Liquid Waste Disposal Vessels (2)	316L	4	9

Table 2.6. Summary of PJMs in WTP Pretreatment and HLW Vitrification Facilities

Vessel Number	Common Name	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
RLD-VSL-00008	HLW Radioactive Liquid Waste Disposal Vessels (2)	316L	4	6
TCP-VSL-00001	LAW Concentrate Storage Vessel	316L	8	93
TLP-VSL-00009A/9B	LAW SBS Condensate Receipt Vessels (2)	316L	8	80
UFP-VSL-00062A/62B/62C	Ultrafiltration Permeate Vessels (2)	316L	6	22
CNP-VSL-00003	Eluate Contingency Storage Vessel (1)	316L	4	12
HLP-VSL-00022	HLW Blend Storage Vessel	316L	12	160
HLP-VSL-00027A/27B	HLW Lag Storage Vessels (2)	316L	8	86
HLP-VSL-00028	HLW Feed Receipt Vessel	316L	8	81
HOP-VSL-00903/904	SBS Condensate Receiver Vessels (2)	C-22	4	6
UFP-VSL-00001A/1B	Ultrafiltration Feed Preparation Vessels (2)	316L	8	48
UFP-VSL-00002A/2B	Ultrafiltration Feed Vessels (2)	304L	6	25

2.3.6.4 Development History and Status

PJM Design Concept Development

The PJM design concept was based on technology developed jointly by United Kingdom Atomic Energy Agency (UKAEA) and British Nuclear Fuels Limited, Inc. (BNFL). The PJM technology is used in some nuclear facilities in the United Kingdom. The PJM design concept for mixing of fluids was used in the initial WTP design completed by BNFL and BNI. A description document (24590-CM-TSA-HXYG.0008) was prepared by BNFL in 2001 to provide the technical basis for the use of the PJMs in the initial WTP conceptual design phase (September 1996 to May 2000). During the conceptual design phase, vessels with PJMs were identified along with the following: vessel capacity and dimensions, number of PJMs, and fluid properties (i.e., temperature, specific gravity, viscosity, and solids content). The basis for the specifications was not provided to DOE.

Following WTP contract award to BNI in December 2000, the design development for the PJMs (and fluidic devices) mixing technology was discontinued until September 2002 when AEA Technology Inc. was subcontracted by BNI to provide the PJM and fluidics systems designs. In December 2002, AEA Technology issued *Fluidics Design and Methodology Report; Pulse Jet Mixing Systems* (24590-QL-POA-MPEQ-00002-04-03; ESI Document No. 2141-04-116). This design methodology report outlined the approach to complete the design of the PJMs and identified the relative roles of AEA Technology and BNI (buyer) in this design process. Major observations and steps in the design methodology included:

- The buyer is to provide the vessel dimensions (diameter, height, liquid operating levels), liquid properties (density, viscosity, temperature, vapor pressure), solids properties (density, particle sizes, concentration), mixing duty requirements, and length of air piping to jet pump pair.
- AEA Technology will complete a preliminary design of the PJMs based on information provided by the buyer and the following major assumptions:
    - The PJMs have a maximum area of influence of 17 m^2 based on vessel plan area.

  - The volume of the pulse tubes assumes 5% of the maximum liquid volume if the solids are less than 5 wt%, and the volume of the pulse tubes is 10% of the maximum liquid volume if the solids are greater than 5 wt%.
  - The height of the pulse tube is below the maximum liquid level. From this information, the diameter of the pulse tube is determined.
  - The pulse tube nozzle diameter is 0.1 m (4 inch).
  - The target drive velocity is 8 m/sec.

  The preliminary design did not take into account the liquid and solid physical properties.

- The buyer will conduct Computational Fluid Dynamic (CFD) modeling to verify the adequacy of the PJM design. AEA Technology will review the CFD analyses.
- AEA Technology recommended that "arduous mixing duties are subjected to physical testing, by construction of a suitable testing facility and operation of a prototype PJM system using simulants." The criteria for decision on whether or not testing is required will include (but are not limited to):

> "The level of confidence in the results of the CFD analysis.
>
> The extent to which difficult to predict chemical reactions may occur within a vessel, which may affect fluid properties.
>
> The Quality Assurance and Quality Control requirements related to the mixing system (e.g., sampling accuracy, homogeneity levels etc.)
>
> The extent to which the mixing duty falls outside previous experience."

In 2003, BNI was unable to achieve acceptable confirmation between their CFD analysis and the proposed AEA Technology PJM designs for the high solids containing vessels (UFP-VSL-00002A/2B, HLP-VSL-00027A/27B, HLP-VSL-00028, and the HLW concentrate receipt vessels (CRV), which have been subsequently removed from the WTP flowsheet). The CFD analysis determined that the CFD model was not capable of simulating the complex non-Newtonian flow relationships and it was decided at that point to launch a test program to evaluate the design. The non-Newtonian fluids in the case of the WTP vessels was bounded by laboratory test data as having a Bingham plastic yield stress of 30 Pa and a consistency viscosity of 30 cP. Non-Newtonian fluids can have high viscosities (>100 Pa) if they are not periodically sheared by mixing systems. This fluid property potentially allows the accumulation of quantities of hydrogen in excess of the lower flammability limit for hydrogen (4%). Based on this analysis, BNI initiated an extensive testing program to develop and validate the designs for these high-solids containing vessels. The testing process led to subsequent phases of research and design development, testing, and ultimately implementation of a significantly different PJM configuration (using a PJM cluster) compared to the WTP conceptual design. This test program determined that PJMs in combination with spargers could successfully mix non-Newtonian fluids to release hydrogen gas.

The potential for excessive hydrodynamic loads from PJM overblows (large surge of air rather than slurry released from the pulse jet nozzle) that could result in a potential accident condition was identified in April 2004. Since the development of a mixing system for the high-solids containing vessels, the program has focused on the development of an integrated control system to assure avoidance of PJM overblows. The control system is currently undergoing testing.

The project timeline for the development of the PJM fluid mixing technology is presented in Table 2.7.

Table 2.7. Timeline of PJM Analysis and Development for the WTP

Date	Event/Activity
June 2000	BNFL completes conceptual design of PJM and fluidics mixing systems for WTP.
August-December 2000	AEA Technology continues fluidics design for WTP. The AEA Technology mixing criteria was simple: Vessels that contain no solids required a pulse volume of 5% of the vessel volume and those with high solids required a pulse volume of 10% of the vessel volume.
January-September 2001	AEA Technology continues to advance WTP conceptual design under CH2M HILL Hanford Group, Inc. Transition Contract (WTP project activities transitioned to BNI in April 2001).
August 2001	BNFL issues *Technical Basis for River Protection Project Waste Treatment Plant (RPP-WTP)-Power Fluidics System Design* (24590-CM-TSA-HXYG.0008). The document indicated adequacy of the PJM concept for WTP application. The report concluded that testing was required to develop and optimize the “suck and drive” type PJMs in high-solids bearing liquors and high-viscosity floc liquors.
October 2001 to September 2002	Extended period of negotiations between BNI, and AEA Technology and BNFL on intellectual property rights on fluidics technology and contracting.
March 2002	Overall plan for Computational Fluid Dynamics (CFD) analysis developed to support vessel delivery schedule. Newtonian vessels are planned for fabrication significantly in advance of non-Newtonian vessels.
April 2003	WTP determines CFD modeling will not accurately reflect actual fluid behavior of non-Newtonian fluids contained in seven WTP facility vessels.
June 2003	BNI’s Pulse Jet Mixer Task Team develops an integrated strategy for scaled testing to validate PJM mixing in WTP vessels containing non-Newtonian fluids. In addition, WTP Project funded work to determine WTP-specific hydrogen generation rate source terms and gas transport characteristics in representative scaled prototypic mixing configurations during PJM operation.
June 17, 2003	WTP Pulsed Jet Mixing and Hydrogen Release for Process Vessels Containing Non-Newtonian Slurries Action Plan approved. Trend 852 - Non-Newtonian Fluid PJM Mixing Tests approved by WTP. Trend 867 - Hydrogen Testing approved by WTP.
August 1, 2003	WTP awards PJM testing scope to Battelle (Pacific Northwest National Laboratory) and Savannah River Technology Center.
August – November 2003	BNI CFD analysis determines that vessels FRP-VSL-00002A/2B/2C/2D and HLP-VSL-00022 may not meet off-bottom suspension criteria.
September 15, 2003	BNI Pulse Jet Mixer Task Team initiates scaled platform testing of pulse jet mixing baseline design.
October 10, 2003	Initial (physical) scaled testing confirmed that the baseline pulse jet designs in the seven vessels containing non-Newtonian fluids did not mix slurries to the extent necessary to meet WTP design requirements. BNI Pulse Jet Mixer Task Team initiates Phase I of PJM testing to determine alternate design.
December 15, 2003	BNI’s Pulse Jet Mixer Task Team presents Phase I "PJM-only" design configurations to Engineering, PT Facility, and HLW Vitrification Facility personnel.

Table 2.7. Timeline of PJM Analysis and Development for the WTP

Date	Event/Activity
January 5, 2004	WTP determines implementation of the PJM-only mixing systems severely impact the WTP facility designs due to increased numbers of PJMs, additional piping, and the significantly larger air consumption necessary to operate the systems. To minimize overall project cost and schedule impact, the BNI Pulse Jet Mixer Task Team initiates Phase II of PJM testing which investigates further alternative designs to assess the effects of slurry rheology changes, reduced tank volume, PJM jet velocity and nozzle size, sparging, and recirculation pump operation.
March 2, 2004	BNI Pulse Jet Mixer Task Team recommends Phase II PJM hybrid mixing systems configurations for UFP and large-scale (LS) to Engineering, Pretreatment, and HLW Vitrification Facility personnel. PT Engineering chooses PJM hybrid mixing systems design configurations.
April 2, 2004	HLW Engineering chooses PJM hybrid mixing systems design configuration for HLW Facility concentrate receipt vessel (CRV).
April 2, 2004	BNI Pulse Jet Mixer Task Team issues document supporting testing basis for the selected UFP-VSL-00002A/B, HLP-VSL-00027A/B, and HLP-VSL-00028 PJM and sparger configurations to Engineering for review.
April 2, 2004	BNI Pulse Jet Mixer Task Team issues document supporting testing basis for the selected UFP-VSL-00002A/B, HLP-VSL-00027A/B, and HLP-VSL-00028 PJM and sparger configurations to Engineering for review.
January 10, 2006	Corrective action on overblow loads issued that required additional testing (24590-WTP-MVE-50-00006).
March 2006	EFRT identifies mixing issues with the PJMs including long mixing times in high-solids vessels and ability of the PJMs to suspend large particles (CCN:132846).
January 11, 2007	Summary Report: *Hydrodynamic Loads for PJM Multiple Over blow Condition* (24590-WTP-RPT-M-06-003).
March 2007	WTP Project analysis (24590-WTP-RPT-PR-07-002) using BHR Group jet correlation indicates that FRP-VSL-00002A/2B/2C/2D, HLP-VSL-00022 and PWD-VSL-00044 will not meet off-bottom suspension criteria and FEP-VSL-00017A/17B, PWD-VSL-00033, PWD-VSL-00043 will not meet off-bottom suspension criteria with 50% of the PJMs operated at a time (50/50 criteria) mixing.
April 2007	Draft test plan to evaluate PJMs for mixing of low solids containing process streams prepared.
April 2007	Testing of ICN control of PJM overblows.

Summary of Testing to Support Low-Solids Containing Fluids: The WTP Contractor has not developed any representative testing data in prototypic PJM mixing test systems to demonstrate the mixing of prototypic low-solids containing (Newtonian) slurries. Some testing was completed by BNFL (the WTP Contractor prior to BNI) on Newtonian slurries. This testing (BNFL-RPT-048) evaluated the mixing performance of PJMs using a Newtonian simulant at solids concentrations of 17 wt%, 28 wt%, and 38 wt%. The Newtonian simulant was based on the properties of tank AZ-101/AZ-102 at a pH of 12. The PJM test configuration was described as having used much higher power per volume of fluid compared to the WTP design. However, the testing documentation does not provide sufficient detail to determine the power level. Despite this, the study concluded:

- The PJM system in the test system, operating at a maximum frequency was able to mix the 28 wt% and 38 wt% fluids.
- With the faster settling slurries (e.g., the 17 wt%), the results indicated stratification in the test vessel occurred at maximum PJM operating frequency.
- BNFL had also summarized the historical use of the PJMs at the Sellafield site (24590-CM-TSA-HXYG.0008). This data shows that the BNFL development program evaluated a number of simple simulants, formed with water and fine silica, potassium carbonate, and magnesium hydroxide at concentrations that varied between 2 and 48 wt%. The vessels used in the Sellafield facilities had volumes that ranged from 133 gallons to 50,000 gallons, which in general are much smaller than the WTP vessels. No mixing performance data other than the data presented in BNFL-RPT-048 was provided in the document.

A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:

- The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling, and paid less attention to Newtonian slurries with low solids concentrations that settle rapidly.
- Large dense particles may be more difficult to suspend than those used in the current design, and may be difficult to re-suspend.
- The zone of influence (ZOI) for the PJMs in Newtonian vessels may be over estimated for large dense, rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is indeterminate.
- The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and should be matched to relevant experimental results.

In response to these issues, the WTP Contractor has prepared an IRP for EFRT issue M-3, “Inadequate Mixing System Design” (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries.

Summary of Testing to Support High-Solids Containing Fluids: Extensive non-radioactive simulant testing has been conducted by the WTP Contractor to test the PJM and vessel design concepts for mixing, off-bottom suspension, solids uniformity, gas retention, and release in wastes containing high-solid concentrations. These studies were focused on establishing the minimum design and operational requirements based on the testing scope for the vessels that are nominally referred to as containing non-Newtonian wastes. These vessels are UFP-VSL-00002A/00002B, HLP-VSL-00027A/00027B, and HLP-VSL-00028.

Nine different test stands were constructed for the phases of the scaled testing. These test stands are identified in Table 2.8. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, ZOI, aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.

Table 2.8. Summary of PJM Test Vessels and Applications

Vessel	Internals	Description	Scale	Volume, gal	Purpose
Applied Process Engineering Laboratory (APEL) Single PJM	1 PJM	Single pulse tube in clear acrylic vessel	NA	250	Select and develop simulant; demonstrate PJM cavern formation.
4 PJM Scaled Vessels					
336 Supernatant Tank (SNT)	4 PJM	4 pulse tubes in stainless steel vessel	1	10,000	Demonstrate scaling approach for PJM mixing and GR&R in WTP vessels containing non-Newtonian slurries. Also, overblow tests in 336 SNT.
APEL 4 PJM	4 PJM	4 pulse tubes in clear acrylic vessel	1/4 scale of 336 4 PJM SNT	250	
Savannah River National Laboratory (SRNL) 4 PJM	4 PJM	4 pulse tubes in clear acrylic vessel	1/9 scale of 336 4 PJM SNT	30	
Scaled prototypes					
UFP Scaled Prototype	Variable PJMs, spargers, recirculation pump	Scaled prototype representing UFP vessel	1/4.94 scale of full-scale UFP vessel	350	Assess performance of a variety of vessel internal configurations, including the number of PJMs, size and angle of PJM nozzles, drive velocity, sparging and recirculation pumps.
Large-scale (LS) Scaled Prototype	Variable PJMs, spargers, recirculation pump	Scaled prototype representing LS and blend vessels	1/4.29 scale of full-scale LS vessel	1,000	
CRV Scaled Prototype	Variable PJMs, spargers, recirculation pump	Scaled prototype representing CRV vessel	1/4 scale of CRV	230	

Table 2.8. Summary of PJM Test Vessels and Applications

Vessel	Internals	Description	Scale	Volume, gal	Purpose
Half-scale LS vessel and cone-bottom tank (CBT)					
HSLS Vessel	8 PJM Cluster (7 around 1), 7 spargers	Half-scale LS vessel	1/2 of full-scale LS vessel	10,000	Assess GR&R and mixing in the LS vessel with WTP operational cycles.
Cone Bottom Tank	Spargers	9 spargers in tank with cone shaped bottom	Similar to 336 SNT	10,000	Develop sparger design guidelines for mixing; provide data on gas release and aerosol entrainment.

Key testing reports and results are summarized below:

- *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is the summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels. This report summarizes the results of technology testing, which includes:
  - Simulant Development: A transparent simulant based on Laponite (a synthetic layered silicate material) was developed and used in the early phases of testing. Laponite properties were varied by changing the concentration. Shear strengths ranged from 30 to 120 Pa and consistency from 10 to 20 cP. An existing kaolin-bentonite clay simulant was tailored for the PJM program by varying the concentration of the clay components in the 20 to 30 wt% range. Most of the testing was conducted near the upper-bound rheological properties of 30 Pa for yield stress and 30 cP for consistency. Over the course of all testing, yield stress varied from about 5 to 47 Pa and consistency from about 14 to 41 cP. Simulant development efforts are summarized in WTP-RPT-111, *Non-Newtonian Slurry Simulant Development and Selection for Pulsed Jet Mixer Testing*. Simulants representing chemical, rheological, and physical properties of pretreated waste samples from Hanford Site tanks AZ-101 and AZ-102 were also used.
  - PJM Scaling Relationship Development: Tests were conducted in three, scaled PJM test stands each containing four PJMs, using Laponite and kaolin-bentonite simulants at large 1/4- and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, and WSRC-TR-2004-00430, *One-Eighth-Scale Pulse Jet Mixer (PJM) - Design Parameters Scale Law Testing*.
  - Large-Scale (LS) PJM Testing: Tests were conducted in the large-scale cone-bottom tank (CBT) using a kaolin-bentonite clay simulant. Test results are reported in WTP-RPT-129, *Technical Basis for Scaling of Air Sparging Systems for Mixing in Non-Newtonian Slurries*, and include the following information:
    1. ZOI and region of bubbles dimensions were determined for air flow rates from 5 to 40 acfm. Measurement methods included ultrasonic velocity probes, a laser reference system coupled with video analysis, and passive integrated transponder tags.
    2. ZOI circulation time was established with dye and tracer tests.
    3. The time to establish steady-state flow profiles was determined with velocity probes.

    4. Aerosol measurements were obtained using impaction plates to collect samples.
    5. GR&R characteristics were determined by generating oxygen in situ by hydrogen peroxide decomposition followed by sparging.

  - Gas Holdup Studies: Several gas holdup (representing hydrogen) and release tests were conducted in the scaled prototypes of the HLW lag storage vessel, ultrafiltration, and concentrate receipt vessels. Various combinations of PJMs, spargers, and recirculation pumps were tested using a kaolin-bentonite clay simulant. Retained oxygen gas was generated in situ by decomposition of hydrogen peroxide. The technical basis is reported in WTP-RPT-114, *Final Report: Gas Retention and Release in Hybrid Pulse Jet-Mixed Tanks Containing non-Newtonian Waste Simulants*, and WSRC-TR-2004-00399, *Final Report – Gas Retention and Release Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*.

  - Demonstrate PJM/hybrid mixing Configurations: Several hundred tests were conducted in scaled prototype vessels representing the LS/blend and UFP vessels and HLW CRV. Tests conducted included mixing, off-bottom suspension, solids uniformity, GR&R, and velocity mapping. Results of the scaled prototype PJM only tests (Phase I) are reported in WTP-RPT-110, *Test Results for Pulse Jet Mixers in Prototypic Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, and WSRC-TR-2004-00398, *Final Report – Hybrid-Mixing Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*. Results of scaled prototype PJM/hybrid tests (Phase II) are summarized in WTP-RPT-128, *Hybrid Mixing System Test Results for Prototype Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, and WSRC-TR-2004-00399.

  - Demonstrate mixing and gas retention and release characteristics: A series of tests was conducted in a half-scale replica of the lag storage vessel. These tests were conducted using the kaolin-bentonite clay simulant. Retained oxygen gas was generated in situ by the decomposition of hydrogen peroxide. These tests demonstrated: (1) a normal operating mode consisting of continuous PJM mixing and intermittent sparging; (2) post-design basis event (DBE) operations consisting of intermittent PJM and sparger mixing; and (3) near-term accident response operations consisting of intermittent sparging (no PJMs). The time to achieve 95% homogeneity was also determined using the chloride tracer method. The results of the half-scale LS demonstration reported in WTP-RPT-114.

- *Demonstration of Ability to Mix in a Small-Scale Pulsed-Jet Mixer Test Facility* (24590-101-TSA-W000-0004-124-03): This report documents the results of small-scale-pulsed jet mixer (SS-PJM) testing focused on addressing several issues associated with the effectiveness of the PJMs in the baseline design of Sr/TRU precipitation and sludge-washing processes. The SS-PJM facility description is not provided in Table 2.8. The objectives of the tests were to determine the following:

  - Influence of a density gradient on the mixer performance.
  - Mixing time of liquids of dissimilar densities.
  - Optimum mode of addition of reactants.
  - Cycle frequency to achieve best mixing performance.
  - Operating volume, pressure and vacuum optimum range to minimize air entrainment.
  - Validation of the TEMPEST CFD model of the PJMs using the data generated in the small tank.

  A mixing time criterion of one hour or less (at SS-PJM scale) was derived from pilot-scale experiments at the SRS. Experiments in the SS-PJM that were performed at the plant design-target specific energy did not produce acceptable mixing even within 90 minutes. (At small scale, all reagents were added in a static layer prior to test commencement to preclude scaling issues related to reagent addition unduly influencing test outcomes). Mixing time was reduced to 40 minutes at

3 times the design-target specific energy; experiments at 5 and 14 times the design-target specific energy produced mixing times of 33 minutes and 15 minutes, respectively. *Although the small tank experiments indicated acceptable to good mixing at three times or higher multiples of the design energy/volume conditions, extreme caution was recommended in using this data to predict full-scale performance due to complexities associated with scaling pulsed jet mixers.*

Objective 2 above was fully achieved, and Objectives 1 and 4 were partially achieved. Objective 3 was addressed insofar as the static bulk addition was a conservative condition for the top-addition (reagent) configuration. No parametric study was performed of air entrainment (Objective 5) because during the review of the test plan this objective was considered out-of-scope for the SS-PJM test series. Validation of the TEMPEST CFD model (Objective 6) was attempted, but results were inconclusive. Significant modifications to the code would be necessary to produce satisfactory results. Because the SS-PJM is not geometrically and kinematically similar to the prototype PJM, it was concluded that the level of effort required to modify the code was not justified.

- *Results of Small-Scale Particle Cloud Tests and Non-Newtonian Fluid Cavern Tests* (24590-101-TSA-W000-0004-72-08): The objective of the cloud height tests was to obtain experimental measurements of the effective mixing heights for BNI to use in benchmarking the FLUENT computer code. The cloud height measurements were obtained for a single steady-state jet directed downward in an elliptical bottom tank. The cloud tests used glass beads in water to evaluate the height of the suspended slurry as a function of jet velocity. The objective of the cavern tests was to obtain experimental data to validate the non-Newtonian fluid modeling capabilities of the computer code for fluid properties similar to those of certain tank wastes. A transparent material that exhibited a yield stress and shear thinning behavior was used to obtain measurements of steady-state cavern heights as a function of jet velocity. The simulant also exhibited time-dependent behavior. To evaluate the influence of the time dependent behavior, constant shear rate tests were carried out. The measured shear stresses dropped continually for the first 20 minutes. After approximately 20 minutes, the change in shear stress was less than 1%. The magnitude of the change in rheological properties at steady-state conditions over the time steady-state measurements were made was negligible.
  This document summarizes the tests and presents the experimental results produced at the SS-PJM test setup in the Applied Process Engineering Laboratory (APEL).

- *Large Tank Experimental Data for Validation for the FLUENT CFD Model of Pulsed Jet Mixers* (24590-101-TSA-W000-0004-118-02): The objectives of the work were to develop and experimentally validate the TEMPEST CFD model of the PJM system using: (1) small-tank hydrodynamic (water) data; (2) large-tank hydrodynamic (water) data; (3) column simulant settling data; and (4) large-tank simulant data. All of the objectives, except Objective 4, were met.
  The inability to validate the model using the large-tank simulant data was primarily due to the asymmetries of the flow fields in the tank, which made the data insufficient to complete the validation of code.

  The settling sub-model validation results indicated that the model predictions matched the experimental density profiles in the settling column for the first few hours of the test, after which discrepancies on the order of 15% were observed. The errors are primarily due to the difficulties in precise estimation of the unhindered settling velocities of the particles in the slurry tested since these particles exhibit a broad range of particle size distribution. Earlier work with settling of actual Hanford Site waste shows that these models can replicate the settling behavior of complex wastes provided a reasonable estimation of the unhindered settling velocities is available. The small-tank hydrodynamic validation results indicated an excellent match between the model predictions and the experimentally measured velocity profiles near the tank-floor and the tank-wall regions.
  These results suggest that the TEMPEST PJM model captures the hydrodynamic flow behavior in previously untested flow regimes. The large-tank hydrodynamic validation results indicated that the

match between the experimental velocity data and the model predictions is acceptable given the asymmetries in the flow behavior and the uncertainties in the velocity and liquid level change measurements (used to determine the drive function). In the case of the large-tank simulant validation, the asymmetries of the flow fields in the tank, made the data insufficient to complete the validation of code. However, none of the results invalidated the code. It was not possible to repeat the large-tank simulant tests due to budgetary and schedule constraints.

- *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries* (24590-101-TSA-W000-0004-114-00016): The purpose of this work was to establish the technical basis for performing scaled testing of PJM systems. This scaling approach was required to design, conduct, and apply results of tests in reduced-scale prototypic Hanford WTP PJM mixing systems. The scaling approach consisted of two key components, theoretical analysis and experimental confirmation.

  Theoretical analysis included developing a physical model for the cavern position resulting from a single, downward-oriented, steady jet operating in a non-Newtonian slurry. This model used heuristic arguments involving elemental turbulent Newtonian jet theory coupled with a static force balance between the impinging jet and slurry cavern boundary. The model was extended to accommodate non-physical model; the dependence of cavern position on various physical parameters was evident. Normalized cavern height (cavern height divided by vessel diameter) was found to depend on the yield, Reynolds number, the jet Reynolds number, the ratio of PJM nozzle diameter to vessel diameter, and the non-dimensional pulse time (ratio of PJM volume to nozzle diameter cubed). Cavern heights predicted by the single PJM model were found to be in good agreement with measured cavern heights in Laponite and clay simulant. The physical model also demonstrates the relative importance of various parameters affecting cavern height and provides insight into the optimal operation of PJMs. In addition to the development of the physical model, dimensional analysis and physical insight were used to identify the important non-dimensional parameters affecting the performance of PJM mixing systems. The relative importance of the various parameters was analyzed, and those considered dominant were identified. Evaluating how these non-dimensional parameters changed with physical test scale led to the scaled testing approach.

  The scaling laws and the non-dimensional parameters determined to be most important to the non-Newtonian mixing problem required experimental validation. Therefore, an experimental test strategy was developed that involved performing mixing tests using 4PJM arrays at three different scales, including a large-scale vessel in the 336 Building at Pacific Northwest Division (PNWD) that had a capacity of about 12,000 gallons, PJM diameter of 24 inches, and PJM nozzle diameter of 4 inches; a 1/4.5-scale version of the 4PJM vessel in the APEL building at PNWD with a capacity of about 250 gallons, PJM diameter of 5.3 inches, and PJM nozzle diameter of 0.9 inches; and a 1/8.9-scale vessel at Savannah River National Laboratory (SRNL) with a capacity of about 18 gallons, PJM diameter of 2.63 inches, and PJM nozzle diameter of 0.45 inches. The tests used two non-Newtonian simulants, a kaolin-bentonite clay mixture, and Laponite. Experimental data collected from the geometrically scaled test stands were compared at similar conditions to confirm and demonstrate the methodology for predicting large-scale behavior from the small-scale test results.

- *Final Report: Gas Retention and Release in Hybrid Pulse Jet Mixed Tanks Containing Non-Newtonian Waste Simulants* (24590-101-TSA-W000-0004-153-00002):
  - <u>Measure and report gas holdup volumes in simulants during steady-state PJM operation</u>: Gas-holdup volumes were measured at several gas-generation rates and with various combinations of mixing methods (spargers, recirculation, and PJMs) in the LS and UFP prototypes using configurations and operating conditions determined in previous mixing studies to have acceptable performance. Gas-holdup tests were also successfully completed in a generic

configuration of four PJMs in three test stands (336 Building 4PJM and APEL 4PJM at Battelle—PNWD and SRNL 4PJM) representing different sizes (scaled) of the system. Holdup varied from less than 1 to over 3 vol%, generally correlating with gas-generation rate, simulant depth and rheology, and PJM drive-cycle parameters.

- Experimentally measure and report gas-release characteristics (i.e., rates and volumes) in a loss-of-power scenario: The transient decrease in gas-volume fraction was measured for restarting mixing systems after a period of gas accumulation in the LS and UFP prototypes with configurations similar to those used in the gas-holdup tests. Additional gas-release tests were completed in the 336 4PJM system, the APEL 4PJM system, and a small-scale 4PJM system at SRNL. Sparging-only gas-release characteristics were investigated separately in the 336 cone-bottom tank. The gas release data show that gas-release behavior is influenced by simulant rheology, gas bubble size as deduced from the more rapid gas releases in tests that accumulated gas overnight, and somewhat by initial gas fraction. Full-coverage sparging was shown to be very effective at releasing retained gas.
- Measure and report consistency of gas-release rates and volumes for a series of intermittent mixing cycles: A series of three repeated gas-release tests was completed in the APEL 4PJM system on consecutive days using the same approximately 100 gallons (~380 L) batch of kaolin-bentonite clay and approximately the same initial gas fraction (3.7 to 4.3 vol%). Rates and volumes are reported. Results indicate release behavior is nominally repeatable.
- Determine mass-transfer coefficients and gas holdup in kaolin-bentonite clay and pretreated tank AZ-101 slurry simulants in bench-scale apparatus: Bench-scale bubble-column devices were used to measure gas holdup and mass-transfer coefficients in two kaolin-bentonite clay dilutions and a pretreated tank AZ-101 slurry simulant. The gas holdup was a significant function of gas superficial velocity, slurry consistency, and the concentrations of $NaNO_3$ and anti-foaming agent. The scaled oxygen mass-transfer coefficients were in good agreement for the three simulants tested at the bench-scale. A similar proof-of-concept gas-stripping test was conducted in the APEL UFP prototype vessel containing an initially oxygen saturated kaolin-bentonite clay simulant. The mass transfer coefficient determined in the UFP test was approximately half that estimated from the correlation established in the bench-scale studies (1.27/hour).

Additional testing has been completed or is underway to evaluate overblow of PJMs using the Building 336 testing system and evaluating the impact of anti-foam on gas release.

The Contractor is relying on CFD analysis, as compared to testing, to validate the performance of the PJM technology for vessels that are mixed with PJMs only. The CFD model has been validated using experimental data from small-scale particle cloud tests (24590-101-TSA-W000-0004-72-08) and the large-scale tank (24590-101-TSA-W000-0004-118-02). The validation of the CFD model is described in 24590-PTF-RPT-PR-06-002, *Benchmarking of Computational Fluid Dynamic Simulation of Pulse Jet Mixers Using Experimental Data*. This assessment demonstrates close agreement between the CFD results and the experimental results in predicting mixing performance, and provides confidence that can be used to judge whether a mixing vessel will pass or fail specified mixing criteria. This assessment however is limited to the range of conditions evaluated.

Materials of construction for the PT Facility vessels have been established through a corrosion evaluation assessment (24590-WTP-GPG-M-047). Corrosion evaluations are based upon a detailed design guide used by the WTP Contractor that considers process chemistry, mechanisms for corrosion, and erosion. These have been previously reviews and evaluated by DOE and have been determined to be acceptable based on current operating conditions (05-WED-019).

2.3.6.5 Relevant Environment

Overall requirements for the PJMs are briefly described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). The relevant operational environment for the PJM system is:

- Support a 40-year operational design life.
- Suspend and mix solids with the bulk fluid to ensure the release of hydrogen.
- Blend solid and liquids to support a determination the received waste is acceptable with the safety and environmental permitting authorization basis.
- Blend solid and liquids to support all process operating requirements including ensuring efficiently of chemical reactions, ensuring uniform process stream transfers and control of the pretreatment and HLW vitrification processes.

2.3.6.6 Comparison of the Relevant Environment and the Demonstrated Environment

The discussion on the comparison of the relevant environment and demonstrated environment is divided into: (1) fluids that contain low-solids content in which the solids rapidly settle (referred to nominally as Newtonian fluids); (2) high-solids content, shear thinning fluids (referred to nominally as non-Newtonian fluids); and (3) adequacy of the definition of technology requirements that are derived from design requirements.

There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed (BNFL-RPT-048) do not sufficiently describe the test conditions that allow a comparison between the test conditions and the current design.

Benchmarking of the CFD simulation using experimental data (24590-PTF-RPT-PR-06-002) indicates that the CFD simulations predict more uniformity than indicated by experiment, and do not provide conservative and bounding estimated of mixing behavior. However, the relatively close agreement between the experimental data and the CFD simulation indicated that the CFD analysis would be useful to rate the adequacy of the PJM design solution.

The testing of high-solids containing slurries has been exhaustive and is described in detail above. However, this testing has been focused on off-bottom suspension, solids uniformity, GR&R in wastes containing high-solid concentrations hydrogen release, and not on meeting other important requirements of the vessel designs. This testing is incomplete based on a review and evaluation of the requirements identified in several project documents described below.

Work associated with the EFRT IRP M3 relating to "Inadequate Mixing System Design" will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

PJM Design Requirements

The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:

- Re-suspend settled solids and maintain suspension of solids within vessels.
- Provide blending of cold chemicals with active process liquids.
- Sufficiently mix the contents of the vessels for sampling.

Specifically, the flow velocities of the PJMs must be great enough to mix the vessel contents sufficiently to meet WTP operational constraints, and to enable disengagement of hydrogen bubbles to mitigate flammability safety concerns.

The *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003) repeated these general mixing requirements for PJMs and provided general requirements for different vessel groups. In some cases, these requirements were quite specific; for example:

- For CNP-VSL-00003/4 (Cs nitric acid recovery and concentrated Cs eluate vessels), the vessel must mix in preparation for sampling. Provide for the blending of 2,400 gallons of 0.25 M NaOH with 3,600 gallons of water within one hour.

In other cases, the mixing requirements have been generalized; for example:

- For HLW-VSL-00022 (HLW feed receipt vessel), the mixing must prevent solids accumulation, facilitate hydrogen evolution, and provide a representative sample to support waste acceptance criteria for feed to the WTP.

24590-PTF-M0D-M40T-00002, *Process Data Sheet: Fluidics*, which is used as an input to PJM design by AEA Technology provides further requirements for mixing. For example, the following requirements (summarized in Table 2.9) are provided for the HLP-VSL-00022:

- Prevent solids accumulation and facilitate hydrogen evolution.
- Provide representative sample to support waste acceptance criteria (95% confidence level).

A recent document defining *Pulse Jet Mixer Mixing Test Performance Criteria* (24590-WTP-RPT-PR-07-003) provides additional requirements to support testing as part of the IRP for EFRT issue M-3 (24590-WTP-PL-ENG-06-013). General requirements included for HLP-VSL-00022:

> "Suspend up to 200 g/l solids for sampling and transfer. Suspend solids in normal operations for hydrogen release. Mobilize solids sufficiently to release hydrogen post-DBE."

The definitions for maintaining solids suspended from 24590-WTP-RPT-PR-07-003 are briefly summarized below:

> "…the mixing must be sufficient to maintain the solids in suspension so that they do not accumulate on the bottom and so they can be transferred out with the fluid, through the pump suction line." [pg. 2]
>
> Sampling to support criticality evaluation is specified in the WTP Criticality Safety Evaluation Report. The criticality evaluation requires a sample of the solid fraction, so the distribution of specific types of particles is important. However, it is expected that the elements of interest to criticality will be in the heavier particles, so the sample taken near the bottom of the vessel will be bounding. Therefore, the just suspended or off-bottom condition is adequate to meet this requirement.

> Additional mixing requirements are defined in the *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001). This document identifies two samples to be taken from the HLP-VSL-00022 to support criticality analyses. The boundaries for solid fraction sample PT17 are that "The vessel contents are completely mixed for a representative sample." The boundaries for liquid fraction sample PT17 are that "The vessel contents should be completely mixed for a representative sample."

In addition, the distinction between Newtonian and non-Newtonian fluids to support an assessment of the adequacy the PJMs to mix vessel contents has not been adequately and completely addressed. In response to resolution of the PJM mixing issues (24590-WTP-PL-ENG-06-013), the Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear.

> "Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (less than 20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."

The lack of clear, consistent, objective design criteria for PJM mixing requirements, which relates the anticipated physical properties in a vessel to specific quantitative mixing requirements, makes it difficult for the Assessment Team to objectively assess the adequacy of the PJM technology and the adequacy of the proposed testing program to resolve mixing issues.

Quantitative mixing criteria related to physical properties are difficult to derive because of the large variability in feeds and lack of comprehensive characterization data. Consequently, a design approach has been pursued providing as robust a mixing system as is practical within the physical limits of the plant systems and utility infrastructure. Conditions that exceed practical design limits may require control of waste feed properties at the tank farms.

The Contractor uses model projections—including the Operational Research Assessment (using WITNESS® software), Tank Utilization Assessments (using the GynSym G2 software), and Steady State Flowsheet (using Aspen Custom Modeler software)—to predict the anticipated WTP flowsheet and production performance and diagnose issues with the design adequacy of the WTP. The Contractor also uses an internally developed Excel-based program to estimate WTP design capability (known as WEBPPS Engineering Mass Balance) and process and mechanical system component calculations to ensure that the WTP design is adequate. These models and calculations all assume that the PT Facility vessels are uniformly mixed within the required time cycle. Based on a review of the CFD model results (24590-PTF-RPT-PR-06-001) and the current identified issues (24590-WTP-RPT-PR-07-002; 24590-PTF-RPT-PR-06-001) with vessel mixing, these projections are optimistic. The *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001) and *WTP Integrated Processing Strategy Description* (24590-WTP-3YD-50-00002) also assume that the vessels are well mixed. The impacts to the production rate and the requirements for process control of WTP have not been evaluated based on limitations of the PJM mixing systems.

However, the impact to the capability of the WTP and the requirements for process control of the WTP have been acknowledged in the currently ongoing capacity improvement design changes whereby alternative mixing approaches, such as in-line mixing of process reagents, is being pursued to reduce dependency on PJM mixing systems for rapid blending.

2.3.6.7 Technology Readiness Level Determination

The PJM system was determined to be a TRL 4 because specific, quantifiable design requirements for the PJM technology have not been established to support testing and design. The definition of the PJM mixing requirements must consider the functional requirements (i.e., safety, environmental, and process control) of the vessels and the anticipated waste characteristics in the vessel.

It is acknowledged that the PJM technology is a viable technology for use in the WTP black cell vessels.

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

Recommendation 7

Clear, quantitative, and documented mixing performance requirements for all PJM mixed vessels in the PT Facility and HLW Vitrification Facility should be established. The requirements should be established for all vessel systems even though only those associated with FRP, HLP, PWD, TLP, and FEP were discussed in this assessment.

These requirements should include requirements from criticality safety, environmental compliance, hydrogen management and mitigation, process control, process operations, and immobilized low-activity waste and immobilized high-activity waste form production. These requirements should be used to assess the adequacy of the design and operation of each of the PJM mixed vessels and provide a basis for the completion of the planned testing work on PJMs planned as part of Issue Response Plan M-3, “Inadequate Mixing System Design.” These requirements should be established jointly with project personnel representing safety, environmental compliance, and process operations, with DOE as owner and operator of the WTP.

Recommendation 8

PJM demonstration testing should be completed. The testing information, supplemented with analysis, should be used to determine the design capability of each PJM mixed vessel and identify any required design changes.

Unresolved Technical Issues

- Process modeling to project the performance of the WTP and confirm design capability should use realistic assumptions on the effectiveness of mixing (both time and efficiency of mixing).

2.3.7 Waste Feed Receipt Process System (FRP)

2.3.7.1 Function of the FRP

The purpose of the FRP is to receive and store waste from the Hanford Site tank farms and, if needed, transfer waste back to the tank farms. Both low-activity and high-level waste can be received. Normally, HLW will be received by the HLP. The waste feed will be pumped from the FRP to processes within the PT Facility.

2.3.7.2 Description of the FRP

The FRP is described in the *System Description for Waste Feed Receipt Process (FRP)* (24590-PTF-3YD-FRP-00001). The FRP includes four feed receipt vessels, a waste feed return pump, and one waste feed transfer pump.

The vessels of the FRP provide feed storage for the PTF, storage for treated LAW from the Treated LAW Concentrate Storage Process System (TCP), high-level waste from HLP, and recycles from the FEP.

The FRP has two pumps. FRP-PMP-00001 is the waste feed return pump, which will be used to return waste to the tank farms, if necessary. FRP-PMP-00002A is the waste feed transfer pump, which will be used to move feed forward into the pretreatment processes (evaporation or ultrafiltration).

The FRP will be used to receive and store waste from the tank farms and transfer feed to PT Facility operations. Three identical pipelines will be available for waste transfers from the tank farms to the PT Facility. The waste feed receipt vessels (FRP-VSL-00002A/B/C/D) can accept tank farm waste if its storage temperature is below 120°F and its solids content is below 5 wt%. These parameters will be confirmed with the Tank Farm Contractor (TFC) before the transfer. Tank farm waste that has a temperature or solids content above these criteria will be sent to the HLW feed receipt vessel (HLP-VSL-00022) because it has a cooling jacket. Waste feed will be pumped from the tank farms at 90 to 140 gpm through one of the three transfer lines. Each transfer pipeline consists of one 3-inch stainless steel pipe contained within a 6-inch carbon steel outer pipe (24590-WTP-ICD-MG-01-019). Transfers will be done every few months during normal operations.

Prior to authorizing a transfer, the TFC will provide samples of the feed to the WTP Contractor. The WTP Contractor will analyze the samples to ensure the waste meets the WTP waste acceptance criteria. Before the transfer to FRP begins, vessel volumes within FRP are verified to ensure enough space is available for the transfer. A main manifold directs the waste to one of the four vessels available for receipt. Valves are aligned to transfer the waste to the first intended vessel. A WTP operator enables the interlock to initiate the transfer. A flush of warm water will be sent from the tank farms to the first FRP vessel to warm the pipe prior to the transfer of tank waste. Once the transfer begins, feed will enter the vessel until a predetermined level setpoint is reached. Then, the valve to the next receiving vessel will be opened, and the valve to the first vessel will be closed. The vertical line between the header and the filled tank will be flushed to prevent solids from clogging the line. This process will continue until the transfer is complete.

Three vessels are required to accommodate an entire million-gallon transfer. After the waste is transferred, the transfer pipeline will be flushed again. The pipeline flush of inhibited water (0.01 M NaOH and 0.011 M $NaNO_2$) will not exceed three times the pipeline volume (7,500 gallons including the pre-transfer flush). The flush will flow from the tank farms source vessel to the receipt vessels. When the motive force provided by the tank farms to transfer the waste and flush is removed (i.e., pump shutdown), the flush remaining in the line will no longer have sufficient head to reach the receipt vessels. Following the flush, any liquid remaining in the pipeline will be drained to PWD-VSL-00043. Level instrumentation in the leak detection pots will detect leakage into the annulus between the transfer line (primary containment) and the outer pipe (secondary containment). If a leak occurs in either the TFC's or the WTP Contractor's transfer/receipt system, the transfer will be interrupted by the TFC or WTP. The TFC master pump shutdown system will be initiated, stopping the tank farm pump. The waste transfer lines are equipped with slow acting valves to prevent a water hammer.

WTP personnel will sample the waste to ensure it is below established criticality specifications per the *Preliminary Criticality Safety Evaluation Report for the WTP* (24590-WTP-RPT-NS-01-001) before it is sent forward to the PT Facility. Until the vessels are sampled, they will have a “not available for transfers” state (outlet valves closed) pending release by the PT Facility operations manager. The *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001) lists the required analyses and technical drivers for each sample taken from the receipt vessels.

The four waste feed receipt vessels are primarily used to receive waste feed from the tank farms and transfer the waste to either the ultrafiltration feed preparation vessels (UFP-VSL-00001A/B) or the waste feed evaporator feed vessels (FEP-VSL-00017A/B). The working volume of each receipt vessel is 375,800 gallons. Each vessel can receive feed from the tank farms or infrequent transfers from the HLW feed receipt vessel (HLP-VSL-00022) or the FEP (FEP-VSL-00017A/B, FEP-SEP-00001A/B). The waste feed receipt vessels are made of stainless steel and each has a “flanged and dished” type bottom and top head. Vessels FRP-VSL-00002A/B/C/D are located in black cells. Level, density, and temperature instrumentation are installed in each vessel. Each vessel has 12 PJMs for mixing to maintain a uniform concentration of solids for waste feed sampling and transfer and to prevent hydrogen accumulation.

The suction-drive jet pump pair associated with a PJM will be located at least one barometric head (33.9 ft H_2O at 4°C) above the highest liquid level attainable within the vessel. Autosamplers located downstream of the waste feed transfer pump, FRP-PMP-00002A, are used for sampling.

There is a potential for the vessel vapor space to accumulate enough hydrogen to form a flammable mixture. To maintain the hydrogen concentration below the lower flammability limit, forced purge air enters the vessel from the Plant Service Air System. Passive air in-bleed to the vessel via a separate nozzle from the C5V system (from the surrounding black cell) is also provided to purge the vessel vapor space of hydrogen and to aid evaporative cooling for the vessel. The vessels will be maintained at a lower pressure than the surrounding cell. Exhaust gases are sent to the vessel vent header except in a loss of site power incident. If power is lost, the forced purge air supply from the Plant Service Air System is lost, and important-to-safety backup air will be provided via a separate supply header. Each vessel will have internal wash rings to aid in decontamination. Each receipt vessel overflows to the ultimate overflow vessel (PWD-VSL-00033).

2.3.7.3 Relationship to Other Systems

The FRP interfaces with the following major process systems:

- Waste Feed Evaporation Process System (FEP): Vessels FRP-VSL-00002A/B/C/D transfers waste feed to vessel FEP-VSL-00017A/B when sodium content is less than 5 M. Vessels FRP-VSL-00002A/B/C/D receive recycle concentrate from vessels FEP-SEP-00001A/B. Vessels FRP-VSL-00002A/B/C/D receive excess recycles from vessels FEP-VSL-00017A/B.

- HLW Lag Storage and Feed Blending Process System (HLP): Transfer pipelines supply HLW feed to vessel HLP-VSL-00022. Vessels FRP-VSL-00002A/B/C/D receive HLW feed from vessel HLP-VSL-00022. Transfer pipelines and pump FRP-PMP-00001 return HLW solids from vessels HLP-VSL-00027A/B and HLP-VSL-00028 to tank farms. They also return HLW feed from vessel HLP-VSL-00022. Transfers from the HLP are not normal transfers to FRP.

- Plant Wash and Disposal System (PWD): Vessels FRP-VSL-00002A/B/C/D overflow to vessel PWD-VSL-00033. Transfer pipeline flushes drain to vessel PWD-VSL-00043.

- Treated LAW Concentrate Storage Process System (TCP): Vessels FRP-VSL-00002A/B/C/D receive treated LAW concentrate from vessel TCP-VSL-00001 and return concentrate to vessel TCP-VSL-00001. This transfer requires the installation of a jumper and the removal of a blind flange.

- Ultrafiltration Process System (UFP): Vessels FRP-VSL-00002A/B/C/D transfer waste feed to vessels UFP-VSL-00001A/B when sodium concentration is 5 M or greater.

The FRP also interfaces with the Hanford Site tank farms for the receipt (and potential return) of tank waste solutions. The major requirements of this interface include:

- Establishing a permissive/shutdown (interlock) signal for the transfer pumps operated by the TFC, which will incorporate the WTP transfer line leak detection system.

- Receive up to a 1 Mgal batch of LAW feed followed by transfer line flush solution from the TFC.

- Document the volume of waste transfer and flush solution received, and reconcile differences with the transfer volume recorded by the TFC.

- Provide capability for emergency returns of feed to the tank farms followed by transfer line flush solution. Transfer line flush solution is performed at the tank farms and the flush will be received in the FRP.

2.3.7.4 Development History and Status

There has been limited technology testing completed to provide the technical basis for the FRP PJM mixing system design related to suspension and re-suspension in Newtonian vessel systems (most of the data was obtained in early testing of PJM systems at Battelle). The Contractor has relied on the expertise and experience of its subcontractor (AEA Technology) to design PJM systems based primarily on testing and plant operations performed in the United Kingdom. The Contractor has used CFD analysis to further assess the designs. Based on specific recommendations of the EFRT Team, the Contractor has devised a specific technology testing plan as part of the EFRT IRP M3, "Inadequate Mixing System Design," (24590-WTP-PL-ENG-06-0013) to resolve EFRT issues on the adequacy of mixing

CFD analysis completed as early as August 2003 (24590-PTF-RPT-M-03-016) by BNI indicated that the FRP vessels would not adequately mix waste with an assumed set of properties. However, there was some uncertainty in the conclusion because the model run was terminated (due to time constraints) before the mixing simulation reached a steady state condition. This analysis assumed that the waste properties had the following characteristics: 3 wt% solids content, 2.9 g/ml solids density, 22 micron particle size, 1.2 g/ml liquid specific gravity, 2.94 cP viscosity at 25°C with Newtonian fluid characteristics.
This analysis indicated that the 8 m/sec PJM drive velocity (normal velocity when the vessel is full) may not be adequate to move the largest particles from the bottom of the vessels, and the 12 m/sec drive velocity (normal velocity when the vessel is full) was recommended by BNI in 2003 to keep large particles in suspension. *(Note: The WTP Contract requirement for solids concentration is 3.8 wt% and the WTP safety basis assumed a 5 wt% solids concentration in the FRP feed.)*

A subsequent FRP mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM designs will not meet the off-bottom suspension criteria at all FRP vessel levels even when the PJM are operated at 12 m/sec discharge velocity. This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: 1.1 g/ml liquid density, 2.9 g/ml solid density, 210 micron particle size, and a maximum of 3.8 wt% solids. This analysis completed by BNI in January 2007 also recommended that testing be completed to verify the adequacy of the PJM design for the FRP vessels. The analysis using the BHR Group correlation is based on a steady jet and does not account for fluid viscosity. Thus, the results can only be considered indicative and the system may not perform as well as expected.

Information to support an assessment of the FRP has included characterization of the initial (i.e., first 10 years of operation) Hanford Site tank wastes that will be received in the FRP vessels. The Contractor has completed chemical, physical, and rheological characterization of the initial Hanford Site tank waste compositions that are planned for delivery to the WTP through the FRP and HLP. A summary of this data is provided in Table 2.9 and shows the following:

- The WTP Contract specifications on allowable feed concentrations in the waste are met, based on the tank waste samples provided, with few exceptions.
- Viscosity of the waste is more heavily related to the chemistry than to the solids concentration as suggested by the WTP Contractor in their design basis for rheology (CCN:074567). For example, the AN-102 blended sample has relatively high viscosities (30 cP) at 2 wt% solids.
- Data is very sparse on the waste characteristics required for design, including the relationship between solids content and viscosity and the anticipated particle size. Historical data on additional Hanford Site tank wastes does not appear to have been included in the assessment of the design basis.

Table 2.9. Summary of Tank Waste Characterization Data from WTP Contractor

Tank	Composition Meets WTP Contract	Solids Content (wt%)	Viscosity (cP)	Particle Size Distribution	Reference
AN-102 blended with C-104 leach solutions in ratio of 1 part to two parts, respectively	Sulfate and Cobalt-60 were found to be 110 and 106% above Contract Specification 7 limit, respectively	2 wt%	30.5, 24.9 18.0 cP at 25°, 35°, and 50°C, respectively Fluid characteristics indicate pseudo-plasticity with best curve fit the Oswald Model	Peak 4.1 micron Mode 0 to 12 micron	WTP-RPT-021
AP-101	All Contract Specification 7 limits met Feed diluted to 4.7 M Na prior to characterization	No solids in sample	4.5, 4.4, 2.7, 3.0 cP at 25°, 30°, 50°, and 80°C, respectively	Two peak modes were determined at 5 and 1 micron	WTP-RPT-022
AP-104	All Contract Specification 7 limits met	Not reported	3.47 and 2.36 cP at 25° and 40°C, respectively	Not determined	WTP-RPT-069
AW-101	All Contract Specification 7 limits met	Not determined low solids content	Not determined	Not determined because of low solids content	WSRC-TR-2002-00509
AY-102/C-104	All Contract Specification 7 limits met except TIC at 123% of Contract value Contract Specification 8 limits met	Not reported	4.3 and 3.1 cP at 25° and 40°C, respectively	Solids up to 400-500 micron comprised of particles less than 10 micron, average particle size less than 10 micron	WSRC-TR-2003-00205
AZ-101	All Contract Specification 7 limits met	14 wt% and 45 wt%	2.82 cP at 14 wt% solids and 13 cP at 45 wt%	14.4 % of solids above 16.6 micron, 51% between 4.4 and 16.6 micron and 32% between 1.1 and 4.4 micron and 3% between 0.3 and 1.1 micron	WTP-RPT-048
AN-104	All Specification 7 limit met except U at 102% of limit	Not reported	27 cP	4 micron to > 40 micron	WSRC-TR-2003-00479
AN-107	All Contract Specification 7 limits met except TRU at 130% of Contract value	Not reported	9.4 cP at 25°C and 5.0 cP at 40°C	No information reported on size	WSRC-TR-2003-00210

2.3.7.5 Relevant Environment

Requirements for operation of the FRP are described in the *System Description for Waste Feed Receipt Process* (FRP) (24590-PTF-3YD-FRP-00001). The relevant operational environment for the FRP is:

- Receive and stage LAW and HLW feed from the Hanford Site tank farms.
- Mix and blend low solids containing (<5 wt%) waste solutions to support tank waste characterization activities and release hydrogen gas generated from radiolysis of the tank wastes.
- Mix and blend low solids containing (<5 wt%) waste solutions and transfer these solutions to the FEP and UFP to support process operations.
- Effectively mix and blend a range of waste feed compositions ranging from Newtonian fluid properties to non-Newtonian properties with PJMs.
- Design and fabricate the FRP vessels, which are located in a black cell, to have an operational design life of 40 years.

2.3.7.6 Comparison of the Relevant Environment and the Demonstrated Environment

The Contractor has not conducted any specific testing to validate the adequacy of the FRP PJM design. However, the Contractor has evaluated the design of the PJMs using CFD and other analyses. Based on these results, the Contractor is recommending that testing be completed to assess design adequacy (24590-WTP-RPT-PR-07-002).

As discussed above, the Contractor is relying on CFD analysis to validate the adequacy of the design. This CFD analysis (24590-PTF-RPT-M-03-016) indicates that the PJMs in the FRP vessels may not support the off-bottom suspension mixing requirements. Additional analysis (24590-WTP-RPT-PR-07-002) indicates that the PJM designs will not meet the off-bottom suspension criteria at all FRP vessel levels even when the PJM are operated at 12 m/sec discharge velocity. The Contractor is also recommending (24590-WTP-RPT-PR-07-002) that the size and density of the particles to be delivered to the FRP be reduced compared to the current WTP Contract requirement due to the projected inability of the FRP vessels to suspend solids. The impacts on the tank farms have not been evaluated to deliver reduced size and density of particles in the HLW and LAW feeds.

Based on an evaluation of the relevant environment and documented environment, the Contractor has not established a firm technical basis for the design of the PJMs for the FRP vessels.

2.3.7.7 Technology Readiness Level Determination

The FRP was determined to be a TRL 4 because specific testing to support the adequacy of the mixing design has not been completed. CFD and other computational analyses completed indicated that the PJMs may not be capable of adequately mixing the liquids and solids under normal conditions.

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

Supporting Recommendation

- An evaluation of the fluids to be received and mixed in the feed receipt vessels (FRP-VSL-00002A/B/C/D) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

2.3.8 HLW Lag Storage and Feed Blending Process System (HLP)

2.3.8.1 Function of the HLP

The primary functions of the HLP are to:

- Receive and stage HLW feed from the Hanford Site tank farms (HLP-VSL-00022).
- Receive and stage HLW intermediate products (i.e., treated solids and Sr/TRU precipitates), and blend Cs concentrates prior to transfer to the HLW Vitrification Facility (HLP-VSL-00027A/B/28).

Secondary functions include the capability to return HLW feed and treated HLW solids back to the Hanford Site tank farms, as required, and to transfer HLW feed to various systems in the PT Facility for treatment. In order to return treated solids back to the tank farms, jumpers need to be installed.

2.3.8.2 Description of the HLP

The HLP is comprised of four vessels as listed in Table 2.10 and described below.

Table 2.10. HLW Lag Storage and Feed Blending Vessels

Vessel Name and Number	Nominal Batch/Working Capacity Kgal	Number of PJMs	Number of Air Spargers for Mixing	Maximum Solids Concentration, wt%	Anticipated Fluid Rheology as identified by the WTP Contractor
HLW Receipt Vessel, HLP-VSL-00022	160	12	0	16.7	Newtonian
HLW Lag Storage, HLP-VSL-00027A	86	8	36	20	non-Newtonian
HLW Lag Storage Vessel, HLP-VSL-00027B	86	8	36	20	non-Newtonian
HLW Feed Blend Vessel, HLP-VSL-00028	81	8	36	20	non-Newtonian

HLW Feed Receipt Vessel (HLP-VSL-00022): HLP-VSL-00022 is designed to receive an uninterrupted transfer of up to 600 m^3 (~160,000 gallons) of HLW tank waste from the Hanford Site tank farms. The received HLW feed is sampled for confirmation of waste acceptance prior to processing in the PT Facility. The HLW feed has a maximum solids concentration of 200 g/L (16.7 wt% solids) as specified in the WTP Contract. Based upon feed staging analysis, approximately 13% of the waste mass to be received in HLP-VSL-00022 will have a solids concentration of between 13 and 16.7 wt% solids. The balance of the waste will be transferred at a lower solids concentration (average of ~6 wt%).

During waste feed receipt, the PJMs in HLP-VSL-00022 will be operated to provide sufficient mixing within the vessel. Following sampling and characterization, the HLW feed will be transferred for processing to one of two systems: the FEP for concentration if required (expected to be a rare occurrence), or the UFP (normal transfer route) for blending with other process streams prior to solids separation and treatment. The transfer routing will be determined by the current plant status and evaluated on a case by case basis during plant operations. There is also the option to return HLW feed from the HLW feed receipt vessel back to the Hanford Site tank farms via the waste feed return pump, FRP-PMP-00001, in the FRP. This might occur if the waste was determined to be unacceptable for processing in the PT Facility. This is considered an infrequent event because the waste feed is initially sampled in the tank farms feed staging tank and subsequently characterized and certified. The reason for sampling in the HLW feed receipt vessel is that this vessel can be mixed more effectively and efficiently, compared to the nominal 1 Mgal tank farms staging tank and variability in the nominal 160 Kgal batch transfers is anticipated. Thus, the sampling of well blended waste from the HLW feed receipt vessel is important to successful PT Facility operations.

The HLW feed receipt vessel is designed with 12 fluidic PJMs to promote mixing for high-solid content feed. The HLW feed receipt vessel is also fitted with a continuous recirculation line to promote solids suspension within the transfer lines, to mitigate line blockages, and to maintain suction within the line. The HLW feed receipt transfer pump, HLP-PMP-00021, is designed to provide this continuous recirculation capabilities to FEP, FRP, UFP, and waste returns to the tank farms (through the FRP).

Requirements for the sampling and analysis of HLP-VSL-00022 have been established and are summarized in several documents.

- The *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001) identified four sample types to be obtained: solids fraction for criticality (sample PT 17); liquid fraction for criticality (sample PT 17); whole sample for processing evaluation (sample PT 17 a); and liquid fraction for processing evaluation (sample PT 17 a). Each of these samples requires a well-mixed vessel and representative sample.

- The *Preliminary Criticality Safety Evaluation Report for the WTP* (24590-WTP-RPT-NS-01-001) requires that the liquid and solid phase of the received waste be sampled to verify that the Pu concentration of the waste is below specific criticality limits. These samples require that the vessel contents be completely mixed and a representative waste sample obtained.

- The *WTP Integrated Processing Strategy Description* (24590-WTP-3YD-50-00002) further defines the requirements for process control of HLP-VSL-00022 and identifies requirements for analysis (however, the specific analyses are not defined) of the sample material including:
    - The facility shall be designed and operated in a manner that prevents nuclear criticality and complies with the requirements of DOE O 420.1B, *Facility Safety*.
    - Analyze samples or use existing information to verify compliance with WTP permits and safety authorization basis.

HLW Lag Storage Vessels (HLP-VSL-00027A/B): HLP-VSL-00027A and HLP-VSL-00027B are used to store the sludge slurry concentrates from the UFP, including Sr/TRU precipitate from treatment of the LAW Envelope C, and washed and leached sludge. These intermediate sludge slurry products are received, segregated, and staged separately in one of the two HLW lag storage vessels (HLP-VSL-00027A or HLP-VSL-00027B). Sampling is done once the vessels are filled and locked out to confirm the composition of the vessel for blending purposes. The requirements for sampling and analyses of these vessel contents are discussed in further detail in 24590-WTP-PL-PR-04-0001.

The nominal operating volume of each HLW lag storage vessels is 86,000 gallons. Transfers from vessels UFP-VSL-00002A or UFP-VSL-00002B will average 10,000 gallons. Because these vessels are designated as non-Newtonian (and thereby require mixing by both PJMs and spargers to release hydrogen gas generated from radiolysis), the PJMs (and spargers) are continually operated unless the vessel contents are below a minimum operating level. Based on nominal waste treatment rates it will take about 20 days of processing in the UFP to fill a lag storage vessel. When required, the HLW intermediate products in the lag storage vessels are transferred to the HLW feed blend vessel (HLP-VSL-00028) and blended with Cs concentrate from the CNP.

Slurry from the lag storage vessels can be returned to the Hanford Site tank farms via the waste feed return pump, FRP-PMP-00001. The return of solids is considered an infrequent event, requiring the installation of jumpers.

For operational flexibility, there is the option to also use vessel HLP-VSL-00027B for HLW feed blending prior to transfer to the HLW Vitrification facility. In this case, the HLW feed blending vessel, HLP-VSL-00028 may be used as a lag storage vessel. Transfer lines from the CNP and future Cs/Sr capsule treatment facilities (to be located outside the PT Facility) are also available to vessel HLP-VSL-00027B in order to achieve this blending function.

The HLW solids transfer pump, HLP-PMP-00017A, is connected to vessel HLP-VSL-00027A, and HLP-PMP-00017B is connected to vessel HLP-VSL-00027B. Both pumps have the capability to transfer to the FRP and to the Hanford Site tank farms, while pump HLP-PMP-00017B has the ability to transfer to the HLW Vitrification Facility. For transfers to the Hanford Site tank farms, pump HLP-PMP-00017A/B will be operated in series with pump FRP-PMP-00001.

Requirements for the sampling and analysis of HLW lag storage vessels are summarized in 24590-WTP-PL-PR-04-0001. These requirements involve characterization for process control and process operations planning. This sampling and analysis require a well mixed vessel and representative sample.

HLW Feed Blend Vessel (HLP-VSL-00028): HLP-VSL-00028 is used to prepare and stage HLW feed from the PT Facility to the HLW Vitrification Facility. The treated solids may be blended with a diversity of high-level wastes including Sr/TRU precipitate slurries and the Cs concentrates recovered from the LAW treatment process. There is also the capability to treated Cs/Sr slurry from the Hanford Cs/Sr capsules. The nominal operating volume of the HLW feed blend vessel is 81,000 gallons. Transfers to the HLW Vitrification Facility are nominally 4,500 gallons and occur every 36 hours. Because the HLW feed blend vessel is designated as non-Newtonian (and thereby require mixing by both PJMs and spargers to release hydrogen gas generated from radiolysis), the PJMs (and spargers) are continually operated unless the vessel contents are below a minimum operating level.

HLW feed blending will occur primarily in vessel HLP-VSL-00028. HLW feed blending depends on feed delivery scheduling and the stage of processing at the time of blending. The HLW feed blend vessel is fitted with two HLW feed pumps, HLP-PMP-00019A/B. One pump is used as a backup pump during repair and maintenance. Limitations of heat duty on the HLW blended feed may restrict the addition rate of some intermediate products. Cs concentrate contains considerable amounts of radiolytic Cs isotopes, which generate high-heat duties from radiolytic decay. In addition, to minimize the production of immobilized high-level waste glass, limitations on the addition of Sr/TRU precipitate is desired.

Requirements for the sampling and analysis of HLW feed blend vessel are summarized in 24590-WTP-PL-PR-04-0001. These requirements involve characterization for process control and process operations planning. This sampling and analysis requires a well-mixed vessel and representative sample.

24590-PTF-M0D-M40T-00002 provides the following mixing requirements for the HLP vessels (Table 2.11).

Table 2.11. Summary of Mixing Requirements for the HLP Vessels

Vessel	Mixing Requirements	Viscosity cP	Temperature °F	Solids Concentration wt%
HLP-VSL-00022	• Prevent solids accumulation and facilitate hydrogen evolution • Provide representative sample to support waste acceptance criteria (95% confidence level)	1 - 94	50 - 190	0.1 - 20
HLP-VSL-00027A	• Prevent solids accumulation and facilitate hydrogen evolution • Mixing to support Quality Assurance Requirements Document (QARD) sampling requirements; Solids concentration gradient should not deviate more that 1% vertically and radially	5 - 230	50 - 113	15 - 25
HLP-VSL-00027B	• Prevent solids accumulation and facilitate hydrogen evolution	5 - 230	50 - 113	15 - 25
HLP-VSL-00028	• Prevent solids accumulation and facilitate hydrogen evolution • Mixing to support QARD sampling requirements; Solids concentration gradient should not deviate more that 1% vertically and radially	5 - 230	50 - 113	15 - 25

2.3.8.3 Relationship to Other Systems

There are three primary interfaces with the HLP, HLP-VSL-00022, HLP-VSL-000027A/HLP-VSL-00027B, and HLP-VSL-000028. Each of these interfaces have their own interfaces as follows:

- HLP-VSL-00022 has the following interfaces:
  - Hanford Site tank farms for the receipt of HLW waste feed. The feed will be delivered in batches up to 600 m^3 (160 Kgal), including flush volume. Each batch will have a solids concentration no greater than 200 g/L and no less than 10 g/L.
  - FRP, FEP, and UFP for further processing of the HLW slurry.

- HLP-VSL-000027A/HLP-VSL-00027B have the following interfaces:
  - UFP for the receipt of washed and leached HLW sludge and Sr/TRU precipitate.
  - HLP-VSL-00028 for the transfer of treated HLW slurry to support waste feed blending.
- HLP-VSL-000028 has the following interfaces:
  - HLP-VSL-00027A/HLP-VSL-00028B for the receipt of washed and leached HLW sludge and Sr/TRU precipitate.
  - CNP-VSL-00004 for the receipt of Cs concentrate.
  - External potential future facility for the receipt of Cs and Sr slurries generated from the treatment of the Hanford Cs and Sr capsules.
  - HLW Vitrification Facility melter feed preparation vessels.

2.3.8.4 Development History and Status

The development history of the HLP is directly related to the design of the fluid mixing systems (PJMs and spargers) and blending of the major process streams. The development of the mixing systems will be addressed in the broad categories of Newtonian (shear insensitive) fluid mixing and non-Newtonian (shear sensitive) fluid mixing.

Newtonian Fluid Mixing Development: The Contractor has not collected any testing data in prototypic PJM test systems to demonstrate the mixing of prototypic Newtonian slurries. The Contractor is relying on CFD analysis to validate the adequacy of the design.

The WTP Contractor has prepared an IRP for EFRT issue M-3, “Inadequate Mixing System Design,” (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries.

Non-Newtonian Fluid Mixing Development: Extensive non radioactive simulant testing has been conducted by the WTP Contractor to test the PJM and vessel design concepts for wastes containing high-solid concentrations. These studies were focused on establishing the design and operational requirements for the vessels that are nominally referred to as containing non-Newtonian wastes. A summary of the extensive technology testing information is provided in Section 2.3.6.4.

2.3.8.5 Relevant Environment

Requirements for operation of the HLP are described in the *System Description for HLW Lag Storage and Feed Blending (HLP)* (24590-PTF-3YD-HLP-00001). The relevant operational environment for the HLP is:

- Receive and stage HLW feed from the Hanford Site tank farms.
- Receive, mix, and stage HLW intermediate products; treated solids and Sr/TRU precipitates, and treated solids and Cs concentrates, prior to transfer to the HLW Vitrification Facility.
- Effectively mix and blend a range of waste feed compositions ranging from Newtonian fluid properties to non-Newtonian properties with PJMs.

- Transfer solids slurries between the HLP vessels and other PT Facility process vessels.
- Transfer solid slurries between the HLP vessels and the HLW Vitrification Facility.

2.3.8.6 Comparison of the Relevant Environment and the Demonstrated Environment

HLW Feed Receipt Vessel (HLP-VSL-00022): As summarized above, testing to demonstrate prototypic mixing in the HLW feed receipt vessel has not been completed. And as summarized in Section 2.3.7.6, the mixing requirements for HLP are not clearly and completely defined.

As assessment of the properties of the as-received HLW, feed was provided in CCN:074567 to provide a basis for design. This assessment evaluated tank waste characterization data from Hanford tanks AZ-101, AZ-102, C-104, and AY-102/C-106. This assessment showed that if the solids concentration is maintained below 200 g/L (equivalent to 16.6 wt% solids), the WTP Contract specification upper limit, that the rheological properties are bounded by a yield stress of 1 Pa and a viscosity of 10 cP. However, if the tank waste concentration increased to 300 to 400 g/L, then the rheological properties could increase to yield stress of 3 to 4 Pa and a viscosity of 30 to 35 cP. This assessment concluded that at less than 200 g/L the waste could be considered Newtonian. This assessment did not evaluate shear stress and shear rate information because of lack of availability of information. Limited shear rate and stress information is available on pretreated HLW tank waste compositions. Data provided in 24590-101-TSA-W000-0004-114-00019 indicated that washed sludge compositions at concentrations of 15 to 22 wt% exhibit Bingham Plastic rheological properties.

24590-PTF-M0D-M40T-00002 provides the following mixing requirements for the HLP vessels (Table 2.11). These design requirements, which are used as a basis for the specification of the PJM by AEA Technology, indicate that the HLP vessels would exhibit Newtonian waste properties based on viscosity and solids content.

CFD analysis completed as early as August 2003 (24590-PTF-RPT-M-03-016) indicated that the HLP-VSL-00022 would not adequately mix waste with an assumed set of properties. This analysis was a steady state simulation. This analysis assumed that the waste properties had the following characteristics: 3 wt% solids content, 2.9 g/ml solids density, 22 micron particle size, 1.2 g/ml liquid specific gravity, and 2.94 cP viscosity at 25°C with Newtonian fluid characteristics. This analysis indicated that the 8 m/sec PJM drive velocity (normal velocity when the vessel is full) may not be adequate to move the largest particles from the bottom of the vessels and the 12 m/sec drive velocity (normal velocity when the vessel is full) is recommended to keep large particles in suspension.

A subsequent HLP mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM design for HLP-VSL-00022 would not meet the off-bottom suspension criteria for HLP-VSL-00022 even when the PJMs are operated at 12 m/sec discharge velocity. This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be 1.1 g/ml density of liquid, 2.9 g/ml density of solid, 210 micron mean particle size, and a maximum of 16.68 wt% solids. The analysis using the BHR Group correlation is based on a steady jet and does not account transients such as the PJM drive, vent, and re-flood modes of operation. Thus, the results can only be considered indicative and the system may not perform as well as projected.

The fabrication of HLP-VSL-00022 has been suspended pending the resolution of the issues associated with the mixing of fluids in this vessel.

2.3.8.7 Technology Readiness Level Determination

The HLP-VSL-00022 was determined to be TRL 4 because the technology requirements have not been clearly formulated, and the technology design has been determined by the WTP Contractor to not support basic requirements.

The HLP-VSL-00027A, HLP-VSL-00027B, and HLP-VSL -00028 were determined to be TRL 5 because of the extensive testing completed by the WTP Contractor to establish the technology requirements for mixing in the vessels. Other requirements of these vessels have not been demonstrated including the ability of these vessels to effectively mix washed and leached sludge solids. In addition, testing of the PJMs is still underway to assess PJM overblow with clay simulants and impacts of anti-foam on gas retention and release.

However, overall the HLP was determined to be a TRL 4 because of the lower score of HLP-VSL-00022.

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

Supporting Recommendation

- An evaluation of the fluids to be received and mixed in the HLW feed receipt vessel (HLP-VSL-00022) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

2.3.9 Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

2.3.9.1 Function of the PWD and RLD

The primary function of the PWD and RLD is to receive washes and recycle streams from other vessels in the PTF, and washes and selected recycle streams from the HLW Vitrification Facility, LAW Vitrification Facility, and Analytical Laboratory.

2.3.9.2 Description of the PWD and RLD

The PWD and RLD are described in the *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD* (24590-PTF-3YD-PWD-00001). The PWD receives effluent for storage, neutralization, and transfer to the evaporation system. The effluent includes plant wash from PT Facility vessel sumps, acidic, and alkaline effluent generated during pretreatment operations, and solids wash permeate from ultrafiltration. PWD also receives plant wash from the HLW and LAW Vitrification Facilities, HLW SBS condensate as well as liquid wastes from the Analytical Laboratory. The PT Facility RLD receives evaporator overhead condensate for recycle as process condensate and LAW caustic scrubber waste for transfer to the Liquid Effluent Retention Facility (LERF), Effluent Treatment Facility (ETF), or back to evaporation depending on sample analysis.

Excess process condensate is also transferred to LERF/ETF. Major plant items for these systems include vessels, breakpots, pumps, and sumps.

2.3.9.3 Relationship to Other Systems

The PWD and RLD interface with virtually all process systems in the PT Facility and the recycle streams from the LAW Vitrification and HLW Vitrification Facilities. The primary interfaces are described in Table 2.12. The system description for the PWD and RLD (24590-PTF-3YD-PWD-00001) defines a more detailed breakdown of the interfaces and will not be repeated here.

Table 2.12. Summary of Major Vessel in the PWD and RLD

Vessel Number	Common Name/Function	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
PWD-VSL-00015	Acidic/Alkaline Effluent Vessels Receive and store Cs in exchange column rinses, Cs evaporator condensate and caustic ultrafilter cleanings. Can also receive, neutralize, and store ultrafiltration solids wash, caustic leach, and nitric acid cleanings. Vessel contents are neutralized and sampled prior to transferring into the process. Transfer to FEP feed vessels. Vessel operates in parallel with PWD-VSL-000016.	316L	8	80
PWD-VSL-00016	Acidic/Alkaline Effluent Vessels Receive and store Cs in exchange column rinses, Cs evaporator condensate and caustic ultrafilter cleanings. Can also receive, neutralize, and store ultrafiltration solids wash, caustic leach, and nitric acid cleanings. Vessel contents are neutralized and sampled prior to transferring into the process. Transfer to FEP feed vessels. Vessel operates in parallel with PWD-VSL-000016.	316L	8	80
PWD-VSL-00033	Ultimate Plant Overflow Vessel Receive and transfer laboratory drains and flushes, other line drains, pit sump and PT Facility vessel overflows. Transfer to other PWD-VSL-00044 vessels.	316L	8	15
PWD-VSL-00043	HLW Effluent Transfer Vessel Receive and store waste from HLW Vitrification Facility plant sump area line drains. Transfer to PWD -VSL-00044.	316L	8	15
PWD-VSL-00044	Plant Wash and Disposal Vessel Plant Wash Vessel-Receive and store plant washes, sumps, and other small miscellaneous streams. The vessel contents are neutralized to ensure proper PH in downstream processing. Primary interface is with the FEP feed vessels.	316L	8	60

Table 2.12. Summary of Major Vessel in the PWD and RLD

Vessel Number	Common Name/Function	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
PWD-VSL-00045	C2 Floor Drain Collection Vessel Receive C2 area wastes, sample wastes, and transfer wastes. Vessel contents are sampled and transferred to BOF-NLD-TK-00001 or to RLD-VSL-00017A/B	316L	NA	2.4
PWD-VSL-00046	C3 Floor Drain Collection Vessel Receive C3 area wastes, sample wastes, and transfer wastes. Vessel contents are sampled and transferred to PWD-VSL-000045 or to RLD-VSL-00017A/B	316L	NA	2.4
RLD-VSL-00017A/B	Alkaline Effluent Vessels Receive and store caustic waste from the LAW vitrification facility offgas scrubber, process condensate area sump, and the C3 drain. Vessel is sampled to determine final destination, recycles either back into process or eventual transfer to LERF/ETF. Normally transfers to process condensate tanks.	316L	4	25
RLD-TK-00006A/6B	Process Condensate Tank Store evaporator overhead condensate and waste from RLD-VSL-00017A/17B. Provide hold point for material prior to transfer to LERF/ETF. Provide storage for process condensate recycled back to process.	316L	NA	265

2.3.9.4 Development History and Status

Active waste processing does not occur in the PWD and RLD. However, the mixing of process streams and neutralization of process streams do occur in selected vessels within the PWD. Therefore, the Contractor has conducted initial mixing studies to examine the interaction of process streams. Additional areas of technology are associated with the PJMs and their ability to effectively blend process fluids and suspend solids.

As described in Section 2.3.6, there has been no specific testing of PJM systems with low solids containing fluids. In response to issues raised by the EFRT (CCN:132846), the WTP Contractor has prepared an IRP for EFRT issue M-3, “Inadequate Mixing System Design,” (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain low solids Newtonian slurries.

A number of mixing studies have been completed to assess the interaction of process streams. An identification of the major reports and conclusions are summarized below.

- *Mixing of Process Heels, Process Solutions, and Recycle Streams: Results of the Small-Scale Radioactive Tests* (*PNWD-3029)*: A precipitate formed when the AN-107 LAW sample was mixed with the solution generated by washing the AN-107 entrained solids. This precipitate was rich in Al, bismuth, iron, manganese, and silicon. Solids formation was also observed upon mixing the AN-107 sample with the AW-101 sample and upon mixing the AN-107 sample with the C-104 sludge leach/ wash solution. During plant operations, mixing of these solutions should be avoided to prevent formation of solids.
- *Mixing of WTP Process Solutions (PNWD-3341):* In selected combinations of test solutions, precipitates were observed. In addition, thermodynamic modeling indicated many other solutions to be saturated or oversaturated in selected components. If the modeling is correct, slow precipitation of solids, even after the filtration step in the WTP, may occur, with potential impacts to downstream operations such as IX. Furthermore, this precipitation of solids may lead to an increase in the amount of material reporting to HLW vitrification. Alternatively, the poor agreement between the Environmental Simulation Program (ESP) modeling conclusion and the observation of the mixed process solution may reveal limitations in the predictive capability of the ESP model or the analytical results.

The EFRT report (CCN:132846) identified issues on process operating limits and gelatin of process streams. These were:

> *Process Operating Limits Not Completely Defined*
>
> "Many of the process operating limits of the WTP unit operations have not yet been determined.
>
> Much of the research and technology work for the WTP has been to validate the process equipment design. This type of work is required, but is certainly not adequate to completely develop a process. The key variables that affect the efficiency of each process must be known. Then, the upper and lower bounds of each process variable must be understood. Finally, possible and unexpected interactions of these variables must be understood. Without this more complete understanding of each process, it will be difficult or impossible to define a practical operating range.
>
> The EFRT recommends additional testing be performed to expand the understanding of WTP process capability and to define practical process operating limits for each unit operation."
>
> *Gelation/Precipitation*
>
> "Some of the feeds to the leaching operation will contain significant amounts of aluminum and other materials that could precipitate. There is the possibility aluminum gel will form in the leach tank itself or in other streams from the leaching operation if unfavorable leaching conditions occur."

The Contractor has prepared *Project Response Plan for Implementation of External Flowsheet Review Team (EFRT) Recommendations - M6: Process Operating Limits Not Completely Defined & P4: Gelation/Precipitation* (24590-WTP-PL-ENG-06-0016). The work planned as part of this IRP (which is in progress) includes:

- Evaluation of the completeness of data on the performance of each process operation as a function of feed characteristics/composition and process operating parameters (temperature, flow rate, pH, and so on) at the process operating limits.

- Identification of the conditions that cause degradation of process operation performance so that those limitations can be documented and those conditions can be avoided during operations.

- Review of the process operating limits for the anticipated range of operating modes including (a) normal processing steps; (b) startup, shutdown, and standby modes during transitions between those operating modes; and (c) anticipated off-normal conditions such as a loss of power.

- Determination of the combination of feed characteristics/compositions and process operating parameters that lead to precipitation or gelation reactions that either plug pipelines or degrade system performance due to ultrafiltration and leaching operations. Determination of the conditions during leaching which are likely to contribute to gelation or precipitation downstream.

- Identification where chemical line plugging due to gelation or precipitation of process streams would be most likely to occur. Development of strategies to reverse or mitigate line plugging if it were to occur. Identify design features or operating techniques to implement those strategies.

2.3.9.5 Relevant Environment

Requirements for operation of the PWD and RLD are described in the *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD* (24590-PTF-3YD-PWD-00001). The relevant operational environment for the PWD/RLD is:

- Receive and neutralize a variety of WTP process streams.
- Mix and sample process streams for subsequent to support planning for subsequent treatment.
- Store process fluids containing solids, mix process fluids containing solids and liquids, and ensure effective release of hydrogen gas and support process operations.

2.3.9.6 Comparison of the Relevant Environment and the Demonstrated Environment

Initial mixing studies have been performed to assess the mixing of wastes and process streams. Very limited testing has been completed to assess the interaction of secondary wastes from process system effluents. This is because the PT process flowsheet has not been completely developed. The work associated with the IRP M6/P4 (24590-WTP-PL-ENG-06-0016) will provide the first major assessment of the impacts of process chemistry on planned operations in the PT flowsheet.

An assessment in March 2007 (24590-WTP-RPT-PR-07-002) of the ability of the PWD and RLD vessels has identified that PWD-VSL-00044 will fail the off-bottom suspension criteria and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time). This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be density of liquid 1.1, density of solid-2.9, particle size 210 micron. The solids concentration was 5 wt%. This analysis recommended that the discharge velocity of the PJMs be increased from 8 m/sec to 12 m/sec. Testing was also recommended to verify the adequacy of the PJMs in the aforementioned vessels.

2.3.9.7 Technology Readiness Level Determination

The equipment technology associated with the RWD and RLD has been determined to be a TRL 4 due to the unresolved issues on the PJMs; i.e., the lack of definition of clear requirements for PJM performance and the unresolved issues in the mixing of low viscosity solids solutions as discussed in Section 2.3.6. An assessment in March 2007 (24590-WTP-RPT-PR-07-002) of the ability of the PWD and RLD vessels has identified that PWD-VSL-00044 will fail the off-bottom suspension criteria and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time).

Initial studies on the mixing of process streams such as would occur in the PWD vessels has been completed. These studies indicate that careful control of the pretreatment process is critical to ensuring that solids will not be created which could lead to adverse process performance. Plans for the resolution of a number of potential mixing issues are in place as part of IRP M6/P4, “Process Limits Not Completely Defined/Gelation Precipitation” (24590-WTP-PL-ENG-06-0016).

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

3.0 Summary, Recommendations, and Supporting Recommendations

3.1 Summary

The TRA for the PT Facility determined that nine systems were CTEs:

- Cesium Nitric Acid Recovery Process System (CNP)
- Cesium Ion Exchange Process System (CXP)
- Waste Feed Evaporation Process System (FEP)
- Treated LAW Evaporation Process System (TLP)
- Ultrafiltration Process System (UFP)
- Pulse Jet Mixer (PJM) system
- Waste Feed Receipt Process System (FRP)
- HLW Lag Storage and Feed Blending Process System (HLP)
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

The results of the TRL assessment for each of the CTEs are summarized in Table 3.1. Consistent with NASA and DoD practices, this assessment used TRL 6 as the level that should be attained before the technology is incorporated in the WTP final design. The CTEs were not evaluated to determine if they had matured beyond TRL 6.

3.2 Recommendations

Based upon the results of this assessment, the following recommendations for specific technologies are made:

Recommendation 1

Design activities associated with the CNP should be discontinued until: (1) a reassessment of the design and operational requirements for the CNP is completed; (2) the engineering specification for the CNP is revised to reflect operational conditions; and (3) the technology concept, which includes the process equipment and control system, is demonstrated through integrated prototypic testing.

> *Rationale*
>
> The design concept for the CNP evaporator has not been previously used in radioactive operations for the recovery of nitric acid, or proven by the Contractor in testing. Engineering calculations for the system design do not represent the variable feed compositions from the CXP and resultant product composition anticipated in the CNP. The CNP nitric acid product will likely require compositional adjustment to support subsequent reuse as an elution agent. The proposed continuous operation of the CNP will not accommodate this required chemical adjustment. Thus, the system as conceptualized appears to be undersized and may not support the waste treatment rate requirements of the PT Facility. This process design deficiency appears to be the result of the "Pretreatment

Reconfiguration" studies that removed two CNP feed vessels and two CNP acid product vessels from the plant flowsheet.

Recommendation 2

The CNP should be functionally tested prior to installation in the black cell. The testing should include: testing with representative process feed compositions; verifying the process control system concept; verifying the ability to control and monitor the composition of the nitric acid product; demonstrating the cesium decontamination factor of 5 million; and demonstrating the ability to adequately decontaminate the demister pads using the sprays installed in the separator vessel.

Rationale

The CNP is not planned to be tested until cold commissioning. The CNP will be installed in a black cell and will be very difficult to modify after installation because of accessibility. Testing prior to installation will demonstrate the adequacy of the design and minimize post-installation modifications.

Recommendation 3

Prototypic equipment testing should be completed prior to continuing design of the hydrogen venting subsystem (nitrogen inerting and hydrogen gas collection piping system, and control system) for removing hydrogen and other gases from the cesium IX columns to demonstrate this design feature over the range of anticipated operating conditions.

Rationale

Integrated testing of all CXP technology components has not been completed. Major components not tested include the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns, and the capability to remove 99% by volume of the spherical RF resin from a prototypic IX column. The hydrogen venting system is a first-of-a-kind engineered design that is essential to safe operations of the CXP. Without proper functioning of this system, the CXP may not meet its required waste treatment rate performance objectives.

Alternatively, the project should consider re-designing (and testing) the hydrogen venting subsystem for the IX columns in order to simplify the system. For example, a small recycle stream from the IX columns to the feed vessel (CXP-VSL-00001) could be used to vent gases from the columns. The recycle stream could be controlled through the use of orifice plates and stop valves for isolation.

Recommendation 4

The adequacy of the design concept for CXP-VSL-00001 should be reevaluated and a determination made if this vessel should be modified to include mixing, chemical addition, and heating/cooling to mitigate anticipated process flowsheet issues with precipitation of solids in the CXP feeds.

Rationale

Bechtel National, Inc. engineering studies conducted in 2005 and 2007 indicate that precipitation of sodium oxalate and gibbsite solids will occur following filtration. The capability of the CXP to effectively treat feeds that contain freshly precipitated sodium oxalate and gibbsite solids is not known. Understanding of the dissolution and precipitation kinetics for sodium oxalate and gibbsite is lacking. The morphology of freshly precipitated sodium oxalate is not completely understood.

The CXP-VSL-00001 has no capability for blending solutions or suspending solids. Flowsheet modeling indicates that solids are likely to precipitate if chemical adjustments are not made to the vessel. The CXP-VSL-00001 has no capability for chemical adjustments to reduce/mitigate the solids concentration in cesium IX feed or dissolve/remove solids. It is not clear that the CXP-VSL-00001 vessel design is adequate to perform its required function and support the waste treatment capacity requirements of the PT Facility.

Recommendation 5

Development and testing at a laboratory-scale with actual wastes, and at an engineering-scale with simulants, should be completed in prototypical process and equipment testing systems to demonstrate all detailed flowsheets for the UFP prior to final design. The testing should validate the scaling methodology for mixing, chemical reactions, and filter surface area sizing; determination of process limits; and recovery from off-normal operating events.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-12, "Undemonstrated Leaching Process," and WTP Baseline testing of the Oxidative Leaching Process.

Rationale

Previous DOE evaluations (D-03-DESIGN-05) have been completed on the adequacy of the UFP process chemistry and ultrafilter sizing. This assessment concluded that the WTP flowsheet was not adding sufficient sodium hydroxide to support the dissolution of aluminum in the HLW sludge and the ultrafilter surface area was undersized by a factor of about 2.6. Partial planning is in place by the Contractor to conduct technology testing to provide the technical basis for the ultrafiltration flowsheet and equipment design.

Recommendation 6

Evaluation of a vertical modular equipment arrangement for the UFP filter elements for increasing the filter surface area should be continued. The design configuration (currently proposed horizontal or vertical orientation of the filters) that has the highest probability of successfully achieving performance requirements should be thoroughly tested in high fidelity, prototypical engineering-scale tests using simulants that represent a range of tank waste compositions. Testing scope should include all filtration system operations, process flowsheets (caustic and oxidative leaching and strontium/transuranic precipitation), high-temperature filtration, and filter back pulsing, cleaning, draining, and replacement. Based on the results of this testing, a design concept (either the horizontal arrangement proposed by the Contractor or the vertical arrangement conceptualized by Energy*Solutions*) should be selected for final design.

Rationale

A review and assessment of a proposed modified ultrafiltration system design was conducted by the Contractor. This design concept was based on deploying five filter elements (two 10 ft sections and three 8 ft sections) in a nominally horizontal arrangement as a single fabricated unit. The expert review team advised that:

- The proposed new arrangement for the ultrafilter with five modules connected in series may not provide sufficient drainage, and may cause problems with residual slurry solids buildup in the lower tubes of each module.

- The need to remove and discard a complete five-module filter system because of a blockage or partial blockage, and its replacement with a new unit, may be both lengthy and costly.
- An alternate vertical arrangement of filter modules was strongly recommended by the reviewers. Such an arrangement would trap residual solids within the tubes themselves and have the potential to allow the removal of individual modules or tube bundles.

Recommendation 7

Clear, quantitative, and documented mixing performance requirements for all PJM mixed vessels in the PT Facility and HLW Vitrification Facility should be established. The requirements should be established for all vessel systems even though only those associated with FRP, HLP, PWD, TLP, and FEP were discussed in this assessment.

These requirements should include requirements from criticality safety, environmental compliance, hydrogen management and mitigation, process control, process operations, and immobilized low-activity waste and immobilized high-activity waste form production. These requirements should be used to assess the adequacy of the design and operation of each of the PJM mixed vessels and provide a basis for the completion of the planned testing work on PJMs planned as part of Issue Response Plan M-3, “Inadequate Mixing System Design.” These requirements should be established jointly with project personnel representing safety, environmental compliance, and process operations, with DOE as owner and operator of the WTP.

Rationale

The lack of requirements for mixing performance of each PJM mixed vessels does not provide a basis for:

- The Contractor’s mixing design for the vessels and PJMs.
- DOE’s assessment, as owner and operator of the WTP, of the adequacy of the WTP to achieve safety and operational requirements.
- The Contractor’s planning and conduct of a technology testing program to generate PJM mixing test information to support design decisions (see Recommendation 8).

Recommendation 8

PJM demonstration testing should be completed. The testing information, supplemented with analysis, should be used to determine the design capability of each PJM mixed vessel and identify any required design changes.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-3, “Inadequate Mixing System Design.”

Rationale

The Contractor has developed a testing program on the PJMs to assess the adequacy of the design and operation of each of the PJM mixed vessels.

3.3 Supporting Recommendations

The following supporting recommendations are made by the Assessment Team. These recommendations supplement the major recommendations presented in the previous section

1. The specific gravity operating limit for controlling the concentrated cesium eluate in the CNP separator to a maximum of 80% saturation should be re-evaluated. Based on the WTP Contractor's plan to neutralize cesium concentrate in the separator, and thereby create solids, this operating constraint may not be required.

2. The engineering specification for the CNP should be modified to include (1) the estimated variable feed composition and (2) factory acceptance testing to demonstrate removal and installation of the demister pads from the separator vessel.

3. The Contractor should reassess the corrosion evaluations for the CNP vessels and piping based on the operating conditions of the system.

4. Testing of spherical RF resin should be conducted to: (1) assess physical degradation for irradiated resin samples; (2) assess effects from anti-foaming agent and separate organics present in the feed to the CXP; and (3) assess the impact of particulates on IX column performance.

5. All currently planned testing and documentation of test results for spherical RF resin should be completed. (*Note: This planned work is in the WTP Baseline.*)

6. Additional research should be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate.

7. The engineering specification for the IX columns should be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the External Flowsheet Review Team recommendations for the CXP.

8. The engineering specification for the CXP should be modified to include factory acceptance testing of the IX column to demonstrate that the system is capable of removing greater than 99% by volume of resin from the IX column, upon completion of the resin removal mode, using a maximum volume of 7,500 gallons of water to displace the resin.

9. The strategy and method to scale the ultrafiltration processes (mixing, chemical reaction, and filter surface area) to predict performance of the ultrafiltration system should be established to ensure a high-fidelity UFP engineering-scale test platform and support useful interpretation of the testing results.

10. Process modeling to project the performance of the WTP and confirm design capability should use realistic assumptions on the effectiveness of mixing (both time and efficiency of mixing).

11. An evaluation of the fluids to be received and mixed in the feed receipt vessels (FRP-VSL-00002A/B/C/D) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

12. An evaluation of the fluids to be received and mixed in the HLW feed receipt vessel (HLP-VSL-00022) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

Table 3.1. Technology Readiness Level Summary for the Pretreatment Critical Elements

Critical Technology Element and Description	Technology Readiness Level	Rationale
Cesium Nitric Acid Recovery Process System (CNP) The function of the CNP is to treat Cs eluate by evaporation from the CXP to recover and recycle the nitric acid. The CNP is an integral part of the CXP operating concept. The recovered nitric acid is used for ion exchange column elution. The evaporator bottoms product is transferred to the HLP. The overhead product from the CNP is sent to the PWD.	3	The design concept for the CNP evaporator has not been previously used in radioactive operations for the recovery of nitric acid, or proven by the Contractor by testing. This concept close couples the CNP with the CXP such that Cs eluate from the CXP IX column is received while nitric acid is recovered and sent back to the column for elution. Engineering calculations for the system design do not represent the variable feed compositions from the CXP and resultant variable product composition anticipated in the CNP. The CNP nitric acid product will likely require compositional adjustment to support subsequent reuse as an elution agent. The proposed continuous operation of the CNP will not efficiently accommodate this required chemical adjustment. This process design deficiency appears to be the result of the Pretreatment Reconfiguration studies that removed two CNP feed vessels and two CNP acid product vessel from the plant flowsheet. Laboratory-scale testing to demonstrate the integrated and simulated operations of the reboiler, separator vessel, condenser components, rectifier, and the demister pads has not been completed. The process control system has not been developed and tested. Analytical simulation of the CNP components has not included the full composition range of feed solutions to the evaporator (reboiler and separator vessel) from the CXP. Proposed operational changes to the CNP from the use of an alternative IX resin (e.g., use of RF resin) have not been factored into the CNP design and operational concept.
Cesium Ion Exchange Process System (CXP) The function of the CXP is to recover Cs-137 from the LAW received from UFP using ion exchange. The treated LAW is transferred to the TLP and the recovered Cs-137 is removed from the ion exchange columns using nitric acid.	5	Integrated testing of all CXP technology components has not been completed. Major items not tested include the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns, and the ability to remove 99% by volume of the spherical RF resin from a prototypic IX column. Process testing has not been conducted, or planned to assess the following process operating conditions, assessment of physical degradation of irradiated resin samples and impact on resin performance from organics in the waste. BNI engineering studies indicate that precipitation of sodium oxalate and gibbsite solids will occur following filtration. The capability of the CXP to effectively treat feeds that contain freshly precipitated sodium oxalate and gibbsite solids, is not known. The CXP-VSL-00001 has no capability for blending solutions, suspending solids or chemical adjustments to reduce/mitigate the solids concentration in Cs IX feed or dissolve/remove solids.

Critical Technology Element and Description	Technology Readiness Level	Rationale
Treated LAW Evaporation Process System (TLP) The function of the TLP is to concentrate the treated LAW from the CXP. The LAW is concentrated by evaporation from about 5 molar Na to 8 to 10 molar Na. The overhead product from the TLP is sent to the RLD.	4	The vessels in the TLP (TLP-VSL-00009A/9B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the TLP, is determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved. The TLP design concept is adapted from a proven design (e.g., the 242-A Evaporator) operating at the Hanford Site and the extensive lab-scale and pilot-scale prototypic testing completed to demonstrate this technology. Technology issues evaluated and resolved included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.
Waste Feed Evaporation Process System (FEP) The function of the FEP is to concentrate tank waste an process streams for feeding to the UFP. The nominal UFP feed will have a Na concentration of 5 molar and a solids content less than 4 wt%. The overhead product from the FEP is used for process flushes or sent to the RLD.	4	The vessels in the FEP (FEP-VSL-00017A/18B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the FEP, are determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved. The FEP design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site, and extensive lab-scale and pilot-scale prototypic testing has been completed to demonstrate this technology. Technology issues evaluated and resolved included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.
Ultrafiltration Process System (UFP) The function of the UFP is to separate the HLW solids from the liquids, concentrate the solids, and wash and leach the solids to remove soluble chemical components. The UFP liquids are transferred to the CXP and the treated solids are transferred to the HLP.	3	Testing to define all requirements of the HLW sludge separation and treatment flowsheet has not been completed. Major flowsheet requirements and their status are: • The sludge treatment flowsheet, which is a combination of water washing, caustic leaching and oxidative leaching, has only been evaluated on paper. Plans for testing are in place. • The oxidative leaching process is limited to proof of principle tests and the final process has not been determined. Additional work required to define the concentrations of NaOH and $NaMnO_4$, the sequence of chemical addition, and the time and temperature of operation is planned or underway. • There is very little prototypical data on the filtration of treated sludge wastes (water, caustic and oxidative leached waste). • The ultrafiltration equipment technology concept has only been conceptualized on paper. There is not a representative testing platform available for technology evaluation. However, the Contractor is completing the design of a pilot-scale testing system for the testing and evaluation.

Critical Technology Element and Description	Technology Readiness Level	Rationale
Pulse Jet Mixer (PJM) system The functions of the PJMs are to mix tank waste liquids and solids to release hydrogen gas, support the mixing of waste with reagents, and blends liquids and solids to support process control and treatment of tank wastes.	4	Specific, quantifiable design requirements for the PJM technology have not been established to support design of the PJMs for the black cell vessels. The definition of the PJM mixing requirements must consider all functional requirements (i.e., safety, environmental, process control) of the vessels and the anticipated solution characteristics in the vessel.
Waste Feed Receipt Process System (FRP) The function of the FRP is to receive low solids containing wastes (less than 3.8 wt%) from the tank farm, store and blend the waste, and transfer the wastes to other process operations in PT.	4	Specific testing to support the adequacy of the mixing design for the FRP-VSL-00002A/2B/2C/2D has not been completed. A Computational Fluid Dynamic (CFD) assessment by the Contractor, and other mixing jet analyses completed, indicate that the current PJM operating specification may not be capable of adequately mixing the liquids and solids under normal conditions or achieve the off-bottom suspension criteria for hydrogen release.
HLW Lag Storage and Feed Blending Process System (HLP) The function of the HLP is to receive high solids containing wastes (up to 17 wt%) from the tank farm, store and blend the HLW slurries produced in the UFP waste, and transfer the wastes to other process operations in PT and the HLW facility.	4	Vessel HLP-VSL-00022 has been determined by the Contractor using CFD and other mixing jet analyses to not support basic mixing (e.g., off-bottom suspension) requirements. Vessels HLP-VSL-00027A, HLP-VSL-00027B and HLP-VSL -00028 were determined to be more mature because of the extensive testing completed by the Contractor to establish the technology requirements for mixing in the vessels. Specific mixing requirements for these vessels have not been clearly established. Other requirements of the HLP have not been demonstrated including the ability of these vessels to effectively mix washed and leached sludge solids. In addition, testing of the PJMs with clay simulants is still underway to assess PJM overblow and impacts of anti-foam on gas retention and release.

Critical Technology Element and Description	Technology Readiness Level	Rationale
Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD) The function of the PWD and RLD is to collect and manage process cycles, process line flushes, equipment flushes and sump drains fluids in the PT.	4	The RWD and RLD equipment technology lacks clear requirements for PJM performance. A mixing jet analyses completed by the Contractor determined that PWD-VSL-00044 will fail the off-bottom suspension criteria, and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time). Initial studies on the mixing of process streams have been completed. These studies indicate that careful control of the pretreatment process is critical for ensuring that solids that could lead to adverse process performance are not be created. Plans for the resolution of a number of potential issues are in place as part of the EFRT IRP M-6/P4, "Process Operating Limits Not Completely Defined."

4.0 References

1. 05-WED-019, *Closure of Black Cell Design Adequacy Oversight Recommendation DOE-1 Establishment of Black Cell Design Rules*, May 26, 2005, U.S. Department of Energy, Richland, Washington.

2. 06-WED-009, *Transmittal of Waste Treatment and Immobilization Plant (WTP), Operations Research, Tank Utilization and Steady State Flowsheet Assessment Design Oversight Report* (D-05-DESIGN-021), February 3, 2006, U.S. Department of Energy, Richland, Washington.

3. 24590-101-TSA-W000-0004-114-00016, Rev. 00A, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, March 15, 2005, Bechtel National Inc., Richland, Washington.

4. 24590-101-TSA-W000-0004-114-00019, Rev. 00B, *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program*, January 20, 2006, Bechtel National Inc., Richland, Washington.

5. 24590-101-TSA-W000-0004-118-02, Rev. 00B, *Large Tank Experimental Data for Validation for the FLUENT CFD Model of Pulsed Jet Mixers*, July 7, 2003, Bechtel National Inc., Richland, Washington.

6. 24590-101-TSA-W000-0004-124-03, Rev. 00B, *Demonstration of Ability to Mix in a Small-Scale Pulsed-Jet Mixer Test Facility*, March 13, 2003, Bechtel National Inc., Richland, Washington.

7. 24590-101-TSA-W000-0004-153-00002, Rev. 00B, *Final Report: Gas Retention and Release in Hybrid Pulse Jet Mixed Tanks Containing Non-Newtonian Waste Simulants*, March 22, 2005, Bechtel National Inc., Richland, Washington.

8. 24590-101-TSA-W000-0004-174-00002, Rev. 00B, *Laboratory Scale Hydraulic Testing of Spherical Resorcinol Formaldehyde Ion Exchange Resins*, WTP-RPT-142, September 2006, Pacific Northwest National Laboratory, Richland, Washington.

9. 24590-101-TSA-W000-0004-1742-00001, Rev. 00A (PNWD-3751), *Small Column Ion Exchange Testing of Spherical Resorcinol-Formaldehyde Resin for 137Cs Removal from Pre-Treated Hanford Tank 241-AN-102 Waste (Envelope C)*, 2006, Battelle Pacific Northwest Division, Richland, Washington.

10. 24590-101-TSA-W000-0004-72-08, Rev. 00B, *Results of Small-Scale Particle Cloud Tests and Non-Newtonian Fluid Cavern Tests*, November 19, 2003, Bechtel National Inc., Richland, Washington.

11. 24590-101-TSA-W000-0004-91-00003 Rev. 00A (PNWD-3388), *Elution Testing of Resorcinol-Formaldehyde Resins with AN-105 Simulant*, 2004, Battelle Pacific Northwest Division, Richland, Washington.

12. 24590-101-TSA-W000-0004-99-00013 Rev. 00A (PNWD-3785), *Comparison Testing of Multiple Resorcinol-Formaldehyde Resins for the River Protection Project – Waste Treatment Plant*, 2006, Battelle Pacific Northwest Division, Richland, Washington.

13. 24590-101-TSA-W000-114-00019, Rev. 00B, *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program*, December 2005, Bechtel National, Inc., Richland, Washington.

14. 24590-1-1-TSA-W000-0004-114-00021, Rev. 00A, *Estimate of Hanford Waste Insoluble Particle Size and Density Distribution,* February 2007, Bechtel National Inc., Richland, Washington.

15. 24590-CM-TSA-HXYG.0008, *Technical Basis for River Protection Project Waste Treatment Plant (RPP-WTP)-Power Fluidics System Design*, August 6, 2001, BNFL.

16. 24590-PTF-3PS-MEVV-T0002, Rev. 4, February 21, 2007, *Engineering Specification for Cesium Nitric Acid Recovery Forced Circulation Vacuum Evaporator System*, Bechtel National Inc., Richland, Washington.

17. 24590-PTF-3PS-MWD0-T0005, Rev. 1, 2005, *Engineering Specification for Cesium Ion Exchange Columns*, Bechtel National Inc., Richland, Washington.

18. 24590-PTF-3YD-CNP-00001, Rev. 0, September 11, 2002, *System Description for the Pretreatment Facility Cs Nitric Acid Recovery Process (CNP) System*, Bechtel National Inc., Richland, Washington.

19. 24590-PTF-3YD-CXP-00001, Rev. 0, September 11, 2002, *System Description for the Cesium Ion Exchange Process – System CXP*, Bechtel National Inc., Richland, Washington.

20. 24590-PTF-3YD-FEP-00001, Rev. 0, *System Description for Waste Feed Evaporation Process (FEP)*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

21. 24590-PTF-3YD-FRP-00001, Rev. 0, *System Description for Waste Feed Receipt Process (FRP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

22. 24590-PTF-3YD-HLP-00001, Rev. 0, *System Description for HLW Lag Storage and Feed Blending (HLP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

23. 24590-PTF-3YD-PJV-00001, Rev. 0, *System Description for PTF Pulse Jet Ventilation System*, September 5, 2003, Bechtel National, Inc., Richland, Washington.

24. 24590-PTF-3YD-PVP-00001, Rev. 0, *System Description for Pretreatment Vessel Vent Process System*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

25. 24590-PTF-3YD-PWD-00001, Rev. 1, *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD*, September 22, 2003, Bechtel National, Inc., Richland, Washington.

26. 24590-PTF-3YD-TLP-00001, Rev. 0, *System Description for Treated LAW Evaporation Process (TLP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

27. 24590-PTF-3YD-UFP-00001, Rev. 0, *System Description for Ultrafiltration Process System (UFP)*, September 2002, Bechtel National, Inc., Richland, Washington.

28. 24590-PTF-ES-PR-05-001, Rev. 0, *Engineering Study on the Pretreatment Oxidative Leaching Reagent Selection and Process Implementation*, February 6, 2006, Bechtel National, Inc., Richland, Washington.

29. 24590-PTF-M0D-M40T-00002, Rev. C., *Process Data Sheet Fluidics*, February 7, 2003, Bechtel National Inc., Richland, Washington.

30. 24590-PTF-M5-V17T-00013, Rev. 2, 2006, *Process Flow Diagram Cesium Ion Exchange Process Columns System CXP*, Bechtel National Inc., Richland, Washington.

31. 24590-PTF-RPT-M-03-016, Rev. 0, *CFD Modeling Report for WTP Vessel FRP-VSL-00002A-D with a PJM Drive Velocity of 12 m/s*, August 28, 2003, Bechtel National Inc., Richland, Washington.

32. 24590-PTF-RPT-PR-06-001, Rev. 0, *Pulse Jet Mixer Computational Fluid Dynamics Final Report*, January 11, 2007, Bechtel National Inc., Richland, Washington.

33. 24590-PTF-RPT-PR-06-002, Rev. 0, *Benchmarking of Computational Fluid Dynamic Simulation of Pulse Jet Mixers Using Experimental Data*, November 2, 2006, Bechtel National Inc., Richland, Washington.

34. 24590-PTF-RPT-RT-03-001, Rev. 1, *Closure Report for R&T Evaporator Studies*, October 13, 2006, Bechtel National Inc., Richland, Washington.

35. 24590-PTF-TSP-RT-06-007, Rev. 0, *Scaled Testing to Determine the Adequacy of the WTP Pulse Jet Mixer Designs*, January 16, 2007, Bechtel National, Inc., Richland, Washington.

36. 24590-QL-POA-MEVV-00002-08-00003, Rev. 00B (32-5037887-00), *Hanford Evaporator Project #2 – Evaporator Mass and Energy Balance Calculation*, 2006, AREVA, Richland, Washington.

37. 24590-QL-POA-MPEQ-00002-04-03, Rev. 00A, *Fluidics Design and Methodology Report; Pulse Jet Mixing Systems,* ESI Document No. 2141-04-116 issued December 9, 2002, August 17, 2004, Bechtel National Inc., Richland, Washington.

38. 24590-WTP-3DP-G04B-00027, Rev. 8, *Design Verification*, Bechtel National Inc., Richland Washington.

39. 24590-WTP-3DP-G04B-00046, Rev. 16, *Engineering Drawings*, Bechtel National Inc., Richland, Washington.

40. 24590-WTP-3DP-G04T-00901, Rev. 10, *Design Change Control*, Bechtel National Inc., Richland Washington.

41. 24590-WTP-3DP-G04T-00913, Rev. 5, *Review of Engineering Documents*, Bechtel National Inc., Richland, Washington.

42. 24590-WTP-3YD-50-00002, Rev. 0, *WTP Integrated Processing Strategy Description*, July 12, 2004, Bechtel National, Inc., Richland, Washington.

43. 24590-WTP-3YD-50-00003, Rev. A, *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems*, May 19, 2004, Bechtel National, Inc., Richland, Washington.

44. 24590-WTP-CE-PC-06-001, Rev. 0, *Hanford Tank Waste Treatment and Immobilization Plant May 2006 Estimate at Completion*, May 31, 2006, Bechtel National Inc., Richland, Washington.

45. 24590-WTP-DB-ENG-01-001, Rev. 1I., *Basis of Design*, November 27, 2006, Bechtel National Inc., Richland, Washington.

46. 24590-WTP-PL-ENG-06-0013, Rev. 000, *Issue Response Plan for Implementation of External Flowsheet Review Team (EFRT) Recommendations-M3, Inadequate Mixing System Design*, August 8, 2006, Bechtel National Inc., Richland, Washington.

47. 24590-WTP-PL-ENG-06-0016, Rev. 0, *Project Response Plan for Implementation of External Flowsheet review Team (EFRT) Recommendations-M6: Process Operating Limits Not Completely Defined & P4: Gelation/Precipitation*, September 20, 2006, Bechtel National, Inc., Richland, Washington.

48. 24590-WTP-PL-ENG-06-0026, Rev. 000, *Issue Response Plan for Implementation of External Flowsheet Review Team (EFRT) Recommendations: M14, M10a, P5, P6, P7 and P8*, 2006, Bechtel National Inc., Richland, Washington.

49. 24590-WTP-PL-MG-01-002, Rev. 4, *WTP Configuration Management Plan*, Bechtel National, Inc., Richland, Washington.

50. 24590-WTP-PL-PR-01-003, Rev. 3, *Risk Management Plan*, 2007, Bechtel National Inc., Richland, Washington.

51. 24590-WTP-PL-PR-04-0001, Rev. 1, *Integrated Sampling and Analysis Requirements Document*, December 22, 2006, Bechtel National, Inc., Richland, Washington.

52. 24590-WTP-PL-RT-01-002, Rev. 2.0, *Research and Technology Plan*, April 15, 2003, Bechtel National, Inc., Richland, Washington.

53. 24590-WTP-PSAR-ESH-01-002-02, Rev. 2B, *Preliminary Safety Analysis Report to Support Construction Authorization; PT Facility Specific Information*, 2007, Bechtel National Inc., Richland, Washington.

54. 24590-WTP-RPT-ENG-05-006, Rev 0., *Technical Report on Oxidative Leaching*, June 30, 2005, Bechtel National Inc., Richland, Washington.

55. 24590-WTP-RPT-M-06-003, Rev 0. *Summary Report: hydrodynamic Loads for PJM Multiple Overblow Condition*, January 11, 2007, Bechtel National Inc., Richland, Washington. ,

56. 24590-WTP-RPT-NS-01-001, Rev. 5, *Preliminary Criticality Safety Evaluation Report for the WTP*, December 2006, Bechtel National, Inc., Richland, Washington.

57. 24590-WTP-RPT-OP-01-001, Rev. 2, *Operations Requirements Document*, Bechtel National Inc., Richland, Washington.

58. 24590-WTP-RPT-PO-05-001, Rev. 0, 2005, *2005 WTP Operational Research Assessment Report*, Bechtel National Inc., Richland, Washington.

59. 24590-WTP-RPT-PO-05-009, *2005 WTP Material Balance and Process Flowsheet Assessment*, November 10, 2005, Bechtel National Inc., Richland, Washington.

60. 24590-WTP-RPT-PR-01-006, Rev. 13, *Risk Assessment Report*, 2006, Bechtel National Inc., Richland, Washington.

61. 24590-WTP-RPT-PR-07-002, Rev. 0, *EFRT Issue M3 Vessel Mixing Model Results-Best Estimate British Hydro-Mechanical Research Group (BHRG) Methodology*, March 2, 2007, Bechtel National Inc., Richland, Washington.

62. 24590-WTP-RPT-PR-07-003, Rev. 0, *Pulse Jet Mixer (PJM) Mixing Test Performance Criteria,* February 2, 2007, Bechtel National Inc., Richland, Washington.

63. 24590-WTP-RPT-PT-02-019, Rev. 1, *Cesium Eluate Concentrator Reconciliation of Test Data*, 2004, Bechtel National, Inc., Richland, Washington.

64. 24590-WTP-RPT-RT-06-001, *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644*, 2006, Bechtel National Inc., Richland, Washington.

65. 24590-WTP-SED-ENS-03-002-02, Rev. 1i, *Safety Envelope Document; PT Facility Specific Information*, 2007, Bechtel National Inc., Richland, Washington.

66. BNFL-RPT-048, Rev. 0, *Demonstration and Optimization of BNFL's Pulsed Jet Mixing and RFD Sampling Systems Using NCAW Simulant*, August 2000, Battelle, Pacific Northwest Division, Richland, Washington.

67. CCN:020148, "Tank Utilization Study-Phase 1 Results," June 5, 2001, Bechtel National Inc., Richland, Washington.

68. CCN:050417, "Evaporator Demister Pads Replacement," January 1, 2003, Bechtel National Inc., Richland, Washington.

69. CCN:074276, "Risk Response Report for Formation of Hazardous Mercury Compounds (Dimethyl Mercury) in Evaporator Overheads," October 31, 2003, Bechtel National Inc., Richland, Washington.

70. CCN:074567, "Rheology of 'As Received' HLW Feed," December 15, 2003, Bechtel National, Inc., Richland, Washington.

71. CCN:132846, "Report of External Flowsheet Review Team for the Hanford Waste Treatment and Immobilization Plant-Final Report Titled: 'Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput'," March 17, 2006, Bechtel National Inc., Richland, Washington.

72. CCN:150033, "M6/P4 Assessment of Design Strategies to Reverse Line Plugging and Operating Strategies to Mitigate Plug Formation for Engineering Consideration," December 22, 2006, Bechtel National Inc., Richland, Washington.

73. CCN:150383, "Path Forward for EFRT Mixing Issue M3," January 11, 2007, Bechtel National Inc., Richland, Washington.

74. Contract No. DE-AC27-01RV14136, Modification No. M076, *WTP Contract Section C Statement of Work*, 2006, U.S. Department of Energy Office of River Protection Project, Richland, Washington.

75. D-03-DESIGN-05, *HLW Feed Preparation System; Ultra-filtration Process System*, April 2004, U.S. Department of Energy, Richland, Washington.

76. D-05-DESIGN-013, *WTP Oxidative Leaching Design Oversight Report*, August 2005, U.S. Department of Energy, Richland, Washington

77. DoD 2004, *Acquisition System Guidebook*, DODI 5000.2, U.S. Department of Defense, November 17, 2004.

78. DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005.

79. DOE 2006, Memorandum from Paul Bosco to James A. Rispoli, “Performance Baseline Validation and Transmittal of the External Independent Review Reports for the Waste Treatment and Immobilization Plant Project at Richland Washington,” December 16, 2006, U.S. Department of Energy, Washington D.C.

80. DOE O 420.1B, *Facility Safety*, December 22, 2005, U.S. Department of Energy, Washington, D.C.

81. ES-5501-G-0001, Rev A, “WTP Pretreatment Facility Ultrafilter Review – Engineering Study Report,” April 23, 2007, Energy*Solutions*, Richland, Washington

82. FMP 064, *Jet Solid Suspension Design Guide*, October 2005, BHR Group Limited, Bedfordshire, UK.

83. GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Can Improve Weapon System Outcomes*, July 1999, United States General Accounting Office.

84. HW-31000, *PUREX Technical Manual*, 1955, General Electric Company, Richland, Washington.

85. Nolte, William L., et al., *Technology Readiness Level Calculator*, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003.

86. Phull, B.S., W.L. Mathay, and R.W. Ross, 2000, *Corrosion Resistance of Duplex and 4-6% Mo-Containing Stainless Steels in FGD Scrubber Absorber Slurry Environments*, Presented at Corrosion 2000, Orlando, Florida, March 26-31, 2000, NACE International, Houston, Texas.

87. PNWD-3029, *Mixing of Process Heels, Process Solutions, and Recycle Streams: Results of the Small-Scale Radioactive Tests*, April 2000, Battelle, Richland, Washington.

88. PNWD-3229, *Chemical Analysis and Physical Property Testing of 241-AN-102 Tank Waste-Supernatant and Centrifuged Solids*, 2002, Battelle Pacific Northwest Division, Richland, Washington.

89. PNWD-3341 (24590-101-TSA-W0000-0004), *Mixing of WTP Process Solutions*, May 2003, Battelle, Richland, Washington.

90. SCT-MOSRL60-00-221-00001, Rev. 00A, *Spherical Resorcinol-Formaldehyde Resin Reactivity with Nitric Acid and Other Hanford RPP-WTP Process Solutions*, 2006, Westinghouse Savannah River Company, Aiken, South Carolina.

91. SCT-M0SRLE60-00-05-00003, Rev. 00A (WSRC-TR-2004-00100, Rev. 0), *Ion Exchange Modeling for Removal of Cesium from Hanford Waste Using Resorcinol-Formaldehyde Resin*, 2004, Westinghouse Savannah River Company, Aiken, South Carolina.

92. SCT-M0SRLE60-00-110-00028, Rev. 00A (WSRC-TR-2005-00270), *Pilot-Scale Hydraulic Testing of Resorcinol Formaldehyde Ion Exchange Resin*, 2006, Westinghouse Savannah River Company, Aiken, South Carolina.

93. SCT-M0SRLE60-00-110-00029, Rev. 00A (WSRC-STI-2006-0071), *Batch, Kinetics, and Column Data from Spherical Resorcinol-Formaldehyde Resin*, 2006, Westinghouse Savannah River Company, Aiken, South Carolina.

94. SCT-M0SRLE60-00-183-01, Rev. 00D (WSRC-TR-2002-00424), *Physical Property Models of Concentrated Cesium Eluate Solutions*, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

95. SCT-M0SRLE60-00-183-02, Rev. 00A (WSRC-TR-2003-00267, Rev. 0), *Validation and Application of Concentrated Cesium Eluate Physical Property Models*, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

96. SCT-M0SRLE60-00-185-01, Rev. 00B, (WSRC-TR-2003-00135), *Cesium Eluate Semi-Batch Evaporation Performance*, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

97. SCT-M0SRLE60-00-33-03, Rev. 00B (WSRC-TR-2003-00156, Rev. 0), *Recycle Stream Blending for High and Low Level Waste*, December 20, 2001, Bechtel National, Inc., Richland, Washington.

98. SCT-MOSRLE60-00-10-00005, Rev. 00A (WSRC-TR-2005-00075, Rev. 0), *Radiolytic, Thermal, and Physical Degradation Testing of Spherical Resorcinol-Formaldehyde (RF) Resin*, Westinghouse Savannah River Company, Aiken, South Carolina.

99. Van Der Cook, R.E. and Ogren, W.E., ARH-F-101, *Vacuum Evaporator-Crystallizer Flowsheet for Waste Liquors*, 1976, Atlantic Richfield Hanford Company, Richland, Washington.

100. WSRC-MS-2005-00756, Rev. 0, *Filtration of a Hanford Site Tank 241-AN-102 Waste Sample with Alternate Sr/TRU Precipitation Conditions at Bench and Pilot Scale*, March 2004, Savannah River National Laboratory, Aiken, South Carolina.

101. WSRC-MS-99-00467, Rev. 0, *Pilot-Scale Cross-Flow Filtration Test for a Radioactive Waste Simulant With High Solids Loading and Sodium Molarity*, Paper at the 4th International Conference on Multiphase Flow, New Orleans, May 27-June 1, 2001.

102. WSRC-TR-2000-00469, Rev. 0, *Bench Scale Evaporation of a Large Hanford Envelop C Sample*, 2001, Westinghouse Savannah River Company, Aiken, South Carolina.

103. WSRC-TR-2003-00204, Rev. 0, *Final Report: Pilot-Scale Cross-Flow Ultrafiltration Test Using a Hanford Site Tank 241-AN-102 Waste Simulant*, May 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

104. WSRC-TR-2003-00216, *Waste Treatment Plant LAW Evaporation: Antifoam Performance*, August 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

105. WSRC-TR-2003-00238, *Studies of Mercury in High Level Waste Systems*, June 6, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

106. WSRC-TR-2003-00240, Rev. 0, *Filtration, Washing, and Leaching of a Hanford AY-102/C-106 Sample*, September 2003, Savannah River National Laboratory, Aiken, South Carolina.

107. WSRC-TR-2003-00295, Rev. 0, *Filtration of a Hanford AN-104 Sample*, September 2003, Savannah River National Laboratory, Aiken, South Carolina.

108. WSRC-TR-2004-00398, Rev. 0 (SRNL-RPP-2004-00060 Rev. 0), *Final Report – Hybrid-Mixing Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*, 2004, Savannah River National Laboratory, Aiken, South Carolina.

109. WSRC-TR-2004-00399, Rev. 0 (SRNL-RPP-2004-00062 Rev. 0), *Final Report – Gas Retention and Release Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*, 2004, Savannah River National Laboratory, Aiken, South Carolina.

110. WSRC-TR-2004-00430, Rev. 0 (SRNL-RPP-2004-00069 Rev. 0), *One-Eighth-Scale Pulse Jet Mixer (PJM) - Design Parameters Scale Law Testing*, November 2004, Westinghouse Savannah River Company, Aiken, South Carolina.

111. WSRC-TR-2005-00105, Rev. 0, *Final Report: RPP-WTP Semi-Integrated Pilot Plant*, June 2005, Bechtel National, Inc., Richland, Washington.

112. WTP-RPT-110, Rev. 0 (PNWD-3496), *Test Results for Pulse Jet Mixers in Prototypic Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, 2004, Battelle – Pacific Northwest Division, Richland Washington.

113. WTP-RPT-111, Rev. 0 (PNWD-3495), *Non-Newtonian Slurry Simulant Development and Selection for Pulsed Jet Mixer Testing*, 2004, Battelle – Pacific Northwest Division, Richland, Washington.

114. WTP-RPT-113, Rev. 0 (PNWD-3551), *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

115. WTP-RPT-114, Rev. 1 (PNWD-3552), *Final Report: Gas Retention and Release in Hybrid Pulse Jet-Mixed Tanks Containing non-Newtonian Waste Simulants*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

116. WTP-RPT-117, Rev. 0, *Oxidative Alkaline Leaching of Washed 241-SY-102 and 241-SX-101 Tank Sludges*, October 2004, Battelle – Pacific Northwest Division, Richland, Washington.

117. WTP-RPT-128, Rev. 0, *Hybrid Mixing System Test Results for Prototype Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

118. WTP-RPT-129, Rev. 0 (PNWD-3541), *Technical Basis for Scaling of Air Sparging Systems for Mixing in Non-Newtonian Slurries*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

119. WTP-RPT-137, Rev. 0, *Oxidative Alkaline Leaching of SX-101 and SY-102 and Its Impact on Immobilized High-Level Waste*, Battelle – Pacific Northwest Division, Richland, Washington.

120. WTP-RPT-151, Rev. 0, *Review of Caustic Leaching Testing With Hanford Tank Waste Sludges*, December 2006, Battelle – Pacific Northwest Division, Richland, Washington.

Appendix A – Determination of Critical Technology Elements

Appendix A– Determination of Critical Technology Elements

The working definition of the critical technology element (CTE) as defined in the *Technology Readiness Assessment (TRA) Deskbook* (2005) was used as a basis for identification of CTEs for the Waste Treatment and Immobilization Plant (WTP). The working definition is as follows:

> *A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel.*
>
> *Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.*

The WTP Project is divided into five project elements:

- Analytical Laboratory (LAB)
- Balance of Facilities (BOF)
- Low-Activity Waste (LAW) Vitrification Facility
- High-Level Waste (HLW) Vitrification Facility
- Pretreatment (PT) Facility

Within each project element, the specific design features of the facility are divided into "systems." Thus, for convenience, the identification of the CTEs was done on a system basis. Most systems within the WTP facility are unique to the five project elements identified above. However, some selected systems are common to the treatment facilities (LAB, LAW, HLW, and PT). Where appropriate, these common systems were allocated to the five project elements identified above.

The process for identification of the CTEs for the PT Facility involved two steps:

1. The complete list of systems for PT Facility was initially screened by the Assessment Team (Appendix D) for potential CTEs. Systems directly involved in the processing of the tank waste, or handling of the primary products were identified as potential CTEs. The complete list of systems and those identified as potential CTEs are shown in Table A.1.

2. The final set of CTEs was determined by assessing the potential CTEs against the two sets of questions presented in Table A.2. A CTE is determined if there is a positive response to at least one of the questions in each of the question sets. This final assessment of the CTEs was completed jointly by the Assessment Team and the WTP Project Technology and Engineering staff.

   The specific responses to each of the questions for each potential CTE are provided in Table A.3.

The rationale for the selection of each of the systems as a CTE is summarized below.

CNP-Cesium Nitric Acid Recovery Process System (24590-WTP-3YD-CNP-00001)

The CNP is used to concentrate the acidic cesium (Cs) eluant from the elution of the Cs ion exchange (IX) columns and steam strip a portion of the nitric acid from the Cs eluant for recycle within the WTP flowsheet. The CNP uses a traditional evaporator design concept in which the pot boiler and vessel are separated. The evaporator vessel and demister tower are located in a black cell where no maintenance is required (except that the demister can be changed through an access plug in the top of the black cell) and the pot boiler is located in a hot cell where the tube bundle can be replaced. The CNP includes a fractionator tower for separating nitric acid from water. The acid fractionator is located in the black cell. The evaporation system is operated under vacuum to reduce the operating temperatures and corrosion rate of the materials. The evaporator system is being provided by a commercial vendor, Averna Technologies.

No schedule risks or cost risks were identified with the availability of the CNP. The end state requirements for the CNP products are known and are specified in the CNP system description (24590-WTP-3YD-CNP-00001). The technology is not new but has been modified and repackaged in that part of the system is designed as a permanent system (in the black cell) and part of the system is replaceable. The system design is unique and has not been demonstrated. Concerns were identified that there is no testing of this equipment concept in the application specified. The solubility limitations of the salts in the Cs eluate have not been completely evaluated. Some simulant testing was completed to investigate solubility relationships of major salts.

CXP-Cesium Ion Exchange System (24590-WTP-3YD-CXP-00001)

The CXP removes Cs from ultrafiltration system permeates. The CXP utilizes four IX columns. Three columns in series are in service while one is in standby mode. The Ultrafiltration Process System (UFP) permeate is transferred from the Cs IX feed vessel through heat exchangers into three IX columns that are operated in series. The first column is designated as the lead column. The second column is designated as the lag column. The third column is designated as the polishing column. The Cs treated LAW is collected in one of three vessels.

An initial design of the IX columns has been completed. The final design will be provided by a vendor yet to be selected. There is no cost risk and the end state requirements for the system are well-defined. Schedule risk results from the selection of a vendor for the final CXP IX column design. The vendor must be qualified to address issues (how to keep the resin bed level, breakthrough detection, flow rates, performance). There is also some schedule risk because the testing work on the IX resins candidates (resorcinol formaldehyde and SuperLig® 644), which could impact the final design, has not been completed. Most of the testing work for the resorcinol formaldehyde resin has been done using simulants based on Hanford tank waste supernatant compositions for tanks AP-101, AZ-102, AN-107, and AN-105, and not a wide range of wastes. Small column IX tests have been done on actual wastes from tanks AP-101 and AN-102.

The IX system is not new or novel, but it is modified. The candidate IX resins (resorcinol formaldehyde and SuperLig® 644) have not been manufactured commercially in large production batches or used in large-scale operations. Concerns were identified with the hydrogen gas removal system for the Cs IX columns, which has not been demonstrated. Additionally, concerns were identified with a device for measuring the level of resin in the IX columns, which has not been demonstrated. This device is crucial to verify removal of spent resin from the columns.

FEP-Waste Feed Evaporation Process (24590-WTP-3YD-FEP-00001)

The FEP is used to concentrate process recycles in the PT Facility and to prepare the ultrafiltration feed at a nominal concentration of 5 M sodium (Na). The FEP uses a vacuum evaporator design concept similar to the Hanford 242-A Evaporator. There are no schedule or cost risks, and end state requirements are known. The technology is not new, novel, or modified.

The evaporation technology is repackaged, because part of the system is in a black cell and part is in a hot cell. The evaporator vessel and demister tower are located in a black cell where no maintenance is required (except that the demister can be changed through an access plug in the top of the black cell) and the pot boiler is located in a hot cell where the tube bundle can be replaced. The system is not expected to perform beyond the demonstrated capability. The evaporator includes more bubble trays than is typically used, but the decontamination factor is not greater than supported by vendor data. Currently, there are unresolved issues with chemical and physical plugging of some of the process pipe lines. The waste feeds have not been completely characterized or evaluated, and there may be chemistry issues with the solubility's of the leachate streams. The evaporator system is being provided by a commercial vendor, Averna Technologies.

FRP-Waste Feed Receipt Process (24590-WTP-3YD-FRP-00001)

The FRP process consists of 4 large vessels (~380,000 gallons), each having 12 pulse jet mixers (PJM). The FRP is used to receive low solids concentration slurries (> 5 wt%) from the Hanford Site tank farms and store process recycles within the PT Facility. The vessels have already been installed in the WTP. There are no known schedule or cost risks. However, based on recent PJM mixing analyses additional limitations may need to be placed on the received waste feeds. The PJMs may not impart enough power to the fluid to suspend solids.

The technology is not new or novel. However, the size of the PJMs is unprecedented in fluidic mixing technology. The PJMs may be expected to perform beyond currently demonstrated capability.

HLP-HLW Lag Storage and Feed Blending (24590-WTP-3YD-HLP-00001)

The HLP vessels are used to store and blend high solids concentration feed slurries and will nominally contain non-Newtonian fluids. There are current concerns with the adequacy of the PJM wear plate thicknesses on vessels HLP-VSL-00027A, HLP-VSL-00027B, and HLP-VSL-00028, and the PJM design for vessel HLW-VSL-00022. In addition, HLP-VSL-00022 may need to be re-designed to support the mixing on non-Newtonian slurries.

The HLP vessels are in the vendor shops being built. There are potential schedule and cost risks because of unresolved design issues with these vessels. The technology is not new, but it has been modified and/or repackaged. The technology was demonstrated for non-Newtonian fluids in PJM testing conducted by the WTP Contractor, but the PJMs must also suspend solids from Newtonian fluids. HLP-VSL-00022 should have been designed to handle higher solids content and may require spargers to assist in mixing.

PJM-Pulse Jet Mixers (24590-WTP-3YD-50-00003)

PJMs are used within the WTP to dissipate gases, blend liquids, and suspend solids for sampling and transport. This system is similar to the system used at the Sellafield site, United Kingdom, for non-Newtonian fluids. For Newtonian fluids, there may not be enough power imparted from the PJM to the bulk fluid to suspend the solids and keep them from settling on the bottom. There are schedule and cost risks, because of unresolved design issues with the PJMs for the Newtonian vessels. These concerns will be resolved as part of an ongoing testing program. End state requirements for PJMs are documented but performance has yet to be validated.

The PJM mixing technology is not new, but it has been modified and repackaged. The PJM discharge velocity for all WTP applications has yet to be determined based upon experimental data. The required operational modifications may require the PJMs to perform beyond their demonstrated capability. Solids concentrations are an order of magnitude higher at the WTP than at the Sellafield application, and the PJM capability for Newtonian off bottom suspension has not been demonstrated. The Sellafield site used PJMs to mix acidic waste streams feed, the WTP uses an alkaline feed. The acidic and alkaline waste streams have significantly different rheological properties and extension of the PJM data from Sellafield may not be possible.

PJV-Pulse Jet Ventilation System (24590-WTP-3YD-PJV-00001)

The PJV is the exhaust system for the vent air for the PJMs. There are no schedule or cost risks.
The demisters, high-efficiency particulate air (HEPA) filters, and fans are well-proven in any application. End state requirements are known, but contamination creep into the system was identified as an issue. However, testing has shown that the efficacy of the flush system for contamination removal.
The technology is not new or novel.

The PJV is modified because it used a HEPA filter configuration that is different than previously used in the U.S. As a result, the vendor has been required to provide additional testing and analysis to prove the HEPA filters can be U.S.-code compliant. The U.S. HEPA code requires the filter to be inline with the direct flow. The British designed system allows air flow radially from the filters. The vendor has had difficulty getting the filter qualified to the U.S. code. The system is repackaged because it uses the British system with a different seal (blue gel with a knife edge) compared to standard HEPA filters, but similar seals have been extensively used at the Hanford Site.

PVP- Pretreatment Vessel Vent Process System (24590-WTP-3YD-PVP-00001)

The PVP is an offgas treatment system for the PJM and RFD air supply. This system uses standard equipment except for the radial HEPA filters. There are no schedule or cost risks, but it may not meet end state requirements if contamination creep occurs in the PVP. A Savannah River National Laboratory (SRNL) report on PJM creep documents the efficacy of the flush system for contamination removal.
The technology is not new or novel, but it is modified. The U.S. HEPA code requires the filter to be inline with the direct flow. The British designed system allows air flow radially from the filters.
The vendor has had difficulty getting the filter qualified to the U.S. code. The system is repackaged because it uses the British system with a different seal (blue gel with a knife edge) compared to standard HEPA filters, but similar seals have been used extensively at the Hanford Site.

PWD-Plant Wash Drain (24590-WTP-3YD-PWD-00001)

The PWD is used to receive recycle streams from the HLW Facility and other pretreatment process streams. The PWD includes leak detection, drains, and overflow systems. Vessels PWD-VSL-00033, -00043, -00045, and -00046 are installed. PWD-VSL-00044 is in fabrication, and PJM modifications are being incorporated. PWD-VSL-00015 and -00016 have been delivered. There are no uncertainties with end state, but there are potential cost and schedule risks if PJM testing shows that PWD-VSL-00033 and -00043 must be modified to include wear plates, or the PJMs in PWD-VSL-00033, -00043, and -00044 require further upgrades to increase drive velocities.

The PJM mixing technology is not new, but it has been modified and repackaged. The PJM discharge velocity for all WTP applications has yet to be determined based upon experimental data. The required operational modifications may require the PJMs to perform beyond their demonstrated capability. Solids concentrations are an order of magnitude higher at the WTP than at the Sellafield application, and the PJM capability for Newtonian off-bottom suspension has not been demonstrated. The Sellafield site used PJMs to mix acidic waste streams feed, the WTP uses an alkaline feed. The acidic and alkaline waste streams have significantly different rheological properties and use of the PJM data from Sellafield may not be possible.

TCP-Treated LAW Concentrate Storage Process (24590-WTP-3YD-TCP-00001)

The TCP consists of one vessel (TCP-VSL-00001) that is a hold point before its contents are transferred to the LAW Vitrification Facility. PJMs are used for mixing, which have yet to be experimentally verified. Issues were identified on the potential for precipitation in the transfer pipelines and methods to remove phosphate plugging are being evaluated. There are no cost risks, schedule risks, but there are some end state questions on the chemistry of vessel contents. The technology is not new, modified, or repackaged. It will not be required to perform beyond the demonstrated capability.

TLP-Treated LAW Evaporation Process (24590-WTP-3YD-TLP-00001)

The TLP is used to concentrate the decontaminated LAW waste stream to support LAW melter operations. The TLP requires the use of vacuum evaporators similar to the Hanford 242-A Evaporator. The LAW melter feed is evaporated to 8 to 10 M Na. There are no cost risks, schedule risks, but there are some end state issues on potential chemistries that might cause chemical and physical plugging that are not resolved. The system is not new, novel, or modified. The system is repackaged, because part of the system is in a black cell and part is in a hot cell. The system is not expected to perform beyond demonstrated capability. There are more bubble trays than is typically used, but the decontamination factor is not greater than what vendor data supports. The evaporator system is being provided by a commercial vendor, Averna Technologies.

UFP-Ultrafiltration Process (24590-WTP-3YD-UFP-00001)

The UFP is used to separate the tank waste solids and liquids, support washing of tank waste solids to reduce their mass, and is a major treatment system in the PT Facility.

In late 2004, DOE identified, as part of their oversight of the WTP PT Facility design, that the UFP was undersized to meet DOE's requirements and the process chemistry used to treat the tank waste solids was incorrect. Subsequently, DOE directed the WTP Contractor to complete a series of engineering studies to correct the process flowsheet and identify changes to increase the design capacity of the UFP. An expert panel review completed in early 2006 also identified the same issues with the UFP. Since the time of the expert panel review, the DOE has further directed the WTP Contractor to:

- Complete extensive testing of the ultrafiltration process using laboratory-scale testing, including testing with actual Hanford Site tank wastes, and
- Complete testing of a pilot-scale ultrafiltration system to validate the proposed plant-scale ultrafiltration system design and obtain data to project plant-scale performance.

There are significant cost risks and schedule risks associated with the technology and uncertainties in the end state requirements. The technology is not new or novel, but it is extensively modified. The technology is not expected to perform outside the demonstrated capability in industrial applications, but it is not known whether the technology will meet the end state requirements. A significant testing program is in place to resolve chemistry and design issues.

The following systems were not selected as CTEs. The rationale for the selection of each of the systems as non-CTEs is summarized below.

CRP-Cesium Resin Addition Process (24590-WTP-3YD-CRP-00001)

This process is to wash resin before it is placed in the WTP IX columns using mixing, filtration, and gravity flow. The resin is then slurried into the columns. The technology is not novel, modified, or repackaged. The environment is similar to other standard industry applications.

PIH-Pretreatment In-Cell Handling System (24590-WTP-3YD-PIH-00001)

PIH includes the in-cell equipment for maintenance including manipulators, cranes, shears, saws, and decontamination tanks. The main crane includes a power manipulator and three hoists (one 30-ton and two 2-ton hoists) that rotate equipment to the position needed by the power manipulator. An expert panel review recently commented that crane utilization should be reduced for cranes that needed to be remotely maintained. The PIH was re-designed to add a second pretreatment bridge crane. There are no schedule risks or costs risks. The operational assessments validated that end state requirements, in terms of crane utilization, can be met with this system. The technology is not novel, modified, or repackaged.
The environment is not different than previous applications.

RDP-Spent Resin Collection/Dewatering Process (24590-WTP-3YD-RDP-00001)

The RDP consists of three vessels (RDP-VSL-00062A/-00062B/-00062C) where spent IX resin is discharged from the CXP. The spent resin is sampled and slurries to a commercial cask/disposal liner system for dewatering. Following dewatering and drying, the resin is removed from the PT Facility for disposal.

The RDP/resin disposal system uses standard equipment. The RDP vessels are mixed with PJMs.
The RDP vessels are in fabrication. The RDP/resin disposal system is not novel, modified,
or repackaged, and it will not be expected to perform beyond the original design attention.
Some poly-styrene resins get soft and mushy when irradiated. The resins can become sticky and result in plugging. The point where oxygen loss and irradiation causes this to happen is not understood, but it will be resolved as part of testing.

RLD-Radioactive Liquid Waste (24590-WTP-3YD-RLD-00001)

The RLD handles liquid waste for interim storage before being transferred to the effluent system.
The RLD consists of four vessels. RLD-VSL-00017A/-00017B receive caustic scrubber solution from the LAW Vitrification Facility offgas system, and vessels RLD-VSL-00006A/-00006B receive overhead from the FEP and TLP and evaporators. Solutions from vessel RLD-VSL-00006B are transferred to Hanford's Liquid Effluent Retention Facility (LERF). These vessels have no PJMs. Vessels RLD-VSL-00017A/ -00017B are in a low radiation areas and vessels RLD-VSL-00006A/-00006B are located outside of the PT Facility. There is no schedule risk, cost risk, or uncertainty in the end state requirements. The system is not new, modified, or repackaged. The technology will not be used beyond its demonstrated capacity.

RWH-Radioactive Solid Waste (24590-WTP-3YD-RWH-00001)

The RWH includes the equipment and containers used to package solid wastes. Spent resins, spent filters, and end cell waste are placed into standard low-level waste disposal containers. Overhead cranes, manipulators, and boggies move baskets of failed and size reduced equipment and filters into the drums and put the lid on the drums. A boggie carries the drum to the truck bay. End cell waste is swabbed prior to acceptance, and it is similarly placed into a cask. There is a carbon dioxide (CO_2) decontamination capability for the disposal cask if required. There are no schedule risks, cost risks, or uncertainty in the end state requirements. The system is not new, modified, or repackaged. Some unique tools may be required for cutting large equipment items like the ultrafilters assembly, but it will not use technology beyond its demonstrated capability. Standard decontamination techniques will be used. More detailed design development of the RWH is in progress.

Table A.1. Identification of Critical Technology Elements (Systems) in the Pretreatment Facility

System Locators	System Title	Document number	Include in Initial CTE Evaluation?
ARV,C1V,C2V, C3V,C5V	Atmospheric Reference Ventilation; Cascade Ventilation System	24590-PTF-3YD-60-00001	No
BNG	Bottled Nitrogen Gas	24590-PTF-3YD-MXG-00001	No
BSA	Breathing Service Air	24590-PTF-3YD-BSA-00002	No
BSA	Breathing Service Air	24590-PTF-3YD-BSA-00001	No
C1V	Cascade Ventilation System	24590-PTF-3YD-C1V-00001	No
C2V	Cascade Ventilation System	24590-PTF-3YD-C2V-00001	No
C3V	Cascade Ventilation System	24590-PTF-3YD-C3V-00001	No
C5V	Cascade Ventilation System	24590-PTF-3YD-C5V-00001	No
CHW	Chilled Water	24590-PTF-3YD-CHW-00001	No
CNP	Cesium Nitric Acid Recovery Process	24590-PTF-3YD-CNP-00001	Yes
CRP	Cesium Resin Addition Process	24590-PTF-3YD-CRP-00001	Yes
CXP	Cesium Ion Exchange Process	24590-PTF-3YD-CXP-00001	Yes
DOW	Domestic Water System	24590-PTF-3YD-DOW-00001	No
FEP	Waste Feed Evaporation Process	24590-PTF-3YD-FEP-00001	Yes
FRP	Waste Feed Receipt Process	24590-PTF-3YD-FRP-00001	Yes
HLP	HLW Lag Storage and Feed Blending Process	24590-PTF-3YD-HLP-00001	Yes
HPS,LPS,SCW	High Pressure Steam	24590-PTF-3YD-HPS-00001	No
ISA	Instrument Service Air	24590-PTF-3YD-ISA-00001	No
PFH	Pretreatment Filter Cave Handling System	24590-PTF-3YD-PFH-00001	No
PIH	Pretreatment In Cell Handling System	24590-PTF-3YD-PIH-00001	Yes
PJV	Pulse Jet Ventilation System	24590-PTF-3YD-PJV-00001	Yes
PSA	Plant Service Air	24590-PTF-3YD-PSA-00001	No
PSA ITS	Plant Service Air/Important to Safety	24590-PTF-3YD-PSA-00002	No
PTJ	Mechanical Handling CCTV	24590-PTF-3YD-PTJ-00001	No
PVP	Pretreatment Vessel Vent Process System	24590-PTF-3YD-PVP-00001	Yes
PVV	Pretreatment Vessel Vent Exhaust System	24590-PTF-3YD-PVV-00001	No
PWD	Plant Wash and Disposal Leak Detection	24590-PTF-3YD-PWD-00002	Yes
PWD	Plant Wash and Disposal/Radioactive Liquid Disposal	24590-PTF-3YD-PWD-00001	Yes
RDP	Spent Resin Collection and Dewatering Process	24590-PTF-3YD-RDP-00001	Yes
RWH	Radioactive Solid Waste	24590-WTP-3YD-RWH-00001	Yes
RLD	Radioactive Liquid Waste	24590-PTF-3YD-RLD-00001	Yes
TCP	Treated LAW Concentrate Storage Process	24590-PTF-3YD-TCP-00001	Yes
TLP	Treated LAW Evaporation Process	24590-PTF-3YD-TLP-00001	Yes
UFP	Ultrafiltration Process	24590-PTF-3YD-UFP-00001	Yes
	Pretreatment Facility Flowsheet	NA	Yes

Table A.2. Questions used to determine the Critical Technology Element for the Pretreatment Facility Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

Table A.3. Summary of Question Responses for the Pretreatment Facility Systems that were determined to be Critical Technology Elements

System	**Cesium Nitric Acid Recovery Process System, CNP**	**Cesium Resin Addition Process System, CRP**	**Cesium Ion Exchange Process System, CXP**	**Waste Feed Evaporation Process System, FEP**	**Waste Feed Receipt Process System, FRP**	**HLW Lag Storage and Feed Blending Process System, HLP**	**Pretreatment In -Cell Handling System, PIH**	**Pulse Jet Mixer System, PJM**	**Pulse Jet Ventilation System, PJV**
Critical Technology Element	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
First Question Set	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1. Does the technology directly impact a functional requirement of the process or facility?	Y	Y	Y	Y	Y	Y	Y	Y	Y
2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required?	N	N	N	N	N	Y	N	Y	N
3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	N	N	N	N	N	Y	N	Y	N
4. Are there uncertainties in the definition of the end state requirements for this technology?	N	N	N	N	Y	Y	N	N	N
Second Question Set	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
1. Is the technology (system) new or novel?	N	N	N	N	N	N	N	N	N
2. Is the technology (system) modified?	N	N	Y	N	Y	Y	N	Y	Y
3. Has the technology been repackaged so that a new relevant environment is realized?	Y	N	Y	Y	Y	Y	N	Y	Y
4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?	N	N	N	N	Y	Y	N	Y	N

Table A.3. Summary of Question Responses for the Pretreatment Facility Systems that were determined to be Critical Technology Elements (cont.)

System	Pretreatment Vessel Vent Process System, PVP	Plant Wash and Disposal System, PWD	Spent Resin and Collection Dewatering Process System, RDP	Radioactive Liquid Waste Disposal System, RLD	Radioactive Solid Waste System, RWH	Treated LAW Concentrate Storage process, TCP	Treated LAW Evaporation Process, TLP	Ultrafiltration Process System, UFP
Critical Technology Element	Yes	Yes	No	No	No	No	Yes	Yes
First Question Set	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1. Does the technology directly impact a functional requirement of the process or facility?	Y	Y	Y	Y	Y	Y	Y	Y
2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required?	N	Y	N	N	N	N	N	Y
3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	N	Y	N	N	N	N	N	N
4. Are there uncertainties in the definition of the end state requirements for this technology?	N	N	N	N	Y	Y	N	N
Second Question Set	Yes	Yes	No	No	No	No	Yes	Yes
1. Is the technology (system) new or novel?	N	N	N	N	N	N	N	N
2. Is the technology (system) modified?	Y	Y	N	N	N	N	N	Y
3. Has the technology been repackaged so that a new relevant environment is realized?	Y	Y	N	N	N	N	Y	Y
4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?	N	Y	N	N	N	N	N	Y

A.1 References

1. 24590-PTF-3YD-CNP-00001, Rev. 0, *System Description for Cesium Nitric Acid Recovery Process-System CNP*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

2. 24590-PTF-3YD-CRP-00001, Rev. 0, *System Description for Cesium Resin Addition Process System CRP*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

3. 24590-PTF-3YD-CXP-00001, Rev. 0, *System Description for Cesium Ion Exchange Process System CXP*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

4. 24590-PTF-3YD-FEP-00001, Rev. 0, *System Description for Waste Feed Evaporation Process (FEP)*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

5. 24590-PTF-3YD-FRP-00001, Rev. 0, *System Description for Waste Feed Receipt Process (FRP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

6. 24590-PTF-3YD-HLP-00001, Rev. 0, *System Description for HLW Lag Storage and Feed Blending (HLP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

7. 24590-PTF-3YD-PIH-00001, Rev. 0, *System Description for Pretreatment In-Cell Handling System*, November 3, 2003, Bechtel National, Inc., Richland, Washington.

8. 24590-PTF-3YD-PJV-00001, Rev. 0, *System Description for PTF Pulse Jet Ventilation System*, September 5, 2003, Bechtel National, Inc., Richland, Washington.

9. 24590-PTF-3YD-PVP-00001, Rev. 0, *System Description for Pretreatment Vessel Vent Process System*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

10. 24590-PTF-3YD-PWD-00001, Rev. 1, *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD*, September 22, 2003, Bechtel National, Inc., Richland, Washington.

11. 24590-PTF-3YD-RDP-00001, Rev. 0, *System Description for Spent Resin Collection and Dewatering Process-System RDP*, September 11, 2003, Bechtel National, Inc., Richland, Washington.

12. 24590-PTF-3YD-RWH-00001, Rev. 0, *System Description for WTP System RHW Radioactive Solid Waste Handling*, July 12, 2005, Bechtel National, Inc., Richland, Washington.

13. 24590-PTF-3YD-TCP-00001, Rev. 1, *System Description for Treated LAW Concentrate Storage process System (TCP)*, March 9, 2006, Bechtel National, Inc., Richland, Washington.

14. 24590-PTF-3YD-TLP-00001, Rev. 0, *System Description for Treated LAW Evaporation Process (TLP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

15. 24590-PTF-3YD-UFP-00001, Rev. 0, *System Description for Ultrafiltration Process System(UFP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

16. 24590-WTP-3YD-50-00003, Rev. A, *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems*, May 19, 2004, Bechtel National, Inc., Richland, Washington.

17. DOD 2005, *Department of Defense, Technology Readiness Assessment (TRA) Deskbook*, May 2005, Prepared by the Deputy Undersecretary of Defense for Science and Technology (DUSD(S&T)).

Appendix B – Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix B – Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix B presents the questions used for assessing the technology maturity of U.S. Department of Energy (DOE) Office of Environmental Management (EM) waste processing and treatment technologies using a modified version of the Air Force Research Laboratory Technology Readiness Level (TRL) Calculator. The following TRL questions were developed for the evaluation of the WTP Pretreatment (PT) Facility systems in their respective tables as identified below.

- Table B.1 for TRL 1
- Table B.2 for TRL 2
- Table B.3 for TRL 3
- Table B.4 for TRL 4
- Table B.5 for TRL 5
- Table B.6 for TRL 6

The TRL Calculator was used to assess the TRL of the WTP critical technology elements (CTE). The assessment begins by using the top-level questions listed in Figure B.1 to determine the anticipated TRL that will result from the detailed questions. The anticipated TRL was determined from the question with the first “yes” answer from the list in Figure B.1. Evaluation of the detailed questions was started one level below the anticipated TRL. If it was determined from the detailed questions that the technology had not attained the maturity of the starting level, the next levels down were evaluated in turn until the maturity level could be determined.

The Calculator provides a standardized, repeatable process for evaluating the maturity of the hardware or software technology under development. The first columns in Tables B.1 to B.6 identify whether the question applies to Hardware (H), Software (S), or both. The second columns in Tables B.1 to B.6 identify the areas of readiness being evaluated: technical (T), programmatic (P), and manufacturing/ quality requirements (M). A technology is determined to have reached a given TRL if column 3 is judged to be 100% complete for all questions.

If Yes, Then Logic		Top Level Question
TRL 9	→	Has the actual equipment/process successfully operated in the full operational environment (hot operations)?
TRL 8	→	Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?
TRL 7	→	Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?
TRL 6	→	Has prototypical engineering-scale equipment/process testing been demonstrated in a relevant environment?
TRL 5	→	Has bench-scale equipment/process testing been demonstrated in a relevant environment?
TRL 4	→	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?
TRL 3	→	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?
TRL 2	→	Has an equipment and process concept been formulated?
TRL 1	→	Have the basic process technology process principles been observed and reported?

Figure B.1. Top Level Questions Establish Expected Technology Readiness Level

Table B.1. Technology Readiness Level 1 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		"Back of envelope" environment
B	T		Physical laws and assumptions used in new technologies defined
S	T		Have some concept in mind for software that may be realizable in software
S	T		Know what software needs to do in general terms
B	T		Paper studies confirm basic principles
S	T		Mathematical formulations of concepts that might be realizable in software
S	T		Have an idea that captures the basic principles of a possible algorithm
B	P		Initial scientific observations reported in journals/conference proceedings/technical reports
B	T		Basic scientific principles observed
B	P		Know who cares about the technology; e.g., sponsor, money source
B	T		Research hypothesis formulated
B	P		Know who will perform research and where it will be done

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table B.2. Technology Readiness Level 2 Questions

H/S/ Both	Cat	% Complete	Criteria
B	P		Customer identified
B	T		Potential system or components have been identified
B	T		Paper studies show that application is feasible
B	P		Know what program the technology will support
B	T		An apparent theoretical or empirical design solution identified
H	T		Basic elements of technology have been identified
B	T		Desktop environment
H	T		Components of technology have been partially characterized
H	T		Performance predictions made for each element
B	P		Customer expresses interest in the application
S	T		Some coding to confirm basic principles
B	T		Initial analysis shows what major functions need to be done
H	T		Modeling and Simulation only used to verify physical principles
B	P		System architecture defined in terms of major functions to be performed
S	T		Experiments performed with synthetic data
B	P		Requirements tracking system defined to manage requirements creep
B	T		Rigorous analytical studies confirm basic principles
B	P		Analytical studies reported in scientific journals/conference proceedings/technical reports.
B	T		Individual parts of the technology work (No real attempt at integration)
S	T		Know what hardware software will be hosted on
B	T		Know what output devices are available
B	P		Preliminary strategy to obtain TRL 6 developed (e.g., scope, schedule, cost)
B	P		Know capabilities and limitations of researchers and research facilities
B	T		Know what experiments are required (research approach)
B	P		Qualitative idea of risk areas (cost, schedule, performance)

H-Hardware element, contains no appreciable amount of software	S-Completely a Software system
B-Some Hardware and Software	T-Technology, technical aspects
M-Manufacturing and quality	P-Programmatic, customer focus, documentation

Table B.3. Technology Readiness Level 3 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Academic environment
H	T		Predictions of elements of technology capability validated by analytical studies
B	P		The basic science has been validated at the laboratory-scale
H	T		Science known to extent that mathematical and/or computer models and simulations are possible
B	P		Preliminary system performance characteristics and measures have been identified and estimated
S	T		Outline of software algorithms available
H	T		Predictions of elements of technology capability validated by Modeling and Simulation (M&S)
S	T		Preliminary coding verifies that software can satisfy an operational need
H	M		No system components, just basic laboratory research equipment to verify physical principles
B	T		Laboratory experiments verify feasibility of application
H	T		Predictions of elements of technology capability validated by laboratory experiments
B	P		Customer representative identified to work with development team
B	P		Customer participates in requirements generation
B	T		Cross technology effects (if any) have begun to be identified
H	M		Design techniques have been identified/developed
B	T		Paper studies indicate that system components ought to work together
B	P		Customer identifies transition window(s) of opportunity
B	T		Performance metrics for the system are established
B	P		Scaling studies have been started
S	T		Experiments carried out with small representative data sets
S	T		Algorithms run on surrogate processor in a laboratory environment
H	M		Current manufacturability concepts assessed
S	T		Know what software is presently available that does similar task (100% = Inventory completed)
S	T		Existing software examined for possible reuse
H	M		Sources of key components for laboratory testing identified
S	T		Know limitations of presently available software (analysis of current software completed)
B	T		Scientific feasibility fully demonstrated
B	T		Analysis of present state of the art shows that technology fills a need
B	P		Risk areas identified in general terms
B	P		Risk mitigation strategies identified
B	P		Rudimentary best value analysis performed for operations
B	P		The individual system components have been tested at the laboratory-scale

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table B.4. Technology Readiness Level 4 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology issues (if any) have been fully identified
H	M		Laboratory components tested are surrogates for system components
H	T		Individual components tested in laboratory/by supplier (contractor's component acceptance testing)
B	T		Subsystems composed of multiple components tested at lab-scale using simulants
H	T		Modeling and simulation used to simulate some components and interfaces between components
S	T		Formal system architecture development begins
B	P		Overall system requirements for end user's application are documented
B	P		System performance metrics measuring requirements have been established
S	T		Analysis provides detailed knowledge of specific functions software needs to perform
B	P		Laboratory testing requirements derived from system requirements are established
H	M		Available components assembled into laboratory-scale system
H	T		Laboratory experiments with available components show that they work together (lab kludge)
S	T		Requirements for each system function established
S	T		Algorithms converted to pseudocode
S	T		Analysis of data requirements and formats completed
S	T		Stand-alone modules follow preliminary system architecture plan
H	T		Analysis completed to establish component compatibility
S	M		Designs verified through formal inspection process
B	P		Science and Technology exit criteria established
B	T		Technology demonstrates basic functionality in simulated environment
S	P		Able to estimate software program size in lines of code and/or function points
H	M		Scalable technology prototypes have been produced
B	P		Draft conceptual designs have been documented
H	M		Equipment-scaleup relationships are understood/accounted for in technology development program
B	T		Controlled laboratory environment used in testing
B	P		Initial cost drivers identified
S	T		Experiments with full-scale problems and representative data sets
B	M		Integration studies have been started
B	P		Formal risk management program initiated
S	T		Individual functions or modules demonstrated in a laboratory environment
H	M		Key manufacturing processes for equipment systems identified
B	P		Scaling documents and designs of technology have been completed
S	T		Some ad hoc integration of functions or modules demonstrates that they will work together
H	M		Key manufacturing processes assessed in laboratory
B	P		Functional work breakdown structure developed (functions established)
B	T		Low fidelity technology "system" integration and engineering completed in a lab environment
H	M		Mitigation strategies identified to address manufacturability/producibility shortfalls
B	P		Technology availability dates established

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table B.5. Technology Readiness Level 5 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology effects (if any) have been fully identified (e.g., system internally consistent)
B	T		Plant size components available for testing
B	T		System interface requirements known (how will system be integrated into the plant?)
B	P		System requirements flow down through work breakdown structure (design engineering begins)
S	T		System software architecture established
B	T		Requirements for technology verification established
S	T		External process/equipment interfaces described as to source, structure, and requirements
S	T		Analysis of internal system interface requirements completed
B	T		Lab-scale similar system tested with limited range of actual wastes, if applicable
B	T		Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)
H	M		Significant engineering and design changes
S	T		Coding of individual functions/modules completed
H	M		Prototypes of equipment system components have been created (know how to make equipment)
H	M		Tooling and machines demonstrated in lab for new manufacturing processes to make component
B	T		High-fidelity lab integration of system completed, ready for test in relevant environments
H	M		Manufacturing techniques have been defined to the point where largest problems defined
H	T		Lab-scale similar system tested with range of simulants
H	T		Fidelity of system mock-up improves from laboratory to bench-scale testing
B	M		Reliability, Availability, Maintainability Index (RAMI) target levels identified
H	M		Some special purpose components combined with available laboratory components for testing
H	P		Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared
B	T		Laboratory environment for testing modified to approximate operational environment
B	T		Component integration issues and requirements identified
H	P		Detailed design drawings have been completed to support specification of pilot testing system
B	T		Requirements definition with performance thresholds and objectives established for final plant design
S	T		Algorithms run on processor with characteristics representative of target environment
B	P		Preliminary technology feasibility engineering report completed
B	T		Integration of modules/functions demonstrated in a laboratory/bench-scale environment
H	T		Formal control of all components to be used in final system
B	P		Configuration management plan in place
B	P		Risk management plan documented
S	T		Functions integrated into modules
S	T		Formal inspection of all modules to be used in the final design
S	T		Individual functions tested to verify that they work
S	T		Individual modules and functions tested for bugs
S	T		Integration of modules/functions demonstrated in a laboratory environment
S	P		Formal inspection of all modules/components completed as part of configuration management
H	P		Individual process and equipment functions tested to verify that they work (e.g., test reports)

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table B.6. Technology Readiness Level 6 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Performance and behavior of subcomponent interactions understood (including tradeoffs)
H	M		Reliability, Availability, Maintainability Index (RAMI) levels established
B	M		Frequent design changes occur
H	P		Draft design drawings for final plant system are nearly complete
B	T		Operating environment for final system known
B	P		Collection of actual maintainability, reliability, and supportability data has been started
B	P		Estimated cost of the system design is identified
B	T		Engineering-scale similar system tested with a range of simulants
B	P		Plan for demonstration of prototypical equipment and process testing completed, results verify design
B	T		Modeling and simulation used to simulate system performance in an operational environment
H	T		Operating limits for components determined (from design, safety, and environmental compliance)
B	P		Operational requirements document available
B	P		Off-normal operating responses determined for engineering-scale system
B	T		System technical interfaces defined
B	T		Component integration demonstrated at an engineering-scale
B	P		Scaling issues that remain are identified and supporting analysis is complete
B	P		Analysis of project timing ensures technology will be available when required
S	T		Analysis of database structures and interfaces completed
B	P		Have begun to establish an interface control process
B	P		Acquisition program milestones established for start of final design (CD-2)
H	M		Critical manufacturing processes prototyped
H	M		Most pre-production hardware is available to support fabrication of the system
B	T		Engineering feasibility fully demonstrated (e.g., will it work?)
S	T		Prototype implementation includes functionality to handle large-scale realistic problems
S	T		Algorithms partially integrated with existing hardware / software systems
H	M		Materials, process, design, and integration methods have been employed (e.g., can design be produced?)
S	T		Individual modules tested to verify that the module components (functions) work together
B	P		Technology ”system” design specification complete and ready for detailed design
H	M		Components are functionally compatible with operational system
H	T		Engineering-scale system is high-fidelity functional prototype of operational system
S	T		Representative software system or prototype demonstrated in a laboratory environment
B	P		Formal configuration management program defined to control change process
B	M		Integration demonstrations have been completed (e.g., construction of testing system)
B	P		Final Technical Report on Technology completed
B	T		Waste processing issues have been identified and major ones have been resolved
S	T		Limited software documentation available
S	P		Verification, Validation, and Accreditation (VV&A) initiated
H	M		Process and tooling are mature to support fabrication of components/system
H	M		Production demonstrations are complete (at least one time)
S	T		"Alpha" version software has been released
S	T		Representative model tested in high-fidelity lab/simulated operational environment

H-Hardware element, contains no appreciable amount of software	S-Completely a Software system
B-Some Hardware and Software	T-Technology, technical aspects
M-Manufacturing and quality	P-Programmatic, customer focus, documentation

Appendix C – Technology Readiness Level Summary for WTP Critical Technology Elements for PT Facility

Appendix C – Technology Readiness Level Summary for WTP Critical Technology Elements for PT Facility

Appendix C summarizes the responses to the specific criteria identified in the Technology Readiness Level (TRL) Calculator (Appendix B) for all systems identified as critical technology elements (CTE). The TRL criteria at the highest level scored or level six are presented. This approach provides a documented record to explain why the next highest level was not achieved. Only the FEP and TLP achieved a TRL 6. The responses to questions that reflected the criterion that was not completed are shown in **bold** in the tables below. The responses to the following TRLs are included in the following tables. .

- Table C.1 – Cesium Nitric Acid Recovery Process System (CNP), (TRL 4)
- Table C.2 – Cesium Ion Exchange Process System (CXP), (TRL 6)
- Table C.3 – Waste Feed Evaporation Process System (FEP), (TRL 6)
- Table C.4 – Treated LAW Evaporation Process System (TLP), (TRL 6)
- Table C.5 – Ultrafiltration Process System (UFP), (TRL 4)
- Table C.6 – Pulse Jet Mixers (PJM), (TRL 5)
- Table C.7 – Waste Feed Receipt Process System (FRP), (TRL 5)
- Table C.8 – HLW Lag Storage and Feed Blending Process System (HLP), (TRL 5)
- Table C.9 - Plant Wash and Disposal System (PWD)/ Radioactive Liquid Waste Disposal System (RLD), (TRL 5)

Table C.1. Technology Readiness Level 4 for the Cesium Nitric Acid Recovery Process System (CNP)

Complete	Criteria	Basis
Y	Cross technology issues (if any) have been fully identified	The engineering specification for the cesium nitric acid recovery system (24590-PTF-3PS-MEVV-T0002, Rev. 4) accounts for process operating requirements including factors such vapor-liquid equilibrium, pressure, temperature, and boil off rate. These have been evaluated and documented in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001).
Y	Laboratory components tested are surrogates for system components	Laboratory components tested were surrogates for the following system components; reboiler (CNP-HX-0001), separator vessel and mist eliminator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004). **However, the laboratory components tested did not include a surrogate for the rectifier column (CNP-DISTC-00001) present in the system components** (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).
N	**Individual components tested in laboratory/by supplier (contractor's component acceptance testing)**	**Laboratory components tested were surrogates for the following system components; reboiler (CNP-HX-0001), separator vessel and mist eliminator/separator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004).** **The laboratory components tested did not include a surrogate for the rectifier column (CNP-DISTC-00001) present in the system components (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).**
N/A	Subsystems composed of multiple components tested at lab-scale using simulants	Not applicable (N/A).
Y	Modeling and simulation used to simulate some components and interfaces between components	The OLI System Inc. Environmental Simulation model was used to simulate the CNP evaporator and condensers, but not the rectifier column (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D). Modeling was used to simulate mass and energy balances for all of the components of the CNP, including the rectifier column (CNP-DISTC-00001) (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B).
Y	Overall system requirements for end user's application are documented	System requirements are documented in the CNP system description (24590-PTF-3YD-CNP-00001) and the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	System performance metrics measuring requirements have been established	System performance metrics have been established in the CNP system description (24590-PTF-3YD-CNP-00001) and the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	Laboratory testing requirements derived from system requirements are established	Laboratory testing requirements and documentation of completion are provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001).

Table C.1. (cont'd)

Complete	Criteria	Basis
Y	Available components assembled into laboratory-scale system	With the exception of the rectifier column, the laboratory-scale system simulated all major equipment components of the CNP (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D, and SCT-M0SRLE60-00-185-01, Rev. 00B).
Y	Laboratory experiments with available components show that they work together (lab kludge)	The laboratory experiments demonstrated integration of the evaporator vessel/reboiler, mist eliminator/separator pad and condensers components (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B). All components tested at the laboratory-scale were shown to work together.
Y	Analysis completed to establish component compatibility	Engineering calculations are completed to establish components compatibility, and integration. Subcontractor is conducting design of evaporator, reboiler, rectifier column, and condensers (24590-PTF-3YD-CNP-00001).
Y	Science and Technology exit criteria established	Science and Technology exit criteria and documentation of completion are provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001).
N	**Technology demonstrates basic functionality in simulated environment**	**The functions of the CNP is concentrate to 80% saturation for the cesium eluate solution, recover 0.5 M nitric acid solution for re-use as eluent by the CXP (24590-PTF-3YD-CNP-00001), and achieve a cesium decontamination factor of 5,000,000 for the recovered nitric acid solution (24590-PTF-3PS-MEVV-T0002, Rev. 4, pg. 49).** **These functions have not been demonstrated.**
Y	Scalable technology prototypes have been produced	No scaling issues have been identified.
Y	Draft conceptual designs have been documented	The conceptual design is described in the CNP system description (24590-PTF-3YD-CNP-00001) and the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	Equipment-scaleup relationships are understood/accounted for in technology development program	Equipment-scaleup relationships (e.g., heat capacities for various streams and nitric acid vapor-liquid equilibrium) were determined and documented (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B). Equipment-scaleup relationships were modeled in the mass and energy balance for the CNP (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B).
Y	Sufficient testing has been completed to define requirements for full-scale system.	Laboratory-scale testing and modeling is complete and used to define requirements for the full-scale system as defined in the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	Controlled laboratory environment used in testing	Laboratory test conditions were defined and controlled as part of the CNP testing program, as documented in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001) and test reports (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).

Table C.1. (cont'd)

Complete	**Criteria**	**Basis**
Y	Initial cost drivers identified	The estimated cost of the CNP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Integration studies have been started	The project has contracted with AREVA for detailed design and fabrication of all three forced circulation evaporator systems (FEP, TLP, and CNP). Lessons learned from the FEP and TLP will be applied to detailed design and fabrication of the CNP: reboiler (CNP-HX-0001), separator vessel and mist eliminator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and the rectifier column (CNP-DISTC-00001).
Y	Formal risk management program initiated	The WTP Project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13).
Y	Key manufacturing processes for equipment systems identified	Equipment is envisioned to be a routine fabrication.
Y	Scaling documents and designs of technology have been completed	Equipment-scaleup relationships (e.g., heat capacities for various streams and nitric acid vapor-liquid equilibrium) were determined and documented (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D, and SCT-M0SRLE60-00-185-01, Rev. 00B). Equipment-scaleup relationships were modeled in the mass and energy balance for the CNP (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B).
Y	Key manufacturing processes assessed in laboratory	Equipment is envisioned to be a routine fabrication.
Y	Functional work breakdown structure developed (functions established)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides a work breakdown structure and an integrated schedule showing how the CNP will be incorporated into the PT Facility.
Y	Low fidelity technology "system" integration and engineering completed in a lab environment	Laboratory components tested were surrogates for the following system components: reboiler (CNP-HX-0001), separator vessel and mist eliminator/separator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004). The laboratory components tested did not include a surrogate for the rectifier column (CNP-DISTC-00001) present in the system components (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D, SCT-M0SRLE60-00-185-01, Rev. 00B).
Y	Mitigation strategies identified to address manufacturability/producibility shortfalls	Equipment is envisioned to be a routine fabrication.
Y	Technology availability dates established	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides a work breakdown structure and an integrated schedule showing how the CNP will be incorporated into the PT Facility.

Table C.2. Technology Readiness Level 6 for the Cesium Ion Exchange Process System (CXP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The performance of the ion exchange (IX) medium is summarized in the *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644* (24590-WTP-RPT-RT-06-001). A preliminary IX model, *Ion Exchange Modeling for Removal of Cesium from Hanford Waste Using Resorcinol-Formaldehyde Resin* (SCT-M0SRLE60-00-05-00003, Rev. 00A) has been prepared which demonstrates performance and behavior interactions of the IX system, including tradeoffs such as flow rate, column height, and diameter. A revision to the IX model is planned for issuance in May 2007 to reflect results of recent testing.
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The conceptual design of the equipment is complete. The final design and fabrication of equipment will be conducted under a subcontract. Most drawings and calculations are identified in the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001, Rev. 0).
Y	Draft design drawings for final plant system are nearly complete	The conceptual design of the equipment is complete. The final design and fabrication of equipment will be conducted under a subcontract. Most drawings and calculations are identified in the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001, Rev. 0).
Y	Operating environment for final system known	The operating environment for the CXP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I), the S*ystem Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001, Rev. 0), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b), and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets for the PT Facility have established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the CXP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering-scale similar system tested with a range of simulants	Testing was conducted at engineering-scale using tank 241-AP-101 simulant to evaluate relevant IX process parameters such as column diameter for scale-up and hydraulic performance (24590-WTP-RPT-RT-06-001).

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Modeling and Simulation used to simulate system performance in an operational environment	Modeling of the CXP using the latest test results is provided in *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644* (24590-WTP-RPT-RT-06-001, Appendix A), which simulates system performance in an operational environment at nominal operating parameters (e.g., 25^{o}C and 22 gpm feed flow rate). The preliminary IX model, *Ion Exchange Modeling for Removal of Cesium from Hanford Waste Using Resorcinol-Formaldehyde Resin* (SCT-M0SRLE60-00-05-00003, Rev. 00A) will need to be updated to reflect these test results and this update is planned to be completed by May 2007. Proposed new process conditions (e.g., 45 to 50^{o}C and 30 gpm feed flow rate) to support operational changes in the UFP will need to be evaluated by the project.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	Prototypic 3, 12, and 24-inch diameter columns were tested with resorcinol formaldehyde resin to demonstrate full-scale column (48-inch diameter) hydraulic conditions to verify design features (24590-101-TSA-W000-0004-174-00002, Rev. 00B; SCT-M0SRLE60-00-110-00028). Resin addition and removal features were demonstrated in the 12-inch and 24-inch diameter prototypic columns (SCT-M0SRLE60-00-110-00028, pp. 116-120). Actual plant equipment will be fabricated by a subcontractor in accordance with engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1), which needs to be revised. This engineering specification does not require prototypic column testing by the subcontractor to verify design features of the IX columns.
N	**Operating limits determined using engineering-scale system (from design, safety, environmental compliance)**	**Not completed. Initial operating limits have been established based for SuperLig 644 resin use in the IX columns and are included in the engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1). However, this engineering specification needs to be revised to incorporate the normal use of 600 gallons of resorcinol formaldehyde resin instead of 415 gallons of SuperLig 644 resin; revision of column process data in Appendix A and resin properties in Appendix B for use of resorcinol formaldehyde resin; and requirements to prevent gas blinding of the resin retention screen during fluidized up-flow mode of operation and minimize gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to update this specification before resuming procurement of the IX columns.** **Operating limits for spherical resorcinol formaldehyde resin have been established as part of the engineering-scale testing conducted with prototypic columns (SCT-MOSRLE60-00-10-00005, Rev. 00A).**

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operational requirements document available	The minimum operating requirements for the CXP are defined in the WTP *Operations Requirements Document* (24590-WTP-RPT-OP-01-001, Rev. 2) and the CXP system description (24590-PTF-3YD-CXP-00001, Rev. 0).
N	**Off-normal operating responses determined for engineering-scale system**	**Engineering-scale hydraulic testing of the IX column containing spherical resorcinol formaldehyde resin explored a range of operating conditions that represented normal and off-normal conditions (SCT-M0SRLE60-00-110-00028). Reactivity of spherical resorcinol formaldehyde resin with 0.5 to 3 M concentrations of nitric acid solution in the temperature range of 25 to 66^{o}C has been evaluated (SCT-MOSRL60-00-221-00001, Rev. 00A). Radiation (0 to 100 Mrad) and thermal (25 to 65^{o}C) degradation testing has been completed with spherical resorcinol formaldehyde resin (SCT-MOSRLE60-00-10-00005, Rev. 00A).** **Physical degradation testing, such as osmotic shock and crushing, for irradiated, spherical resorcinol formaldehyde resin samples was not conducted (SCT-MOSRLE60-00-10-00005, Rev. 00A, pg. 4). Spherical resorcinol formaldehyde resin has shown no physical degradation during 14 cycles of chemical testing as part of the hydraulic tests using engineering-scale columns (SCT-M0SRLE60-00-110-00028, pg. 67).**
Y	System technical interfaces defined	Interfaces for the CXP are defined the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I) and Section 9 the CXP system description (24590-PTF-3YD-CXP-00001, Rev. 0).
N	**Component integration demonstrated at an engineering-scale**	**Engineering-scale testing has been completed for the IX column, resin addition, and resin removal design features (SCT-MOSRLE60-00-10-00005, Rev. 00A). The design for managing hydrogen gas generation in the columns has not been demonstrated at the engineering-scale.** **Lab-scale testing with a 3-inch diameter column has shown gas blinding of the resin retention screen during fluidized up-flow mode of operation and gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to modify the IX column engineering specifications (24590-PTF-3PS-MWD0-T0005, Rev. 1) to mitigate these gas retention issues, but the specification does not currently require the subcontractor to conduct testing to verify suitability of the column design.**
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified.
Y	Analysis of project timing ensures technology will be available when required	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the CXP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Have begun to establish an interface control process	The interfaces between the CXP and the balance of the PT Facility are described in the CXP system description (24590-PTF-3YD-CXP-00001, Rev. 0). These include both physical and process interfaces with the PT Facility.
Y	Acquisition program milestones established for start of final design (CD-2)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the CXP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	Equipment is envisioned to be a routine fabrication. The External Flowsheet Review Team (EFRT) identified an issue with the manufacture of the IX columns citing the need to ensure the subcontractor has suitable experience in design and fabrication of similar columns. Manufacturing production of the spherical resorcinol formaldehyde resin has been demonstrated by two vendors (24590-WTP-RPT-RT-06-001, Section 8.5).
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
N	**Engineering feasibility fully demonstrated (e.g., will it work?)**	**Not completed. The design for managing hydrogen gas generation in the columns has not been demonstrated at the engineering-scale.** **Lab-scale testing with a 3-inch diameter column has shown gas blinding of the resin retention screen during fluidized up-flow mode of operation and gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to modify the IX column engineering specifications (24590-PTF-3PS-MWD0-T0005, Rev. 1) to mitigate these gas retention issues, but the specification does not currently require the subcontractor to conduct testing to verify suitability of the column design.**
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	**Technology "system" design specification complete and ready for detailed design**	**The engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1) for the IX columns needs to be revised to incorporate the normal use of 600 gallons of resorcinol formaldehyde resin instead of 415 gallons of SuperLig 644 resin; revision of column process data in Appendix A and resin properties in Appendix B for use of resorcinol formaldehyde resin; and requirements to prevent gas blinding of the resin retention screen during fluidized up-flow mode of operation and minimize gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to update this specification before resuming procurement of the IX columns (24590-WTP-PL-ENG-06-0026, Rev. 000).** **Vendor drawings will be used to document the final design.**
Y	Components are functionally compatible with operational system	Functions of the components are defined in the engineering specification for the IX columns (24590-PTF-3PS-MWD0-T0005, Rev. 1).
N	**Engineering-scale system is high-fidelity functional prototype of operational system**	The engineering-scale system for the IX columns is a high-fidelity functional prototype of the operational system (SCT-M0SRLE60-00-110-00028, Rev. 00A), which demonstrated hydraulic features of the spherical resorcinol formaldehyde resin, resin pretreatment, loading, elution and regeneration, resin addition, and removal functions. **However, the engineering-scale system did not include design features for management of hydrogen gas generated from the IX columns and this system was not prototyped.**
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	Integration was demonstrated as part of the engineering-scale system for the IX columns (SCT-M0SRLE60-00-110-00028, Rev. 00A).
N	**Final Technical Report on Technology completed**	**Not completed. The final technical report will follow completion of Stage 2 (update of Verse code IX model report WSRC-TR-2004-00100) and Stage 3 (aging and storage) testing of the spherical resorcinol formaldehyde resin. The project expects to issue Stage 2 and Stage 3 test reports in May 2007. A closure report will then be prepared for the CXP.**

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	**Waste processing issues have been identified and major ones have been resolved**	**The effect(s) of anti-foaming agent (DOW Q2-318A) and other organic compounds expected to be present in the feed to the CXP have not been evaluated.** **Anti-foaming agent has not been included in any of the actual tank waste samples or simulants used in laboratory-scale column tests. A laboratory-scale column containing spherical resorcinol formaldehyde resin was tested with actual pretreated waste sample from tank 241-AN-102 (24590-101-TSA-W000-0004-1742-00001, Rev. 00A). The tank 241-AN-102 sample had been previously characterized to determine the concentration of various chelating organic compounds (PNWD-3229). Small-scale column tests were conducted with tank 241-AN-105 (oxalate, glycolic acid, acetate, and formate) simulant (24590-101-TSA-W000-0004-91-00003, Rev. 00A) and 241-AP-101 (oxalate, acetate, and formate) simulant included some of the organic compounds known to be present in Hanford tank wastes.** **However, these tests have not demonstrated the effects to the CXP from the anti-foaming agent, the range of organic compounds, including chelating organic compounds (e.g., tri-sodium hydroxy-ethylene-diamine-triacetate), nor separable organics (tri-butyl phosphate and normal paraffin hydrocarbon).** **The effect of separable organics on the process is required to be evaluated by WTP Contract, Standard 2: Research, Technology, and Modeling, item (3) (viii), Effect of Separable Organics (WTP Contract No. DE-AC27-01RV14136).**
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Production demonstrations are complete (at least one time)	Manufacturing production of the spherical resorcinol formaldehyde resin has been demonstrated by two vendors (24590-WTP-RPT-RT-06-001, Section 8.5). Other system components are commercially available or will be manufactured from commercially available components.

Table C.3. Technology Readiness Level 6 for the Waste Feed Evaporation Process System (FEP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the FEP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the FEP System to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if submerged bed scrubber (SBS) condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the equipment is in progress. Areva has been retained as the FEP evaporator designer.
Y	Draft design drawings for final plant system are nearly complete	The final design of the plant equipment is in progress. Most drawings and calculations are identified in the *System Description for Waste Feed Evaporation Process (FEP)* (24590-PTF-3YD-FEP-00001).
Y	Operating environment for final system known	The operating environment for the FEP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C), the FEP system description (24590-PTF-3YD-FEP-00001), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b) and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets have been established in WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1I). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the FEP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering-scale similar system tested with a range of simulants	Pilot-scale testing was performed in the Semi-Integrated Pilot Plant (SIPP) evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1 psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when-scaled support the production rate goals equivalent to at least 30 gpm.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the FEP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the FEP will support project requirements.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001). Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Operating limits determined using engineering-scale system (from design, safety, environmental compliance)	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operational requirements document available	The minimum operating requirements for the FEP are defined in the WTP *Operations Requirements Document* (24590-WTP-RPT-OP-01-001, Rev. 2) and the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1).
Y	Off-normal operating responses determined for engineering-scale system	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the FEP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the FEP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	System technical interfaces defined	Interfaces for the FEP are defined the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C) and Section 9 of the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1).
Y	Component integration demonstrated at an engineering-scale	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C).
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified. Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). Equipment will be tested at full-scale during cold commissioning.

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Analysis of project timing ensures technology will be available when required	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the FEP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the FEP and the balance of the PT Facility are described in the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1). This includes both physical and process interfaces with the PT Facility.
Y	Acquisition program milestones established for start of final design (CD-2)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the FEP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Engineering feasibility fully demonstrated (e.g., will it work?)	Pilot-scale testing completed in the SIPP provided a basis for the demonstration of the feasibility of the FEP.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Technology "system" design specification complete and ready for detailed design	The equipment system is being designed and is being fabricated. Vendor drawings will be used to document the final design. The design calculations to support detailed design prepared by BNI include: 24590-PTF-MEC-FEP-00001, Rev. B, *Process Data for Waste Feed Evaporator, Feed Vessels and Feed/Concentrate Pumps*, and 24590-PTF-MTC-FEP-00001, Rev. B, *Waste Feed Evaporator Feed Vessel (FEP-VSL-00017A/B)*. A preliminary design of the FEP was completed by BNI and is provided in the following documents: 24590-PTF-MV-FEP-00001, Rev. A, *Equipment Assembly Waste Feed Evaporator Feed Vessel FEPVSL-00017A (Q)*, and 24590-PTF-MV-FEP-00002, Rev. A, *Equipment Assembly Waste Feed Evaporator Feed Vessel FEPVSL-00017B (Q)*.
Y	Components are functionally compatible with operational system	Functions of the components are defined in the in the *System Description for Waste Feed Evaporation Process (FEP)* (24590-PTF-3YD-FEP-00001). Testing in the SIPP demonstrated the basic operation of the proposed equipment technology.
Y	Engineering-scale system is high-fidelity functional prototype of operational system	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression.

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Final Technical Report on Technology completed	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Waste processing issues have been identified and major ones have been resolved	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the FEP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the FEP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations.
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Production demonstrations are complete (at least one time)	This is envisioned to be a routine vessel and reboiler fabrication. No issues with the manufacturability of the equipment have been identified.

Table C.4. Technology Readiness Level 6 for the Treated LAW Evaporation Process System (TLP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the TLP is in progress. Some engineering drawings and calculations are identified in the TLP system description (24590-PTF-3YD-TLP-00001).
Y	Draft design drawings for final plant system are nearly complete	The final design of the equipment has been completed. Most drawings and calculations are identified in the TLP system description (24590-PTF-3YD-TLP-00001).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	**Criteria**	**Basis for Completion**
Y	Operating environment for final system known	The operating environment for the TLP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C), the TLP system description (24590-PTF-3YD-TLP-00001), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b) and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the TLP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering-scale similar system tested with a range of simulants	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the TLP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the TLP will support project requirements.

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Frequent design changes occur	Final design of equipment is completed. Most drawings and calculations are identified in the TLP system description (24590-PTF-3YD-TLP-00001).
Y	Draft design drawings for final plant system are nearly complete	The final design of the plant equipment is in progress. Most drawings and calculations are identified in the *System Description for Treated LAW Evaporation Process (TLP)* (24590-PTF-3YD-TLP-00001).
Y	Operating environment for final system known	The operating environment for the TLP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C), the TLP system description (24590-PTF-3YD-TLP-00001), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b) and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets for LAW Vitrification Facility have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the TLP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Engineering-scale similar system tested with a range of simulants	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the TLP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the TLP will support project requirements.
Y	Plan for and process testing completed, results verify design	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001). Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Operating limits determined using engineering-scale system	Operating limits for process system have been estimated from pilot-scale testing performed in the SIPP evaporation system. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). Operational parameters during full-scale will be tested at cold commissioning.
Y	Operational requirements document available	The minimum operating requirements for the TLP are defined in the WTP *Operations Requirements Document* (24590-WTP-RPT-OP-01-001, Rev. 2) and the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Off-normal operating responses determined for engineering-scale system	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations.
Y	System technical interfaces defined	Interfaces for the TLP are defined in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C) and Section 9 of the TLP system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Component integration demonstrated at an engineering-scale	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C).
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified. Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). Equipment will be tested at full-scale during cold commissioning.
Y	Analysis of project timing ensures technology will be available when required	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the TLP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the TLP and the balance of the PT Facility are described in the TLP system description (24590-PTF-3YD-TLP-00001). This includes both physical and process interfaces with the PT Facility.

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Acquisition program milestones established for start of final design (CD-2)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the TLP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Engineering feasibility fully demonstrated (e.g., will it work?)	Pilot-scale testing completed in the SIPP provided a basis for the demonstration of the feasibility of the TLP.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Technology "system" design specification complete and ready for detailed design	The equipment system is being designed and is being fabricated. Vendor drawings will be used to document the final design. A preliminary design of the TLP was completed by BNI and is referenced in the system description.
Y	Components are functionally compatible with operational system	Functions of the components are defined in the in the *System Description for Treated LAW Evaporation Process (TLP)* (24590-PTF-3YD-TLP-00001). Testing in the SIPT demonstrated the basic operation of the proposed equipment technology.
Y	Engineering-scale system is high-fidelity functional prototype of operational system	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression.
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	**Criteria**	**Basis for Completion**
Y	Final Technical Report on Technology completed	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Waste processing issues have been identified and major ones have been resolved	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations.
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Production demonstrations are complete (at least one time)	This is envisioned to be a routine vessel and reboiler fabrication. No issues with the manufacturability of the equipment have been identified.

Table C.5. Technology Readiness Level 4 Summary for the Ultrafiltration Process System (UFP)

Complete	Criteria	Basis
Y	Cross technology issues (if any) have been fully identified	The UFP system description (24590-PTF-3YD-0001, Rev. 0) and *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 0) describe process operating requirements and identify cross technology issues.
Y	Laboratory components tested are surrogates for system components	SIPP and cells unit filter (CUF) tests on a variety of wastes demonstrates basic functionality of ultrafilters, caustic leaching, and washing, (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756). Basic functionality for oxidative leaching is demonstrated (WTP-RPT-117, WTP-RPT-137).
Y	Individual components tested in laboratory/by supplier (contractor's component acceptance testing)	SIPP and CUF tests tested ultrafilters (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
N	**Subsystems composed of multiple components tested at lab-scale using simulants**	**Completed for ultrafilters (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756); not completed for oxidative leaching.**
Y	Modeling and simulation used to simulate some components and interfaces between components	G-2 modeling runs have been carried out in the design evaluation supporting resolution of EFRT issue M-12 (24590-WTP-RTP-ENG-06-014).
Y	Overall system requirements for end user's application are documented	Section C of the WTP contract defines throughputs and other requirements.
Y	System performance metrics measuring requirements have been established	Section C of the WTP contract defines throughputs and other requirements.
Y	Laboratory testing requirements derived from system requirements are established	Test plans are documented for all testing; e.g., see WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756; WTP-RPT-117; WTP-RPT-137.
Y	Available components assembled into laboratory-scale system	Ultrafilter test systems (CUF and SIPP) have been assembled (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
Y	Laboratory experiments with available components show that they work together (lab kludge)	Ultrafilter test systems (CUF and SIPP) have been assembled (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
Y	Analysis completed to establish component compatibility	Ultrafilter test systems (CUF and SIPP) have been assembled (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
N	**Science and Technology exit criteria established**	**Exit criteria are established in the M12/13 Issue Response Plans for caustic leaching and ultrafilters. No exit criteria established for oxidative leaching.**

Table C.5. (cont'd)

Complete	Criteria	Basis
Y	Technology demonstrates basic functionality in simulated environment	SIPP and CUF tests on a variety of wastes demonstrates basic functionality of ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756). Basic functionality for oxidative leaching is demonstrated (WTP-RPT-117; WTP-RPT-137).
Y	Scalable technology prototypes have been produced	Ultrafilter test systems (SIPP and CUF) have been produced and used (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
Y	Draft conceptual designs have been documented	The M12/M13 engineering studies have document conceptual designs 24590-WTP-RPT-ENG-06-011 and -014.
N	**Equipment-scaleup relationships are understood/accounted for in technology development program**	**Ultrafilter scalability not demonstrated (WSRC-TR-2005-00105; WSRC-MS-2005-00756). Mixing scalability not demonstrated (Report of the External Flowsheet Review Team, March 2006).**
Y	Controlled laboratory environment used in testing	Testing documented for ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756) and oxidative leaching (WTP-RPT-117, WTP-RPT-137)
Y	Initial cost drivers identified	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001) provides a baseline estimate of UFP costs. BNI is developing trends for upgrades of UFP.
Y	Integration studies have been started	Some studies for ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756) and oxidative leaching (WTP-RPT-117; WTP-RPT-137) have been completed. M12/13 studies have been started.
Y	Formal risk management program initiated	WTP Project has established a WTP Risk Management Plan (24590-WTP-RPT-PR-01_006).
Y	Key manufacturing processes for equipment systems identified	Ultrafilters and other UFP components have been manufactured.
N	**Scaling documents and designs of technology have been completed**	**Designs exist but scalability of filters and mixing processes has not been demonstrated (WSRC-TR-2005-00105; WSRC-MS-2005-00756, Report of the External Flowsheet Review Team, March 2006).**
Y	Key manufacturing processes assessed in laboratory	Ultrafilters and other UFP components have been manufactured.
Y	Functional work breakdown structure developed (functions established)	The *System Description for Ultrafiltration Process System (UFP)* (24590-PTF-3YD-UFP-0001, Rev. 0) and *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 0) establish the UFP functions.

Table C.5. (cont'd)

Complete	Criteria	Basis
N	**Low fidelity technology "system" integration and engineering completed in a lab environment**	**Laboratory system integration exists for ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756), but not for and oxidative leaching (WTP-RPT-117; WTP-RPT-137).**
Y	Mitigation strategies identified to address manufacturability/producibility shortfalls	Ultrafilters and other UFP components have been manufactured.
N	**Technology availability dates established**	**A date (June 2008) has been established for ultrafiltration, washing, and caustic leaching in the M12/13 Issue Resolution Plans. None exists for oxidative leaching.**

Table C.6. Technology Readiness Level 5 Summary for the Pulse Jet Mixers (PJM)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels and the parameters that affect their performance. No testing has been completed to assess operational parameters for lower solids containing vessels.** **There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams.** **The testing of high solids containing slurries has been exhaustive and is described in detail in *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019). However, this testing has been focused on hydrogen release and not on meeting other important requirements of the vessel designs. This testing is incomplete based on a review and evaluation of the requirements identified in several project documents described below.**
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9- to 1/2-scale. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.
Y	System interface requirements known (how will system be integrated into the plant?)	The PJM and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.

Table C.6. (cont'd)

Complete	Criteria	Basis
N	**System requirements flow down through work breakdown structure (design engineering begins)**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Requirements for technology verification established**	**Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:** • **The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly.** • **Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend.** • **The zone of influence (ZOI) for the PJMs in Newtonian vessels may be overestimated for large, dense, rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable.** • **The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems, and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.** **In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3 "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear.** **"Distinction between Newtonian and non-Newtonian has been based on anticipated solids**

Table C.6. (cont'd)

Complete	Criteria	Basis
		concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity." **A test plan to support an evaluation of the PJMs has not been prepared and approved.**
Y	Lab-scale similar system tested with limited range of actual wastes, if applicable	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing-scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
N	**Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)**	**Testing was completed on a 1/2-scale testing system to represent the UFP 02 vessels. No realistic testing has been completed to evaluate the PJM performance for low solids containing slurries.**
Y	Significant engineering and design changes	The design of the PJMs and PJM support systems has not been completed. Additional work is in progress on the FRP vessels and selected HLP and PWD vessels.
Y	Prototypes of equipment system components have been created (know how to make equipment)	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing-scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	Fabrication of the PJMs and supporting equipment (jet pump pairs) is routine.
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Manufacturing techniques have been	Fabrication of the PJMs and supporting equipment (jet pump pairs) is routine.

Table C.6. (cont'd)

Complete	Criteria	Basis
	defined to the point where largest problems defined	
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms was tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in-scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	The PJM design is an integral part of the vessel design and is designed with the vessel. All PJM mixed vessel have been designed.
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms was tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, ¼-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for-scaled testing. The technical basis for testing-scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. No testing has been completed for lower solids containing fluids.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.

Table C.6. (cont'd)

Complete	Criteria	Basis
	pilot testing system	
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work

Table C.6. (cont'd)

Complete	Criteria	Basis
		processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13)
N	Individual process and equipment functions tested to verify that they work (e.g., test reports)	A range of test platforms was tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three-scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. No testing has been completed for lower solids containing fluids.

Table C.7. Technology Readiness Level 5 for the Waste Feed Receipt Process System (FRP)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels (HLP and UFP) and the parameters that affect their performance. No testing has been completed to assess operational parameters for lower solids containing vessels (FRP).** **There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams.** **CFD analysis completed as early as August 2003 (24590-PTF-RPT-M-03-016) indicated that the FRP vessels would not adequately mix waste with an assumed set of properties. This analysis assumed that the waste properties had the following characteristics: solids content-3 wt%, solids density-2.9, particle size-22 micron, liquid specific gravity-1.2, viscosity at 25°C-2.94 cP with Newtonian fluid characteristics. This analysis indicated that the 8 mps PJM drive velocity (normal velocity when the vessel is full) may not be adequate to move the largest particles from the bottom of the vessels and the 12 mps drive velocity (normal velocity when the vessel is full) is recommended to keep large particles in suspension.** **A subsequent FRP mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM designs will not meet the off-bottom suspension criteria at all FRP vessel levels even when the PJM are operated at 12 mps discharge velocity. This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: density of liquid 1.1, density of solid-2.9, particle size 210 micron and a maximum of 3.8 wt% solids. This analysis also recommended that testing be completed to verify the adequacy of the PJM design for the FRP vessels. The analysis using the BHR Group correlation is based on a steady jet and does not account for fluid viscosity. Thus, the results can only be considered indicative and the system may not perform as well as expected.**

Table C.7. (cont'd)

Complete	Criteria	Basis
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the-scaled PJM testing and range from 1/9 to 1/2-scale of the UFP vessel. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.
Y	System interface requirements known (how will system be integrated into the plant?)	The pulse jet mixer and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Interfaces with the FRP are described in the *System Description for Waste Feed Receipt Process (FRP)* (24590-PTF-3YD-FRP-00001).
N	**System requirements flow down through work breakdown structure (design engineering begins)**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents.**

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Requirements for technology verification established**	**Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:** • **The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly.** • **Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend.** • **The zone of influence (ZOI) for the PJMs in Newtonian vessels may be overestimated for large dense rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable.** • **The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.** **In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3, "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear.** **"Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."**

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Lab-scale similar system tested with limited range of actual wastes, if applicable**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **The test platforms to evaluate the HLP-VSL-00022 have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
Y	**Interfaces between components/ subsystems in testing are realistic (benchtop with realistic interfaces)**	**The test platforms to evaluate the HLP-VSL-00022 have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
NA	Significant engineering and design changes	The design of the PJMs and PJM support systems has been completed for the FRP vessels.
Y	Prototypes of equipment system components have been created (know how to make equipment)	The FRP vessels have been fabricated.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	The FRP vessels have been fabricated.
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess FRP vessel design.
Y	Manufacturing techniques have been defined to the point where largest problems defined	The FRP vessels have been fabricated.

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in-scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	The FRP vessels have been fabricated.
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess FRP vessel design.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).

Table C.7. (cont'd)

Complete	Criteria	Basis
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13)
N	**Individual process and equipment functions tested to verify that they work (e.g., test reports)**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**

Table C.8. – Technology Readiness Level 5 for the HLW Lag Storage and Feed Blending Process System (HLP)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels (HLP and UFP) and the parameters that affect their performance.** **No testing has been completed to assess operational parameters for lower solids containing vessels (HLP-VSL-00022).** **There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams.** **An HLP-VSL-00022 mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM designs will not meet the off-bottom suspension criteria for all vessel levels even when the PJM are operated at 12 mps discharge velocity. This analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: density of liquid 1.1, density of solid-2.9, particle size 210 micron and a maximum of 16.7 wt% solids (Contract value). The analysis using the BHR Group correlation is based on a steady jet and does not account for fluid viscosity. Thus, the results can only be considered indicative and the system may not perform as well as expected.**
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale of the UFP vessel. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests. Modification of the test stands may be required to represent vessel HLP-VSL-00022.

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	System interface requirements known (how will system be integrated into the plant?)	The pulse jet mixer (PJM) and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Interfaces with the HLP are described in the system description (24590-PTF-3YD-HLP-00001).
N	**System requirements flow down through work breakdown structure (design engineering begins)**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents.**
N	**Requirements for technology verification established**	**Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:** • **The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly.** • **Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend.** • **The Zone of Influence (ZOI) for the PJMs in Newtonian vessels may be over estimated for large dense rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable.** • **The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.**

Table C.8 (cont'd)

Complete	Criteria	Basis
		In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3, "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear. **"Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."**
N	**Lab-scale similar system tested with limited range of actual wastes, if applicable**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **The test platforms to evaluate HLP-VSL-00022 has not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
N	**Interfaces between components/ subsystems in testing are realistic (benchtop with realistic interfaces)**	**The test platforms to evaluate the HLP vessels have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
Y	Significant engineering and design changes	The design of HLP vessels is not final because of outstanding issues on erosion wear of the vessel bottom caused by the PJMs and the capability of the HLP-VSL-00022 to adequately mix fluids.
Y	Prototypes of equipment system components have been created (know how to make equipment)	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess HLP vessel design.
Y	Manufacturing techniques have been defined to the point where largest problems defined	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess HLP vessel design.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel, and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13)
N	**Individual process and equipment functions tested to verify that they work (e.g., test reports)**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**

Table C.9 - Technology Readiness Level 5 for the Plant Wash and Disposal System (PWD)/ Radioactive Liquid Waste Disposal System (RLD)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels (HLP and UFP) and the parameters that affect their performance. No testing has been completed to assess operational parameters for lower solids containing vessels (PWD/RLD). There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams. An assessment in March 2007 (24590-WTP-RPT-PR-07-002) of the ability of the PWD and RLD vessels has identified that PWD-VSL-00044 will fail the off-bottom suspension criteria and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time). This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: density of liquid 1.1, density of solid-2.9, particle size 210 micron. The solids concentration was not specified. This analysis recommended that the discharge velocity of the PJMs be increased from 8 mps to 12 mps. Testing was also recommended to verify the adequacy of the PJMs in the aforementioned vessels.**
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale of the UFP vessel. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	System interface requirements known (how will system be integrated into the plant?)	The Pulse Jet Mixer (PJM) and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Interfaces with the PWD/RLD are described in the *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD* (24590-PTF-3YD-PWD-00001).
N	**System requirements flow down through work breakdown structure (design engineering begins)**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The Basis of Design (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents.**
N	**Requirements for technology verification established**	**Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:** • **The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly.** • **Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend.** • **The zone of influence (ZOI) for the PJMs in Newtonian vessels may be over estimated for large dense rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable.** • **The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.**

Table C.9. (cont'd)

Complete	Criteria	Basis
		In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3, "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear. **"Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."**
N	**Lab-scale similar system tested with limited range of actual wastes, if applicable**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **The test platforms to evaluate the PWD/RLD vessels have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
N	**Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)**	**The test platforms to evaluate the PWD/RLD vessels have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
NA	Significant engineering and design changes	The design of the PJMs and PJM support systems has not been completed for the FRP vessels.
Y	Prototypes of equipment system components have been created (know how to make equipment)	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess PWD/RLD vessel design.
Y	Manufacturing techniques have been defined to the point where largest problems defined	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess PWD/RLD vessel design.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13).
N	**Individual process and equipment functions tested to verify that they work (e.g., test reports)**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**

C.1 References

1. 24590-101-TSA-W000-0004-114-00016, Rev. 00A, *Technical Basis for Testing-scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, March 15, 2005, Bechtel National Inc., Richland, Washington.

2. 24590-101-TSA-W000-0004-114-00019, Rev. 00B, *Overview of the Pulse Jet Mixer Non-Newtonian-Scaled Test Prog*ram, WTP-RPT-127, Rev. 0, January 20, 2006, Bechtel National Inc., Richland, Washington.

3. 24590-101-TSA-W000-0004-118-02, Rev. 00B, *Large Tank Experimental Data for Validation for the FLUENT CFD Model of Pulsed Jet Mixers*, July 7, 2003, Bechtel National Inc., Richland, Washington.

4. 24590-101-TSA-W000-0004-124-03, Rev. 00B, *Demonstration of Ability to Mix in a Small-Scale Pulsed-Jet Mixer Test Facility*, March 13, 2003, Bechtel National Inc., Richland, Washington.

5. 24590-101-TSA-W000-0004-153-00002, Rev. 00B, *Final Report: Gas Retention and Release in Hybrid Pulse Jet Mixed Tanks Containing Non-Newtonian Waste Simulants*, March 22, 2005, Bechtel National Inc., Richland, Washington.

6. 24590-101-TSA-W000-0004-174-00002, Rev. 00B, *Laboratory Scale Hydraulic Testing of Spherical Resorcinol Formaldehyde Ion Exchange Resins*, WTP-RPT-142, October 2006, Pacific Northwest National Laboratory, Richland, Washington.

7. 24590-101-TSA-W000-0004-1742-00001, Rev. 00A (PNWD-3751), *Small Column Ion Exchange Testing of Spherical Resorcinol-Formaldehyde Resin for 137Cs Removal from Pre-Treated Hanford Tank 241-AN-102 Waste (Envelope C)*, 2006, Battelle Pacific Northwest Division, Richland, Washington.

8. 24590-101-TSA-W000-0004-72-08, Rev. 00B, *Results of Small-Scale Particle Cloud Tests and Non-Newtonian Fluid Cavern Tests*, November 19, 2003, Bechtel National Inc., Richland, Washington.

9. 24590-101-TSA-W000-0004-91-00003, Rev. 00A (PNWD-3388), *Elution Testing of Resorcinol-Formaldehyde Resins with AN-105 Simulant,* 2004, Battelle Pacific Northwest Division, Richland, Washington.

10. 24590-101-TSA-W000-0004-99-00013, Rev. 00A (PNWD-3785), *Comparison Testing of Multiple Resorcinol-Formaldehyde Resins for the River Protection Project – Waste Treatment Plant*, 2006, Battelle Pacific Northwest Division, Richland, Washington.

11. 24590-101-TSA-W000-114-00019, Rev. 00B, *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program*, December 2005, Bechtel National, Inc., Richland, Washington.

12. 24590-1-1-TSA-W000-0004-114-00021, Rev. 00A, *Estimate of Hanford Waste Insoluble Particle Size and Density Distribution*, February 2007, Bechtel National Inc., Richland, Washington.

13. 24590-CM-TSA-HXYG.0008, *Technical Basis for River Protection Project Waste Treatment Plant (RPP-WTP)-Power Fluidics System Design*, August 6, 2001, BNFL.

14. 24590-PTF-3PS-MEVV-T0002, Rev. 4, *Engineering Specification for Cesium Nitric Acid Recovery Forced Circulation Vacuum Evaporator System*, February 21, 2007, Bechtel National Inc., Richland, Washington.

15. 24590-PTF-3PS-MWD0-T0005, Rev. 1, *Engineering Specification for Cesium Ion Exchange Columns*, 2005, Bechtel National Inc., Richland, Washington.

16. 24590-PTF-3YD-CNP-00001, Rev. 0, *System Description for the Pretreatment Facility Cs Nitric Acid Recovery Process (CNP) System*, September 11, 2002, Bechtel National Inc., Richland, Washington.

17. 24590-PTF-3YD-CXP-00001, Rev. 0, *System Description for the Cesium Ion Exchange Process – System CXP*, September 11, 2002, Bechtel National Inc., Richland, Washington.

18. 24590-PTF-3YD-FEP-00001, Rev. 0, *System Description for Waste Feed Evaporation Process (FEP)*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

19. 24590-PTF-3YD-FRP-00001, Rev. 0, *System Description for Waste Feed Receipt Process (FRP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

20. 24590-PTF-3YD-HLP-00001, Rev. 0, *System Description for HLW Lag Storage and Feed Blending (HLP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

21. 24590-PTF-3YD-PJV-00001, Rev. 0, *System Description for PTF Pulse Jet Ventilation System*, September 5, 2003, Bechtel National, Inc., Richland, Washington.

22. 24590-PTF-3YD-PVP-00001, Rev. 0, *System Description for Pretreatment Vessel Vent Process System*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

23. 24590-PTF-3YD-PWD-00001, Rev. 1, *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD*, September 22, 2003, Bechtel National, Inc., Richland, Washington.

24. 24590-PTF-3YD-TLP-00001, Rev. 0, *System Description for Treated LAW Evaporation Process (TLP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

25. 24590-PTF-3YD-UFP-00001, Rev. 0, *System Description for Ultrafiltration Process System (UFP)*, September 2002, Bechtel National, Inc., Richland, Washington.

26. 24590-PTF-M0D-M40T-00002, Rev. C., *Process Data Sheet Fluidics*, February 7, 2003, Bechtel National Inc., Richland, Washington.

27. 24590-PTF-M5-V17T-00013, Rev. 2, *Process Flow Diagram Cesium Ion Exchange Process Columns System CXP*, 2006, Bechtel National Inc., Richland, Washington.

28. 24590-PTF-MV-FEP-00001, Rev. A, *Equipment Assembly Waste Feed Evaporator Feed Vessel FEPVSL-00017A (Q)*, Bechtel National, Inc., Richland, Washington.

29. 24590-PTF-MV-FEP-00002, Rev. A, *Equipment Assembly Waste Feed Evaporator Feed Vessel FEPVSL-00017B (Q),* Bechtel National, Inc., Richland, Washington.

30. 24590-PTF-RPT-M-03-016, Rev. 0, *CFD Modeling Report for WTP Vessel FRP-VSL-00002A-D with a PJM Drive Velocity of 12 m/s*, August 28, 2003, Bechtel National Inc., Richland, Washington.

31. 24590-PTF-RPT-PR-06-001, Rev. 0, *Pulse Jet Mixer Computational Fluid Dynamics Final Report*, January 11, 2007, Bechtel National Inc., Richland, Washington.

32. 24590-PTF-RPT-PR-06-002, Rev. 0, *Benchmarking of Computational Fluid Dynamic Simulation of Pulse Jet Mixers Using Experimental Data*, November 2, 2006, Bechtel National Inc., Richland, Washington.

33. 24590-PTF-RPT-RT-03-00 1, Rev. 1, *Closure Report for R&T Evaporator Studies*, October 13, 2006, Bechtel National Inc, Richland, Washington.

34. 24590-QL-POA-MEVV-00002-08-00003, Rev. 00B (32-5037887-00), *Hanford Evaporator Project #2 – Evaporator Mass and Energy Balance Calculation*, 2006, AREVA, Richland, Washington.

35. 24590-QL-POA-MPEQ-00002-04-03, Rev. 00A, *Fluidics Design and Methodology Report; Pulse Jet Mixing Systems,* ESI Document No. 2141-04-116 [issued December 9, 2002], August 17, 2004, Bechtel National Inc., Richland, Washington.

36. 24590-WTP-3DP-G04B-00027, Rev. 8, *Design Verification*, Bechtel National Inc., Richland Washington.

37. 24590-WTP-3DP-G04B-00046, Rev. 16, *Engineering Drawings*, Bechtel National Inc., Richland, Washington.

38. 24590-WTP-3DP-G04T-00901, Rev. 10, *Design Change Control*, Bechtel National Inc., Richland Washington.

39. 24590-WTP-3DP-G04T-00913, Rev. 5, *Review of Engineering Documents*, Bechtel National Inc., Richland, Washington.

40. 24590-WTP-3YD-50-00002, Rev. 0, *WTP Integrated Processing Strategy Description*, July 12, 2004, Bechtel National, Inc., Richland, Washington.

41. 24590-WTP-3YD-50-00003, Rev. A, *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems*, May 19, 2004, Bechtel National, Inc., Richland, Washington.

42. 24590-WTP-CE-PC-06-001, Rev. 0, *Hanford Tank Waste Treatment and Immobilization Plant May 2006 Estimate at Completion*, May 31, 2006, Bechtel National Inc., Richland, Washington.

43. 24590-WTP-DB-ENG-01-001, Rev. 1I, *Basis of Design*, 2006, Bechtel National Inc., Richland, Washington.

44. 24590-WTP-PL-ENG-06-0013, Rev. 000, *Issue Response Plan for Implementation of External Flowsheet Review Team (EFRT) Recommendations-M3, Inadequate Mixing System Design*, August 8, 2006, Bechtel National Inc., Richland, Washington.

45. 24590-WTP-PL-ENG-06-0016, Rev. 0, *Project Response Plan for Implementation of External Flowsheet review Team (EFRT) Recommendations-M6: Process Operating Limits Not Completely Defined & P4: Gelation/Precipitation*, September 20, 2006, Bechtel National, Inc., Richland, Washington.

46. 24590-WTP-PL-ENG-06-0026, Rev. 000, *Issue Response Plan for Implementation of External Flowsheet Review Team (EFRT) Recommendations: M14, M10a, P5, P6, P7 and P8*, 2006, Bechtel National Inc., Richland, Washington.

47. 24590-WTP-PL-MG-01-002, Rev. 4, *WTP Configuration Management Plan*, Bechtel National Inc., Richland, Washington.

48. 24590-WTP-PL-PR-01-003, Rev. 3, *Risk Management Plan*, 2007, Bechtel National Inc., Richland, Washington.

49. 24590-WTP-PL-PR-04-001, Rev. 1., *Integrated Sampling and Analysis Requirements Document,* December 22, 2006, Bechtel National Inc., Richland, Washington.

50. 24590-WTP-PL-RT-01-002, Rev. 2.0, *Research and Technology Plan*, April 15, 2003, Bechtel National, Inc., Richland, Washington.

51. 24590-WTP-PSAR-ESH-01-002-02, Rev. 2b, March 2007, *Preliminary Safety Analysis Report to Support Construction Authorization; PT Facility Specific Information*, Bechtel National Inc., Richland, Washington. .

52. 24590-WTP-RPT-NS-01-001, Rev. 5, *Preliminary Criticality Safety Evaluation Report for the WTP*, December 2006, Bechtel National, Inc., Richland, Washington.

53. 24590-WTP-RPT-OP-01-001, Rev. 2, *Operations Requirements Document*, May 5, 2003, Bechtel National, Inc., Richland, Washington.

54. 24590-WTP-RPT-PO-05-001, Rev. 0, *2005 WTP Operation Research Assessment*, August 29, 2005, Bechtel National, Inc., Richland, Washington.

55. 24590-WTP-RPT-PO-05-008, Rev. 0, *2005 WTP Tank Utilization Assessment*, August 8, 2005, Bechtel National, Inc., Richland, Washington.

56. 24590-WTP-RPT-PO-05-009, Rev. 0, *2005 WTP Material Balance and Process Flowsheet Assessment*, November 10, 2005, Bechtel National, Inc., Richland, Washington.

57. 24590-WTP-RPT-PR-01-006, Rev. 13, *Risk Assessment Report*, May 31, 2006, Bechtel National, Inc., Richland, Washington.

58. 24590-WTP-RPT-PR-07-002, Rev. 0, *EFRT Issue M3 Vessel Mixing Model Results-Best Estimate British Hydro-Mechanical Research Group (BHRG) Methodology*, March 2, 2007, Bechtel National Inc., Richland, Washington.

59. 24590-WTP-RPT-PR-07-003, Rev. 0, *Pulse Jet Mixer (PJM) Mixing Test Performance Criteria,* February 2, 2007, Bechtel National Inc., Richland, Washington.

60. 24590-WTP-RPT-PT-02-019, Rev. 1, *Cesium Eluate Concentrator Reconciliation of Test Data*, 2004, Bechtel National Inc., Richland, Washington.

61. 24590-WTP-RPT-RT-06-001, *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644*, 2006, Bechtel National Inc., Richland, Washington.

62. 24590-WTP-SED-ENS-03-002-02, Rev. 1i, *Safety Envelope Document; PT Facility Specific Information*, 2007, Bechtel National Inc., Richland, Washington.

63. BNFL-RPT-048, Rev. 0, *Demonstration and Optimization of BNFL's Pulsed Jet Mixing and RFD Sampling Systems Using NCAW Simulant*, August 2000, Battelle, Pacific Northwest Division, Richland, Washington.

64. CCN:050417, "Evaporator Demister Pads Replacement," January 1, 2003, Bechtel National Inc, Richland, Washington.

65. CCN:020148, "Tank Utilization Study-Phase 1 Results," June 5, 2001, Bechtel National Inc, Richland, Washington.

66. CCN:074276, "Risk Response Report for Formation of Hazardous Mercury Compounds (Dimethyl Mercury) in Evaporator Overheads," October 31, 2003, Bechtel National Inc, Richland, Washington.

67. CCN:074567, "Rheology of 'As Received' HLW Feed," December 15, 2003, Bechtel National, Inc., Richland, Washington.

68. CCN:132846, "Report of External Flowsheet Review Team for the Hanford Waste Treatment and Immobilization Plant-Final Report Titled: 'Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput'," March 17, 2006, Bechtel National Inc., Richland, Washington.

69. CCN:150033, "M6/P4 Assessment of Design Strategies to Reverse Line Plugging and Operating Strategies to Mitigate Plug Formation for Engineering Consideration," December 22, 2006, Bechtel National Inc, Richland, Washington.

70. CCN:150383, "Path Forward for EFRT Mixing Issue M3", January 11, 2007, Bechtel National Inc., Richland, Washington.

71. Contract No. DE-AC27-01RV14136, Modification No. M076, 2006, *WTP Contract Section C Statement of Work*, U.S. Department of Energy Office of River Protection Project, Richland, Washington.

72. D-03-DESIGN-05, *HLW Feed Preparation System; Ultra-filtration Process System*, April 2004, U.S. Department of Energy, Richland, Washington.

73. D-05-DESIGN-013, *WTP Oxidative Leaching Design Oversight Report*, August 2005, U.S. Department of Energy, Richland, Washington

74. FMP 064, *Jet Solid Suspension Design Guide*, October 2005, BHR Group Limited, Bedfordshire, UK.

75. HW-31000, *PUREX Technical Manual*, 1955, General Electric Company, Richland, Washington.

76. Phull, B.S., W.L. Mathay, and R.W. Ross, 2000, *Corrosion Resistance of Duplex and 4-6% Mo-Containing Stainless Steels in FGD Scrubber Absorber Slurry Environments*, Presented at Corrosion 2000, Orlando, Florida, March 26-31, 2000, NACE International, Houston, Texas.

77. PNWD-3029, *Mixing of Process Heels, Process Solutions, and Recycle Streams: Results of the Small-Scale Radioactive Tests*, April 2000, Battelle, Richland, Washington.

78. PNWD-3229, *Chemical Analysis and Physical Property Testing of 241-AN-102 Tank Waste-Supernatant and Centrifuged Solids*, 2002, Battelle Pacific Northwest Division, Richland, Washington.

79. PNWD-3341 (24590-101-TSA-W0000-0004), *Mixing of WTP Process Solutions*, May 2003, Battelle, Richland, Washington.

80. SCT- MOSRL60-00-221-00001, Rev. 00A, *Spherical Resorcinol-Formaldehyde Resin Reactivity with Nitric Acid and Other Hanford RPP-WTP Process Solutions*, 2006, Westinghouse Savannah River Company, Aiken, South Carolina.

81. SCT-M0SRLE60-00-05-00003, Rev. 00A (WSRC-TR-2004-00100, Rev. 0), *Ion Exchange Modeling for Removal of Cesium from Hanford Waste Using Resorcinol-Formaldehyde Resin*, 2004, Westinghouse Savannah River Company, Aiken, South Carolina.

82. SCT-M0SRLE60-00-110-00028, Rev. 00A (WSRC-TR-2005-00270), *Pilot-Scale Hydraulic Testing of Resorcinol Formaldehyde Ion Exchange Resin*, 2006, Westinghouse Savannah River Company, Aiken, South Carolina.

83. SCT-M0SRLE60-00-110-00029, Rev. 00A (WSRC-STI-2006-0071), *Batch, Kinetics, and Column Data from Spherical Resorcinol-Formaldehyde Resin*, 2006, Westinghouse Savannah River Company, Aiken, South Carolina.

84. SCT-M0SRLE60-00-183-01, Rev. 00D (WSRC-TR-2002-00424), *Physical Property Models of Concentrated Cesium Eluate Solutions*, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

85. SCT-M0SRLE60-00-183-02, Rev. 00A (WSRC-TR-2003-00267, Rev. 0), *Validation and Application of Concentrated Cesium Eluate Physical Property Models*, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

86. SCT-M0SRLE60-00-185-01, Rev. 00B, (WSRC-TR-2003-00135), *Cesium Eluate Semi-Batch Evaporation Performance*, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

87. SCT-MOSRLE60-00-10-00005, Rev. 00A (WSRC-TR-2005-00075, Rev. 0), *Radiolytic, Thermal, and Physical Degradation Testing of Spherical Resorcinol-Formaldehyde (RF) Resin*, Westinghouse Savannah River Company, Aiken, South Carolina.

88. Van Der Cook, R.E. and W.E. Ogren, *Vacuum Evaporator-Crystallizer Flowsheet for Waste Liquors*, 1976, Atlantic Richfield Hanford Company, Richland, Washington.

89. WSRC-MS-2005-00756, Rev. 0, *Filtration of a Hanford Site Tank 241-AN-102 Waste Sample with Alternate Sr/TRU Precipitation Conditions at Bench and Pilot-Scale*, March 2004, Savannah River National Laboratory, Aiken, South Carolina.

90. WSRC-MS-99-00467, Rev. 0, *Pilot-Scale Cross-Flow Filtration Test for a Radioactive Waste Simulant With High Solids Loading and Sodium Molarity*, Paper at the 4th International Conference on Multiphase Flow, New Orleans, May 27-June 1, 2001.

91. WSRC-TR-2003-00204, Rev. 0, *Final Report: Pilot-Scale Cross-Flow Ultrafiltration Test Using a Hanford Site Tank 241-AN-102 Waste Simulant*, May 2003, Savannah River National Laboratory, Aiken, South Carolina.

92. WSRC-TR-2003-00216, *Waste Treatment Plant LAW Evaporation: Antifoam Performance*, November 5, 2003, Bechtel National, Inc., Richland, Washington.

93. WSRC-TR-2003-00238, *Studies of Mercury in High Level Waste Systems*, June 6, 2003, Westinghouse Savannah River Company, Aiken, South Carolina.

94. WSRC-TR-2003-00240, Rev. 0, *Filtration, Washing, and Leaching of a Hanford AY-102/C-106 Sample*, September 2003, Savannah River National Laboratory, Aiken, South Carolina.

95. WSRC-TR-2003-00295, Rev. 0, *Filtration of a Hanford AN-104 Sample*, September 2003, Savannah River National Laboratory, Aiken, South Carolina.

96. WSRC-TR-2004-00398, Rev. 0 (SRNL-RPP-2004-00060 Rev. 0), *Final Report – Hybrid-Mixing Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*, 2004, Savannah River National Laboratory, Aiken, South Carolina.

97. WSRC-TR-2004-00399, Rev. 0 (SRNL-RPP-2004-00062 Rev. 0), *Final Report – Gas Retention and Release Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*, 2004, Savannah River National Laboratory, Aiken, South Carolina.

98. WSRC-TR-2004-00430, Rev. 0 (SRNL-RPP-2004-00069 Rev. 0), *One-Eighth-Scale Pulse Jet Mixer (PJM) - Design Parameters-Scale Law Testing,* November 2004, Westinghouse Savannah River Company, Aiken, South Carolina.

99. WSRC-TR-2005-00105, Rev. 0, *Final Report: RPP-WTP Semi-Integrated Pilot Plant*, June 2005, Bechtel National, Inc., Richland, Washington.

100. WTP-RPT-110, Rev. 0 (PNWD-3496), *Test Results for Pulse Jet Mixers in Prototypic Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, 2004, Battelle – Pacific Northwest Division, Richland Washington.

101. WTP-RPT-111, Rev. 0 (PNWD-3495), *Non-Newtonian Slurry Simulant Development and Selection for Pulsed Jet Mixer Testing,* 2004, Battelle – Pacific Northwest Division, Richland, Washington.

102. WTP-RPT-113, Rev. 0 (PNWD-3551), *Technical Basis for Testing-Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

103. WTP-RPT-114, Rev. 1 (PNWD-3552), *Final Report: Gas Retention and Release in Hybrid Pulse Jet-Mixed Tanks Containing non-Newtonian Waste Simulants*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

104. WTP-RPT-117, Rev. 0, *Oxidative Alkaline Leaching of Washed 241-SY-102 and 241-SX-101 Tank Sludges*, October 2004, Battelle – Pacific Northwest Division, Richland, Washington.

105. WTP-RPT-128, Rev. 0, *Hybrid Mixing System Test Results for Prototype Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

106. WTP-RPT-129, Rev. 0 (PNWD-3541), *Technical Basis for Scaling of Air Sparging Systems for Mixing in Non-Newtonian Slurries*, 2005, Battelle – Pacific Northwest Division, Richland, Washington.

107. WTP-RPT-137, Rev. 0, *Oxidative Alkaline Leaching of SX-101 and SY-102 and Its Impact on Immobilized High-Level Waste,* Battelle – Pacific Northwest Division, Richland, Washington.

108. WTP-RPT-151, Rev. 0, *Review of Caustic Leaching Testing With Hanford Tank Waste Sludges*, December 2006, Battelle – Pacific Northwest Division, Richland, Washington.

Appendix D – Participants in the TRL Assessment

Appendix D
Participants in the TRL Assessment

Tables D.1 and D.2 provide lists of participants in the Technology Readiness Level Assessment for Pretreatment Facility for each individual critical system evaluated. The participants are divided into the Assessment Team and the Waste Treatment and Immobilization Plant (WTP) Project Technology and Engineering support teams.

The Assessment Team was compromised of staff and consultants representing the U.S. Department of Energy (DOE), Office of River Protection (ORP) (Hanford Site) and Office of Project Recovery (DOE Headquarters).

The Assessment Team was assisted by WTP Project Technology and Engineering teams comprised of subject matter experts associated with the critical technology elements that were being evaluated. These subject matter experts were either responsible for testing the technologies or incorporating the technology design into the WTP. In general, technology testing is managed by staff from Washington Group International (WGI), and engineering of the systems is managed by staff from Bechtel National, Inc. (BNI).

Table D.1. Participants in the Technology Readiness Level Assessment for the WTP Pretreatment Facility

		System Evaluated					
Name	**Affiliation**	**Cesium Nitric Acid Recovery Process System (CNP)**	**Cesium Ion Exchange Process (CXP)**	**Waste Feed Evaporation Process (FEP)**	**Waste Feed Receipt Process (FRP)**	**HLW Lag Storage and Feed Blending (HLP)**	**Pulse Jet Mixers (PJM)**
Assessment Team							
Alexander, Don	DOE/ORP	X	X	X	X	X	X
Holton, Langdon	ORP-PNNL	X	X	X	X	X	X
Johnson, Mike	CH2M Hill Hanford Inc.	X	X	X	X	X	X
Sutter, Herb	DOE EM Consultant	X	X	X	X	X	X
WTP Project Technology and Engineering							
Barnes, Steve	WGI-Process Technology						X
Corriveau, Clarence	BNI-System Engineer				X	X	X
Damerow, Fred	WGI-Process Technology	X	X	X	X	X	X
Lee, Ernie	WGI-Process Technology		X	X	X		
Olson, John	BNI-System Engineer	X	X				
Papp, Ivan	BNI-Process Technology						
Peterson, Reid	PNNL-Process Technology	X	X	X	X	X	
Saunders, Scott	WGI-Process Technology	X					
Slaathaug, Eric	BNI-Process Technology			X		X	
Sundar, P. S.	WGI-Process Technology						
Thorson, Murray	WGI-Process Technology	X	X				

Table D.2. Participants in the Technology Readiness Level Assessment for the WTP Pretreatment Facility (cont'd)

Name	Affiliation	System Evaluated					
		Pulse Jet Ventilation System (PJV)	**Pretreatment Vessel Vent Process System (PVP)**	**Plant Wash Drain (PWD)**	**Treated LAW Evaporation Process (TLP)**	**Ultrafiltration Process (UFP)**	**Flow Sheet/Process Control**
Assessment Team							
Alexander, Don	DOE/ORP	X	X	X	X	X	X
Holton, Langdon	ORP-PNNL	X	X	X	X	X	X
Johnson, Mike	CH2M Hill Hanford Inc.	X	X	X	X	X	X
Sutter, Herb	DOE EM Consultant	X	X	X	X	X	X
WTP Project Technology and Engineering							
Barnes, Steve	WGI-Process Technology	X	X	X		X	
Corriveau, Clarence	BNI-System Engineer	X	X	X			
Damerow, Fred	WGI-Process Technology	X	X	X	X	X	X
Lee, Ernie	WGI-Process Technology	X	X	X	X	X	X
Olson, John	BNI-System Engineer						
Papp, Ivan	BNI-Process Technology						X
Peterson, Reid	PNNL-Process Technology				X	X	X
Saunders, Scott	WGI-Process Technology						X
Slaathaug, Eric	BNI-Process Technology				X	X	
Streiper, Ed	BNI-System Engineer			X			
Sundar, P. S.	WGI-Process Technology					X	X
Thorson, Murray	WGI-Process Technology						X