Savannah River Site Tank 48H Waste Treatment Project

Technology Readiness Assessment

Harry D. Harmon
Joan B. Berkowitz
John C. DeVine, Jr.
Herbert G. Sutter
Joan K. Young

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Prepared by the
U.S. Department of Energy
Aiken, South Carolina

Signature Page

Harry D. Harmon, Team Lead — Date: 8/1/07

Joan B. Berkowitz, Team Member — Date: 7-31-07

John C. DeVine, Jr., Team Member — Date: 7/31/07

Herbert G. Sutter, Team Member — Date: 8/1/07

Joan K. Young, Team Member — Date: July 31, 2007

Executive Summary

The purpose of this assessment was to determine the technology maturity level of the candidate Tank 48H treatment technologies that are being considered for implementation at DOE's Savannah River Site (SRS).

Tank 48H is a 1.3 million gallon tank, one of 49 tanks at SRS still containing high level waste (HLW). One of DOE's primary missions at SRS is to process the remaining HLW and close tanks. However, the tank has been isolated from the system and unavailable for use since 1983, because its contents – approximately 250,000 gallons of salt solution containing Cesium-137 (Cs-137) and other radioisotopes – are contaminated with significant quantities of tetraphenylborate (TPB), a material which can release benzene vapor to the tank head space in potentially flammable concentrations. It is therefore an important element of the DOE-SR mission to remove, process and dispose of the contents of Tank 48H, both to eliminate the hazard it presents to the SRS H-Tank farm and to make possible Tank 48H return to service, to support ongoing HLW SRS processing and orderly tank closures.

To that end, the Washington Savannah River Company (WSRC), the SRS prime contractor, has evaluated alternatives and selected two processes, Wet Air Oxidation (WAO) and Fluidized Steam Bed Reforming (FBSR) as candidates for Tank 48H processing. Over the past year WSRC has been sponsoring and reviewing the results of testing of these two processes, and is nearing a final selection.

In parallel with WSRC's ongoing work, DOE convened a team of independent qualified experts (the Assessment Team) to conduct this Technology Readiness Assessment (TRA). Resumes for the Team members are provided in Appendix D.

The methodology used for this Technology Readiness Assessment (TRA) is based on 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 critical technology elements (CTE). It was adapted for DOE assessments 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 TRA consists of three parts:

- Determination of the CTEs for each of the candidate processes.
- Evaluation of the TRLs of each CTE for each process using the technical readiness scale applied by DoD and the National Aeronautics and Space Administration (NASA) and adapted by the Assessment Team for use by DOE.

[1] Department of Defense, *Technology Readiness Assessment (TRA) Deskbook*, 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.

- Defining of the technology testing or engineering work necessary to bring immature technologies to the appropriate maturity levels.

CTEs are those elements (such as subsystems) of an overall process that are essential to its success, are new, or are being applied in new or novel ways or in new environments. Appendix A summarizes the systems evaluated. The Assessment Team identified the CTEs for each process, as listed below.

1. Wet Air Oxidation (WAO):
   - Reactor System
   - Offgas Treatment System

2. Fluidized Bed Steam Reforming (FBSR):
   - Steam Reformer System
   - Offgas Treatment System
   - Product Handling System

The specific responses to each of the TRL questions for each CTE evaluated in this TRA are presented in Appendix C.

The TRL for each of the technologies evaluated, including subsystems, is presented in Section 4.0, Table 4.1. This table presents the technology/subsystem, TRL rating, the rationale for the TRL rating, and the major technology development activities required to bring the technology to a level of maturity that would support design implementation. The TRA methodology assigns a TRL to a technology based on the lowest TRL assigned to any CTE of that technology. Thus, the overall TRL for WAO is 2 and the TRL for FBSR is 3. Based on the precedent set by the DoD and NASA, an assessment level of TRL 6 indicates that a technology is sufficiently mature for incorporation into the final design. However, as noted in this report, assessments of radioactive material processing (such as evaluated here) and the attendant difficulty of full scale testing of the actual materials to be processed, tends to lower TRL scores developed using the TRA methodology. In the view of the Assessment Team, the numerical score produced in the evaluation is less important than the underlying methodical assessment process and comparison of alternatives and it may be appropriate to proceed with systems evaluated at TRL levels lower than TRL 6.

Based on the results of this TRA, the Assessment Team concluded the following:

Wet Air Oxidation. The Feed Receipt, Preparation, and Feed System, and the Product Handling systems were not considered CTEs because they are not new, novel, or repackaged. The WAO Reactor (TRL 3) and offgas system (TRL 2) technologies used for WAO were determined to be relatively immature due to the lack of testing using actual Tank 48H waste, no pilot-scale simulant testing, and limited development of the continuous design concepts and project requirements for implementation of these technologies. However, based on previous testing of these technologies with Tank 48H simulant and multiple commercial applications, the Assessment Team considers that the reactor technology can be brought to an appropriate level of maturity through pilot-scale testing with simulants, laboratory bench scale testing with actual wastes, and concept development to support design implementation.

Although desirable from a standpoint of demonstrating technology maturity, laboratory and bench-scale testing with actual wastes for the offgas system may not be feasible. If it is not practical to conduct laboratory offgas testing with actual wastes, conducting offgas testing using tracers and at hot commissioning should be considered.

Fluidized Bed Steam Reforming. The component subsystems of FBSR technology, as applied for immobilization of Tank 48H wastes, are based on significant technology development: The Feed Receipt, Preparation, and Feeding System was not determined to be a CTE, because that system is not new, novel, or repackaged.. The Steam Reformer Subsystem (TRL 4); and the Offgas Treatment System (TRL 4) was nearing maturity. However, the FBSR Product Handling System is less mature (TRL 3).

The mature stage of technology development for the Steam Reformer Reactor and Offgas Subsystems is attributable to the commercial application of this technology and development of the technology for the Studsvik Facility at Erwin, Tennessee, the planned Integrated Waste Treatment Unit at the DOE Idaho Site, and engineering-scale tests using Tank 48H simulant by THOR Treatment Technologies at Hazen Research, Inc. facility. Lack of actual waste testing prevented these subsystems from achieving a TRL of 5. Also, the Steam Reformer Subsystem requires further testing and development of the cyclone downcomer and other components.

The functionality and equipment requirements for the Product Handling Subsystem have not been defined. SRS Tank 48H will use a unique "dry to wet" product handling system. Small scale tests have been conducted [LWO-PIT-2007-00013, WSRC-MS-2004-00288] that demonstrated FBSR sodium carbonate product easily dissolves at the same rate as published values. The samples were filtered and analyzed, and some minor components were captured on the filters. Samples were more dilute than what will be slurried in the full-scale plant. Product-handling has not been demonstrated at the wt% solids anticipated for the full-scale plant. Further testing and development is recommended because of the difficulty in transferring solids in general and the interface from dry product storage to the humid vapor space of the dissolving tank. Waste must be thoroughly dissolved and mixed to avoid plugging in the transfer lines. Also, potential technical issues have been identified with meeting the Waste Acceptance Criteria (WAC) for the Tank Farm Receipt tank and the Defense Waste Processing Facility (DWPF) and wet product sieving and/or waste blending may be required [LWO-PIT-2007-00013, WSRC-MS-2004-00288].

In conclusion, both WAO and FBSR technologies appear to be viable. Of the two, FBSR is the more mature, although as would be anticipated for a radioactive treatment process neither meets the TRL 6 level usually considered by DoD and NASA to be prerequisite to final design. However, since the Tank 48H waste treatment project is approaching Critical Decision 1 (Approve Alternative Selection and Cost Range), a lower technology readiness level score is considered by the Assessment Team to be an adequate basis for moving forward.

It is not the role of the Assessment Team to recommend which technology should be chosen for further development. The Team notes however that it may be most practical to choose one of the two systems as the primary path forward and apply the bulk of the effort and investment to further pilot-scale development of that technology. The other technology could then be carried at a significantly lower level of investment, as necessary to be confident that it could be employed as a backup if unanticipated problems arise with the primary path.

Table of Contents

Executive Summary ii
Table of Contents vi
Acronyms and Abbreviations ix
Units of Measure x
Glossary xi
1. Introduction 1-1
1.1 Background 1-1
1.2 Assessment Objectives 1-2
1.3 Description of TRA Process 1-2
1.3.1 Background 1-2
1.3.2 TRA Process 1-3
2. TRL Assessment 2-1
2.1 TRL Process Description 2-1
2.2 Determination of CTEs 2-1
3. Summary of the Technology Readiness Assessment 3-1
3.1 Wet Air Oxidation (WAO) 3-1
3.1.1 WAO Reactor System 3-1
3.1.1.1 Function of the WAO Reactor System 3-1
3.1.1.2 Description of the WAO Reactor System 3-1
3.1.1.3 Relationship to Other Systems 3-2
3.1.1.4 Development History and Status 3-2
3.1.1.5 Relevant Environment 3-4
3.1.1.6 Comparison of the Relevant Environmental and the Demonstrated Environment 3-5
3.1.1.7 Technology Readiness Level Determination 3-5
3.1.2 WAO Offgas System 3-5
3.1.2.1 Function of the WAO Offgas System 3-5
3.1.2.2 Description of the WAO Offgas System 3-6
3.1.2.3 Relationship to Other Systems 3-6
3.1.2.4 Development History and Status 3-6
3.1.2.5 Relevant Environment 3-6
3.1.2.6 Comparison of the Relevant Environmental and the Demonstrated Environment 3-7
3.1.2.7 Technology Readiness Level Determination 3-7
3.2 Fluidized Bed Steam Reforming 3-7
3.2.1 Steam Reformer System 3-9
3.2.1.1 Function of the FBSR Steam Reformer System 3-9
3.2.1.2 Description of the Steam Reformer System 3-9
3.2.1.3 Relationship to Other Systems 3-11
3.2.1.4 Development History and Status 3-12
3.2.1.5 Relevant Environment 3-14
3.2.1.6 Comparison of the Relevant Environmental and the Demonstrated Environment 3-14
3.2.1.7 Technology Readiness Level Determination 3-15

Table of Contents (Continued)

3.2.2 FBSR Offgas Treatment System 3-15
3.2.2.1 Function of the FBSR Offgas Treatment System 3-15
3.2.2.2 Description of the Offgas Treatment System 3-16
3.2.2.3 Relationship to Other Systems 3-16
3.2.2.4 Development History and Status 3-16
3.2.2.5 Relevant Environment 3-17
3.2.2.6 Comparison of the Relevant Environmental and the Demonstrated Environment 3-17
3.2.2.7 Technology Readiness Level Determination 3-19
3.2.3 FBSR Product Handling System 3-19
3.2.3.1 Function of the Product Handling System 3-20
3.2.3.2 Description of the Product Handling System 3-20
3.2.3.3 Relationship to Other Systems 3-20
3.2.3.4 Development History and Status 3-20
3.2.3.5 Relevant Environment 3-21
3.2.3.6 Comparison of the Relevant Environmental and the Demonstrated Environment 3-21
3.2.3.7 Technology Readiness Level Determination 3-22
4. Summary of Needs 4-1
4.1 Wet Air Oxidation 4-1
4.1.1 Description of WAO Needs 4-1
4.1.2 Assessment of WAO Advancement Degree of Difficulty 4-7
4.2 Fluidized Bed Steam Reforming 4-10
4.2.1 Description of FBSR Needs 4-10
4.2.2 Assessment of FBSR Advancement Degree of Difficulty 4-12
5. Conclusions 5-1
5.1 Conclusions on Technology Readiness 5-1
5.2 Conclusions on the TRA Process 5-1
6. References 6-1

Appendices

Appendix A Determination of the Critical Technology Elements A-1
Appendix B Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management B-1
Appendix C Technology Readiness Level Summary for Tank 48H Critical Technology Elements C-1
Appendix D Technology Readiness Assessment Meeting Attendees and Team Resumes D-1

Table of Contents (Continued)

Tables

Table 1.1 Technology Readiness Levels Used in this Assessment.. 1-4
Table 1.2 Relationship of Testing Requirements to the TRL 1-5
Table 2.1 Questions used to Determine the Critical Technology Element for This Technology Readiness Level Assessment 2-1
Table 3.1 Results of Bench-Scale WAO Testing with Nonradioactive Simulant for Tank 48H 3-3
Table 3.2 WAO Optimization Test Results 3-4
Table 3.3 Emission Data Summary for CP1 and CP2 Testing and Tank 48H Testing 3-18
Table 4.1 Technology Readiness Level Conclusion for Critical Technology Elements 4-2
Table 4.2 Advancement Degree of Difficulty for Technology Maturation of WAO and FBSR to TRL 6 4-7

Figures

Figure 3.1 Typical WAO Flow Diagram.. 3-2
Figure 3.2 Proposed Tank 48H Flowsheet 3-11

Acronyms and Abbreviations

1PB	phenylboronic acid
2PB	diphenylborinic acid
3PB	triphenylborane
CD	critical decision
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
CRR	carbon reduction reformer
CTE	critical technology element
DMR	denitration mineralization reformer
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE-SR	U.S. Department of Energy-Savannah River Operations Office
DWPF	Defense Waste Processing Facility
EDTA	ethylenediaminetetraacetic acid
EM	Office of Environmental Management
EPA	U.S. Environmental Protection Agency
ESTD	Engineering Scale Test Demonstration
FBSR	fluidized bed steam reforming
FFA	Federal Facility Agreement
FY	fiscal year
GAO	Government Accountability Office
Hazen	Hazen Research Facility
HEPA	high-efficiency particulate air
HLW	high-level waste
HTF	high temperature filter
ILAW	immobilized low-activity waste
INL	Idaho National Laboratory, formerly Idaho National Engineering and Environment Laboratory (INEEL)
IWTU	Integrated Waste Treatment Unit
LAW	low-activity waste
LFL	lower flammability limit
MACT	maximum achievable control technology
NASA	National Aeronautics and Space Administration
OGTS	Offgas Treatment System
PNNL	Pacific Northwest National Laboratory
R&D	research and development
RPP	River Protection Project
SBW	sodium-bearing waste
SRS	Savannah River Site
SRNL	Savannah River National Laboratory
SAIC	Science Applications International Corporation
STAR	Science and Technology Application Research [Center]

Acronyms and Abbreviations (Continued)

THC	total hydrocarbon
THOR	Thor Treatment Technologies LLC
TPB	tetraphenylborate
TRA	technical readiness assessment
TRL	technology readiness level
WAC	Waste Acceptance Criteria
WAO	Wet Air Oxidation
WSRC	Washington Savannah River Company
WTP	Waste Treatment and Immobilization Plant

Units of Measure

cm	centimeter
dscm	dry standard cubic meter
ft	feet
gph	gallons per hour
gpm	gallons per minute
hr	hour
L	liter
lb	pound
m	meter
M	molar
mg/L	milligrams per liter
ppm	parts per million
psi	pounds per square inch
psig	pounds per square inch gauge
R/hr	rems per hour

Glossary

Term	Definition
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.

Glossary (Continued)

Term	Definition
Relevant Environment	A testing environment that simulates the key aspects of the operational environment (e.g., range of simulants plus limited range of actual waste).
Similar System	The 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 Introduction

1.1 Background

The U.S. Department of Energy (DOE) operates the Savannah River Site (SRS). One of DOE's primary missions at SRS is to retrieve and treat the high level waste (HLW) remaining in SRS and close the F&H tank farms. At present, a significant impediment to timely completion of this mission is the presence of significant organic chemical contamination in Tank 48H.

Tank 48H is a 1.3 million gallon tank with full secondary containment, located and interconnected within the SRS tank system. However, the tank has been isolated from the system and unavailable for use since 1983, because its contents – approximately 250,000 gallons of salt solution containing Cesium-137 (Cs-137) and other radioisotopes – are contaminated with nearly 22,000 Kg of tetraphenylborate (TPB), a material which can release benzene vapor to the tank head space in potentially flammable concentrations.

It is therefore an important element of the DOE SRS mission to remove, process, and dispose of the contents of Tank 48H, both to eliminate the hazard it presents to the SRS H-Tank Farm and to make possible Tank 48H return to service, in support of ongoing HLW SRS processing and orderly tank closures. Tank 48H must be returned to service to support operation of the Salt Waste Processing Facility (SWPF)[3] operation and to free up SRS HLW tank space, as needed to meet Federal Facility Agreement (FFA) commitments.

The overall plan for HLW processing at SRS is captured in the CBU-PIT-2006-00070, *Liquid Waste Disposition Process Plan*, May 2006.

Technology selection activities have been ongoing since 2002 to define the technology to destroy TPB and bring Tank 48H back into service. A WSRC systems engineering evaluation [G-ADS-H-00011] identified Fluidized Bed Steam Reforming (FBSR) and Wet Air Oxidation (WAO) as the two most promising technologies. This was followed by the Independent Technical Review (ITR) in 2006 [ITR-T48-2006-001] which concurred with the conclusions reached during the systems engineering evaluation. The ITR also concluded that time is of the essence, and that final technology selection should be made as soon as possible. The ITR Team concluded that FBSR is the preferred method for bulk treatment of the Tank 48H material, and work should continue, on a high priority basis, to confirm its viability, per the recommended actions. WAO should be carried as a backup, but developed only to the degree necessary to confirm its technical viability. The last WSRC systems engineering evaluation [G-AES-H-00009] recommended FBSR as the baseline treatment for Tank 48H.

Early this year, WSRC established a Tank 48H path forward comprising development and application of one of two technologies, FBSR and WAO, with a third method, called Aggregation, as a backup.

[3] SWPF is a high capacity system for processing of the Cesium-laden salt waste in SRS tanks. The system is currently under design and is expected to be operational in 2012.

A Critical Decision (CD)-1 Package was submitted (LWO-SPT-2006-00100). This TRA and a technical assessment conducted by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) [CRESP 2007] provide input to DOE's decision on the technology selection for CD-1.

1.2 Assessment Objectives

The purpose of this TRA was to determine the maturity level of the Tank 48H treatment technologies using a prescribed methodology. This TRA was intended to:

- Identify critical technology elements (CTE).
- Determine the Technology Readiness Level (TRL) associated with each CTE.
- Determine the degree of difficulty (measured by cost and schedule) in improving the maturity level of each of the technologies.

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." ([Department of Defense [DoD] 2005)

In 1999, the U.S. Government Accountability 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 the 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) TRLs as a means of assessing technology maturity before design transition.

In 2001, the DoD Deputy Undersecretary 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], dated November 2004. Subsequently, the DoD developed detailed guidance for using TRLs in the *2003 Technology Readiness Assessment Deskbook*, which was updated in May 2005. The DoD Milestone Decision Authority must certify to Congress that the technology has been demonstrated in a relevant environment before transition of weapons system technologies to design or justify any waivers. NASA also uses TRL 6 as the level required for technology insertion into design. Based on historical use of the TRA process, DOE has decided to use the DoD TRL process as a method for assessing the level of technology readiness for the Tank 48H treatment technologies.

1.3.2 TRA Process

The TRA process as defined by the DoD consists of three parts: (1) identifying the CTEs, (2) assessing the TRL 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, are combinations of existing technologies in new or novel ways, or will be used in a new environment. Appendix A 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 before 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 further understand the relationship between the scale of testing, fidelity of testing system, testing environment, and the TRL. This scale requires that for TRL 6, testing must be completed at an engineering or pilot scale, with testing of the system fidelity that is similar to the actual application and with a range of simulated waste and/or limited range of actual waste, if applicable.

The assessment of the TRLs was aided by questions based on a TRL Calculator methodology that was originally developed by the U.S. Air Force (Nolte et al. 2003) and modified for DOE-EM applications. The TRL Calculator questions used in this assessment are described in more detail in Appendix B.

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.	The technology is in its final form and operated 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.	The 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 actual waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This 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 actual waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with actual 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 actual waste and simulants.
	TRL 4	Component and/or system validation in laboratory environment	The 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 (R&D) 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.
Basic Technology Research	**TRL 2**	Technology concept and/or application formulated	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.
	TRL 1	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied 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	Laboratory	Similar	Relevant
4	Laboratory	Pieces	Simulated
3	Laboratory	Pieces	Simulated
2	Paper	Paper	Paper
1	Paper	Paper	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 TRL Assessment

2.1 TRL Process Description

The Assessment Team was comprised of staff from Pacific Northwest National Laboratory (PNNL) and technical consultants to DOE. See Appendix D for identification of the Assessment Team and supporting contractor and vendor personnel. The Assessment Team members have extensive experience on related nuclear waste treatment technologies.

The WSRC engineering staff, Savannah River National Laboratory (SRNL) scientists, and personnel from Thor Treatment Technologies LLC (THOR) and Siemens presented descriptions of the Tank 48H treatment systems, described the technology research and testing results, and participated in the completion of the responses to the individual questions in the TRL Calculator. Each response to a specific TRL Calculator question was recorded, along with references to the appropriate documents.

The Assessment Team completed independent due-diligence reviews and evaluations of the testing and design information to validate the input obtained in the working sessions. Appendix C provides the TRL Calculator results for each CTE.

The Assessment Team evaluated the processes and mechanical systems used to treat Tank 48H waste. The Team did not evaluate the software systems used to control the processes and mechanical equipment because these software systems have not been sufficiently developed.

2.2 Determination of CTEs

The process for identifying the CTEs for the facilities involved a technology system evaluation by the treatment subject matter experts on the Assessment Team. The Assessment Team identified as potential CTEs the technology subsystems that are directly involved in processing the tank waste. The Team evaluated the potential CTEs against the two sets of questions presented in Table 2.1.

Table 2.1. Questions used to Determine the Critical Technology Element for This 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?

A system was determined to be a CTE if a positive response was provided to at least one of the questions in each of the two sets of questions. The complete list of systems evaluated as CTEs is provided in Appendix A, and the specific responses to each of the questions for each system are given in Tables A.1 and A.2.

The Team identified the systems listed below as CTEs.

- Fluid Bed Steam Reforming: FBSR Steam Reformer System, FBSR Offgas Treatment System (OGTS); and FBSR Product Handling System
- Wet Air Oxidation: WAO Reactor System and WAO Offgas Treatment System

3 Summary of the Technology Readiness Assessment

The Team completed a TRL assessment for each CTE, and the results are summarized in this section. The TRL Calculator 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 technology readiness level, for the TRL assessment. Each system was evaluated using the questions in Figure B.1. The Assessment Team initiated the TRA at one level below the highest TRL expected based on qualitative engineering judgment.

2. The TRL assessment was begun using a series of detailed questions in Appendix C starting at one level below the levels identified in step 1 above. If the starting TRL question set was completed with all positive responses, the Assessment Team evaluated the next higher TRL question set (e.g., if the technology passed all the questions in TRL 4, then the Team proceeded to TRL 5). If the starting TRL question set had any negative responses, the Assessment Team evaluated the next lower TRL question set (e.g., if the technology did not pass all the questions in TRL 4, then the Team proceeded to TRL 3) . The Team recorded the responses to the TRL questions; these are provided in Appendix C for each CTE. For each CTE, the discussions below describe the CTE function, 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.

3.1 Wet Air Oxidation (WAO)

Siemens Water Technologies Corporation (formerly US Filter/Zimpro) is the vendor for WAO. WAO is an aqueous phase process in which organic and inorganic components are oxidized using air. The reaction products are typically CO_2, H_2O, SO_4, HCl, and low molecular weight short chain oxygenated organics (acetic acid and other carboxylic acids).

3.1.1 WAO Reactor System

3.1.1.1 Function of the WAO Reactor System

The primary function of the WAO reactor system is to destroy organic constituents in the feed slurry through oxidation.

3.1.1.2 Description of the WAO Reactor System

The WAO reactor system includes feed heaters, reactor, and product coolers. The system also includes ancillary and support equipment, such as feed tanks, high pressure feed pumps and air compressors, gas-fired hot oil unit, product separator, and a cold chemical storage tank. The feed solution is delivered to the reactor through a high pressure pump. A schematic flow diagram is shown in Figure 3.1.

Based on recent bench-scale autoclave tests with Tank 48H simulants and prior pilot plant experience with other wastes, Siemens anticipates that the Tank 48H WAO reactor would have design features of 3 gpm feed rate, 3 hours reaction time, at operating temperature and pressure of 300°C and 2,300 psi. Air is injected to the process, resulting in three phases within the reactor: gas, solid (from insoluble components in the waste feed), and aqueous solution.

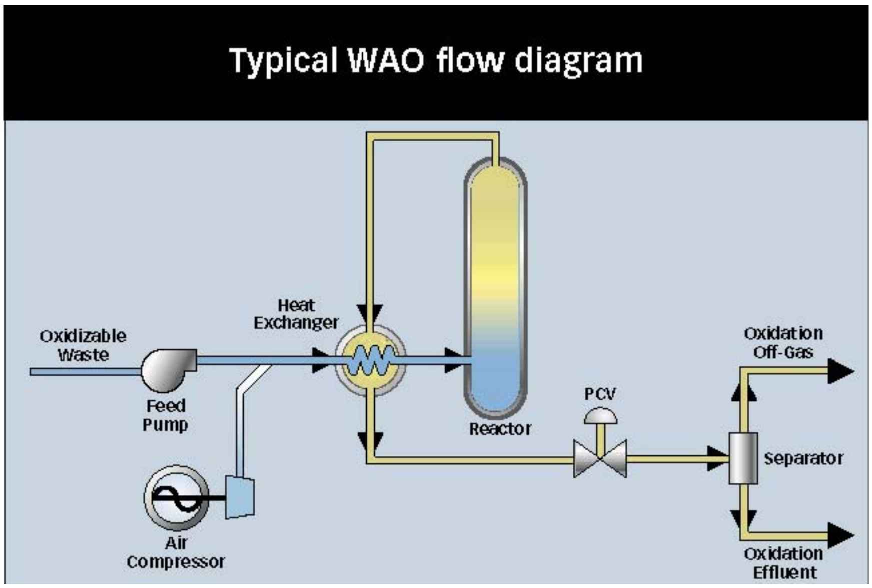

Figure 3.1. Typical WAO Flow Diagram

3.1.1.3 Relationship to Other Systems

The relationship of the WAO reactor system to other systems is as follows:

- Feed is received for the WAO system in a feed receipt and preparation system.
- The primary process effluents are exhaust gas and aqueous slurry.
- Exhaust gas is treated in the WAO offgas treatment system.
- Aqueous slurry is returned to the SRS tank farms.

3.1.1.4 Development History and Status

The Zimpro WAO process has been used commercially for over 50 years to treat a variety of waste streams, including sludges from municipal and industrial wastewater treatment, pulp and paper wastes, and spent caustics from ethylene process facilities, oil refineries and other industries. The process is operating successfully in more than 150 full-scale commercial applications. Siemens is the current vendor for the process. Systems have operated as long as 30 years with minimal maintenance.

In January 2007, Siemens began operation of a 27 gpm WAO plant for destruction of hydrolysate from prior treatment of non-stockpile binary weapon components. The plant is located at the Texas Molecular facility in Deer Park, Texas [LWO-SPT-2007-00084, WSRC-STI-2007-00314, Rev. 1]. The work is being done under contract to DoD. The system was tested in a 5 gph pilot plant unit in Rothchild, WI. The scale up of 300:1 to the full scale 27 gpm unit is considerably higher than generally recommended in chemical engineering. During the TRA meeting at SRS (June 13, 2007), vendors said they were comfortable with scale ups as high as 1000:1, because reactor dynamics are well understood.

Bench-scale WAO was successfully tested at the Hanford Site in the 1990s to destroy organic complexing agents in actual radioactive waste [PNL-10108, PNL-10765]. At 280^{o}C and 1 hour, organics destruction based on total organic carbons for both simulant and radioactive actual waste was > 98%. Nitrite destruction was minimal (< 9%).

A two-stage Kenox-designed WAO system went into operation in 1993 at Ontario Hydro's Bruce Spent Solvent Treatment Facility. The waste feeds were spent aqueous solutions from cleaning of the secondary side of Ontario Hydro's nuclear steam generators. The principle solution components were ethylenediaminetetraacetic acid (EDTA), copper and iron, contaminated with low levels of radionuclides (Co-60, Cs-137, Sb-124, and tritium). Design flow was 12 gpm. The reactors were operated at temperatures of 200 -250^{o}C and a pressure of 725 psig. Destruction of EDTA was greater than 95 percent and the dissolved iron precipitated virtually quantitatively as a mixture of hematite and magnetite. The Kenox technology operates at somewhat lower temperatures and pressures than the Zimpro process, but both are based on the same principles [ICOA 1995].

Table 3.1 presents the results of bench-scale testing with nonradioactive simulant for Tank 48H conducted in 2006 (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035). Off-gas and treated stimulant compositions were analyzed in eleven bench-scale, batch autoclave experiments. Offgas contained low molecular weight volatile organic compounds, including benzene, and biphenyl. The total hydrocarbon concentration (THC) in the offgas ranged from 1140 to 1612 ppm by volume, reported as ethane. Over half of the offgas THC was benzene, but at levels less than 24% of its lower flammability limit (LFL). The maximum THC value measured was 0.34% and the benzene LFL is 1.4% @ 25°C. Bench scale tests demonstrated 99.99% destruction of TPB (< 2 mg/L). Biphenyl was observed floating on the surface of the treated simulant. Supplemental treatment may be required to remove biphenyl.

Table 3.1 Results of Bench-Scale WAO Testing with Nonradioactive Simulant for Tank 48H

	Units	**Undiluted Feed**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 9**	**Test 10**	**Test 11**
TPB	mg/L	17,980	---	<0.8	---	<0.8	---	<1.0	<0.8	<1.0	2	3
3PB	mg/L	<10	---	<10	---	<10	---	<10	<10	<10	<10	<10
2PB	mg/L	<10	---	<10	---	<10	---	<10	<10	<10	<10	<10
1PB	mg/L	<10	---	<10	---	<10	---	<10	<10	<10	<10	<10
Phenol	mg/L	958	---	<10	---	<10	---	<10	<10	<10	<10	<10
Soluble Biphenyl	mg/L	---	---	<10	---	<10	---	<10	<10	<10	<10	<10
Floating Biphenyl	mg/L	560	---	85	---	<10	---	503	1,190	61	43	176
pH	---	---	12.0	9.4	12.6	12.8	12.9	14.5	14.1	14.4	14.3	14.4

Four optimization tests were conducted. Table 3.2 displays the optimum test conditions identified after the screening and optimization tests. Four confirmation tests were run under the conditions shown in Table 3.2. Additional tests identified the materials-of-construction (MOC) and provided data for preliminary full-scale system design parameters and evaluation of process economics.

Table 3.2 WAO Optimization Test Results

Temp (ºC)	300
Time (hr)	3
Baffles	Yes
Antifoam-IIT B52	2000
Cu Catalyst (mg/L)	500
Feed Slurry Dilution	1:1 (2 M NaOH)

Corrosion should not be a problem. Siemens conducted a single 100-hour test of stressed coupons in the autoclave under slightly more severe conditions than the confirmation runs. Inconel 600, Inconel 690, Ni 201, and Monel K-500 were found to be potentially suitable materials for a full-scale WAO reactor. Plugging could be a problem because of the formation of carbonate salts by reaction of CO_2 (reaction by-product) with caustic. It was a problem in pilot tests on H-neutralent. The problem was solved by using KOH as a diluent instead of NaOH. The solubility of K_2CO_3 is higher than that of Na_2CO_3, so that no solids were formed.

Pilot-scale continuous flow simulant testing at the Siemens facility in Rothschild has been proposed to refine optimum conditions and to determine offgas and product composition. Bench-scale testing of actual Tank 48H radioactive wastes at SRS has been proposed to confirm destruction efficiencies and rates.

The CRESP report also recommended pilot-scale testing on WAO to (a) establish operating conditions necessary to reliably achieve process objectives, (b) establish stable continuous operations at design conditions for periods long enough to achieve steady state, and (c) verify recommended materials of construction.

3.1.1.5 Relevant Environment

The relevant environment for WAO Reactor System is as follows:

- The tank contains approximately 430,000 curies of Cs-137 and lesser amounts of other radionuclides.
- Destroy and remove greater than 99% of the organic content
- Retain radionuclides in the treated slurry.

- Transfer liquid waste to a receipt tank in the Tank Farm at a nominal flow rate of 30 gpm with a minimum transfer flow velocity of 3 ft per second in normal operation Minimum pH: > 9.5 for liquid waste.

- Generate no by-products capable of generating toxic gases, vapors or fumes in quantities harmful to people.

3.1.1.6 Comparison of the Relevant Environment and the Demonstrated Environment

The technology has not yet been demonstrated in a relevant environment. WAO Reactor System is less developed than FBSR for this application and has had very limited demonstrated performance in processing of radioactive material. Most importantly, the batch autoclave testing that has been done on Tank 48H simulants is not adequate for scale-up. Test results would need to be obtained for a continuously run system. Siemens' experience has been that operating pressures are generally up to 30 percent lower in a continuous flow system than in the autoclave, and that offgas data may be different.

WAO offers potential benefits. It is a continuous process with fairly short reaction times. It requires a relatively small process footprint and generally requires use of no chemicals, except 2M NaOH and copper catalyst. The waste may have to be diluted to reduce COD and thereby control temperature in the reactor.

3.1.1.7 Technology Readiness Level Determination

The WAO Reactor System was determined to be TRL 3 because only bench-scale, batch testing with simulants has been completed. The technology could reach TRL 6 if pilot-scale testing with simulants and bench-scale autoclave testing with actual wastes were completed and the results incorporated into the conceptual design for the full-scale WAO System.

Although the bench scale, batch type autoclave tests give a good indication of the quality of treated product that can be expected from WAO, the tests are not totally representative of what will be achieved by a continuous flow process [Siemens 03-09-2007]. Siemens recommended additional pilot-scale testing to assess the impact of treating the Tank 48H waste slurry in a continuous flow system and additional longer term bench-scale testing to confirm the best selection of MOC materials

3.1.2 WAO Offgas System

3.1.2.1 Function of the WAO Offgas System

The offgases will need to be treated to levels specified in the air permit prior to release to the external environment.

3.1.2.2 Description of the WAO Offgas System

The WAO Offgas System has not yet been defined. The conventional equipment includes a water scrubber to remove particulates and water soluble gases, generating an aqueous slurry. Thermal oxidizers or thermal catalytic oxidizers also have been used. For radioactive applications, the significant components would likely include particulate removal equipment, fans and blowers, and high-efficiency particulate air (HEPA) filters.

3.1.2.3 Relationship to Other Systems

The relationship of the WAO offgas system to other systems is as follows:

- Feed is received from process water/gas separator
- Condensate will feed into process effluent
- Offgas system provides pressure relief path for reactor system
- Aqueous slurry effluent from WAO may require further treatment to remove biphenyl
- Aqueous slurry is returned to the SRS tank farms
- Steam utilities provide heat for process
- Compressed air system for the high pressure pump.

3.1.2.4 Development History and Status

WAO has had a successful bench test. It has not been tested in a continuous flow system for the Tank 48H application, and the offgas treatment system has not yet been defined.

3.1.2.5 Relevant Environment

The relevant environment for the WAO Offgas System is as follows:

- Tank 48H contains high levels of radionuclides (approximately 430,000 curies of Cs-137) and the offgas stream will contain radioactivity that must be removed.
- Organic vapor control: the waste stream less than or equal to 5% organic contribution to the composite lower flammability limit (LFL) at 100°C.
- Hydrogen generation rate: the hydrogen generation from radiolysis for waste stream <1.5E-5 FT3 of hydrogen/hour/gallon.
- Process off-gas stream and secondary confinement shall not exceed 121°C upstream of the off-gas HEPA housing inlet.

- The outlet gas temperature shall be maintained above the dew point for all operating modes.

- The final product output streams shall have no toxic gases, vapors, and fumes in quantities harmful to people.

- Process offgas shall contain no Resource Conservation Recovery Act hazardous (40 Code of Federal Regulation Part 261) air pollutants other than the current inventory present in the Tank 241-948 material.

3.1.2.6 Comparison of the Relevant Environment and the Demonstrated Environment

The system was not demonstrated in a relevant environment. The offgas treatment system has not been defined and, thus, no relevant testing has been conducted.

3.1.2.7 Technology Readiness Level Determination

The offgas system technology is a TRL 2, because there has not been testing of the integrated, prototypical system. Pilot-scale testing of an integrated prototypical system that includes offgas components is recommended.

3.2 Fluidized Bed Steam Reforming

The FBSR process, marketed by THOR Treatment Technologies LLC (THOR), is a candidate process to treat SRS Tank 48H TPB waste. In the THOR process, waste feed, superheated steam, and co-reactants are introduced into a fluid bed steam reformer vessel where liquids are evaporated, organics are destroyed, and reactive chemicals in the waste are converted to a stable waste product that incorporates the radio nuclides.

FBSR is a commercially operational technology that is currently used at the Studsvik Processing Facility in Erwin, Tennessee. The Studsvik Processing Facility processes commercial nuclear power plant radioactive wastes composed principally of ion exchange resins, plastics, cellulose, carbon, and oils. The plant has processed high salt content waste and high organic content resins. The plant has been in operation for over seven years and has processed over 200,000 ft^3 of low-level waste. The Studsvik Processing Facility operates two fluidized bed steam reformers, a 45-inch-diameter main unit and an auxiliary 18-inch-diameter unit. The system can handle wastes with high radionuclide content (up to 400 R per hour). All organics are processed through the reformer process system and are converted to carbon dioxide and water vapor with Destruction and Removal Efficiency exceeding 99.99%. Radionuclides (i.e., cesium, technetium, and cobalt) in the waste feed are retained (>99.9%) in the solid, mineralized product, with the exception of tritium, carbon-14, and iodine that are largely volatized [WM04 2004].

Lessons learned for the Studsvik facility have been documented [WM03 2003]. The Studsvik Processing Facility commenced limited commercial operations in summer of 1999; however, many of the facility's balance of plant systems designed by the facility's design/build contractor were not capable of achieving their design capacities. This resulted in an extensive ramp-up period. Problems were noted with plugging in resin transfer systems. Pilot scale test programs on "similar" solutions proved to be inadequate for the design of the offgas treatment system.

The waste in Tank 48H is high in nitrates, nitrites, and tetraphenylborate (TPB). FBSR was considered to reduce or eliminate the levels of these compounds in the Tank 48H waste. The project has completed a risk analysis and conceptual design and it has completed CD-1. CD-1 establishes acceptance of the project conceptual design. Some of the programmatic documentation is listed below:

- G-CDP-H-00019, Gober, M., *Conceptual Design Package for Tank 48H Treatment Process (TTP)*, Revision 0, November 2006.

- G-TC-H-00046, Shah, S., *Task Requirements and Criteria, Tank 48 Disposition by Fluidized Bed Stream Reforming Project*, Revision 3, July 2007.

- Y-RAR-H-00065, Winship, G.C., *Project #G-002 Tank 48 Treatment Process (TTP) Risk Analysis Report*, Revision 0, November 2006.

- LWO-SPT-2006-00100, Cederdahl, B. and Spires, R., *Critical Decision (CD) 1 Package, Tank 48 Treatment Proces*s, Revision 2, February 2007.

A technical assessment was recently conducted by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) [CRESP 2007] to provide input to DOE's decision on the technology selection for CD-1. The CRESP reviewers recommended additional pilot-scale testing of FBSR to demonstrate (a) stable continuous operations at design conditions for periods long-enough to achieve steady-state (i.e., greater than on complete bed turnover, (b) reliability of key process components (i.e., injection nozzles and locations, filters), and (c) reliable, physical separation and transfer system for the particulate product. CRESP also recommended a more detailed, thorough evaluation of the backend solid to slurry process for preparation of the DWPF feed and the FBSR product compatibility with DWPF acceptance criteria considering the characteristics and processing of the other wastes that treated Tank 48H waste will be blended with to form DWPF feed batches.

FBSR is planned for application to radioactive waste at other DOE sites. Idaho National Laboratory (INL) is in the process of constructing a steam reforming plant (Integrated Waste Treatment Unit [IWTU]) to process approximately one million gallons of sodium-bearing waste into a solid waste form suitable for disposition at the Waste Isolation Pilot Plant [WM06 2006, INEEL/EXT-04-02564, RT-ESTD-PMR-001]. The IWTU is designed to treat 3.1 gpm of sodium-bearing waste. The project received CD-2 approval from the Under Secretary of Energy on December 29, 2006. Waste treatment will start in 2009 and will treat all one million gallons of waste and tank rinses by 2012. A reliability, availability, and maintainability analysis was completed for INL's IWTU. The analysis showed that the total facility would be >80% percent reliable with use of minimal redundant hardware.

The same basic process used for the IWTU and the Studsvik Processing Facility applications, with some modifications, was proposed for treating the Hanford Site low activity waste (LAW).

WSRC and THOR performed preconceptual engineering and cost studies in 2003 [WSRC-TR-2002-00317, Washington Project 26674-001, and THOR 2003]. THOR developed a cost model that reflects the life cycle costs of the Hanford Program, and assumed waste emissions would be modeled for permit applications and results would be verified during startup tests. Where the IWTU uses only a single 48-inch fluidized bed unit, the proposed Hanford supplemental treatment LAW design would use four 48-inch fluidized bed units in the same facility or two 72-inch fluidized bed systems. The Hanford design would process approximately 10 gpm. In addition, where the IWTU produces a carbonate waste form (e.g., they have made both to satisfy WIPP), a mineralized waste form would be required for the Hanford Site waste. Pilot-scale tests in 2004 using Hanford LAW at the Science and Technology Applications Research (STAR) Center indicated that aluminum and chromium, on a weight percent basis, partitioned to the bed product; rhenium, sodium, potassium, calcium, phosphorous, and chlorine distributed somewhat evenly. Silicon, sulfur, and cesium clearly partitions to the filter fines [INEEL/EXT-04-02492].

FBSR non-radioactive pilot scale units are available for testing of the Tank 48H flowsheet at the Science Applications International Corporation (SAIC) / Science and Technology Application Research [Center] (STAR) facility (6-inch FBSR) (Idaho Falls, Idaho) and at Hazen Research (Golden, Colorado) (6-inch FBSR and 15-inch FBSR). A Bench-scale Steam Reformer is available at SRNL that has conducted testing with highly basic and acidic simulated wastes [Hanford LAW, INL sodium-bearing waste (SBW)].

3.2.1 FBSR Steam Reformer System

3.2.1.1 Function of the Steam Reformer System

This Steam Reformer System (Subsystem) includes the denitration mineralization reformer (DMR), high temperature filter (HTF), and carbon reduction reformer (CRR). The function of the Steam Reformer System is to (a) receive the waste from the Feed Receipt, Preparation, and Feeding System, (b) atomize the waste slurry into the fluidized bed, (c) react the waste with chemicals and heat to evaporate water in the waste, (d) reform organics to carbon dioxide, carbon monoxide, and hydrogen gas, (e) convert nitrates and nitrites into nitrogen gas, and (f) convert inorganic constituents (sodium and potassium) and radionuclides (e.g., sodium, potassium, radionuclides, chlorine, fluorine, sulfate) into a granular product.

The HTF is installed at the offgas outlet of the DMR. The function of the filter is to remove entrained solids from the DMR offgas before transferring the offgas to the carbon reduction reformer (CRR). Solids from the HTF can periodically be returned to DMR for reprocessing and used as “seeds” to grow the particle size larger if desired.

3.2.1.2 Description of the FBSR Steam Reformer System

Figure 3.2 illustrates the proposed flow diagram for processing of Tank 48H TPB in the 241-96H facility and is used to describe the process. The flowsheet is described in more detail in *Tank 48H Flowsheet for Steam Reforming*, LWO-PIT-2006-00041, Westinghouse Savannah River Company, October 9, 2006. Approximately 3 M sodium (Na) slurry (sodium hydroxide and sodium salts) is pumped from Tank 48H to the Feed System in the Steam Reformer Process. The slurry is stored in a feed tank and then transferred to a feed batch vessel that continuously supplies concentrated waste to the Steam Reformer System.

Denitration Mineralization Reformer System. The DMR is a fluidized bed vessel that uses low pressure superheated steam, oxygen, and a solid carbon reductant (coal) to create heat and promote a number of chemical reactions and generate heat. The fluidized bed solids are created and maintained by the injected slurry coating and drying on seed particles in the bed. The DMR vessel includes a lower fluidized bed section and a larger-diameter upper section to enable particle disengagement and retention in the bed. A cyclone in the upper section allows large particles to be returned to the fluid bed rather than being elutriated to the HTF. An auger is attached at the bottom of the DMR to remove solid product from the DMR and into the pneumatic transfer line.

Waste is fed into the fluidized bed normally through a series of atomizing nozzles (the Hazen test unit was equipped with only a single feed nozzle). The waste reacts with the steam, heat, and carbon reductant in the fluidized bed material, causing the liquids to be evaporated, organic materials destroyed, and nitrates and nitrites converted into nitrogen gas. The resulting waste form is a granular carbonate, which is periodically removed from the bed via an auger and pneumatically transferred to the Product Receiver to maintain an acceptable DMR bed level.

High Temperature Filter. As the gases leave the DMR bed, the smaller particle carbonate product is carried out of the bed and captured in the process filter. The filters are cleaned by back-pulsing with nitrogen, and the product fines are captured and pneumatically transported to the Product Receiver.

Carbon Reduction Reformer. The process gases flow from the HTF to the fluidizing gas inlet distributors of the CRR located near the bottom of the vessel. Air enriched with oxygen is injected into the CRR several inches above the process gas inlet distributors. The bed region between the inlet distributors and this oxygen injection level operates in a reducing mode to enhance overall nitrogen oxide destruction, while the bed region above operates in an oxidizing mode to convert residual carbon monoxide, hydrogen, and short-chained hydrocarbons to carbon dioxide and water. Higher in the CRR bed, additional oxygen is injected to control the oxygen concentration of the process outlet gas, which in turn keeps the process offgas carbon monoxide concentration low. Propylene Glycol is fed to the system to provide fuel for the reaction.

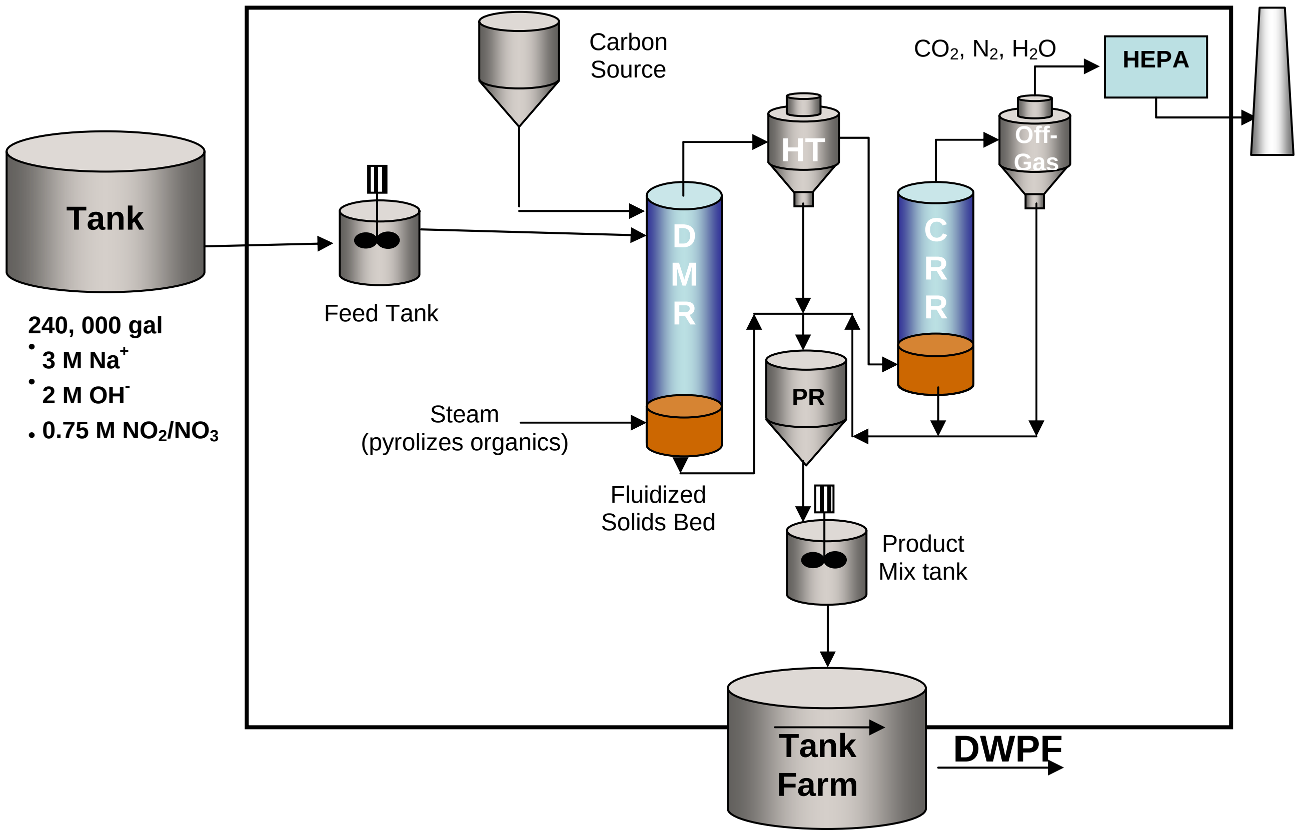

Figure 3.2. Proposed Tank 48H Flowsheet

3.2.1.3 Relationship to Other Systems

This project will require modifications to utilities, infrastructure, shielding, confinement and containment, and waste transfer systems in Building 241-96H. The Steam Reformer System interfaces with the Feed Receipt, Preparation, and Feeding System; Carbon Feed System; Superheated Steam System; Oxygen Injection System; Offgas Treatment System, and the Product Handling System. The relationship of the DMR, HTF, and CRR to other systems is as follows:

- The Feed Receipt, Preparation, and Feeding System atomizes the waste feed and injects it into the DMR.
- Nitrogen is used as purge gas and to cool feed injection nozzles.
- Superheated steam fluidizes bed material in DMR and CRR.
- Solids from DMR, HTF, and CRR are augered/transferred to Product Handling System.

- Parts of the CRR and DMR must be accessible for maintenance. The fluid gas distributors at the bottom of the CRR and DMR may have to be replaced by maintenance staff every 2 years.

- Coal is the reductant for the DMR, and propylene glycol is the fuel source for the CRR.

- The CRR receives propylene glycol and oxygen air to feed the reactions that destroy the residual short chain organics.

- Air flow (and pressure) through DMR, HTF, and CRR come from offgas blower.

3.2.1.4 Development History and Status

FBSR has been used to treat highly radioactive waste. The Studsvik Facility can process ion exchange resins, charcoal, graphite, sludge, oils, solvents, and cleaning solutions with contact radiation levels of up to 400 R/hr. The major isotopes are Co-60 (50%) and Cs-137 (30%). Fluid bed operation, a significant part of FBSR, was employed in high radiation operations in the Calciner facility at INL for about 20 years.

The FBSR technology has been evaluated or tested for remediation of the following:

- SRS evaluated FBSR at the bench and pilot scale for converting the Tank 48H HLW supernate with TPB into either carbonates or silicates compatible with subsequent vitrification in DWPF. Results are documented in the following reports:
  - 28927-RT-00001, Revision 0, *Pilot Plant Report For Treating Tank 48H Simulants Carbonate Flowsheet*, THOR Treatment Technologies, June 2007.
  - WSRC-TR-2003-00352, Revision 1, *Disposition of Tank 48H Organics by Fluidized Bed Steam Reforming (FBSR),* Washington Savannah River Company, March 24, 2004.
  - INEEL/EXT-03-01118, Revision 1, *SRS Tank 48H Waste Steam Reforming Proof-of-Concept Test Results,* Idaho National Environmental and Engineering Laboratory, May 2004.
  - WSRC-MS-2004-00288, *Fluidized Bed Steam Reforming of Organic and Nitrate Containing Salt Supernate.* Washington Savannah River Company, May 17, 2004.
  - LWO-SPT-2007-00050, Revision 1, Shah S., et al., *THOR® Treatment Technologies Pilot Plant Report Summary for Treating Tank 48H Simulant Carbonate Flowsheet*, March 2007.
  - SRNL-PSE-2007-00003, Revision 0, Edwards, R., *THOR Treatment Technologies Pilot Plant Report for Treating Tank 48H Simulants Carbonate Flowsheet*, January 2007.

- Hanford evaluated FBSR for use in the Initial Processing Module (IPM) in 1993 and 1994 [INEEL/EXT-04-01493] and for converting Hanford low-activity waste (LAW) into either carbonates or silicates that can subsequently be vitrified [WSRC-TR-2002-00317].

- Hanford LAW and SRS salt supernate were evaluated using FBSR to convert waste into a final waste form for land disposal [WSRC-TR-2002-00317, PNWD-3288, WSRC-MS-2003-00595, WSRC-STI-2006-0027].

- INL SBW will use FBSR to convert sodium-bearing waste into a carbonate form acceptable to Waste Isolation Pilot Plant (WIPP) as a final waste form or into sodium aluminosilicate as a final waste form for land disposal [INEEL/EXT-03-00437].

The Tank 48H CD-1 Package describes a sodium carbonate product that will be dissolved with water and transferred back to the tank farm [LWO-SPT-2006-00100]. The CD-1 package states that in 2003, steam reforming bench top testing on Tank 48H simulant waste was performed at SAIC's STAR facility in Idaho Falls, Idaho. The test used an externally heated 6-inch diameter reformer and successfully demonstrated the viability of the process to destroy organics in Tank 48H waste. The simplified and fragmented test configuration employed in bench-top testing could not adequately simulate an integrated and continuous process nor fully replicate the operation of production scale units.

An Engineering Scale Test Demonstration (ESTD) unit was constructed and operated at the Hazen Research Facility in Golden, Colorado as a one-tenth scale version of the Idaho IWTU [RT-ESTD-PMR-001]. It is also a three-quarters scale for the proposed Tank 48H unit. With the exception of product handling equipment, the ESTD unit includes all process operations present in the full-scale system proposed for Tank 48H waste treatment. During September and October of 2006, a series of optimization and production run tests were performed. The optimization and production testing simulated variable operating conditions which include feed composition, feed rate, and temperature. In the course of 126 hours of testing, 3,310 gallons of Tank 48H simulant were processed into 5,174 pounds of solid, non-TPB laden granular product. The Final Hazen Reports were issued in early 2007 [LWO-SPT-2007-00050, SRNL-PSE-2007-00003, 28927-RT-00001].

Pilot phase testing at the Hazen Research Facility [28927-RT-00001] tested various reductant/energy sources for the DMR (polyethylene (PE) beads, PG, PE beads + PG, Sugar, Coal, Sugar + Coal). Only coal as DMR reductant produced acceptable results. Propylene glycol (PG) was tested as the CRR fuel source. CRR operation with PG was superior to that with solid carbon for rapid response, ease of material handling and process operation. The DMR was operated at 640ºC and CRR at 950ºC with simulant feed rates from 0.20 to 0.25 gpm. Both feed rates produced acceptable feed nozzle and DMR operation.

Production tests produced good quality sodium carbonate-based product. Integrated system operation was good (feed nozzle, DMR), except that the cyclone plugged more often than expected (perhaps due to above bed reactions in the DMR). Tests verified DMR and CRR operating parameters and confirmed coal as the energy source/reductant for DMR and PG as the CRR energy source. Production tests demonstrated TPB Destruction Efficiency > 99%. The process off-gas met maximum achievable control technology (MACT) and other anticipated regulatory requirements and support permitting. A potential need for two particle size reduction operations was identified (1) to remove very large carbon particles from the DWPF feed (>12 to 16 mesh) and (2) to recycle fines from the HTF product to use as feed particles to the DMR.

The Task Requirements and Criteria Document, G-TC-H-006 defines the requirements for process design, installation, and operation of a modular full-scale FBSR System. Performance requirements for FBSR to treat Tank 48H wastes are contained in LWO-SPT-2007-00101, *FBSR Performance Requirements.* The tanks and mixing apparatus for receiving and blending tank waste and coal are commercially available.

3.2.1.5 Relevant Environment

The Steam Reformer System process parameters are as follows:

- The waste feed will vary form 1% to 10% insoluble solids.
- Approximately 20-inch DMR would be sufficient for Tank 48H waste operating at $650^{o}C$ to $675^{o}C$ and 2 to 4 psig.
- The CRR operating conditions are 850^{o}–$1050^{o}C$ and -2 psig.
- The coal input to the DMR is 200–300 lb/hr.
- Process energy is produced by carbon reductant, steam, and oxygen (autothermal steam reforming).
- Water is evaporated.
- Organics are oxidized or decomposed (e.g., to carbon monoxide, methane and eventually to carbon dioxide before exhausting).
- Nitrates and nitrites are converted to nitrogen gas under reducing conditions.
- Due to erosion, the waste feed injection nozzles must be replaced approximately every two years.

3.2.1.6 Comparison of the Relevant Environment and the Demonstrated Environment

The DMR, HTF, and CRR have been demonstrated in a high-fidelity relevant environment, but not with actual wastes. Pilot-scale tests at the Hazen facility were conducted with nonradioactive Tank 48H waste simulant. Related information from the IWTU testing and operational experience at the Studsvik Processing Facility provides high confidence that the design will work with radioactive wastes.

Researchers tested an injection nozzle using Tank 48H simulant in a 6-inch diameter (15 cm) DMR at the Hazen Research Facility. No bridging across the DMR of solidified bed material was observed. However, bridging occurred when Hanford LAW was tested. DMR bed particle size control was a challenge throughout Tank 48H tests [28927-RT-00001]. Cyclone downcomer pluggage was discussed in the final THOR report on Tank 48H tests [28927-RT-00001]) and in the THOR presentation to the CRESP team.

During THOR testing, a plugged gas outlet on the DMR cyclone may have impeded the efficiency of the cyclone. The DMR cyclone is designed to return small particles to the DMR as seed material for control of DMR bed growth. If the gas outlet is plugged, particles are carried over into the HTF, which negatively impacts HTF performance. Improved cyclone design or an enlarged freeboard of the DMR could increase ease of particle size control. THOR testing also determined that fine particles in the DMR product from Tank 48H simulant could be sieved from the DMR product and recycled back to the DMR for particle size control [LWO-SPT-2007-00050]. Additional testing of the design modifications that address the problems identified during THOR testing would validate that the Steam Reformer System process meets expected performance requirements in a relevant environment.

3.2.1.7 Technology Readiness Level Determination

The Steam Reformer System was determined to be TRL 4 because laboratory and/or bench-scale testing have not been conducted with actual waste. High-fidelity testing has been conducted on the Steam Reformer System at Hazen Research Facility on a mineralization flowsheet; actual waste has been treated at the Studsvik Processing Facility for seven years; and the design of the DMR for the Idaho Site IWTU (a 48-inch DMR vessel) has been completed and fabrication is underway. The design elements (including size, materials of construction, corrosion allowances, system connections, and structural integrity) should apply directly to the Tank 48H installation. TRL 6 would be achieved if laboratory or engineering-scale tests were conducted with actual Tank 48H wastes.

Another series of production scale tests are needed to refine the process flowsheet. Tasks include testing performance of dry / wet sieving mechanism for particle size control and providing additional small particles for use inside the DMR bed and resolving issues with the plugging of the cyclone downcomer.

3.2.2 FBSR Offgas Treatment System

3.2.2.1 Function of the FBSR Offgas Treatment System

The function of the OGTS is to reduce the temperature of the hot offgas received from the CRR vessel, filter out any solids, including entrained CRR bed material (alumina) particulates, and remove contaminants from the offgas stream before the offgas exits from the stack. The CRR offgas stream, consisting of mostly nitrogen, oxygen, water, and carbon dioxide, is cooled and filtered. After passing through a re-heater, the offgas is then discharged to a stack via a HEPA filter.

3.2.2.2 Description of the Offgas Treatment System

The main system components are described below.

Offgas Cooler. The offgas cooler, located alongside the CRR, is a metal vessel with an atomizing water sprayer at the top. The water spray quickly cools the hot offgases to 170°–190°C. The cooled offgas flows to the reheater, which is an electric heater that maintains the gas stream temperature at 150°C to prevent condensation.

Offgas Filter. The cooled offgas enters the offgas filter near the bottom of the filter vessel. The purpose of the offgas filter is to remove any fine particulates that remain in the offgas stream from attrition of mineralization media in the CRR. There are essentially no particles present in the CRR offgas, as these are removed by the process gas filter located upstream of the CRR. The particles removed in the offgas filter would typically be very fine particulates from the CRR bed. The small amount of fines that accumulate over time in the offgas filter are pneumatically transferred to the Product Receiver, as are other solids from the DMR, HTF, and CRR.

Mercury Absorber and Offgas Blowers. If there is mercury in the offgas, then just before discharge, the offgas passes through the mercury absorber. This will not be required for the Tank 48H full scale unit [WSRC-TR-2007-00082, *Tank 48H GAC Bed Evaluation*, March 2007].

Process and System Offgas Measurement. The process and system offgas streams are continuously monitored.

Process Data Acquisition and Control System. Process electronic data is obtained and process control is provided by the Data Acquisition and Control System. The system uses programmable automation controllers for control and data acquisition.

3.2.2.3 Relationship to Other Systems

The relationship of the Offgas Treatment System to other systems as follows:

- The OGTS streams are continuously monitored by the Continuous Process Monitoring Systems.
- Manual samples are obtained from ports in the stack and the OGTS as required by the air permit to verify system performance.
- Gas samples are analyzed in accordance with U.S. Environmental Protection Agency (EPA) methods.
- The Data Acquisition and Control System provides electronic data and process control. The system uses programmable automation controllers for control and data acquisition.

3.2.2.4 Development History and Status

Pilot plant testing of the THOR® FBSR process to produce carbonate was conducted at the Hazen Research Facility in Golden, Colorado in a two-phase demonstration program. Phase 1 carbonate testing (CP1) was performed during the period November 2005 through February 2006 and Phase 2 carbonate testing (CP2) was during the period May 2006 through June 2006. [*Pilot Plant Report for Treating Sodium-Bearing Waste Surrogates Carbonate Flowsheet*, RT-ESTD-PMR-001, Revision 0, October 2006.] SRS Tank 48H testing was conducted for the DMR, CRR, Filtration System, and OGTS later in 2006. The Final Hazen Reports were issued in early 2007 [LWO-SPT-2007-00050, SRNL-PSE-2007-00003, 28927-RT-00001].

An analysis of the offgas data collected from the Continuous Emissions Monitoring System and the EPA protocol grab samples during Tests CP1, CP2, and Tank 48H tests indicate that the production scale process will meet all applicable environmental discharge limits. These include the maximum achievable control technology (MACT) and anticipated air permit limits for metals, hydrogen chloride/chlorine gas, particulate matter, dioxins, furans, volatile organic compounds, semivolatile organic compounds, total hydrocarbons, and carbon monoxide, as well as the site discharge limits for nitric oxides and sulfur oxides. A summary of the emissions data from Tests CP1 and CP2 and Tank 48H testing is shown in Table 3.3.

3.2.2.5 Relevant Environment

The relevant environment of the OGTS for the FBSR System is treatment of Tank 48H FBSR offgas to meet all Federal, State, and local requirements. The operating requirements include the following:

- Control offgases in a radioactive environment.
- Maintain the offgas at levels required for regulatory purposes.
- No byproducts capable of generating toxic gases, vapors, or fumes in quantities harmful to people.
- Maintain the outlet gas temperature above the dew point.
- Retain radionuclides in the solid product.

3.2.2.6 Comparison of the Relevant Environment and the Demonstrated Environment

The OGTS was demonstrated in a relevant environment, but not with radioactive wastes. The offgas system was tested during the Tank 48H pilot scale production runs with non radioactive simulant. Nonradioactive offgases met all regulatory requirements. Offgases may be radioactive because of cesium in the waste. Cesium can become entrained in the offgas streams or be accidentally released if offgas components become plugged.

Table 3.3. Emission Data Summary for CP1 and CP2 Testing and Tank 48H Testing

Pollutant	Concentration (Corrected to 7% Oxygen)	Percent of MACT Limit	Results and Comments
Radioactive Surrogates (cesium, cerium [for plutonium])	Nondetectable	N/A	Removal efficiency >99.999% No HEPA filters in test system
Low Volatility Metals (arsenic, beryllium, chromium)	1–3 micrograms/dscm	~10%	Meets MACT Chromium removal efficiency >99.95% No beryllium in Tests CP1/2 or Test 48H simulants
Semivolatile Metals (cadmium, lead)	Tests CP1/2: <1 Test 48H: 5.1–5.5 micrograms/dscm	Tests CP1/2: <10% Test 48H: 53%	Meets MACT Lead removal efficiency >99.99% No cadmium in Tests CP1/2 simulant
Volatile Metals (mercury)	Tests CP1/2: 2–6 Test 48H: 1.9–2.6 micrograms/dscm	Tests CP1/2: 25–75% Test 48H: 23–33%	Meets MACT
Hydrogen chloride/chlorine gas	0.6–8 ppm	3 –33%	Meets MACT
Particulate Matter	Tests CP1/2: 0.3–2 Test 48H: 3.3–4.5 milligram/dscm	Tests CP1/2: 10–60% Test 48H: 97–132%	Meets MACT No HEPA filters in test system Tank 48H system will be compliant with HEPAs
Dioxins/furans	Nondetectable to 0.02 nanograms/dscm	<10%	Meets MACT
Polychlorinated Biphenyls	5–17 nanograms/dscm	N/A	Most polychlorinated biphenyl congeners not detected Dioxin-like coplanar polychlorinated biphenyls not detected
Volatile Organic Compounds (Principal organic hazardous constituent was MCB)	Tests CP1/2: Mostly nondetectable	<5%	Meets MACT No MCB detected MCB removal efficiency >99.998% Benzene removal efficiency 99.99% for Test 48H
Semivolatile Organic Compounds	Mostly nondetectable	N/A	Two semivolatile organic compounds detected, each only once near the detection limit
Nitrogen Oxide	Tests CP1/2: Typically <1000 Test 48H: Averaged <100 ppm	N/A	One CP1/2 run was ~2,600 ppm Nitrogen oxide destruction averaged ~98% for Tests CP1/2 Nitrogen oxide destruction averaged ~92% for Test 48H
Total Hydrocarbons	<1 ppm	<10%	Meets MACT
Carbon Monoxide	6–60 ppm	6–60%	Meets MACT
Sulfur Oxides	<60 ppm	N/A	One CP1/2 run was ~200 ppm

A comparison of the relevant environment and the demonstrated environment shows that extensive use of the OGTS at similar facilities is applicable to the final design configuration for Tank 48H. The OGTS for Hanford Site LAW and the IWTU is almost identical to the system in use in the Studsvik Processing Facility in Erwin, Tennessee, with the exception of use of a water spray cooler for Hanford Site LAW and the IWTU instead of the concentrating quencher/evaporator that is used at the Studsvik facility

The engineering-scale demonstration of pilot plant FBSR tests for sodium-bearing waste was conducted at Hazen to produce a carbonate product. The gaseous emissions from the process were found to be within regulatory limits. Based on the engineering-scale test demonstration, the detailed engineering design for a full-scale plant for treatment of DOE sodium-bearing waste at INL is being completed. DOE has approved CD-3A for a long-lead procurement items. The review of CD-3, *Start of Construction*, for the full-scale plant IWTU is scheduled in the fall of 2007.

Operating experience at Erwin, INL, and pilot testing with simulants to produce the carbonate product for Tank 48H validate the ability of standard technology to treat offgases to regulatory limits. However, lessons learned for the Studsvik facility [WM03 2003] stated that pilot-scale test programs on "similar" solutions have proved to be inadequate for the design of the offgas treatment system.

3.2.2.7 Technology Readiness Level Determination

The OGTS was determined to be TRL 4 because high-fidelity prototypes of all of the subsystems have been tested in a relevant environment, but not with actual waste. TRL 6 requires a pilot scale tests with simulants with laboratory scale tests, at a minimum, with actual wastes. Integrated, prototypical testing facilities exist at the pilot scale for Tank 48H using nonradioactive simulants. This equipment or smaller scale equipment could be used to verify the final design concept before completing the design of the actual full-scale system. A further test program is recommended, as described below, or as a part of integrated testing to address other technical issues.

Offgas systems can be very complex and expensive for some processes (e.g., up to 60% of the initial capital investment). Design of the offgas system must be closely linked to the chosen processing technologies and expected waste properties [IAEA-TECDOC-1527]. Additional laboratory or engineering-scale Tank 48H testing with radioactive tracers in the simulant is recommended to confirm that the gaseous emissions are compliant with regulatory limits, including MACT and other environmental standards. This includes overall regulatory acceptance by gathering environmental data for permitting the full-scale production facility, including an air permit (National Emission Standards for Hazardous Air Pollutants Permit from the EPA) and a construction permit. If radioactive testing is not conducted, then documentation should be prepared that crosswalks the radioactive contaminants expected in Tank 48H offgas with the relevant operational experience and removal efficiencies from similar facilities treating actual radioactive wastes.

3.2.3 FBSR Product Handling System

The product will be transferred back to the tank farms for subsequent treatment in the DWPF.

3.2.3.1 Function of the FBSR Product Handling System

The function of the Product Handling System is collection of solid carbonate product and transport to the Product Receiver/Cooler; transfer of the waste product from the Product Receiver/Cooler to the Product Mixing Tank; addition of water; mixing, lag storage, and transportation to a HLW tank. The Product Receiver/Cooler is installed at the solid product outlet of the DMR, HTF, and CRR.

3.2.3.2 Description of the Product Handling System

The Product Handling System includes auger, transfer lines, the Product Receiver/Cooler and equipment for subsequent treatment and transfer of the solid product from the Product Mixing Tank to tank farm. The Product Receiver/Cooler is a process vessel that receives product solids that are pneumatically transferred from the DMR, CRR, and HTF. The Product Receiver will provide residence time for the fine product solids to cool before draining to the Product Mixing Tank. The Product Receiver may be fitted with a nitrogen purge gas ring to assist in product cooling. The drain valve and Product Mixing Tank will be designed to contain solids with temperatures of up to 400°C. After confirming the product in the Product Mixing Tank has undergone sufficient cooling in the Product Receiver, process water is added to dissolve and slurry the product while a tank agitator provides the mixing ability. When slurrying and dissolution has been completed, the slurried product is transferred to Tank 51H. Periodic samples are taken from the Product Mixing Tank to confirm process operation.

3.2.3.3 Relationship to Other Systems

The relationship of the Product Handling System to other systems is as follows:

- Discharges from the DMR, HTF, and CRR are sent to the Product Receiver via the Product Handling System.
- Gases from the Product Receiver/Cooler are recycled to the DMR.
- The Product Receiver/Cooler interfaces with the Nitrogen System.
- The slurried product interfaces with the tank farm and waste acceptance criteria for DWPF.

3.2.3.4 Development History and Status

To date, there have not been any engineering-scale FBSR tests run for the Product Handling System (except for the DMR auger coupled with nitrogen operated pneumatic transfer line and Product Receiver at Hazen) with Tank 48H simulants. The engineering-scale test demonstration unit is equipped with a 15-inch-diameter fluidized bed, but the Product Handling System was manual and not prototypic of the Tank 48H flowsheet. Relevant prototypical laboratory scale tests on actual waste have not been conducted.

3.2.3.5 Relevant Environment

The Task Requirements and Criteria [G-TC-H-00046], the FBSR Performance Requirements [LWO-SPT-2007-00101], and the Jantzen study [WSRC-STI-2007-270S] identify key process variables for feed to the DWPF. WSRC Manual 1S: *SRS Waste Acceptance Criteria* [WSRC 2003] describes SRS Tank Farm waste acceptance criteria.

3.2.3.6 Comparison of the Relevant Environment and the Demonstrated Environment

The Product Handling System has not been tested in a relevant prototypical environment (except for the DMR auger and the Product/Receiver Cooler). As described earlier in this report, mineralizing flowsheets have been demonstrated using 6-inch and 15-inch reformers at Hazen and the STAR Center. Hazen and STAR tests used a manual product handling system. A full-scale facility is operating in Erwin, Tennessee that produces a dry waste form. The Studsvik facility uses automated product handling components. However, the Tank 48H flowsheet will dissolve the dry waste form from the DMR in a mixing tank, and the waste would then be sent to the SRS Tank Farm for eventual vitrification in the DWPF.

There are two issues with the product being sent to the tank farms from the FBSR System. The first is that the coal used for the DMR contains carbon and other elements that end up in the final product, and the DWPF has a sludge batch criteria for percent carbon and potentially other elements in the coal. An analysis of the DWPF flowsheet shows that the DMR output can be handled by the DWPF [28927-RT-0001] if Hazen adds a 12 mesh sieve to the product line. Jantzen [WSRC-TR-2003-00352] characterized the carbon in the DMR products as a percent of particle size. During these tests, Jantzen removed large particles (>100 mesh) and indicated that the resulting product will meet the DWPF WAC. However, tests are needed in addition to the Jantzen report [WSRC-STI-2007-270S] to indicate if the product with 12-100 mesh particles would meet the DWPF WAC. If the product does not meet the DWPF WAC, engineering “fixes” like wet sieving, bleeding in oxygen, or running at the highest DMR temperature to consume more coal could be implemented.

The <12 mesh coal may well be acceptable to DWPF. Tests to prove this should use new product that was made in runs that optimized coal consumption and used the beaters. If it is not acceptable, there is a need for tests of the engineering “fixes” on the DMR process to determine if the product with engineering fixes will meet DWPF WAC limits. The alternative is to determine whether the risk mitigation strategy of blending would allow the FBSR product to meet the DWPF WAC.

There also may be issues with the solids transfer line plugging from the Steam Reformer System to the Product Receiver/Cooler. Liquid waste transfer line plugging could result from incomplete dissolution of the DMR product in the Product Mixing Tank. Gels are not expected to be a problem as Jantzen left this material sit in water in the lab for several weeks and observed no gel formation. Waste chemistry should be verified to assure that the line would be capable of pumping slurried waste (liquid waste containing some solids) without plugging.

3.2.3.7 Technology Readiness Level Determination

The Product Handling System was determined to be TRL 3 because this is the first FBSR flowsheet with radioactive waste that dissolves the steam reformer dry product and transfers it to the tank farm and waste vitrification facility. No laboratory or pilot-scale tests have demonstrated all product handling steps using either simulated or actual waste. Since the sodium carbonate product for the FBSR will be dissolved and transferred back to the tank farm, testing must demonstrate that the dissolved product does not plug transfer lines and that it is compatible with tank farm requirements and DWPF WAC.

4 Summary of Needs

The TRL of each CTE was determined against a scale developed for this assessment that is consistent with the scales originally developed by NASA and the DoD. A TRL Calculator, described in Appendix B, was used to provide a structured, consistent assessment to determine the TRL of each identified CTE.

The TRL for each of the technologies evaluated, including subsystems, is presented in Table 4.1. This table presents the technology/subsystem, the TRL rating, the rationale for the TRL rating, and summary of the major technology development activities to mature the technology to support design implementation.

The list of testing and documentation needs required to reach TRL 6 for WAO and FBSR presented in Table 4.2 are provided for comparison purposes as an aid to DOE in selecting the preferred technology for Tank 48H waste treatment. However, this list must not be misunderstood. The Team is not recommending that all of the work must be done for both WAO and FBSR. The Team believes that sufficient information is available for DOE to select the preferred or primary technology. This conclusion is based on the Tank 48H test reports, related technical documents in the reference list, our understanding of additional test work that is needed, and substantial industrial experience with both technologies. Development of the primary technology should continue following the needs outlined below in Sections 4.1.1 and 4.2.1. Also, the Team believes it would be prudent to continue limited testing of the backup technology to the extent that resources will permit.

4.1 Wet Air Oxidation

4.1.1 Description of WAO Needs

The advancement degree of difficulty is a description of what is required to move a technology from the one TRL to another. Based on evaluation of reference documents, the Assessment Team's judgment, and the TRL responses in Appendix B, the technology testing requirements and documentation needed to advance WAO from TRL 2 to TRL 6 are listed below:

1. Conduct autoclave testing with actual Tank 48H waste in SRNL shielded cells.
   - Use similar equipment as used by Siemens in autoclave tests with simulant.
   - Verify optimum conditions defined in Siemens simulant tests.
   - Determine total organic content of treated waste.
   - Capture offgases for characterization when the autoclave is vented.

Table 4.1. Technology Readiness Level Conclusions for Critical Technology Elements

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology
Supplement Pretreatment Technologies			
Wet Air Oxidation **Wet Air Oxidation Reactor System** The function of the WAO Reactor System is to remove organic constituents from the feed slurry through oxidation.	**3**	The Wet Air Oxidation technology was determined to be TRL 3 because continuous testing has not been completed to support the proposed application at Tank 48H. The technology is commercially available, has had significant testing and development by the vendor for DOD, and has been operated at bench scale with simulants for potential application at SRS. It is considered that the technology could be rapidly matured to support design implementation.	Major activities to develop the WAO reactor technology include the following: • Provide a basis for technology development and testing requirements. • Complete prototypical testing with simulants and radioactive waste (if required) at the appropriate scale to support full-scale design implementation. • Prepare project documentation to achieve TRL 6.
Wet Air Oxidation **Offgas Treatment System (OGTS)** The function of the OGTS is to treat the reactor system offgas before release.	**2**	The OGTS is determined to be TRL 2 because testing is required to demonstrate the system's ability to capture and recycle particulates. This testing will provide assurance that a majority of the cesium-137 in the tank waste will be incorporated into the liquid waste stream.	Prototypical testing is needed to demonstrate operation of the dust capture and recycle function. Cross-technology effects are not completely understood. This testing will allow the process interfaces between components/subsystems in the OGTS to be more completely evaluated.
Wet Air Oxidation Technology Overall	**2**		

Table 4.1. Technology Readiness Level Conclusions for Critical Technology Elements (Continued)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology
Fluidized Bed Steam Reforming Technology **Steam Reformer System** The function of the Steam Reformer System is to (a) react the waste with chemicals and heat to evaporate the water, (b) reform the organics, (c) convert nitrates and nitrites into nitrogen gas, and (d) convert the inorganic constituents into a granular carbonate product.	**4**	The Reformer System was determined to be TRL 4 because high-fidelity prototypes of the subsystems have been tested with Tank 48H simulant waste. Also actual radioactive waste has been treated at the Studsvik Processing Facility for 7 years; and the design for the Idaho IWTU (a 48-inch DMR vessel) has been completed and fabrication is underway. However, no laboratory-scale testing has been conducted with actual Tank 48H waste. Furthermore, existing tests indicate that design modifications to the cyclone and DMR may be needed, and some sieving of the DMR product would be beneficial to recycle the fines back to the DMR as seed particles.	Integrated, prototypical testing of a pilot-scale FBSR Reformer System to verify the final design concept of the Reformer System before completing the design for the actual full-scale system. Follow up tests at Hazen should verify requirements avoiding plugging of the cyclone downcomer and for the separation of fine carbon particles for recycle back to the DMR Laboratory tests, at a minimum, with actual wastes should be conducted. These tests are planned but are on hold (SRNL-PSE-2007-000022). A laboratory test plan should be prepared. Engineering scale tests on the full range of simulants using a prototypical system should be completed (Tests are not completed for the 3 to 10 weight % solids range).

Table 4.1. Technology Readiness Level Conclusions for Critical Technology Elements (Continued)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology
Fluidized Bed Steam Reforming Technology **Offgas Treatment System (OGTS)** The function of the OGTS is to treat the process gases and entrained solids from the DMR. These gases are transported to the CRR vessel, where any carbon compounds are converted to carbon dioxide and water and the acid gases are neutralized. The process gases are then transported to the OGTS. The OGTS will reduce the temperature of the hot gas received from the CRR vessel and filter out any hazardous solids from the offgas before the offgas exits to air from the stack.	**4**	The OGTS was determined to be TRL 4 because high-fidelity prototypes of all of the subsystems have not been tested using Tank 48H simulated waste. Integrated, prototypical testing data to support confirmation of the OGTS design has been generated at the pilot scale for the INL IWTU and the Studsvik Processing Facility. The Tank 48H design would be adapted from these design concepts.	Final Technical Report on technology should be completed after additional laboratory scale testing (or greater scale) with radioactive tracer at a minimum. This should be part of the planned laboratory tests that are currently on hold [SRNL-PSE-2007-000022).

Table 4.1. Technology Readiness Level Conclusions for Critical Technology Elements (Continued)

Critical Technology Element and Description	Technology Readiness Level	Rationale	Required Project Activities to Mature Technology
Fluidized Bed Steam Reforming Technology **Product Handling System** The function of the Product-Handling System is to convert solid waste from the Steam Reformer System into a liquid feed suitable for the tank farm and DWPF.	**3**	The Product Handling System was determined to be a TRL 3. Transferring solids from dry storage containers to the "wet" atmosphere of the product mixing tank will be the key technical issue. Additional engineering-scale tests at the THOR Hazen facility may be needed to resolve issues of large particle size control in the DMR product (12-200 mesh).	Laboratory and engineering-scale testing and/or documentation is needed on the Product Handling System to: • Reduce the carbon in the DMR product if necessary • Test the mixing and transport processes for the DMR product. • Characterize the physical, chemical and rheological properties for the dissolved waste and water mixture. Prepare the conceptual facility design. Follow up tests at Hazen should verify requirements to avoid line plugging and for the separation of fine carbon particles for recycle back to the DMR.
Fluidized Bed Steam Reforming Technology Overall	**3**		

2. Conduct continuous, integrated system testing of the Tank 48H flowsheet at the Siemens pilot-scale facility. Some of the objectives of the pilot-scale tests include:

   - Determine organic destruction efficiency in continuous flow system.
   - Obtain improved characterization of properties of treated effluent from a continuous flow treatment system over time.
   - Propose and test methods for dealing with solid phase biphenyl.
   - Characterize offgas from a continuous flow treatment system. Confirm that offgas has negligible NOx, SOx, and particulates.
   - Determine the amount of dilution that would be required to treat the slurry in a continuous flow system. (Dilution may not be required.)
   - Determine if the copper concentration can be reduced to less than 500 mg/L and maintain acceptable effluent quality.
   - Determine whether cesium in the waste presents an off-gas problem. (Cesium can become entrained in the offgas streams or be accidentally released if offgas components become plugged.)
   - Determine material balances based on integrated pilot-scale testing.
   - Conduct longer term, 1,000-hour tests to confirm the materials of construction after the operating conditions have been confirmed. (Use of long-term autoclave tests may be required due to expense of long-term pilot-scale tests)
   - Allow process interfaces between components/subsystems to be more completely evaluated.
   - Start collection of actual maintainability, reliability, and supportability data and establish availability and reliability (RAMI) levels.
   - Determine off-normal operating responses.

3. Finalize the project documentation as shown below.

   - Technology Development Program Plan,
   - Final Technical Report on completed technology development,
   - Conceptual design report,

- Risk Management Plan,
- Configuration Management Plan,
- Draft high level design drawings for final plant system,
- Estimate cost of system design, and
- Establish acquisition program milestones for start of final design.

4.1.2 Assessment of WAO Advancement Degree of Difficulty

The advancement degree of difficulty can be quantified by cost of the testing and documentation efforts and by the time required to complete this work. Estimates of cost and duration for the WAO activities described in Section 4.1.1 are shown in Table 4.2. The cost estimate ranges from $4.5 to $9.0 million over a 24-36 month period. Development of more detailed scopes of work and specific test plans would be needed to obtain more accurate cost and schedule estimates.

Table 4.2. Advancement Degree of Difficulty for Technology Maturation of WAO and FBSR to TRL 6

Technology	**Testing/Documentation Needed**	**Cost , Dollars in Thousands(1)**	**Duration, Month(1)**
WAO	Autoclave testing with actual Tank 48 waste in SRNL shielded cells • Use similar equipment as used by Siemens in autoclave tests with simulant. • Use optimum conditions defined in Siemens tests. • Determine organic content of treated waste. • Capture offgases for characterization when the autoclave is vented.	$1,000 - $1,500	9 - 15
WAO (2)	Continuous, integrated system testing at the Siemens pilot-scale facility Phase I - • Determine organic destruction efficiency in continuous flow system. • Obtain improved characterization of properties of treated effluent from a continuous flow treatment system over time. • Propose and test methods for dealing with solid phase biphenyl. • Characterize offgas from a continuous flow treatment system. Confirm that offgas has negligible NOx, SOx, and particulates.	Phase I $2,000 – 3,000 (include $1,000 for simulant)	18 - 24

Table 4.2. Advancement Degree of Difficulty for Technology Maturation of WAO and FBSR to TRL 6 (Continued)

Technology	Testing/Documentation Needed	Cost , Dollars in Thousands(1)	Duration, Month(1)
WAO (Cont'd)	• Determine the amount of dilution that would be required to treat the slurry in a continuous flow system. (Dilution may not be required.) • Determine if the copper concentration can be reduced to less than 500 mg/L and maintain acceptable effluent quality. Phase II - • Determine whether cesium in the waste presents an off-gas problem. (Cesium can become entrained in the offgas streams or be accidentally released if offgas components become plugged.) • Determine material balances based on integrated pilot-scale testing (including offgas system). • Conduct longer term, 1,000-hour MOC tests to confirm the materials of construction after the operating conditions have been confirmed. • Allow process interfaces between components/subsystems to be more completely evaluated. • Establish availability and reliability (RAMI) levels. • Start collection of actual maintainability, reliability, and supportability data. • Determine off-normal operating responses.	Phase II $500 – 2,500	
WAO	Project Documentation (CD-0 / CD-1); see Footnote 3. • Technology Development Program Plan, • Final Technical Report • Conceptual design report, • Risk Management Plan, • Configuration Management Plan, • Draft high level design drawings for final plant system, • Estimate cost of system design, and • Establish acquisition program milestones for start of final design.	$1,000 - $2,000	6 - 9
	WAO Total	**$4,500 - $9,000**	**24 - 36**
FBSR	Laboratory-scale crucible tests with actual Tank 48 waste • Confirm performance of simulants • Characterize gaseous emissions (DMR only) • Predict waste chemistries during mixing and transfer	$500 – $1,500	6 - 9

Table 4.2. Advancement Degree of Difficulty for Technology Maturation of WAO and FBSR to TRL 6 (Continued)

Technology	Testing/Documentation Needed	Cost , Dollars in Thousands(1)	Duration, Month(1)
FBSR	Bench-scale steam reforming tests with actual Tank 48 waste • Demonstrate performance including proposed design modifications with bench-scale fluidized bed reformer • Verify gaseous emissions are compliant with regulatory limits	$1,500 - $2,000	12 - 15
FBSR	Additional engineering-scale tests at THOR Hazen facility • Resolving issues with the plugging of the cyclone downcomer. • Produce a waste product that meets the waste acceptance criteria for DWPF. • Reduce the carbon in the waste to DWPF if necessary. • Demonstrate waste chemistries will not result in inadequate mixing or line plugging in Product Handling System.	$1,150 – 2,750 (includes $500 for simulant)	6 - 12
FBSR	Integrated testing of Product Handling System • Demonstrate transfer of solids without plugging and erosion of piping • Demonstrate sieving and mechanism for return of sieved material back to DMR • Conduct laboratory tests to determine chemical and physical properties of dissolved FBSR product • Resolve potential DWPF WAC issue of excess carbon in FBSR product	$1,000 - $1,500	6 - 12
FBSR	Project Documentation (CD-0 / CD-1); see Footnote 3. • Technology Development Program Plan, • Final Technical Report • Conceptual design report, • Risk Management Plan, • Configuration Management Plan, • Draft high level design drawings for final plant system, • Estimate cost of system design, and • Establish acquisition program milestones for start of final design.	$40 - 100	1 - 2
	FBSR Total	**$4,190 – 7,850**	**13 - 17**

Notes: (1) Cost estimates and schedule information were provided by WSRC. To the extent possible, the data were validated by the Team as reasonable ranges based on a consistent set of assumptions. The costs are Rough Order of Magnitude (ROM) estimates and provide a basis for comparison of the technologies. They should not be used for budgetary purposes. All durations assume adequate funding and no delay for approval to proceed.

(2) This testing will need to be conducted in multiple phases. Results of the first phase (flow through WAO) will characterize off-gas and output properties. This information will feed any additional treatment requirements and subsequent testing. Cost of preliminary design is not included. Total preliminary design costs could be as high as $7 – 10 million including all project costs (subcontractors, design reviews, etc.).

(3) Ready to start final design corresponds with CD-2, completion of preliminary design.

4.2 Fluidized Bed Steam Reforming

4.2.1 Description of FBSR Needs

The Steam Reformer System (TRL 4) and the OGTS (TRL 4) are at an advanced stage of technology development as a result of engineering-scale tests with Tank 48H simulants. The advanced stage of technology development for the majority of Steam Reformer equipment is also attributable to the commercial application of this technology at the Erwin, Tennessee facility and engineering-scale development of the technology for the Hanford LAW and the IWTU at the INL. The FBSR Product Handling System was determined to be immature (TRL 3) for Tank 48H due to lack of defined performance specifications and lack of laboratory, integrated pilot-scale or engineering-scale testing.

Technology testing requirements and documentation required to advance FBSR technology from TRL 3 to TRL 6 are listed below:

1. Laboratory-scale crucible tests with actual Tank 48H waste.

   - Confirm performance of simulants.

   - If feasible, characterize gaseous emissions.

   - Predict waste chemistries during mixing and transfer.

2. Bench-scale FBSR tests with actual Tank 48H waste following scope of work described in SRNL-PSE-2007-00022.

   - Demonstrate performance with bench-scale fluidized bed reformer.

   - If feasible, verify gaseous emissions are compliant with regulatory limits.

3. Additional engineering-scale tests at THOR Hazen facility.

   - Test the Waste Feed System under wider envelope of feed composition. The waste feed to FBSR is expected to vary from as high as 10 weight % insoluble solids to less than 1 weight %.

   - Test the feed transport system from feed tank to Denitration and Mineralization Reformer (DMR) including feed pump, flow measuring device, and any potential for line plugging.

   - Test the DMR Feed nozzle performance / potential of plugging.

   - Test the performance of cyclone / cyclone downcomer in DMR, including downcomer bridging / plugging. This will require engineering evaluation of new

DMR design (height) to ensure that it can be installed in 241-96H building with current requirements.

4. Integrated testing of Product Handling System.

- Key process variables/parameters must be fully identified for the Product Handling System. Follow up tests at Hazen should verify Product Handling System design requirements to avoid line plugging. One design requirement is moving solids through the system without eroding the pipes, which was an issue at the Studsvik facility. There is also some concern about mixing and plugging in tanks that might have high humidity in the head space. Plugging of transfer lines from the product mixing tank to the tank farms is less problematic, but it is costly and time consuming if plugs occur and must be removed. The draft conceptual design should be completed including the design requirements of the Product Handling System.

- Test the performance of dry / wet sieving mechanism for feeding of sieved material back into DMR and the mechanism to return large sieved material back into DMR.

- It must be determined whether there is too much carbon for the present DWPF WAC. Follow up tests at Hazen should verify the need for separation of large carbon particles (12-200 mesh) in the DMR product before transfer to the tank farms.

- Waste chemistries should be understood at the laboratory-scale with waste simulants to identify potential problems with corrosion, mixing, and/or transfer line plugging. The physical, chemical, and rheological properties for the dissolved waste and water mixture must be understood.

5. Finalize the project documentation as shown below:

- Technology Development Program Plan,
- Final Technical Report on completed technology development,
- Conceptual design report,
- Risk Management Plan,
- Configuration Management Plan,
- Draft high level design drawings for final plant system,
- Estimate cost of system design, and
- Establish acquisition program milestones for start of final design.

4.2.2 Assessment of FBSR Advancement Degree of Difficulty

The advancement degree of difficulty can be quantified by the cost of the testing and documentation efforts and by the time required to complete this work. Estimates of cost and duration for the FBSR activities described in Section 4.2.1 are shown in Table 4.2. The cost estimate ranges from $4.19 to $7.85 million over a 13-17 month period. Development of more detailed scopes of work and specific test plans would be needed to obtain more accurate cost and schedule estimates. FBSR cost is somewhat less than WAO, but the shorter schedule is the most significant difference in the advancement degree of difficulty for FBSR versus WAO.

5 Conclusions

5.1 Conclusions Regarding Technology Readiness

Based on its TRA evaluation of the WAO and FBSR technologies for treatment of Tank 48H waste, the Team concluded that both are viable technologies, but that of the two, FBSR has a higher overall degree of maturity. The maturity of reformer and off-gas systems was particularly important in this comparative evaluation.

The TRA methodology assigns a TRL to a technology based on the lowest TRL assigned to any CTE of that technology. Thus, the overall TRL for WAO is 2 and the TRL for FBSR is 3. This approach is logical - because the ultimate success of any technological process is likely to be paced by its weakest component - but it can be misleading in comparison of relative readiness of candidate systems. In this case, the FBSR Product Handling has had little or no test work and therefore received a low score for that CTE, and this substantially lowers the FBSR overall score. But both the FBSR Steam Reformer System and the FBSR Offgas System were assigned TRLs of 4.

The primary testing needs to advance the TRL for WAO are laboratory-scale actual waste testing and continuous pilot-scale operation using prototypical equipment. The pilot-scale development work could be conducted relatively quickly, but procuring a large quantity of Tank 48H simulant will take several months. The actual waste testing could take 9-15 months due to the time required to modify autoclave equipment for use in shielded cells. Product Handling for WAO is straightforward because it is a liquid stream, and no testing is anticipated.

For FBSR, the Product Handling System must be designed and integrated components should be tested at pilot-scale. The Team believes that transferring solids from dry storage containers to the “wet” atmosphere of the product dissolving tank will be the key technical issue. Additional engineering-scale tests at the THOR Hazen facility are needed to resolve a number of issues.

In summary, both FBSR and WAO appear to be viable technologies for treatment of Tank 48H legacy waste. FBSR has a higher degree of maturity than WAO, but additional technology development (summarized in Table 4.2) will be required for both technologies. However, the Assessment Team believes that sufficient information is available for DOE to select the preferred or primary technology. Limited testing of the backup technology should be conducted as a risk mitigation strategy.

5.2 Conclusions Regarding the TRA Process

The TRA process is a useful tool for assessing the developmental maturity of a technology being considered for implementation or the relative maturity of several candidate technologies. The process facilitates a structured and objective determination of a system’s readiness for implementation, along with identification of specific actions needed to reduce programmatic risk to an acceptable level prior to a final commitment and major investment in that system.

As with most decision analysis tools, the TRA's primary value is its capability to yield methodical and transparent diagnosis of technologically complex systems. The TRA process includes assignment of numerical scores, which are particularly useful for comparison of alternatives as well as for support of programmatic decisions regarding application of new technologies. However, the quantitative TRA scores are in fact translations of qualitative judgments on a wide variety of issues - therefore, they are more meaningful as relative measures than as absolute determinations of "go/no go" acceptability.

Furthermore, the Team notes that DOE-EM technology applications are in many respects different from DoD/NASA applications, and therefore the DoD/NASA TRL process requires some refinement before it can be considered fully suitable for DOE-EM use. The modifications incorporated in the process prior to this evaluation constitute an excellent start in this respect, but this assessment did reveal several areas in which further refinement will improve its use for DOE-EM applications. These are:

- Some questions in the TRL scoring process are ambiguous and need further clarification (or perhaps deletion) for application to EM projects.

- DOE technology development programs have not traditionally required some of the programmatic and project-oriented documents at early stages of the technology development programs that implicitly called for in the TRL questions. For example, to achieve TRL 2 (defined as "Technology concept and/or application formulated"), system development must include:
  - Requirements tracking system defined to manage requirements creep
  - Preliminary strategy to obtain TRL 6 developed (e.g., scope, schedule, cost)

  While such programmatic requirements could certainly be met, it is not clear that they should be considered prerequisite to TRL 2.

- A number of manufacturing questions that are pertinent for DoD and NASA hardware acquisitions do not apply well for DOE-EM projects like design-build waste treatment facilities. Such questions could be deleted or marked "(if applicable)".

- The TRLs have not been aligned with the Critical Decision points in DOE projects as required in DOE Order 413.3A. If the TRL assessments are to be used to assist DOE management in the project Critical Decisions, this alignment needs to be completed.

- For radioactive material processing applications, the practical difficulties and limitations of full scale or large scale testing using actual (i.e., radioactive) fluids or gases, needs to be taken into account. In some cases the cost, complexity and risk of such testing may outweigh its value.

Taking all of these factors into account, the Team strongly endorses continued refinement and application of the TRA process in DOE-EM decision making. For the Tank 48 TRA evaluation, however, conducted using the TRA process in its current form, the Team does not consider the TRL 6 (as traditionally invoked by DoD/NASA) as an essential indication of sufficient technology maturity to support selection and proceeding with one of the candidate Tank 48 waste processing technologies.

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Appendix A
Determination of the Critical Technology Elements

The working definition of critical technology elements (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) Project. 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.*

CTEs for these project elements are those that are essential to successful operation of the facility, are new, or are being applied in new or novel ways or in new environments. The Assessment Team identified the CTEs listed below.

- Wet Air Oxidation (WAO)
- Fluidized Bed Steam Reforming (FBSR)

The team determined the CTEs by assessing the potential CTEs against the two sets of questions presented in Table A.1. A CTE was determined if there is a positive response to at least one of the questions in each of the question sets. The specific responses to each of the questions for each potential CTE is provided in Tables A.1 and A.2.
The rationale for the selection of each of the technologies/systems as a CTE is summarized below.

<u>WAO Feed Receipt and Preparation System</u>

The WAO Feed Receipt and Preparation System was not a CTE. While it is essential for the flowsheet concept, the technology is not expected to operate in a new relevant environment that may be beyond its demonstrated capability.

This system must supply feed to the WAO from Tank 48H. The system does not include the services that the site would provide to pump and transfer services to get material to the WAO plant. The system does not include the high pressure pump and reactor injection system. It was assumed that once the feed is received by the WAO facility, additional feed preparation that is not part of the vendor package would not be required. The technology is not repackaged to address a new relevant environment. The safety questions surrounding storage of the waste from Tank 48H are assumed to be resolved (e.g. Tank 48H generates benzene when the waste is agitated).

Furthermore, dissolution and transfer of Tank 48H waste to the WAO facility should remove as much of the residual heel as possible. This performance requirement would be addressed as part of the tank retrieval system.

WAO Reactor System

The Wet Air Oxidation Reactor System is a CTE. This System includes the high pressure pump, the heat exchanger, the reactor, and the separator. Limitations in the understanding of the technology result in schedule and cost risks. While the system has been widely used, the system would need to be modified to address radioactive waste. The extent of these modifications has not been determined, and the design might be repackaged or

WAO Offgas System

The Wet Air Oxidation Offgas System is a CTE. The offgas system treats the waste gas that exits the separator. While offgases related to TBP destruction are known as a result of bench-scale testing, the issues of chemically created off gases have not been addressed. Limitation in understanding of offgas composition represents both a cost and schedule risk because the off gas system has not been designed. End-state requirements to meet state-issued permits are known. The technology is not new or novel, but it would be modified to meet Tank 48H requirements. Offgas components must operate in a radioactive environment. The specifications for the demonstrated facility have not been defined.

WAO Product Handling System

The product handling system is not a CTE. Product handling addresses systems to handle the liquid waste that exits the Separator. No additional treatment of liquid waste from the reactor is assumed. The burden of whether the waste meets tank farm specifications is part of the reactor system. The assumption is that the reactor would produce waste that is acceptable for transfer to the tank farms. Cost and schedule risk is minimal and the end-state of the technology is known. Product handling technology is not new or novel. The relevant environment is the standard tank farm operating envelope. The technology is well demonstrated.

FBSR Feed Receipt and Preparation System

The FBSR Feed Receipt and Preparation System was not a CTE. While it is essential for the flowsheet concept, the technology is not expected to operate in a new relevant environment that may be beyond its demonstrated capability.

The Feed System concentrates transfers feed to a feed batch vessel that continuously supplies waste to the Fluidized Bed Steam Reformer.

The Feed Receipt system is a mature, commercially operational technology similar to the system in use at the Studsvik Processing Facility in Erwin, Tennessee. The Erwin plant processes commercial nuclear plant power plant waste composed of ion exchange resins, plastics, cellulose, carbon, and oils. The plant has processed high salt content waste and high organic content resins. The plant has been in operation for over seven years and has processed over 200,000 ft3 of low-level waste.

FBSR Steam Reformer System

The Steam Reformer System was determined to be a CTE because (1) it is essential for the treatment flowsheet concept, (2) the concept design has not been fully demonstrated for Tank 48H applications; therefore, there are costs and schedule risks associated with the deployment technology, (3) the requirements for the waste form are not fully defined, and (4) the technology may need to be modified for the new environment based on the results of future testing.

Steam Reforming utilizes the Denitration Mineralization Reactor (DMR). The DMR, a fluidized bed system, uses superheated steam and reacting chemicals in its fluidized bed. When waste is brought into physical contact with the heat and chemicals in the fluidized bed, liquids are evaporated, organic materials in the waste are destroyed, nitrates and nitrites are converted to nitrogen gas, and the waste is immobilized into small particles (5–100 microns) within the fluidized bed. The offgas from the DMR is transported to the CRR, a fluidized bed system where any carbon compounds are converted to carbon dioxide and water.

FBSR Offgas System

The FBSR Offgas System was determined to be a CTE. The offgas from the CRR is filtered, and any mercury in the waste is removed by using a carbon-bed mercury absorption unit. At this point, the treated offgas is discharged through a stack. Acid gases are also neutralized.

Related information from the IWTU testing and operational experience at the Studsvik Processing Facility provides confidence that the design will work. However, offgas compositions will be different for Tank 48H than the pilot scale for INL's IWTU and the Studsvik Processing Facility. The offgas treatment flowsheet will be repackged to specifically address gaseous effluents for the Tank 48H waste.

FBSR Product Handling System

The FBSR Product Handling System was determined to be a CTE. The waste forms from the DMR and the CRR are transported to a product receiver, where the waste is allowed to cool before dissolution. The solids will be transferred from the product receiver to the mixing tank. The dry solid is mixed with solution in a mixing tank and transferred via transfer line to the tank farm. This complete system has not been demonstrated in the relevant environment required for Tank 48H waste.

Table A.1 Wet Air Oxidation Critical Technology Elements

System	Feed Receipt and Prep System	Reactor System (Pump through Separator)	Offgas System (Gas that exits the Separator))	Product Handling (Liquid waste that exits the Separator)
First Question Set				
1. Does the technology directly impact a functional requirement of the process or facility?	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	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	Y	Y	N
4. Are there uncertainties in the definition of the end state requirements for this technology?	Y	Y	Y	N
Second Question Set				
1. Is the technology (system) new or novel?	N	N	Y	N
2. Is the technology (system) modified?	N	Y	Y	N
3. Has the technology been repackaged so that a new relevant environment is realized?	N	Y	Y	N
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	Y	N

Table A.2 Fluidized Bed Steam Reforming Critical Technology Elements

System	Feed Receipt and Prep System (includes waste and additive feed)	Reactor System (Additive Feed Included)	Offgas System (R2 Cooler to the Stack)	Product Handling (Includes the Waste Form)
First Question Set				
1. Does the technology directly impact a functional requirement of the process or facility?	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	Y	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	Y	Y
4. Are there uncertainties in the definition of the end state requirements for this technology?	N	Y	N	Y
Second Question Set				
1. Is the technology (system) new or novel?	N	Y	N	Y
2. Is the technology (system) modified?	N	Y	N	Y
3. Has the technology been repackaged so that a new relevant environment is realized?	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?	N	Y	Y	Y

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 the 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 Waste Treatment and Immobilization Plant (WTP) Project Analytical Laboratory, Balance of Facilities, and Low-Activity Waste (LAW) 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 would 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 TRL 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. TRL 1 Questions for Critical Technical Element

T/P /M	Y /N	Criteria	Documentation
T		"Back of envelope" environment	
T		Physical laws and assumptions used in new technologies defined	
T		Paper studies confirm basic principles	
P		Initial scientific observations reported in journals/conference proceedings/technical reports.	
T		Basic scientific principles observed and understood.	
P		Know who cares about the technology, e.g., sponsor, money source	
T		Research hypothesis formulated	
T		Basic characterization data exists	
P		Know who would perform research and where it would be done	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table B.2. TRL 2 Questions for Critical Technical Elements

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

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table B.3. TRL 3 Questions for Critical Technical Elements

T/P /M	Y /N	Criteria	Documentation
T		Academic (basic science) environment	
P		Some key process requirements are identified	
T		Predictions of elements of technology capability validated by analytical studies	
P		The basic science has been validated at the laboratory scale	
T		Science known to extent that mathematical and/or computer models and simulations are possible	
P		Preliminary system performance characteristics and measures have been identified and estimated	
T		Predictions of elements of technology capability validated by Modeling and Simulation (M&S)	
M		No system components, just basic laboratory research equipment to verify physical principles	
T		Laboratory experiments verify feasibility of application	
T		Predictions of elements of technology capability validated by laboratory experiments	
P		Customer representative identified to work with development team	
P		Customer participates in requirements generation	
T		Key process parameters/variables have begun to be identified.	
M		Design techniques have been identified/developed	
T		Paper studies indicate that system components ought to work together	
P		Customer identifies transition window(s) of opportunity (When technology is needed)	
T		Performance metrics for the system are established (What must it do)	
P		Scaling studies have been started	
M		Current manufacturability concepts assessed	
M		Sources of key components for laboratory testing identified	
T		Scientific feasibility fully demonstrated	
T		Analysis of present state of the art shows that technology fills a need	
P		Risk areas identified in general terms	
P		Risk mitigation strategies identified	

Table B.3. TRL 3 Questions for Critical Technical Elements (Continued)

T/P /M	Y /N	Criteria	Documentation
P		Rudimentary best value analysis performed for operations	
T		Key physical and chemical properties have been characterized for a number of waste samples	
T		A simulant has been developed that approximates key waste properties	
T		Laboratory scale tests on a simulant have been completed	
T		Specific waste(s) and waste site(s) has (have) been defined	
T		The individual system components have been tested at the laboratory scale	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table B.4. TRL 4 Questions for Critical Technical Elements

T/P /M	Y /N	Criteria	Documentation
T		Key process variables/parameters have been fully identified.	
M		Laboratory components tested are surrogates for system components	
T		Individual components tested in laboratory/ or by supplier	
T		Subsystems composed of multiple components tested at lab scale using simulants	
T		Modeling & Simulation used to simulate some components and interfaces between components	
P		Overall system requirements for end user's application are known	
T		Overall system requirements for end user's application are documented	
P		System performance metrics measuring requirements have been established	
P		Laboratory testing requirements derived from system requirements are established	
M		Available components assembled into laboratory scale system	
T		Laboratory experiments with available components show that they work together (lab kludge)	
T		Analysis completed to establish component compatibility (Do components work together)	

Table B.4. TRL 4 Questions for Critical Technical Elements (Continued)

T/P /M	Y /N	Criteria	Documentation

T/P /M	Y /N	Criteria	Documentation
P		Science and Technology exit criteria established (S&T targets understood, documented, and agreed to by sponsor)	
T		Technology demonstrates basic functionality in simulated environment	
M		Scalable technology prototypes have been produced (Can components be made bigger than lab scale)	
P		Draft conceptual designs have been documented	
M		Equipment scaleup relationships are understood/accounted for in technology development program	
T		Controlled laboratory environment used in testing	
P		Initial cost drivers identified	
M		Integration studies have been started	
P		Formal risk management program initiated	
M		Key manufacturing processes for equipment systems identified	
P		Scaling documents and designs of technology have been completed	
M		Key manufacturing processes assessed in laboratory	
P/T		Functional process description developed. (Systems/subsystems identified)	
T		Low fidelity technology "system" integration and engineering completed in a lab environment	
M		Mitigation strategies identified to address manufacturability/producibility shortfalls	
T		Key physical and chemical properties have been characterized for a range of wastes	
T		A limited number of simulants have been developed that approximate the range of waste properties	
T		Laboratory scale tests on a limited range of simulants and real waste have been completed	
T		Process/parameter limits are being explored	
T		Test plan documents for prototypical lab scale tests completed	
P		Technology availability dates established	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table B.5. TRL 5 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Documentation
T		The relationships between major system and sub-system parameters are understood on a laboratory scale.	
T		Plant size components available for testing	
T		System interface requirements known (How would system be integrated into the plant?)	
P		Preliminary design engineering begins	
T		Requirements for technology verification established	
T		Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)	
M		Significant engineering and design changes	
M		Prototypes of equipment system components have been created (know how to make equipment)	
M		Tooling and machines demonstrated in lab for new manufacturing processes to make component	
T		High fidelity lab integration of system completed, ready for test in relevant environments	
M		Manufacturing techniques have been defined to the point where largest problems defined	
T		Lab scale similar system tested with range of simulants	
T		Fidelity of system mock-up improves from laboratory to benchscale testing	
M		Availability and reliability (RAMI) target levels identified	
M		Some special purpose components combined with available laboratory components for testing	
P		Three dimensional drawings and P&IDs for the prototypical engineering scale test facility have been prepared	
T		Laboratory environment for testing modified to approximate operational environment	
T		Component integration issues and requirements identified	
P		Detailed design drawings have been completed to support specification of engineering scale testing system	

Table B.5. TRL 5 Questions for Critical Technical Elements

T/P /M	Y /N	Criteria	Documentation
T		Requirements definition with performance thresholds and objectives established for final plant design	
P		Preliminary technology feasibility engineering report completed	
T		Integration of modules/functions demonstrated in a laboratory/bench scale environment	
T		Formal control of all components to be used in final prototypical test system	
P		Configuration management plan in place	
T		The range of all relevant physical and chemical properties has been determined (to the extent possible)	
T		Simulants have been developed that cover the full range of waste properties	
T		Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes	
T		Laboratory scale tests on the full range of simulants using a prototypical system have been completed	
T		Laboratory scale tests on a limited range of real wastes using a prototypical system have been completed	
T		Test results for simulants and real waste are consistent	
T		Laboratory to engineering scale scale-up issues are understood and resolved	
T		Limits for all process variables/parameters are being refined	
P		Test plan for prototypical lab scale tests executed – results validate design	
P		Test plan documents for prototypical engineering scale tests completed	
P		Risk management plan documented	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table B.6. TRL 6 Questions for Critical Technical Elements

T/P /M	Y /N	Criteria	Documentation
T		The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	
M		Availability and reliability (RAMI) levels established	
M		Frequent design changes occur	
P		Draft high level design drawings for final plant system are nearly complete	
T		Operating environment for final system known	
P		Collection of actual maintainability, reliability, and supportability data has been started	
P		Estimated cost of the system design is identified	
T		Operating limits for components determined (from design, safety and environmental compliance)	
P		Operational requirements document available	
P		Off-normal operating responses determined for engineering scale system	
T		System technical interfaces defined	
T		Component integration demonstrated at an engineering scale	
P		Scaling issues that remain are identified and understood. Supporting analysis is complete	
P		Analysis of project timing ensures technology would be available when required	
P		Have begun to establish an interface control process	
P		Acquisition program milestones established for start of final design (CD-2)	
M		Critical manufacturing processes prototyped	
M		Most pre-production hardware is available to support fabrication of the system	
T		Engineering feasibility fully demonstrated (e.g. would it work)	
M		Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	
P		Technology ”system” design specification complete and ready for detailed design	

Table B.6. TRL 6 Questions for Critical Technical Elements

T/P /M	Y /N	Criteria	Documentation
M		Components are functionally compatible with operational system	
T		Engineering scale system is high-fidelity functional prototype of operational system	
P		Formal configuration management program defined to control change process	
M		Integration demonstrations have been completed (e.g. construction of testing system)	
P		Final Technical Report on Technology completed	
M		Process and tooling are mature to support fabrication of components/system	
T		Engineering scale tests on the full range of simulants using a prototypical system have been completed	
T		Engineering to full scale scale-up issues are understood and resolved	
T		Laboratory and engineering scale experiments are consistent	
T		Limits for all process variables/parameters are defined	
T		Plan for engineering scale testing executed - results validate design	
M		Production demonstrations are complete (at least one time)	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Appendix C
Technology Readiness Level Summary for Tank 48H Critical Technology Elements

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 following systems were evaluated:

Wet Air Oxidation System (WAO)

- Table C.1. Technology Readiness Level 3 Summary for WAO Reactor System
- Table C.2. Technology Readiness Level 4 Summary for WAO Reactor System
- Table C.3. Technology Readiness Level 3 Summary for WAO Offgas Treatment System

Fluidized Bed Steam Reforming System (FBSR)

- Table C.4. Technology Readiness Level 5 Summary for FBSR Offgas Treatment System
- Table C.5. Technology Readiness Level 6 Summary for FBSR Offgas Treatment System
- Table C.6. Technology Readiness Level 5 Summary for the FBSR Steam Reformer System
- Table C.7. Technology Readiness Level 6 Summary for the FBSR Steam Reformer System
- Table C.8. Technology Readiness Level 4 Summary for FBSR Product Handling System

Table C.1. Technology Readiness Level 3 Summary for WAO Reactor System

T/P /M	Y /N	Criteria	Documentation
T	Y	Academic (basic science) environment	Systems are described Zimpro website. The Seimens.com website directs users to the Zimpro studies. Bench-scale test results are documented (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
P	Y	Some key process requirements are identified	FBSR Performance Requirements have been published that also apply to WAO (LWO-SPT-2007-00101).
T	Y	Predictions of elements of technology capability validated by analytical studies	Bench-scale test results are documented that validate the technology capability (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
P	Y	The basic science has been validated at the laboratory scale	Systems are described Zimpro website. The Seimens.com website directs users to the Zimpro studies. Bench-scale test results are documented (SRNL-CST-2006-00109, SRNL-CST-2007-0035, Siemens 03-09-2007)
T	Y	Science known to extent that mathematical and/or computer models and simulations are possible	The CRESP study refers to the existence a number of Zimpro proprietary models to predict WAO performance.
P	Y	Preliminary system performance characteristics and measures have been identified and estimated	Bench-scale tests show that WAO destroys TPB (<1 mg/L), 3PB, 2PB, 1PB, phenol (<10 mg/L) when operated for 3 hours at 300°C with Cu-catalyst; antifoam, 1:1 dilution with 2M NaOH. The Cu catalyst improves residual biphenyl destruction and lowers THC in the off-gas. The catalytic effect of Cu diminishes at Cu concentrations > 750 mg/L, less than 500 mg/L may be adequate (Siemens 03-09-2007).
T	Y	Predictions of elements of technology capability validated by Modeling and Simulation (M&S)	The CRESP study refers to the existence a number of Zimpro proprietary models to predict WAO performance.
M	Y	No system components, just basic laboratory research equipment to verify physical principles	Bench-scale test use a standard autoclave. Test results are documented that validate the technology capability (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	Y	Laboratory experiments verify feasibility of application	Bench-scale test results are documented that validate the technology capability (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	Y	Predictions of elements of technology capability validated by laboratory experiments	Predictions of the vendor were validated in the bench-scale tests (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
P	Y	Customer representative identified to work with development team	The customer is the DOE-SR HLW Program.
P	Y	Customer participates in requirements generation	FBSR Performance Requirements have been published (LWO-SPT-2007-00101). The customer participated in the process of developing these requirements.
T	Y	Key process parameters/variables have begun to be identified.	FBSR Performance Requirements have been published (LWO-SPT-2007-00101).

Table C.1. Technology Readiness Level 3 Summary for WAO Reactor System (Continued)

T/P /M	Y /N	Criteria	Documentation
M	Y	Design techniques have been identified/developed	Design techniques are described on the Siemens Website and 200 commercial units have been constructed.
T	Y	Paper studies indicate that system components ought to work together	Actual system operation of 200 commercial units
P	Y	Customer identifies transition window(s) of opportunity (When technology is needed)	The Liquid Waste Processing Plan (CBU-PIT-2006-00070) identifies when the technology is needed.
T	Y	Performance metrics for the system are established (What must it do)	FBSR Performance Requirements have been published (LWO-SPT-2007-00101).
P	Y	Scaling studies have been started	Scaling issues are understood. The technology is easily scaled. During the TRA meeting at SRS (June 13, 2007). Vendor representatives were comfortable with scale up of 1000:1 because reactor dynamics are well understood.
M	Y	Current manufacturability concepts assessed	The technology is commercially available. Current manufacturability is proven.
M	Y	Sources of key components for laboratory testing identified	Batch scale autoclave units were easily procured for bench-scale tests (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	Y	Scientific feasibility fully demonstrated	Scientific feasibility was validated in the bench-scale tests (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	Y	Analysis of present state of the art shows that technology fills a need	The CD-0 package was prepared and approved (LWO-SPT-2007-00101)
P	Y	Risk areas identified in general terms	The ITR and Systems Engineering evaluations identified risks. (ITR-T48-2006-001, G-ADS-H-00011, G-AES-H-00009)
P	Y	Risk mitigation strategies identified	The ITR and ITR Response Plan address risks.(ITR-T48-2006-001, SPD-07-060)
P	Y	Rudimentary best value analysis performed for operations	The Zimpro Report addresses the system cost (Siemens 03-09-2007).
T	Y	Key physical and chemical properties have been characterized for a number of waste samples	Samples of Tank 48H are pulled annually. Detailed characterization reports are available (CBU-PIT-2005-00036, CBU-PIT-2005-00066, CBU-PIT-2005-0049).
T	Y	A simulant has been developed that approximates key waste properties	A stimulant recipe has been document in report (SRT-LWP-2004-0042).
T	Y	Laboratory scale tests on a simulant have been completed	Batch scale autoclave units were used with simulants (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	Y	Specific waste(s) and waste site(s) has (have) been defined	The CD-0 package was prepared and approved (LWO-SPT-2007-00101)
T	Y	The individual system components have been tested at the laboratory scale	Batch scale autoclave units were used with simulants (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table C.2. Technology Readiness Level 4 Summary for WAO Reactor System

T/P /M	Y /N	Criteria	Documentation
T	Y	Key process variables/parameters have been fully identified.	Tradeoffs have been explored in some of the variables evaluated in the technology reports. Bench-scale tests show that WAO destroys TPB (<1 mg/L), 3PB, 2PB, 1PB, phenol (<10 mg/L) when operated for 3 hours at 300°C with Cu-catalyst; antifoam, 1:1 dilution with 2M NaOH. The Cu catalyst improves residual biphenyl destruction and lowers THC in the off-gas. The catalytic effect of Cu diminishes at Cu concentrations > 750 mg/L, less than 500 mg/L may be adequate (Siemens 03-09-2007).
M	Y	Laboratory components tested are surrogates for system components	SRS performed testing with the vendor using stimulant. The autoclave was a surrogate for the WAO reactor (Siemens 03-09-2007).
T	Y	Individual components tested in laboratory/ or by supplier	SRS tested individual components and conducted bench-scale testing with the vendor using stimulant (Siemens 03-09-2007).
T	N	Subsystems composed of multiple components tested at lab scale using simulants	The autoclave unit was not a subsystem of multiple components.
T	N	Modeling & Simulation used to simulate some components and interfaces between components	Modeling and simulation are not used, except to note the sizing requirements.
P	Y	Overall system requirements for end user's application are <u>known</u>	The technology requirement assumptions are documented in the FBSR Performance Requirements that also apply to WAO system (LWO-SPT-2007-00101).
T	Y	Overall system requirements for end user's application are <u>documented</u>	Overall system requirements are documented in the FBSR Performance Requirements that also apply to WAO system (LWO-SPT-2007-00101).
P	Y	System performance metrics measuring requirements have been established	Performance metrics for measuring the key elements of system performance are under stood (LWO-SPT-2007-00101).
P	Y	Laboratory testing requirements derived from system requirements are established	Tests for measuring the key elements of system performance were derived from the FBSR Performance Requirements, which apply to the WAO system (LWO-SPT-2007-00101).
M	Y	Available components assembled into laboratory scale system	Bench-scale test result validate the reactor technology capability (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	N	Laboratory experiments with available components show that they work together (lab kludge)	Actual system operation of 200 commercial units demonstrate that components work together, but bench-scale tests used the autoclave only and do not show that components work together.

Table C.2. Technology Readiness Level 4 Summary for WAO Reactor System (Continued)

T/P/M	Y/N	Criteria	Documentation
T	N	Analysis completed to establish component compatibility (Do components work together)	Actual system operation of 200 commercial units demonstrate that components work together, but bench-scale tests used the autoclave only and do not show that components work together.
P	N	Science and Technology exit criteria established (S&T targets understood, documented, and agreed to by sponsor)	The FBSR Performance Requirements, which apply to the WAO system, define some S&T performance targets (LWO-SPT-2007-00101). These were not adequate.
T	Y	Technology demonstrates basic functionality in simulated environment	Bench-scale tests validate the functionality of the reactor concept with simulants (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
M	Y	Scalable technology prototypes have been produced (Can components be made bigger than lab scale)	The technology is commercially available. Current manufacturability is proven. There are 200 commercial plants.
P	N	Draft conceptual designs have been documented	They don't have conceptual design yet.
M	Y	Equipment scaleup relationships are understood/accounted for in technology development program	Flowsheet is available; but it doesn't show details, Siemens report 11. Not an issue, experience vendor, if authorized to due pilot scale.
T	Y	Controlled laboratory environment used in testing	Bench-scale tests were conducted in a controlled laboratory environment (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
P	Y	Initial cost drivers identified	Initial cost drivers were identified in the Bench-Scale Test Program Final Report (Siemens 03-09-2007).
M	N	Integration studies have been started	The autoclave unit used for testing was not a subsystem of multiple components, so integrated studies could not be conducted.
P	N	Formal risk management program initiated	Formal risk management program has not been initiated.
M	Y	Key manufacturing processes for equipment systems identified	The technology is commercially available. Current manufacturability is proven. There are 200 commercial plants.
P	N	Scaling documents and designs of technology have been completed	They don't have conceptual design yet.
M	Y	Key manufacturing processes assessed in laboratory	The technology is commercially available. Current manufacturability is proven. There are 200 commercial plants.
P/T	Y	Functional process description developed (Systems/subsystems identified)	Functional process description were identified in the Bench-Scale Test Program Final Report (Siemens 03-09-2007).
T	N	Low fidelity technology "system" integration and engineering completed in a lab environment	The autoclave unit used for testing was not a subsystem of multiple components.
M	Y	Mitigation strategies identified to address manufacturability/ producibility shortfalls	Not applicable. There are no manufacturability/ producibility shortfalls.

Table C.2. Technology Readiness Level 4 Summary for WAO Reactor System (Continued)

T/P /M	Y /N	Criteria	Documentation
T	Y	Key physical and chemical properties have been characterized for a range of wastes	Not applicable. Siemens' contract was for Tank 48H only (Siemens 03-09-2007).
T	Y	A limited number of simulants have been developed that approximate the range of waste properties	Simulants have been developed that approximate the range of waste properties (CBU-PIT-2005-00046, CBU-PIT-2005-00066, CBU-PIT-2005-00049, SRT-LWP-2004-0042).
T	N	Laboratory scale tests on a limited range of simulants and real waste have been completed	Laboratory scale tests on real waste have not been completed.
T	Y	Process/parameter limits are being explored	Process parameters were evaluated in bench-scale tests. Bench-scale tests show that WAO destroys TPB (<1 mg/L), 3PB, 2PB, 1PB, phenol (<10 mg/L) when operated for 3 hours at 300°C with Cu-catalyst; antifoam, 1:1 dilution with 2M NaOH. The Cu catalyst improves residual biphenyl destruction and lowers THC in the off-gas. The catalytic effect of Cu diminishes at Cu concentrations > 750 mg/L, less than 500 mg/L may be adequate (Siemens 03-09-2007).
T	N	Test plan documents for prototypical lab scale tests completed	There are no test plan documents for a multi-component, high fidelity laboratory system.
P	N?	Technology availability dates established	Test plans do not document technology availability. However, past System Engineering Studies (G-AES-H-00009) developed schedules for processing alternatives.

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table C.3. Technology Readiness Level 3 Summary for WAO Offgas System

T/P /M	Y /N	Criteria	Documentation
T	Y	Academic (basic science) environment	Offgas systems are standard. Systems are described Zimpro website. The Seimens.com website directs users to the Zimpro studies. Bench-scale test results document offgas issues (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
P	Y	Some key process requirements are identified	FBSR Performance Requirements have been published that also apply to WAO (LWO-SPT-2007-00101).
T	Y	Predictions of elements of technology capability validated by analytical studies	Bench-scale test results are documented that validate the technology capability (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035). Offgas system capabilities are validated by industrial experience.
P	Y	The basic science has been validated at the laboratory scale	Systems are described Zimpro website. The Seimens.com website directs users to the Zimpro studies. Offgas system capabilities are validated by industrial experience.
T	Y	Science known to extent that mathematical and/or computer models and simulations are possible	The CRESP study refers to the existence a number of Zimpro proprietary models to predict WAO performance. Offgas system capabilities are validated by industrial experience.
P	N	Preliminary system performance characteristics and measures have been identified and estimated	Bench-scale tests show that WAO destroys TPB (<1 mg/L), (Siemens 03-09-2007). However, organics, e.g., benzene decomposition products from TPB and phenols have to be destroyed as well.
T	Y	Predictions of elements of technology capability validated by Modeling and Simulation (M&S)	The CRESP study refers to the existence a number of Zimpro proprietary models to predict WAO performance.
M	Y	No system components, just basic laboratory research equipment to verify physical principles	Bench-scale test use a standard autoclave. Test results are documented that validate the technology capability (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	Y	Laboratory experiments verify feasibility of application	Bench-scale test results are documented that validate the technology capability (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035).
T	Y	Predictions of elements of technology capability validated by laboratory experiments	Predictions of the vendor were validated in the bench-scale tests (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035). Offgas system capabilities are validated by industrial experience.
P	Y	Customer representative identified to work with development team	Customer is identified within the DOE-SR HLW Program and Tank 48H documents (ITR-T48-2006-001, CBU-PIT-2006-00070, SPD-07-060).
P	Y	Customer participates in requirements generation	The customer participated in the process of developing the Tank 48H PEP requirements.

Table C.3. Technology Readiness Level 3 Summary for WAO Offgas System (Continued)

T/P /M	Y /N	Criteria	Documentation
T	Y	Key process parameters/variables have begun to be identified.	FBSR Performance Requirements have been published (LWO-SPT-2007-00101).
M	Y	Design techniques have been identified/developed	Design techniques are described on the Siemans Website and 200 commercial units have been constructed. Offgas system capabilities are validated by industrial experience.
T	Y	Paper studies indicate that system components ought to work together	Actual system operation of 200 commercial units. Offgas system capabilities are validated by industrial experience.
P	Y	Customer identifies transition window(s) of opportunity (When technology is needed)	The Liquid Waste Processing Plan (CBU-PIT-2006-00070) identifies when the technology is needed.
T	Y	Performance metrics for the system are established (What must it do)	FBSR Performance Requirements have been published (LWO-SPT-2007-00101). Air permit requirements also provide performance metrics.
P	Y	Scaling studies have been started	Not applicable. Scaling issues are understood. Offgas system scaling methods are validated by industrial experience.
M	Y	Current manufacturability concepts assessed	The technology is commercially available. Current manufacturability is proven.
M	Y	Sources of key components for laboratory testing identified	The technology is commercially available. Current manufacturability is proven.
T	Y	Scientific feasibility fully demonstrated	The technology is commercially available. Current manufacturability and feasibility are proven.
T	Y	Analysis of present state of the art shows that technology fills a need	The CD-0 package was prepared and approved (LWO-SPT-2007-00101)
P	Y	Risk areas identified in general terms	The ITR and Systems Engineering evaluations identified risks (ITR-T48-2006-001, G-ADS-H-00011, G-ADS-H-00009)
P	N	Risk mitigation strategies identified	The ITR and ITR Response Plan address risks (ITR-T48-2006-001, SPD-07-060), but risk mitigation strategies are not identified.
P	N	Rudimentary best value analysis performed for operations	The Test Plan Summary Report addresses the estimated system cost (Siemens 03-09-2007), but it does not include off gas components.
T	N	Key physical and chemical properties have been characterized for a number of waste samples	Samples of Tank 48H are pulled annually. Detailed characterization reports are available (CBU-PIT-2005-00046, CBU-PIT-2005-00066, CBU-PIT-2005-00049). However, the feed to the offgas system is not fully known.
T	N	A simulant has been developed that approximates key waste properties	A simulant recipe has been document in report (SRT-LWP-2004-0042). However, simulants to approximate the offgas stream have not been developed.

Table C.3. Technology Readiness Level 3 Summary for WAO Offgas System (Continued)

T/P /M	Y /N	Criteria	Documentation
T	N	Laboratory scale tests on a simulant have been completed	Batch scale autoclave units were used with simulants (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035). However, simulants to approximate the offgas stream have not been developed, so tests did not evaluate offgas system performance.
T	Y	Specific waste(s) and waste site(s) has (have) been defined	The CD-0 package was prepared and approved (LWO-SPT-2007-00101)
T	Y	The individual system components have been tested at the laboratory scale	Batch scale autoclave units were used with simulants (Siemens 03-09-2007, SRNL-CST-2006-00109, SRNL-CST-2007-00035). However, simulants to approximate the offgas stream have not been developed, so tests did not evaluate offgas system performance.

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table C.4. Technology Readiness Level 5 Summary for FBSR Offgas Treatment System

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	The relationships between major system and sub-system parameters are understood on a laboratory scale.	The technology tradeoff issues have been identified in the production testing. Tradeoffs evaluated include product composition and carbon source (WSRC-TR-2003-00352, 28927-RT-00001).
Y	Plant-size components available for testing	Engineering-scale components exist at Hazen. However, actual SRS Tank 48H wastes have not been tested using a DMR. Plant-size components have been tested with SRS waste simulants.
Y	System interface requirements known (How would system be integrated into the plant?)	Pilot-scale testing of Tank 48H waste simulant was conducted at the Hazen Center. (28927-RT-00001)
N	Preliminary design engineering begins	The CD-1 package has been submitted (LWO-SPT-2006-00100), which describes the conceptual design.
Y	Requirements for technology verification established	The operating requirements are found in the TRAC (G-TC-H-00046). There are differences between SRS, the IWTU and Hanford Site designs. Coal and glycol are added to the Tank 48 H flowsheet.
Y	Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)	Pilot-scale testing of Hanford Site waste simulant was conducted at the Hazen Center (28927-RT-00001). Pilot-scale testing of Hanford Site waste simulant was conducted at the STAR Center. The test was conducted using a 15-cm-diameter reactor vessel. To remove particulates the pilot-scale facility was equipped with a cyclone separator and heated sintered metal filters. A thermal oxidizer was used to reduce gas species and destroy nitrogen oxide. A packed, activated carbon bed was employed to capture residual volatile species).
Y	Significant engineering and design changes	Design changes were identified during pilot testing (28927-RT-0000).
Y	Prototypes of equipment system components have been created (know how to make equipment)	Materials, process, design, and integration methods were employed to build the Erwin, Tennessee, facility and during pilot testing (28927-RT-0000).

Table C.4. Technology Readiness Level 5 Summary for FBSR Offgas Treatment System (Continued)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Tooling and machines demonstrated in laboratory for new manufacturing processes to make component	Materials, process, design, and integration methods were employed to build the Erwin, Tennessee, facility and during pilot testing (28927-RT-0000).
Y	High-fidelity laboratory integration of system completed, ready for test in relevant environments	Pilot-scale testing of Hanford Site waste simulant was conducted at the Hazen Center (28927-RT-00001). More laboratory testing with actual waste is needed to further develop the final design (INEEL/EXT-04-02492).
Y	Manufacturing techniques have been defined to the point where largest problems defined	A final technical report is available for bench to full-scale systems [INEEL/EXT-03-01118, 28927-RT-00001, and EPRI-2003 (International Low-Level Waste Conference and Exhibit Show, *Studsvik Processing Facility Update*, July 16-18, New Orleans, Louisiana)].
Y	Laboratory-scale similar system tested with range of simulants	Crucible and bench-scale tests have been conducted or SRS waste simulants (WSRC-TR-2003-00352, INEEL/EXT-03-01118). A range simulants has been tested to support SRS Tank 48H wastes (28927-RT-00001, INEEL/EXT-03-01118).
Y	Fidelity of system mock-up improves from laboratory- to bench-scale testing	Crucible and bench-scale tests have been conducted or SRS waste simulants (WSRC-TR-2003-00352, INEEL/EXT-03-01118). A range simulants has been tested to support SRS Tank 48H wastes (28927-RT-00001, INEEL/EXT-03-01118).
Y	Reliability, availability, maintainability index target levels identified	LWO-SPT-2007-00101 and G-TC-H-00046 reports on reliability, availability, and maintainability targets. A similar index analysis was completed for the IWTU facility that shows greater than 90% reliability (28266-21-002-00).
Y	Some special purpose components combined with available laboratory components for testing	Pilot-scale testing of waste simulant was conducted at the Hazen Center (28927-RT-00001).
Y	Three dimensional drawings and piping and instrumentation diagrams have been prepared	Pilot-scale testing of Tank 48H waste simulant was conducted at the Hazen Facility (28927-RT-00001).
Y	Laboratory environment for testing modified to approximate operational environment	Pilot-scale testing of Tank 48H waste simulant was conducted at the Hazen Facility (28927-RT-00001).
Y	Component integration issues and requirements identified	Pilot-scale testing of Tank 48H waste simulant was conducted at the Hazen Facility (28927-RT-00001).
Y	Detailed design drawings have been completed to support specification of pilot testing system	Pilot-scale testing of Tank 48H waste simulant was conducted at the Hazen Facility (28927-RT-00001).
Y	Requirements definition with performance thresholds and objectives established for final plant design	System performance requirements are contained in the TRAC (G-TC-H-00046) and FBSR Performance Requirements document (LWO-SPT-2007-00101),
Y	Preliminary technology feasibility engineering report completed	Pilot-scale testing of Tank 48H waste simulant was conducted at the Hazen Facility (28927-RT-00001).

Table C.4. Technology Readiness Level 5 Summary for FBSR Offgas Treatment System (Continued)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Integration of modules/functions demonstrated in a laboratory/bench scale environment	Pilot-scale testing of Tank 48H waste simulant was conducted at the Hazen Facility (28927-RT-00001). To remove particulates the pilot scale facility was equipped with a cyclone separator and heated sintered metal filters. A thermal oxidizer was used to reduce gas species and destroy nitrogen oxide. A packed activated carbon bed was employed to capture residual volatile species (28927-RT-00001).
Y	Formal control of all components to be used in first prototypical test system	A formal configuration management program is defined in the Hazen TTTNQA-1 quality assurance program used for all testing. This program was applied in 28927-RT-00001.
Y	Configuration management plan in place	A plan was in place for the Hazen Test Facility.
Y	The range of all relevant simulants have been developed	There is a suite of Tank 48H Characterization Reports for developing simulants. • CBU-PIT-2005-00046, Revision 1, J.L. Thomas, Tank 48H Radionuclide Characterization, Westinghouse Savannah River Company, 2006. • CBU-PIT-2005-00066, Revision 2, J.L. Thomas, Tank 48H Radionuclide Characterization, Westinghouse Savannah River Company, February 2006. • CBU-PIT-2005-00049, Revision 2, W.B. Dean, Tank 48H TBP Characterization, Westinghouse Savannah River Company, March 2006. • SRT-LWP-2004-0042, Revision 1, D.P. Lambert, Tank 48H Simulant Recipe Development and Documentation, Westinghouse Savannah River Company, June 2004.
N	Test has verified that the properties performance of the simulants matches the performance of the actual waste	The same simulant has been used since 2000. There is no actual waste testing to verify the performance of the simulants.
Y	Laboratory scale tests on full range of simulants using a prototypical system have been completed.	There is no comparison of simulant to actual waste.
Y	Laboratory scale tested on a limited range of actual wastes using a prototypical system	Pilot-scale testing of waste simulant was conducted at the Hazen Facility (28927-RT-00001).
N	Test results for simulants and real wastes are consistent	Laboratory tests with real wastes are planned but are on hold (SRNL-PSE-2007-000022).

N	Test results for simulants and real waste are consistent	Laboratory tests with real wastes are planned but are on hold (SRNL-PSE-2007-000022).

Table C.4. Technology Readiness Level 5 Summary for FBSR Offgas Treatment System (Continued)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Laboratory to engineering scale scale-up issues are understood and resolved	The process has been tested at pilot scale (28927-RT-00001) and smaller scale (INEEL/EXT-03-01118).
Y	Limits for all process variables/parameters are being refined	The process has been tested at pilot scale (28927-RT-00001) and smaller scale (INEEL/EXT-03-01118).
Y	Test plan for prototypical lab scale tests executed – results validate design	Laboratory tests with real wastes are planned but are on hold (SRNL-PSE-2007-000022). However results with waste simulants validate the design. Test plans are prepared
N	Test plan documents for prototypical engineering scale tests completed	Risk analysis report prepared (Y-RAR-H-00065) but no test plan has been prepared.
Y	Risk management plan documented	Risk analysis report prepared (Y-RAR-H-00065).

Table C.5. Technology Readiness Level 6 Summary for FBSR Offgas Treatment System

Y /N	Criteria	Documentation
Y	The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	The relationships between system and sub-system parameters are understood at engineering scale (28927-RT-00001).
Y	Availability and reliability (RAMI) levels established	The FBSR Performance Requirements Document (LWO-SPT-2007-00101) discusses availability. A THOR document was prepared on RAMI levels for Erwin, Tennessee Plant (EPRI-2003).
NA	Frequent design changes occur	Pilot test is prototypical system (28927-RT-00001).
N	Draft high level design drawings for final plant system are nearly complete	The draft design drawings for the final plant system are not completed for the system.
Y	Operating environment for final system known	The operating requirements are found in documents (LWO-SPT-2007-00101, G-TC-H-00046) and the conceptual design package (G-CDP-H-00019).
Y	Collection of actual maintainability, reliability, and supportability data has been started	A THOR document was prepared on RAMI levels (EPRI-2003) for Erwin Plant.
Y	Estimated cost of the system design is identified	The CD package (LWO-SPT-2006-00100) and task requirements document (G-TC-H-00046) includes the cost of the system.
Y	Operating limits for components determined (from design, safety and environmental compliance)	The CD package (LWO-SPT-2006-00100), G-CDP-H-00019, and TRAC document (G-TC-H-00046) includes the operating limits of the system. The pilot plant report for Hazen tests (28927-RT-00001) identifies how operating limits were determined.
Y	Operational requirements document available	Design basis planning data (CBU-PIT-2006-00048,) and TRAC document (G-TC-H-00046) includes the operating limits of the system.
Y	Off-normal operating responses determined for engineering scale system	NQA procedures for Hazen facility include off-normal response (Reference 28927-RT-00001). See Operating Instructions Alarm response OI 1.4 Rev 6.
Y	System technical interfaces defined	System interfaces were designed for an engineering-scale similar system tested with simulants as documented in the THOR report (28927-RT-00001)
Y	Component integration demonstrated at an engineering scale	Component integration for an engineering-scale similar system tested with simulants as documented in the THOR report (28927-RT-00001).
Y	Scaling issues that remain are identified and understood. Supporting analysis is complete	Scaling issues will be minimal. Hazen 15-inch DMR used for the production scale tests. Tank 48H will use a 20-inch DMR.
Y	Analysis of project timing ensures technology would be available when required	The Liquid Waste Disposition Plan addresses project timing (CBU-PIT-2006-00070).

Table C.5. Technology Readiness Level 6 Summary for FBSR Offgas Treatment System (Continued)

Y /N	Criteria	Documentation
Y	Have begun to establish an interface control process	An interface control process is identified in the conceptual design package for tank 48H treatment (G-CDP-H-00019) and the TRAC (G-TC-H-00046).
Y	Acquisition program milestones established for start of final design (CD-2)	Acquisition program milestones were established in the CD-1 package (LWO-SPT-2006-00100)
Y	Critical manufacturing processes prototyped	The Erwin, Tennessee system is operating successfully (EPRI 2003).
Y	Most pre-production hardware is available to support fabrication of the system	The Erwin, Tennessee system is operating successfully (EPRI 2003).
Y	Engineering feasibility fully demonstrated (e.g. would it work)	Engineering feasibility for an engineering-scale system tested with simulants was documented in the THOR report (28927-RT-00001).
Y	Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	The Erwin, Tennessee system is operating successfully (EPRI 2003).
Y	Technology "system" design specification complete and ready for detailed design	Design specifications found in *Task Requirements and Criteria*, G-TC-H-00046.
Y	Components are functionally compatible with operational system	Pilot scale tests on simulants using a prototypical system have been completed (28927-RT-00001).
Y	Engineering scale system is high-fidelity functional prototype of operational system	Pilot scale tests on simulants using a prototypical system have been completed (28927-RT-00001).
Y	Formal configuration management program defined to control change process	WSRC E7 Manual describes the configuration management program.
Y	Integration demonstrations have been completed (e.g. construction of testing system)	Component integration for an engineering-scale similar system tested with simulants as documented in the THOR report (28927-RT-00001).
N	Final Technical Report on Technology completed	Pilot-scale tests on simulants using a prototypical system have been completed and documented (28927-RT-00001) but a second round of engineering tests and laboratory-scale tests with actual wastes are not completed.
Y	Process and tooling are mature to support fabrication of components/system	The Erwin, Tennessee system is operating successfully (EPRI 2003).
N	Engineering scale tests on the full range of simulants using a prototypical system have been completed	Pilot scale tests on simulants using a prototypical system have been completed (28927-RT-00001) but a second round of engineering tests and laboratory-scale tests with actual wastes are not completed. .

Table C.5. Technology Readiness Level 6 Summary for FBSR Offgas Treatment System (Continued)

Y /N	Criteria	Documentation
Y	Engineering to full scale scale-up issues are understood and resolved	Crucible and bench-scale tests have been conducted on SRS waste simulants (WSRC-TR-2003-00352, INEEL/EXT-03-01118). A range nonradioactive simulants have been tested to support SRS Tank 48H wastes (28927-RT-00001, INEEL/EXT-03-01118).
Y	Laboratory and engineering scale experiments are consistent	Crucible and bench-scale tests have been conducted on SRS waste simulants (WSRC-TR-2003-00352, INEEL/EXT-03-01118). A range of nonradioactive simulants has been tested to support SRS Tank 48H wastes (28927-RT-00001, INEEL/EXT-03-01118).
Y	Limits for all process variables/parameters are defined	Design specifications are found in *Task Requirements and Criteria*, G-TC-H-00046.
N	Plan for engineering scale testing executed - results validate design	Pilot scale test results partially validate design but a second round of engineering tests and laboratory-scale tests with actual wastes are not completed (28927-RT-00001).
Y	Production demonstrations are complete (at least one time)	The Erwin, Tennessee system is operating successfully (EPRI 2003).

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table C.6. Technology Readiness Level 5 Summary for FBSR Steam Reformer System

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	The relationship between major systems and subsystem parameters are understood on a laboratory scale.	The technology tradeoff issues have been identified in the Hazen testing (WSRC-TR-2003-00352, 28927-RT-00001).
Y	Plant-size components available for testing	The Erwin, Tennessee system is operating successfully. Engineering-scale components exist at Hazen (28927-RT-00001). Plant-size components have been tested with SRS waste simulants.
Y	System interface requirements known (how would system be integrated into the plant?)	System interfaces were identified for engineering-scale components at Hazen (28927-RT-00001).
N	Preliminary design engineering begins	Conceptual design includes preliminary design engineering (G-CDP-H-00019)
Y	Requirements for technology verification established	The operating requirements are found in 28927-RT-00001.
Y	Interfaces between components/subsystems in testing are realistic (bench-top with realistic interfaces)	System interfaces were identified for engineering-scale components at Hazen (28927-RT-00001).
Y	Significant engineering and design changes	Tests at Hazen result in recommended design changes (28927-RT-00001).
Y	Prototypes of equipment system components have been created (know how to make equipment)	System interfaces were identified for engineering-scale components at Hazen (28927-RT-00001). Materials, process, design, and integration methods were employed to build the Erwin, Tennessee, facility (EPRI-2003).
Y	Tooling and machines demonstrated in laboratory for new manufacturing processes to make component	Materials, process, design, and integration methods were employed to build the Erwin, Tennessee, facility and during pilot testing (28927-RT-00001).
Y	High-fidelity laboratory integration of system completed, ready for test in relevant environments	Pilot-scale testing was conducted at the Hazen Center (28927-RT-00001).
Y	Manufacturing techniques have been defined to the point where largest problems defined	Materials, process, design, and integration methods were employed to build the Erwin, Tennessee, facility and during pilot testing (28927-RT-0000).
Y	Laboratory-scale similar system tested with range of simulants	Crucible and bench-scale tests have been conducted on SRS waste simulants (WSRC-TR-2003-00352, INEEL/EXT-03-01118). A range simulants has been tested to support SRS Tank 48H wastes (28927-RT-00001, INEEL/EXT-03-01118).
Y	Fidelity of system mock-up improves from laboratory- to bench-scale testing	Pilot-scale testing was conducted at the Hazen Center (28927-RT-00001, INEEL/EXT-03-01118)
Y	Reliability, availability, maintainability index target levels identified	TRAC (G-TC-H-00046) and CD-1 Package (LWO-SPT-2007-00101) reports on reliability, availability, and maintainability targets.

Table C.6. Technology Readiness Level 5 Summary for FBSR Steam Reformer System (Continued)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Some special purpose components combined with available laboratory components for testing	Pilot-scale testing of waste simulant was conducted at the Hazen Center (28927-RT-00001). To remove particulates the pilot scale facility was equipped with a cyclone separator and heated sintered metal filters.
Y	Three dimensional drawings and piping and instrumentation diagrams have been prepared	Three dimensional drawings and piping and instrumentation diagrams have been prepared for pilot tests as part of Hazen Facility NQA Program (28927-RT-00001).
Y	Laboratory environment for testing modified to approximate operational environment	Pilot-scale testing of, Tank 48H waste simulant was conducted at the Hazen Center (28927-RT-00001).
Y	Component integration issues and requirements identified	Component integration issues have been identified (28927-RT-00001).
Y	Detailed design drawings have been completed to support specification of pilot testing system	A pilot testing facility exists at Hazen (28927-RT-00001).
Y	Requirements definition with performance thresholds and objectives established for final plant design	System performance requirements are contained in the TRAC and CD-1 Package (G-TC-H-00046, LWO-SPT-2007-00101).
Y	Preliminary technology feasibility engineering report completed	An engineering study was completed by THOR (28927-RT-00001).
Y	Integration of modules/functions demonstrated in a laboratory/bench scale environment	Pilot-scale testing of H Tank 48 H waste simulant was conducted at the Hazen Facility (28927-RT-00001). The test was conducted using a 15-cm-diameter reactor vessel.
Y	Formal control of all components to be used in first prototypical test system	A formal configuration management program is defined in the Hazen TTTNQA-1 quality assurance program used for all testing (28927-RT-00001). This program is described in Hazen reference.
Y	Configuration management plan in place	A plan is in place for the Hazen Test Facility (28927-RT-00001).

Table C.6. Technology Readiness Level 5 Summary for FBSR Steam Reformer System (Continued)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	The range of all relevant simulants have been developed	There is a suite of Tank 48H Characterization Reports with information for developing simulants. (CBU-PIT-2005-00046, CBU-PIT-2005-00066, CBU-PIT-2005-00049, SRT-LWP-2004-0042)
N	Test has verified that the properties performance of the simulants matches the performance of the actual waste	The same simulant has been used since 2000. There is no actual waste testing to verify the performance of the simulants. Simulant report (SRT-LWP-2004-00042)
N	Laboratory scale tests on full range of simulants using a prototypical system have been completed.	There has been a comparison of simulant to actual waste for off gas components. However, it may not be feasible to use real wastes for off gas tests.
N	Laboratory scale tested on a limited range of actual wastes using a prototypical system	Pilot-scale testing of waste simulant was conducted at the Hazen Facility (28927-RT-00001).
N	Test results for simulants and real wastes are consistent	Laboratory tests with real wastes are planned but are on hold (SRNL-PSE-2007-000022).
N	Test results for simulants and real waste are consistent	Laboratory tests with real wastes are planned but are on hold (SRNL-PSE-2007-000022).
Y	Laboratory to engineering scale scale-up issues are understood and resolved	The system was easily scaled from smaller scale (INEEL/EXT-03-01118) to pilot scale (28927-RT-00001).
Y	Limits for all process variables/parameters are being refined	Limits for all process variables/parameters are being refined at during the pilot scale tests (28927-RT-00001).
Y	Test plan for prototypical lab scale tests executed – results validate design	Laboratory tests with real wastes are planned but are on hold (SRNL-PSE-2007-000022). However results with waste simulants validate the design (28927-RT-00001). Test plans are prepared.
N	Test plan documents for prototypical engineering scale tests completed	Project documentation (Y-RAR-H-00065 and 28927-RT-00001) as part of NQA, but test plans not specifically developed.
Y	Risk management plan documented	Risk management plan was documented (NQA and Y-RAR-H-00065).

Table C.7. Technology Readiness Level 6 Summary for FBSR Steam Reformer System

Y /N	Criteria	Documentation
Y	The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	Tradeoffs understood at pilot scale (28927-RT-00001).
Y	Availability and reliability (RAMI) levels established	The FBSR Performance Requirements Document (LWO-SPT-2007-00101) discusses availability. A THOR document was prepared on RAMI levels (EPRI-2003)
NA	Frequent design changes occur	28927-RT-00001 test is prototypical system
N	Draft high level design drawings for final plant system are nearly complete	The draft design drawings for the final plant system are not completed for the system.
Y	Operating environment for final system known	The operating requirements are found in documents (LWO-SPT-2007-00101, G-TC-H-00046). The conceptual design package (G-CDP-H-00019).
Y	Collection of actual maintainability, reliability, and supportability data has been started	A THOR document was prepared on RAMI levels (EPRI-2003).
Y	Estimated cost of the system design is identified	The CD package (LWO-SPT-2006-00100) and task requirements document (G-TC-H-00046) includes the cost of the system.
Y	Operating limits for components determined (from design, safety and environmental compliance)	The CD-1 package (LWO-SPT-2006-00100), G-CDP-H-00019) and TRAC document (G-TC-H-00046) includes the operating limits of the system. The pilot plant report for Hazen tests (28927-RT-00001) identifies how operating limits were determined.
Y	Operational requirements document available	Design basis planning data (CBU-PIT-2006-00048), and TRAC document (G-TC-H-00046) includes the operating limits of the system.
Y	Off-normal operating responses determined for engineering scale system	NQA procedures for Hazen facility include off-normal response (28927-RT-00001).
Y	System technical interfaces defined	System interfaces were designed for an engineering-scale similar system tested with simulants as documented in the THOR report (28927-RT-00001).
Y	Component integration demonstrated at an engineering scale	Component integration for an engineering-scale similar system tested with simulants as documented in the THOR report (28927-RT-00001.
Y	Scaling issues that remain are identified and understood. Supporting analysis is complete	Scaling issues will be minimal. Hazen 15-inch DMR used for the production scale tests. Tank 48H will use a 21-inch DMR.
Y	Analysis of project timing ensures technology would be available when required	The Liquid Waste Disposition Plan addresses project timing (CBU-PIT-2006-00070).

Table C.7. Technology Readiness Level 6 Summary for FBSR Steam Reformer System (Continued)

Y /N	Criteria	Documentation
Y	Have begun to establish an interface control process	An interface control process is identified in the conceptual design package for Tank 48H treatment (G-CDP-H-00019) and the TRAC (G-TC-H-00046).
Y	Acquisition program milestones established for start of final design (CD-2)	Acquisition program milestones were established in the CD-1 package (LWO-SPT-2006-00100)
Y	Critical manufacturing processes prototyped	The Erwin, Tennessee system is operating successfully (EPRI 2003).
Y	Most pre-production hardware is available to support fabrication of the system	The Erwin, Tennessee system is operating successfully (EPRI 2003).
Y	Engineering feasibility fully demonstrated (e.g. would it work)	Engineering feasibility for an engineering-scale system tested with simulants was documented in the THOR report (28927-RT-00001).
Y	Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	The Erwin, Tennessee system is operating successfully (EPRI 2003).
Y	Technology "system" design specification complete and ready for detailed design	Design information found in G-TC-H-00046, *Task Requirements and Criteria.*
Y	Components are functionally compatible with operational system	Pilot-scale testing was conducted at the Hazen Center (28927-RT-00001).
Y	Engineering scale system is high-fidelity functional prototype of operational system	Pilot-scale testing was conducted at the Hazen Center (28927-RT-00001).
Y	Formal configuration management program defined to control change process	WSRC E7 Manual (WSRC 2003) describes the configuration management program.
Y	Integration demonstrations have been completed (e.g. construction of testing system)	Component integration for an engineering-scale similar system tested with simulants as documented in the THOR report (EPRI 2003).
N	Final Technical Report on Technology completed	This will be completed after additional production scale testing.
Y	Process and tooling are mature to support fabrication of components/system	The Erwin, Tennessee system is operating successfully (EPRI-2003).
N	Engineering scale tests on the full range of simulants using a prototypical system have been completed	Tests are not completed for the 3% to 10% range.

Table C.7. Technology Readiness Level 6 Summary for FBSR Steam Reformer System (Continued)

Y /N	Criteria	Documentation
Y	Engineering to full scale scale-up issues are understood and resolved	System operated at pilot scale (28927-RT-00001).
Y	Laboratory and engineering scale experiments are consistent	WSRC-TR-2003-00352 (crucible level), INEEL/EXT-03-01118 (6 inch) and 28927-RT-00001 (15 inch).
Y	Limits for all process variables/parameters are defined	The TRAC document defines operational limits (G-TC-H-00046).
N	Plan for engineering scale testing executed - results validate design	Follow up for engineering testing is planned. Follow up tests at Hazen will verify the separation of carbon in the DMR product.
Y	Production demonstrations are complete (at least one time)	The Erwin, Tennessee system is operating successfully (EPRI 2003).

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table C.8. TRL 4 Questions for FBSR Product Handling System

Y /N	Criteria	Documentation
N	Key process variables/parameters have been fully identified.	Key process variables/parameters found in G-TC-H-00046 (TRAC). FBSR Performance Requirements (LWO-SPT-2007-00101) and Jantzen study (WSRC-STI-2007-270S) identify key process variables. Hazen coal for FBSR product contains carbon and other elements from the coal. DWPF has a sludge batch criteria for percent carbon. Jantzen characterized the coal in the DMR products as a percent of particle size. During the Jantzen tests, there were some large particles (>100 mesh – there was almost nothing on the -100 to +200 mesh screen). Jantzen removed these particles by wet sieving and indicated that the resulting product will meet the WAC. Hazen plans to add a beater to the product line. (It is there for coal reuse as well as to remove it from the product.) What is not known is if there is an engineering solution to the removal of the excess coal. There may be a need for carbon removal to meet WAC limits (WSRC-STI-2007-270S). Even if there is too much carbon for the present WAC, there is a risk mitigation strategy of blending that would allow the plant to meet the WAC.
N	Laboratory components tested are surrogates for system components	Hazen tests did not have a complete Product Handling System, and little or no laboratory tests have been completed. Erwin facility proves automated product handling components. There may be issues with the line plugging due to moisture with Tank 48 H.
N	Individual components tested in laboratory/ or by supplier	Hazen tests did not have a complete Product Handling System, and little or no laboratory tests have been completed. Erwin facility proves automated product handling components. There may be issues with the line plugging due to moisture with Tank 48 H.
N	Subsystems composed of multiple components tested at lab scale using simulants	Hazen tests did not have a complete Product Handling System, and little or no laboratory tests have been completed. Erwin facility proves automated product handling components. There may be issues with the line plugging due to moisture with Tank 48 H.
N	Modeling & Simulation used to simulate some components and interfaces between components	No Modeling & Simulation studies have been conducted.
Y	Overall system requirements for end user's application are known	FBSR performance requirements (LWO-SPT-2007-00101) and DWPF WAC (X-SD-G-0004, Rev. 7)

Table C.8. TRL 4 Questions for FBSR Product Handling System (Continued)

T/P /M	Y /N	Criteria	Documentation
T	Y	Overall system requirements for end user's application are documented	Overall system requirements found in FBSR performance requirements document (LWO-SPT-2007-00101) and the DWPF (X-SD-G-0004)
P	Y	System performance metrics measuring requirements have been established	FBSR performance requirements (LWO-SPT-2007-00101) and the DWPF (X-SD-G-0004).
P	Y	Laboratory testing requirements derived from system requirements are established	LWO-SPT-2007-00050 establishes test targets including targets for carbon in the final DMR product. Transfer of solids might result in erosion of equipment or plugging of the transfer line. A laboratory test plan was not prepared. However, Hazen test report (28927-RT-00001) identifies system requirements.
M	N	Available components assembled into laboratory scale system	A laboratory test plan was not prepared.
T	N	Laboratory experiments with available components show that they work together (lab kludge)	A laboratory test plan was not prepared.
T	N	Analysis completed to establish component compatibility (Do components work together)	A laboratory test plan was not prepared.
P	N	Science and Technology exit criteria established (S&T targets understood, documented, and agreed to by sponsor)	A laboratory test plan was not prepared.
T	N	Technology demonstrates basic functionality in simulated environment	A laboratory test plan was not prepared.
M	N	Scalable technology prototypes have been produced (Can components be made bigger than lab scale)	No components have been produced.
P	N	Draft conceptual designs have been documented	Draft conceptual designs have not been documented.
M	N	Equipment scale-up relationships are understood/accounted for in technology development program	Scale-up relationships must account for plugging.
T	N	Controlled laboratory environment used in testing	A laboratory test plan was not prepared.
P	Y	Initial cost drivers identified	CD-1 provides an overall cost (LWO-SPT-2006-00100) for transfer of product to DWPF.
M	Y	Integration studies have been started	WSRC has conducted studies on waste blending (G-CDP-H-00019).
P	Y	Formal risk management program initiated	Formal risk management program documented inY-RAR-H-00065.
M	N	Key manufacturing processes for equipment systems identified	The system has not been designed.
P	N	Scaling documents and designs of technology have been completed	The system has not been designed.

Table C.8. TRL 4 Questions for FBSR Product Handling System (Continued)

T/P /M	Y /N	Criteria	Documentation
M	N	Key manufacturing processes assessed in laboratory	A laboratory test plan was not prepared.
P/T	Y	Functional process description developed. (Systems/subsystems identified)	G-CDP-H-00019 and LWO-SPT-2007-00101
T	N	Low fidelity technology "system" integration and engineering completed in a lab environment	The system has not been designed.
M	N	Mitigation strategies identified to address manufacturability/producibility shortfalls	The system has not been designed.
T	N	Key physical and chemical properties have been characterized for a range of wastes	DMR product has been characterized. Dissolution properties of the product have not been characterized.
T	Y	A limited number of simulants have been developed that approximate the range of waste properties	Product from the next round of Hazen Tests is testing with a wider range of simulants.
T	N	Laboratory scale tests on a limited range of simulants and real waste have been completed	A laboratory test plan was not prepared.
T	Y	Process/parameter limits are being explored	Limits explored in pilot tests (28927-RT-00001).
T	N	Test plan documents for prototypical lab scale tests completed	A laboratory test plan was not prepared.
P	Y	Technology availability dates established	DPP (CBU-PIT-2006-00070) and (LWO-SPT-2006-00100) establishes the technology availability date.

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Appendix D
Technology Readiness Assessment Meeting Attendees and Team Resumes

D.1 MEETING ATTENDEES

The Tank 48H Technology Readiness Assessment Meetings were held on June 13-14. The participants are listed by name and organization:

Harry Harmon, Team Lead, Pacific Northwest National Laboratory
Herbert Sutter, Team Member, Consultant to DOE-HQ
Joan Berkowitz, Team Member, Farkas Berkowitz & Company
Jack DeVine, Team Member, Polestar Applied Technology
Joan Young, Team Member, Pacific Northwest National Laboratory
Vickie Wheeler, DOE-SR
Patricia Suggs, DOE-SR
Dennis Conrad, WSRC
Charles Lampley, WSRC
Brett Cederdahl, BSRI
Kofi Adu-Wusu, WSRC/SRNL
Sam Shah, WSRC
Gene Daniel, WSRC/SRNL
Brad Mason (by telecommunication), THOR Treatment Technologies, LLC
Kevin Ryan (by telecommunication), THOR Treatment Technologies, LLC
Mark Clark (by telecommunication), Siemens Water Technologies Corporation
Bryan Kumfer (by telecommunication), Siemens Water Technologies Corporation

D.2 TECHNOLOGY READINESS ASSESSMENT TEAM RESUMES

The Team resumes are provided below.

HARRY D. HARMON

Education

B.S. Chemistry, Carson-Newman College
Ph.D. Inorganic and Nuclear Chemistry, University of Tennessee-Knoxville

Employer

Battelle, Pacific Northwest National Laboratory

Representative Skills and Experience

Dr. Harmon has over 33 years experience in nuclear materials processing and radioactive waste management. The last 15 years of his career focused primarily on high-level waste processing and related technology development activities. He worked for E. I. duPont and Westinghouse Savannah River Company at the Savannah River Site for 19 years and for over 3 years with Westinghouse Hanford Company as Vice President of the Tank Waste Remediation System. After four years in the private sector pursuing DOE contracts and consulting in radioactive waste management, Dr. Harmon joined Pacific Northwest National Laboratory as Technology Development Manager of the Salt Processing Program at the Savannah River Site. In this role, he is responsible for planning and managing the execution of the Salt Processing R&D program, involving work at five major DOE sites, several universities, and vendor sites. He also provides technical support to DOE-SR in their management of the Salt waste Processing Facility design and other related project activities.

Publications

Dr. Harmon has authored or co-authored over 45 journal articles, technical reports, and independent reviews in the fields of separations science, nuclear materials processing, and nuclear waste management.

Affiliations

American Chemical Society, Sigma Xi, and Southeast Environmental Management Association.

JOAN B. BERKOWITZ

Education

B.A. Chemistry, Swarthmore College
Ph.D. Physical Chemistry, University of Illinois – Urbana
Post-Doctoral Fellow, Physical Chemistry, Yale University
Senior Executive, MIT Sloan School

Employer

Farkas Berkowitz & Company

Representative Skills and Experience

Dr. Berkowitz has close to 50 years experience in consulting to government and industry on issues related to environmental technology and infrastructure. For the last 17 years, as Managing Director of Farkas Berkowitz & Company, she has focused on evaluation of waste treatment, disposal, and remediation technologies, and assessment of their market potential. She was a member of an independent oversight committee established by Westinghouse to review the environmental management systems at Department of Energy facilities where Westinghouse had operating contracts. She has served on several National Research Council committees to evaluate alternatives to incineration for the destruction of nerve agent wastes. Dr. Berkowitz worked for Arthur D. Little, Inc. for 30 years, becoming vice-president and manager of the firm's world-wide environmental practice. She left Arthur D. Little to take on the presidency of Risk Science International, a subsidiary of Frank B. Hall specializing in environmental due diligence for liability insurance and property acquisition. She is the recipient of the Achievement Award of the Society of Women Engineers for her pioneering contributions in the field of hazardous waste management. She is an adjunct professor in the University of Maryland University College's Graduate School of Management and Technology and recipient of the Drazek Award for excellence in teaching.

Publications

Dr. Berkowitz has authored or co-authored over 50 journal articles, technical reports, and independent reviews in the fields of high temperature chemistry, solid and hazardous waste management, and water pollution control.

Affiliations

American Chemical Society, Phi Beta Kappa, Sigma Xi, and The Electrochemical Society (past-president)

JOHN C. DEVINE, JR.

Education

B. S. Mathematics , U.S. Naval Academy

Employer

Polestar Applied Technology

Representative Skills and Experience

John C. DeVine Jr. (Jack) is co-founder, Principal and Chairman of the Board of Polestar Applied Technology, Inc., and he remains actively engaged in guiding the company's operations and growth. He is a well-known and widely respected leader in the nuclear power industry. Since Polestar's inception in 1992, Mr. DeVine has provided a wide range of professional services to private and public sector clients. His activities have included strategic and management consulting, ongoing periodic assessment of engineering and management effectiveness at several commercial U.S. nuclear stations and leadership of numerous independent assessment teams in support of DOE spent nuclear fuel management and facility deactivation and decommissioning work. As part of Polestar contract with Washington Group International (WGI), Mr. DeVine served as Chief Closure Officer at the Savannah River Site with overall executive responsibility for site closure activities conducted by several thousand WGI and partner employees and management of annual budgets in excess of one billion dollars.

Prior to forming Polestar, Mr. DeVine was with the General Public Utilities (GPU) system for 23 years. From 1970 through 1979, he held engineering and management positions involving design and construction of new nuclear plants and major plant modifications. He had a major role in the response and recovery from the March 1979 nuclear accident at the GPU Three Mile Island Unit 2, serving as part of the Emergency Response Team immediately following the accident, and in the following years as Recovery Engineering Manager and Technical Planning Director.

On special assignment to the Electric Power Research Institute (EPRI) in Palo Alto, California (1986 - 1989) Mr. DeVine was the U.S. Advanced Light Water Reactor (ALWR) Senior Program Manager, with responsibility for overall program direction, coordinating U.S. and international utility industry efforts in developing advanced reactor design concepts for the next generation. Subsequently, from 1989 through 1992, he served as the GPU Nuclear Corporation Vice President & Director - Technical Functions, with overall responsibility for all engineering work in support of the company's operating nuclear plants, and as a member of the GPU Nuclear Board of Directors. His work at GPU also included executive-level participation in utility industry activities, including Project Management Board of the Advanced Reactor Corporation, the EPRI Nuclear Power Division Advisory Committee, the Executive Board of the Edison Electric Institute (EEI) Utility Waste Management Group, and others. He also served as a commissioned officer aboard the fast attack nuclear submarine USS Sunfish (SSN-649).

HERBERT G. SUTTER

Education

A.B. Chemistry, Hamilton College
Ph.D. Physical Chemistry, Brown University
Post Doctoral Theoretical Chemistry, Cambridge University, UK

Employer

Consultant

Representative Skills and Experience

Dr. Sutter has more than twenty-seven years experience in the fields of separations science, high and low level radioactive waste treatment, waste water treatment, vitrification, and analytical chemistry. For the past thirteen years he has provided technical and programmatic support to DOE's Office of Environmental Management (EM). Dr. Sutter has provided technical assistance to the DOE programs at Hanford, Savannah River, and other sites in: (1) separation technologies; (2) technology development; (3) high level waste disposal; (4); nuclear waste characterization; (5) vitrification; and (6) analytical laboratory management.

From 2005 to present, Dr. Sutter assists EM in the development of a long-term, complex-wide Project Plan for Technology Development and Demonstration that will incorporate all EM's TDD needs through completion of the EM cleanup mission. In 2002-2004, he was a senior scientist for Kenneth T. Lang Associates, Inc. and provided support to EM in several areas including the evaluation of HLW vitrification technologies at Hanford and pretreatment and separation technologies at Savannah River. He has also been a consultant to private industry on separation technologies. In 1990-2002 as a scientist for Science Applications International Corporation supported EM in the areas of nuclear waste treatment and characterization and analytical chemistry. In 1982-1990, Dr. Sutter was Vice President and Chief Scientist at Duratek Corporation and responsible for technical direction of all Duratek research and development and commercialization programs in ion exchange, filtration and separation techniques. Relevant experience includes: waste water treatment, bench and pilot testing, and waste treatment studies.

Publications

Dr. Sutter has authored or co-authored over 30 journal articles and technical reports.

Affiliations

Member of the American Chemical Society and the American Nuclear Society.

JOAN K. YOUNG

Education

B.S. Chemical Engineering, South Dakota School of Mines and Technology
M.S. Engineering Management

Employer

Battelle, Pacific Northwest National Laboratory

Representative Skills and Experience

Joan Young has over 30 years experience in systems engineering and engineering management with significant NEPA and permitting experience. She recently conducted the Technology Readiness Level assessments at Hanford's Waste Treatment Plant for the critical LAB/BOF/LAW, HLW, and Pretreatment systems as identified in Bechtel System Description documents. The project identified approximately ten critical systems that needed additional testing at the prototypic scale before completing final designs. Joan applies a rigorous, standards-based process called CORE™ to provide functions and requirements definition and to develop technical specifications at the system, subsystem and component level. The CORE™ software was used in a recent project for Department of Homeland Security (DHS) facilities.

Joan has evaluated numerous waste treatment plant design alternatives (cost and resource requirements) for Hanford clients. One project calculated return on investment for the deployment of the Pit Viper.

Her NEPA and permitting experience included: reviews for coal conversion projects for private sector clients and California Energy Commission siting materials for proposed power plants projects.

Affiliations

President of Eastern Washington Section of Society of Women Engineers (SWE) and member of SWE national professional development committee. Past session leader and panelist at American Institute of Chemical Engineers Conferences.