LWO-SPT-2007-00249
Rev. 1

Technology Maturation Plan (TMP)

Fluidized Bed Steam Reforming (FBSR)

For Tank 48H Treatment Project (TTP)

November, 2007

DISCLAIMER

APPROVAL PAGE

Prepared By: 11-29-07
Satish (Sam) Shah **Date**
DA Engineer / TTP, LWO

Reviewed By: 11-28-07
William E. Daniel, Jr. **Date**
Technology Engineer, SRNL

Approved By: 11/28/07
Walter L. Isom, Jr. **Date**
Project Engineering Manager / TTP, LWO

Russell E. Eibling for Allan B. Barnes 11-28-07
Allan B. Barnes **Date**
Advanced Process Development Manager, SRNL

11-28-07
Jon R. Lunn **Date**
Project Manager / TTP, LWO

11/29/07
Charles G. Lampley **Date**
Project Owner / TTP, LWO

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ABBREVIATIONS AND ACCRONYMS

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
FY	Fiscal Year
Hazen	Hazen Research Facility
HEPA	High-Efficiency Particulate Air
HLW	High-Level Waste
HTF	High Temperature Filter
INL	Idaho National Laboratory
IWTU	Integrated Waste Treatment Unit
MACT	Maximum Achievable Control Technology
PBF	Process Baghouse Filter
PNNL	Pacific Northwest National Laboratory
PMT	Product Mixing Tank
PR	Product Receiver
R&D	Research and Development
SEE	System Engineering Evaluation
SRS	Savannah River Site
SRNL	Savannah River National Laboratory
SAIC	Science Applications International Corporation
STAR	Science and Technology Application Research [Center]
THOR®	THOR® Treatment Technologies LLC
TPB	Tetraphenylborate
TRA	Technical Readiness Assessment
TRL	Technology Readiness Level
TTP	Tank 48H Treatment Project
WAC	Waste Acceptance Criteria
WAO	Wet Air Oxidation
WSRC	Washington Savannah River Company

ACKNOWLEDGEMENTS

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1 INTRODUCTION

1.1 *Purpose of the Tank 48H Waste Treatment Project*

Tank 48H is a 1.3 million gallon Type IIIA tank, one of 49 tanks at the Savannah River Site (SRS) still containing High Level Waste (HLW). The tank has been isolated from the system and unavailable for use since 1983, because its contents – approximately 250,000 gallons of radioactive salt solution with significant quantities of organic tetraphenylborate (TPB), a material not compatible with the Tank Farm operation. It is therefore an important element of the U.S. Department of Energy-Savannah River Operations Office (DOE-SR) mission to remove, process and dispose of the contents of Tank 48H, both to eliminate the flammability hazard it presents to the SRS H-Tank Farm and return the tank to Tank Farm service to support ongoing HLW SRS processing and orderly tank closures.

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 treatment. Over the past year WSRC has been sponsoring and reviewing the results of testing of these two technologies to support DOE in making the final technology selection.

1.2 *Purpose of the Technology Maturation Plan*

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

- Activities and schedules to resolve the Fluidized Bed Steam Reforming (FBSR) technology maturity issues.
- Relationship of the Technology Readiness Assessments (TRA), The Consortium for Risk Evaluation with Stakeholder Participation (CRESP), and Independent Technical Review issues.
- Plan to manage the closure of the FBSR technology issues.

This plan was modeled after the Technology Maturation Plan for the Hanford Waste Treatment and Immobilization Plant.[1]

The proposed testing, costs and schedule are preliminary information based on the current maturity of this project and should only be used as general guidelines. This plan is a living document and will be reviewed to refine the testing, costs and schedule as the program develops.

[1] DOE/ORP-2007-02 – *Technology Maturation Plan for the Waste Treatment and Immobilization Plant*, Volume I, U.S. Department of Energy, Office of River Protection, August 2007.

2 TECHNOLOGY ASSESSMENTS OF THE TANK 48H WASTE TREATMENT PROCESSES

2.1 *Tank 48H Independent Technical Review*

On June 6th 2006, an Independent Technical Review (ITR) Team convened at the SRS to assess the technical viability of the current WSRC path forward for resolution of the long-standing problems posed by the TPB contamination in SRS HLW Tank 48H. The DOE-approved Charter outlined the objectives of the Tank 48 ITR, the requisite size and composite capabilities of the ITR Team, the methods to be employed, and the evaluation time frame. Included in the Charter were nine lines of inquiry, addressing specific issues to be addressed by the ITR Team[2]

In summary the ITR Team concluded the two TPB processing methods chosen by WSRC as lead candidates (FBSR and WAO) are technically sound, likely viable methods, and offer the best prospects for success among the approximately 80 alternatives considered.

However, the ITR Team also identified several areas in which the previous evaluations have not been sufficiently complete. As examples, heel management (removal of residual material and tank cleanup after removal of the bulk of the material currently in the tank), consideration of parallel-path options as outlined below, and understanding of the form, quantities, concentrations and implications of TPB processing by-products are all topics very important to success that received relatively superficial treatment in the alternative evaluations. These require further consideration, as delineated in the report.

The ITR Team concluded that Fluidized Bed Steam Reforming (FBSR) was the most mature of the candidates, particularly for radioactive material applications, considering the advanced design work for FBSR remote operations currently in-progress for treatment of sodium bearing tank wastes at Idaho National Laboratory. Its processing products can most likely meet SRS needs.

2.2 *CRESP Review of Alternatives for Treatment of Waste in SRS Tank 48H*

DOE requested that an independent review of the testing programs for FBSR and WAO in support of treatment of Tank 48H waste be conducted by CRESP under the leadership of Prof. David Kosson (Vanderbilt University and CRESP). The following presents their findings and recommendations resulting from review of the testing program in support of design of the FBSR process and WAO. Other findings and recommendations on schedule, compatibility of process with Building 241-96H, and safety evaluation are discussed in the CRESP report, but are less pertinent to the technology maturation of FBSR and WAO.[3]

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[2] ITR-T48-2006-001 - DeVine, J.C. et al., *Independent Technical Review (ITR) of the Path Forward for Savannah River Site (SRS) Tank 48*, Revision 0, August 2006.

[3] CRESP 2007 – Kosson, D.S., Case, J.T., Garrick, B.J., Mathis, J.F., Matthews, R.B., and Sandler, S., *Factual Accuracy Review (FAR)Report: CRESP Review of Alternatives for*

Specific to FBSR technology, the CRESP review found that extensive pilot-scale testing of FBSR was carried out at the Hazen test facility (Golden, Colorado). However, additional pilot-scale testing of FBSR was recommended to demonstrate (1) stable continuous operations at design conditions for periods long-enough to achieve steady-state (i.e., greater than one complete bed turnover), (2) reliability of key process components (i.e., injection nozzles and locations, filters), and (3) demonstrate reliable, physical separation and transfer system for the particulate product. It is estimated that approximately 6 - 12 months would be required to schedule and complete the required testing.

The CRESP review found that the compatibility of Tank 48H waste after FBSR treatment with downstream processing including anticipated DWPF waste acceptance criteria was evaluated in detail. In summary, the CRESP review concluded that SRS should aggressively go forward with both FBSR and WAO technologies in a manner that does not adversely impact overall programmatic schedule.

2.3 *Fluidized Bed Steam Reforming (FBSR) Technology Readiness Assessment*

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 SRS. DOE convened a team of independent qualified experts (the Assessment Team) to conduct this Technology Readiness Assessment (TRA).[4]

The methodology used for the TRA was based on detailed guidance for conducting TRAs contained in the Department of Defense (DoD), *Technology Readiness Assessment Deskbook*.[5] The assessment utilized a slightly modified version of the Technology Readiness Level (TRL) Calculator[6] originally developed by Nolte et al. to determine the TRL for the Critical Technology Elements (CTE). 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. The calculator 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 scale used in this assessment is shown in Table 1.

Treatment of Wastes in SRS Tank 48, Consortium for Risk Evaluation with Stakeholder Participation, July 2007.

[4] SPD-07-195 – Harmon, H.D., Berkowitz, J.B., DeVine, Jr., J.C., Sutter, H.G., and Young, J.K., *Savannah River Site Tank 48H Waste Treatment Project Technology Readiness Assessment*, July 31, 2007, U.S. Department of Energy, Savannah River Operations Office.

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

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

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

The TRA methodology assigns a TRL to a technology based on the lowest TRL assigned to any CTE of that technology. Specific to FBSR technology, the Assessment Team identified following the CTEs. Figure 1 identifies these CTEs with their assigned TRL.

- Fluidized Bed Steam Reformer System
- Offgas Treatment System
- Product Handling System

The component systems of FBSR technology, as applied for treatment of Tank 48H wastes, are based on significant technology development:

The Feed Receipt, Preparation, and Feed System was not determined to be a CTE, because that system is not new, novel, or repackaged.

The Fluidized Bed Steam Reformer System (TRL-4); and the Offgas Treatment System (TRL-4) was nearing maturity, and is attributed to 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 systems from achieving a TRL-5. Also, the Fluidized Bed Steam Reformer System requires further testing and development of the cyclone downcomer and other components.

However, the FBSR Product Handling System is less mature (TRL-3). The functionality and equipment requirements for the Product Handling System have not been defined. SRS Tank 48H will use a unique "dry to wet" product handling system. Small scale tests have been conducted that demonstrated FBSR sodium carbonate product easily dissolves at the same rate as published values[7],. 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 weight percent 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.

[7] LWO-PIT-2007-00013 – Maxwell, D., Jantzen, C.M., *Tank Selection for Fluidized Bed Steam Reformer (FBSR) Product Receipt*, Revision 1, July 23, 2007.

In conclusion, the TRA determined that both WAO and FBSR technologies appear to be viable. Of the two, FBSR is more mature. Neither technology meets the TRL 6 level usually considered by DoD and National Aeronautics and Space Administration to be prerequisite to final design, a lower technology readiness level score was considered by the Assessment Team to be an adequate basis for moving forward as the Tank 48H Waste Treatment Project is approaching Critical Decision (CD) 1 (*Approve Alternative Selection and Cost Range).*

Table 1

Technology Readiness Levels Used in Tank 48H TRA

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.

2.4 *Technology Heritage*

Fluidized Bed Steam Reformer System

FBSR has been used to treat highly radioactive waste. The FBSR at Studsvik Processing Facility (SPF), Erwin, Tennessee can process ion exchange resins, charcoal, graphite, sludge, oils, solvents, and cleaning solutions with contact radiation levels of up to 400 R per hour. 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 Idaho National Laboratory for about 20 years.

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 References[8, 9, 10, 11, and 12].

The Tank 48H CD-1 Package describes a sodium carbonate product that will be dissolved with water and transferred back to the tank farm[13]. The CD-1 package states that in 2003, Fluidized Bed 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

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[8] 28927-RT-00001 - *Pilot Plant Report For Treating Tank 48H Simulants Carbonate Flowsheet*, THOR® Treatment Technologies, Revision 0, June 2007.

[9] WSRC-TR-2003-00352, Revision 1, *Disposition of Tank 48H Organics by Fluidized Bed Steam Reforming (FBSR),* Washington Savannah River Company, March 24, 2004.

[10] 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

[11] 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.

[12] SRNL-PSE-2007-00003, Revision 0, Edwards, R., THOR® *Treatment Technologies Pilot Plant Report for Treating Tank 48H Simulants Carbonate Flowsheet*, January 2007.

[13] LWO-SPT-2006-00100 - Cederdahl, B. and Spires, R., *Critical Decision (CD) 1 Package, Tank 48 Treatment Process,* Washington Savannah River Company, Revision 3, September 2007.

Idaho Integrated Waste Treatment Unit (IWTU) [14]. 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 unit 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[8, 11, 12].

Engineering scale testing at the Hazen Research Facility[8] tested various reductant/energy sources for the denitration mineralization reformer (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 carbon reduction reformer (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 640 - 675ºC and CRR at 950ºC with simulant feed rates from 0.20 to 0.25 gallons per minute. 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 offgas 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-00046[15] defines the requirements for process design, installation, and operation of a modular full-scale FBSR System. The tanks and mixing apparatus for receiving and blending tank waste and coal are commercially available.

Offgas Treatment System

Pilot plant testing Idaho National Laboratory (INL) 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

[14] RT-ESTD-PMR-001 – *Pilot Plant Report for Treating Sodium Bearing Waste Surrogates Carbonate Flowsheet*, Revision 0.

[15] G-TC-H-00046 – Shah, S., *Task Requirements and Criteria, Tank 48 Disposition by Fluidized Bed Stream Reforming Project*, Washington Savannah River Company, Revision 3, July 2007.

during the period May 2006 through June 2006[14]. SRS Tank 48H testing was conducted for the DMR, CRR, Filtration System, and Offgas Treatment System later in 2006. The final Hazen reports were issued in early 2007.[9,12,13]

An analysis of the offgas data collected from the Continuous Emissions Monitoring System and the U.S. Environmental Protection Agency (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 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 is included in the test reports.

Product Handling System

The product handling system for Tank 48H FBSR will include transfer of product solids from DMR, HTF, PBF and CRR to a Product Receiver (PR). The solid product from PR is transferred to a Product Mixing Tank (PMT) and dissolved with water. The slurry is then transferred out to HLW tank receipt tank. The engineering-scale FBSR tests run with Tank 48H simulant slurry at Hazen Facility demonstrated transfer of solid products from DMR to PR for the Product Handling System (DMR auger coupled with nitrogen operated pneumatic transfer line) but the unit was not configured to demonstrate transfer of solid product from HTF, PBF and CRR to the PR, nor transfer and dissolution of solid product from PR into PMT. 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.

2.5 *Tank 48H Waste Treatment Project Activities and Technology Maturation*

WSRC had performed four System Engineering Evaluations (SEE) in FY-02, FY-04, FY-05, and FY-06 to identify technologies that could treat and/or disposition the waste in Tank 48H and return the tank to service. The most recent SEE [16] narrowed the selection of technology for Tank 48H disposition between two leading candidates, FBSR and WAO. After a number of independent reviews, DOE has selected FBSR as the primary or baseline technology and WAO will be developed as the backup technology.

The Tank 48H Treatment Process (TTP) project scope for the recommended alternative includes modifications to utilities, infrastructure, and waste transfer systems to support operation of the primary option, Fluidized Bed Steam Reformer technology in Building 241-96H. This Building is an operating SRS facility which currently houses the Actinide Removal Process in the south section shielded cells. The project is planning to locate the FBSR process in the north section of the building. Meanwhile WAO will be developed as the backup technology until ongoing technology development on FBSR has proven that all technical issues have been resolved.

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[16] G-ADS-H-00011 - Winship, G.C., *Liquid Waste Disposition Projects, Tank 48 Return to Service Systems Engineering Evaluation (SEE) Results Report*, Washington Savannah River Company, Revision 0, April 2006.

Technology risks identified by WSRC and independent reviews will be addressed in the Technology Maturation Plans for FBSR as described in Section 3.0. Technology performance risks also may emerge during the cold and hot commissioning phases of the Tank 48H Waste Treatment Project. These risks will be identified and mitigated during technology installation and acceptance, and cold and hot commissioning of the actual plant equipment systems.

2.6 *Management of Technology Maturity*

The Liquid Waste Organization (LWO) of WSRC and the Savannah River National Laboratory (SRNL) will provide management with oversight from DOE-SR Waste Disposition Programs Division, and DOE-Headquarters, Office of Environmental Management, (EM-20) Engineering and Technology. Management of technology maturity for FBSR will follow the guidance of this TMP and of detailed tests plans and test procedures that will follow. Detailed schedules will be prepared for each major activity in the TMP and the LWO will maintain schedule status based on weekly updates from SRNL and vendor(s) performing pilot-scale tests. Any changes in scope and schedule will require change control following established procedures.

3 TECHNOLOGY MATURATION PLAN

3.1 *Development of Technology Maturation Requirements*

Development of the maturation plan for the FBSR CTEs involved an assessment of the functions and critical design requirements of the Tank 48H Waste Treatment Project and a review of the project risk assessment. However, most of the risks were not technology-specific. Thus, the development of the maturation plan for the FBSR CTEs was based primarily on the recommendations from the three previous independent reviews discussed in Section 2.0, WSRC documents referenced in those reviews, and the requirements and criteria for achieving TRL 6 (see Appendix B). This approach ensured that:

- Maturation plans for the CTEs were developed using a systematic approach.
- Tank 48H FBSR project-specific and life-cycle schedule implications of maturing the CTEs were recognized.
- Opportunities for improving operational performance, reducing cost, or simplifying the system were considered.

3.2 *Life-Cycle Benefit*

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

- Methodical evaluation of all systems in the FBSR process to ensure identification of all technology maturation needs.
- Reduced overall project costs by resolving technology maturity issues and avoiding engineering re-work and potential delays in FBSR commissioning.
- Higher confidence that the FBSR design will achieve program mission operating requirements by the assessment of technology readiness and the completion of required technology maturation activities.

Technology maturation costs are small compared to impacts from design re-work and potential delays in the FBSR operating schedule. The TRA process is also designed to ensure that future performance issues associated with the technology systems are identified and resolved before operations.

3.3 *Specific Technology Maturation Plans*

3.3.1 Fluidized Bed Steam Reformer System

3.3.1.1 Key Technology Addressed

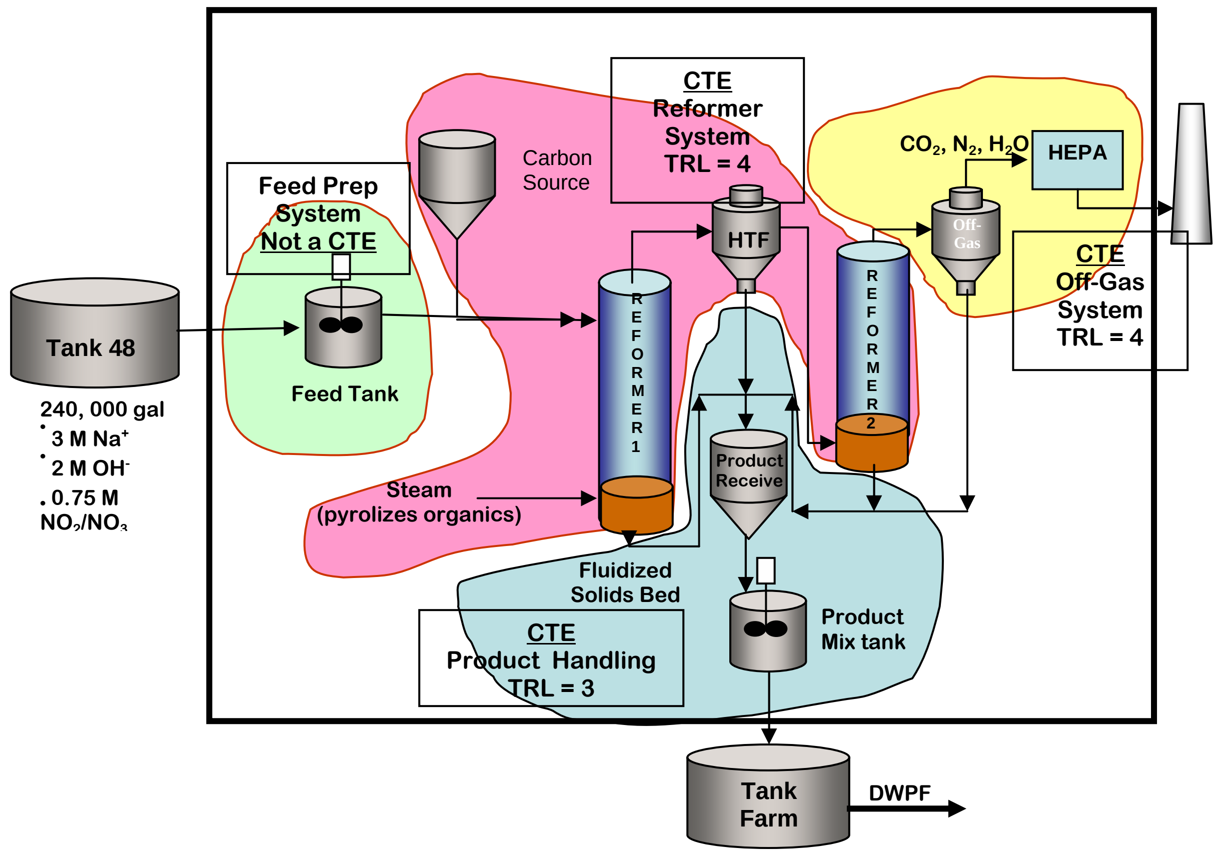
Destruction of organic compounds, nitrates, and nitrites, and conversion of inorganic constituents and radionuclides into a granular product.

3.3.1.2 Objective

This Fluidized Bed Steam Reformer System includes the Denitration Mineralization Reformer (DMR), High Temperature Filter (HTF), and Carbon Reduction Reformer (CRR) (see Figure 1). The function of the Fluidized Bed Steam Reformer System is to

(1) receive the waste from the Feed Receipt, Preparation, and Feeding System, (2) atomize the waste slurry into the fluidized bed, (3) react the waste with chemicals and heat to evaporate water in the waste, (4) reform organics to carbon dioxide, carbon monoxide, and hydrogen gas, (5) convert nitrates and nitrites into nitrogen gas, and (6) convert inorganic constituents (sodium and potassium) and radionuclides (e.g., sodium, potassium, radionuclides, chlorine, fluorine, sulfate) into a granular product.

Figure 1 - Tank 48H FBSR Flowsheet



The DMR is equipped with an internal cyclone at its offgas outlet. The function of the cyclone is to separate solids including fines in the offgas prior to leaving the DMR and return the solids to the DMR fluidized bed for reprocessing and use as "seeds" to grow the particle size. Offgas from the DMR then enters into the HTF. 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). The solids from the HTF are periodically removed to the PR.

3.3.1.3 Approach

The maturation approach for the Fluidized Bed Steam Reformer system is divided in two activities: (1) crucible-scale and bench-scale tests using Tank 48H actual waste at Savannah River National Laboratory (SRNL), and (2) engineering validation tests at the selected vendor test facility.

The SRNL crucible test includes design, fabrication and mock up test, followed by Tank 48H actual waste test in a shielded cell to demonstrate organic TPB destruction by FBSR technology. The SRNL bench-scale, continuous test includes design, fabrication and mock up test of reformers set up, prototypical to FBSR process. The initial bench-scale tests will be conducted with Tank 48H simulant slurry to validate the set up. This will be followed by Tank 48H actual waste test in a shielded cell to confirm the organic TPB destruction under FBSR continuous processing conditions. The bench scale also includes characterization of product that it meets the DWPF waste acceptance criteria, and characterization of offgas if feasible.

The tests at the selected vendor test facility will complete the remaining engineering-scale FBSR technology validations using Tank 48H simulant slurry as identified by the TRA report. This includes resolving issues with DMR cyclone downcomer plugging; demonstrate transfer of solid product without plugging and erosion of transfer line; reduction of carbon / coal in the final product by its reduced feed to DMR and/or sieving from product solids; demonstration of sieving carbon/coal large chunks from product and mechanism of sieved material back to DMR; and demonstrate no line plugging of Product Handling System due to inadequate mixing.

3.3.1.4 Scope

SRNL activity:

- Crucible Test: Design, fabricate and perform crucible test using actual waste.
- Bench-Scale Test: Design, fabricate and perform bench scale test with prototypical FBSR process set up using simulant slurry, and actual waste under FBSR processing conditions.

Additional engineering-scale tests:

- Statement of work, cost / schedule and Vendor selection,
- Incorporating modifications to Vendor's test unit,
- Procuring / preparation of Tank 48H simulant slurry,
- Performing tests,
- Evaluating results and issuing test report.

3.3.1.5 Current State of Art – TRL 4

The Fluidized Bed Steam Reformer System was determined to be TRL 4 as summarized below.

The FBSR laboratory and/or bench-scale testing using actual Tank 48 waste have not been conducted. High-fidelity engineering-scale testing has been conducted on the Fluidized Bed Steam Reformer System at the Hazen Research Facility on a mineralization and carbonate Flowsheet, similar to the one for Tank 48 application; an actual radioactive waste treatment facility using similar to the Hazen Facility FBSR configuration is in service for seven years at the Studsvik Processing Facility (SPF) Erwin, Tennessee; and the design of the DMR for the Idaho Site IWTU (a 48-inch DMR vessel), similar to the Hazen Facility configuration, 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. Additional engineering-scale validation tests are needed to refine the Tank 48H 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. TRL 6 would be achieved if laboratory or engineering-scale tests were conducted with actual Tank 48H wastes. See Table 2 for the required testing, schedule, and TRL changes for Fluidized Bed Steam Reformer System.

Table 2

Fluidized Bed Steam Reformer System

Year (**)	Milestones	Performance Target	TRL Achieved at Milestone[a]
3Q 2008	Laboratory-scale crucible tests with actual Tank 48H waste	• Confirm performance of simulants • Determine product chemistries during mixing and transfer	5
4Q 2008	Integrated Engineering-scale Validation tests by FBSR Vendor	• Demonstrate stable, continuous operations for greater than one complete bed turnover. • 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.	5
2Q 2009	Bench-scale, continuous fluidized bed steam reforming tests with actual Tank 48H waste	• Demonstrate performance including proposed design modifications with bench-scale, continuous fluidized bed reformer	6
3Q 2009	Design Documentation required for TRL-6 (***) • 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.	• Complete documentation during preliminary design.	6

[a]Major test activities required to reach the TRL are shown in this table. However, as presented in Appendix B, numerous other activities must be completed to fully satisfy the criteria for the TRLs listed above. It is assumed that the other activities can be completed by the dates shown in the first column above.
(**) Schedule is only an estimate based on current maturity of the project and should only be used as a guideline.
(***)During the maturation period Design documents will be revised and updated as the technology is achieved to higher TRL.

3.3.2 Fluidized Bed Steam Reforming Offgas Treatment System

3.3.2.1 Key Technology Addressed

Removal of volatile components, particulates, and radioactivity to meet air permit limits.

3.3.2.2 Objective

The function of the Offgas Treatment System 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.

3.3.2.3 Approach

The maturation approach for the FBSR Offgas Treatment System will be included in SRNL bench-scale, continuous test with Tank 48H actual waste if feasible (see Section 3.3.1.3).

3.3.2.4 Scope

The scope for maturation of this activity is included in SRNL bench-scale, continuous test with Tank 48H actual waste (see Section 3.3.1.4).

3.3.2.5 Current State of Art – TRL 4

The Offgas Treatment System was determined to be TRL 4 as summarized below.

The FBSR high-fidelity prototypes of all of the systems have been tested in a relevant environment on an engineering-scale Fluidized Bed Steam Reformer System at Hazen Research Facility, but not with actual Tank 48 waste. TRL 6 requires a pilot scale tests with simulants with laboratory scale tests, at a minimum, with actual wastes. The 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.[17] Additional laboratory or engineering-scale Tank 48H testing with radioactive tracers in the simulant was recommended by the TRA review to confirm that the gaseous emissions are compliant with regulatory limits, 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. See Table

[17] IAEA-TECDOC-1527 – *Application of Thermal Technologies for Processing of Radioactive Waste*. International Atomic Energy Agency, December 2006.

3 for the required testing, schedule, and TRL changes for FBSR Offgas Treatment System.

Table 3

Fluidized Bed Steam Reforming Offgas Treatment System

Year (**)	Milestones	Performance Target	TRL Achieved at Milestone[a]
2Q 2009	Bench-scale, continuous Fluidized Bed Steam Reforming tests with actual Tank 48H waste	• Characterization of offgas if feasible.	6
3Q 2009	Design Documentation required for TRL-6 (***). • 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.	• Complete documents during preliminary design.	6

[a]Major test activities required to reach the TRL are shown in this table. However, as presented in Appendix B, numerous other activities must be completed to fully satisfy the criteria for the TRLs listed above. It is assumed that the other activities can be completed by the dates shown in the first column above.
(**) Schedule is only an estimate based on current maturity of the project and should only be used as a guideline.
(***)During the maturation period Design documents will be revised and updated as the technology is achieved to higher TRL.

3.3.3 Fluidized Bed Steam Reforming Product Handling System

3.3.3.1 Key Technology Addressed

Collection of solid carbonate product, dissolution, and transfer to waste tank farm.

3.3.3.2 Objective

The function of the Product Handling System is collection of solid carbonate product and transport to the PR/Cooler; transfer of the waste product from the PR/Cooler to the PMT; addition of water; mixing, lag storage, and transportation to a HLW tank. The solid product from DMR, HTF and CRR is pneumatically transferred and collected in the PR/Cooler. The cooler solid product from PR is transferred into the PMT and dissolved with water prior to returning to a receipt tank in HLW Tank Farm.

3.3.3.3 Approach

The maturation approach for the FBSR Product Handling System is included in engineering validation test at the selected vendor facility using Tank 48H simulant slurry (see Section 3.3.1.3).

3.3.3.4 Scope

The scope for maturation of this activity is included in engineering validation test at the selected vendor facility using Tank 48H simulant slurry (see Section 3.3.1.3).

3.3.3.5 Current State of Art – TRL 3

The Product Handling System was determined to be TRL 3 as summarized below.

Tank 48 FBSR technology with soluble carbonate flowsheet will the first one for a radioactive waste application that dissolves the dry product and transfers it to the tank farm and waste vitrification facility. Neither laboratory nor FBSR high-fidelity engineering-scale testing at Hazen Research Facility included an integrated product handling system. TRL 6 requires a pilot scale tests with simulants with laboratory scale tests, at a minimum, with actual wastes. Since the sodium carbonate product for the FBSR will be dissolved and transferred back to the tank farm, testing needs to demonstrate that the dissolved product will not plug the transfer lines and that it is compatible with tank farm requirements and DWPF WAC. See Table 4 for the required testing, schedule, and TRL changes for FBSR Product Handling System.

Table 4

Fluidized Bed Steam Reforming Product Handling System

Year (**)	Milestones	Performance Target	TRL Achieved at Milestone[a]
4Q 2008	Integrated Engineering-scale Validation tests by FBSR Vendor including 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	5
2Q 2009	Bench-scale, continuous fluidized bed steam reforming tests with actual Tank 48H waste	• Conduct and determine handling performance including chemical and physical properties of solids and dissolved FBSR product from actual waste	6
3Q 2009	Design Documentation required for TRL-6. (***) • 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.	• Complete documents during preliminary design.	6

[a]Major test activities required to reach the TRL are shown in this table. However, as presented in Appendix B, numerous other activities must be completed to fully satisfy the criteria for the TRLs listed below
(**) Schedule is only an estimate based on current maturity of the project and should only be used as a guideline.
(***)During the maturation period Design documents will be revised and updated as the technology is achieved to higher TRL.

4 TECHNOLOGY MATURITY SCHEDULE

Figure 2 shows the DOE O 413.3[18] project management process, as applied to the Tank 48H Waste Treatment Project.

Figure 3 shows the technology maturation schedule for FBSR testing activities. The completion of the TMP activities to achieve TRL-6, including the bench-scale actual waste tests supports the current Tank 48H project milestone of CD-2/3 by May 2009. The Final Technical Report will be ready three months after CD-2 milestone date, The maturity schedule is based on completing (1) FBSR vendor contract award by March 31, 2008, and vendor submittal of initial FBSR process design data by April 30, 2008, to facilitate the SRNL to design, fabrication, and test a prototypical bench scale reformer unit, and (2) Tank 48H simulant slurry ready by March 31, 2008 for FBSR Vendor to perform integrated engineering-scale validation and product handling system tests, and Vendor completing Task 2 of the 'Statement of Work'[19] by October 7, 2008.

Figure 2 also shows the relationship of the Critical Decision (CD) process with major project activities (e.g., design construction, commissioning, and operations) and the maturity level of FBSR CTEs. The figure illustrates the TRLs for FBSR at CD-0 (approximate) and at CD-1 based on the TRA[4]. It is desirable to reach TRL-5 or 6 by CD-2 or early in final design.

Figure 3 schedule also includes a decision point after the completion of engineering-scale tests and the actual waste crucible tests. If these tests do not meet the performance targets and/or resolve the remaining FBSR technology issues, the recommended path is to revert to the backup technology, WAO.

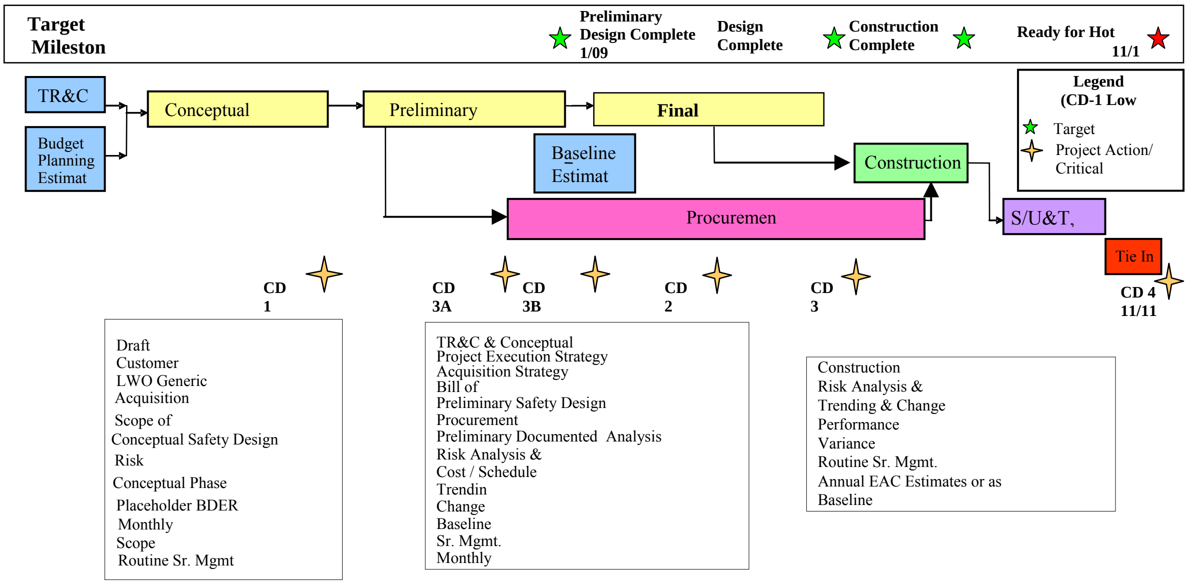
Figure 2 also shows the TRL status of the Wet Air Oxidation technology (WAO-backup technology) as the FBSR is progressing through the maturation plan.

The proposed testing, costs and schedule are preliminary information based on the current maturity of this project and should only be used as general guidelines. This plan is a living document and will be reviewed to refine the testing, costs and schedule as the program develops.

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

[19] M-SOW-H-00162- Wood M. B., et al., Statement of Work – Fluidized Bed Steam Reformer System, Washington Savannah River Company, Revision 2, August 27, 2007.

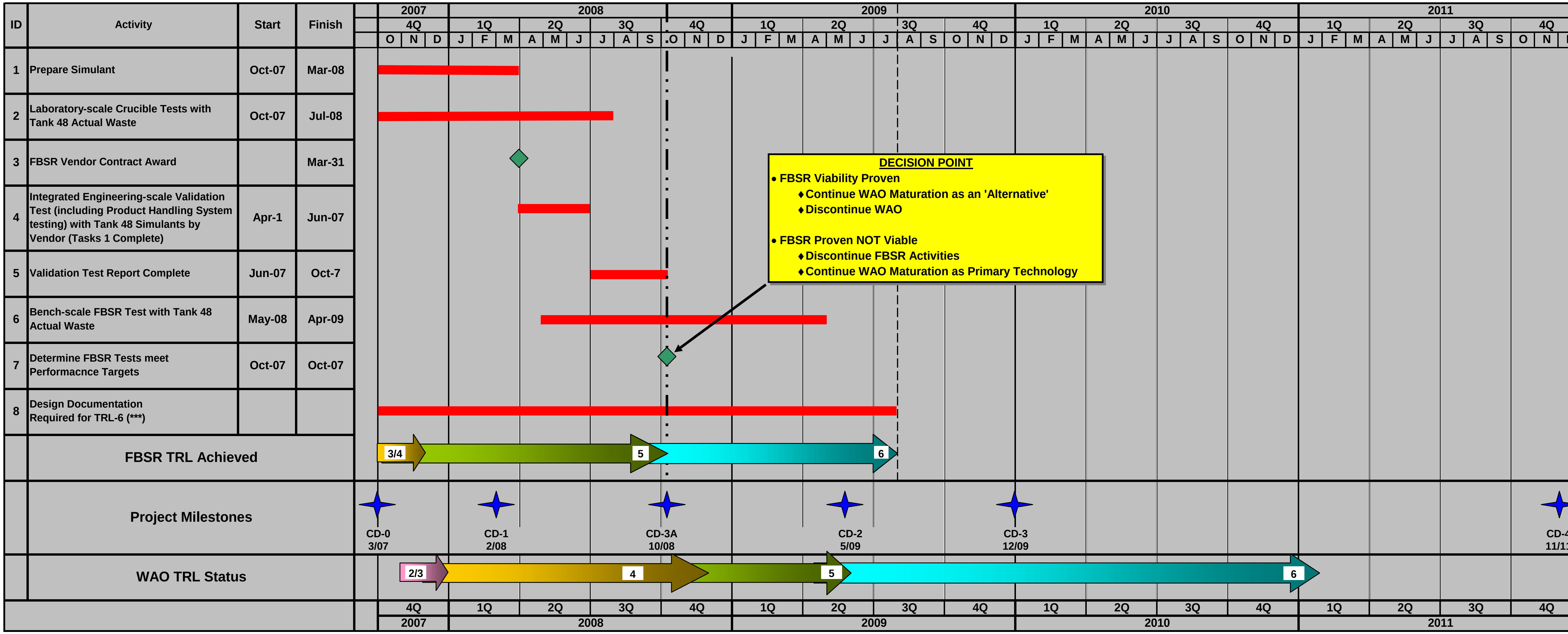
Figure 2 - Tank 48 Project Execution Strategy



Low & High Schedule Ranges (Low Shown Above)

	CD-1	CD-2	CD-3	CD-4
Low BDER	**2/08**	**5/09**	**12/09**	**11/11**
High BDER	**2/08**	**8/09**	**03/10**	**08/12**

Figure 3 - FBSR Technology Maturity Schedule to Achieve TRL-6



(***)During the maturation period Design documents will be revised and updated as the technology is achieved to higher TRL.

5 TECHNOLOGY MATURITY COST

The technology maturity budget for the activities described in this TMP is shown below for FBSR. This funding must be available in early FY-08 to achieve the technology maturity schedule shown in Section 4.0 above.

Table 5

<u>Technology Maturity Budget for FBSR</u>

Required Testing	**Technology Development Cost ($K) (**)**
Prepare Tank 48H simulant (5,000 gallons)	$850
Laboratory-scale crucible tests with actual Tank 48H waste	$750
Bench-scale steam reforming tests with actual Tank 48H waste	$1,500 - 2,000
Additional engineering-scale tests at the selected vendor facility	$1,200 - 3,000
Integrated testing of product handling system	$1,000 - 1,500
Design Documentation required for TRL-6	$500 - 1,000
Total	**$5,800 – 9,100**

(**) Cost is only an estimate based on current maturity of the project and should only be used as a guideline.

APPENDIX A

FBSR TECHNOLOGY DEVELOPMENT RECOMMENDATIONS
CROSSWALK OF TANK 48 H INDEPENDENT TECHNICAL REVIEW, CRESP REVIEW, AND TANK 48H TECHNOLOGY READINESS ASSESSMENT

Major Tests	ITR	CRESP	TRA
Laboratory-scale crucible tests with actual Tank 48H waste			X
Bench-scale steam reforming tests with actual Tank 48H waste			X
Additional engineering-scale tests	X	X	X
Integrated testing of Product Handling System		X	X
Design Documentation required for TRL-6			X

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, Office of Environmental Management 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 used in Technology Readiness Assessments (TRA) conducted at Hanford and the Savannah River Site.

- 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 Tank 48H waste treatment 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 column 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	

T/P /M	Y /N	Criteria	Documentation
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 (Continued)

TRL 4 Questions for Critical Technical Elements

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 (Continued)

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 (Continued)

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