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Savannah River Site Tank 48H Waste Treatment Project Technology Readiness Assessment

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ABSTRACT

One of U.S. Department of Energy's (DOE) primary missions at Savannah River Site (SRS) is to retrieve and treat the high level waste (HLW) remaining in SRS tanks 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 Cs-137 and other radioisotopes – are contaminated with nearly 22,000 Kg of tetraphenylborate, a material which can release benzene vapor to the tank head space in potentially flammable concentrations.

An important element of the DOE SRS mission is 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 return Tank 48H to service. Tank 48H must be returned to service to support operation of the Salt Waste Processing Facility, to free up HLW tank space, and to allow orderly tank closures per Federal Facility Agreement commitments.

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 testing and evaluating these two processes, and DOE is nearing a final technology selection in late 2007.

In parallel with WSRC's ongoing work, DOE convened a team of independent qualified experts to conduct a Technology Readiness Assessment (TRA). The purpose of the TRA was to determine the maturity level of the Tank 48H treatment technology candidates – WAO and FBSR. The methodology used for this TRA is based on detailed guidance for conducting TRAs contained in the Department of Defense (DoD), Technology Readiness Assessment Deskbook. The TRA consists of three parts:

- Determination of the Critical Technology Elements (CTEs) for each of the candidate processes.
- Evaluation of the Technology Readiness Levels (TRLs) of each CTE for each process.
- 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. Based on the assessment, the overall TRL for WAO was 2 and the TRL for FBSR was 3. WAO was limited by the current lack of definition for the off-gas treatment system (TRL of 2). The FBSR Product Handling had little or no test work and therefore received the lowest score (TRL of 3) for the FBSR CTEs.

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 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.

INTRODUCTION

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 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's 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)[1] 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 documented in the CBU-PIT-2006-00070, *Liquid Waste Disposition Process Plan*.[1]

Although multiple activities will be required (removing bulk material, removing the heel, cleaning the tank to meet and demonstrate compliance with release criteria) to return Tank 48H for service, one of the most challenging will be the processing of the TPB-contaminated liquid waste removed from the tank. 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 [2] 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 [3] 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. The ITR Team felt that 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 [4] recommended FBSR as the baseline treatment for Tank 48H.

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[1] 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.

Early in 2007, WSRC established a Tank 48H path forward comprising development and application of technologies, FBSR and WAO, with a third method, called Aggregation, as a backup.

DOE commissioned this TRA [5] and a technical assessment conducted by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) [6] to provide input to their pending decision on the technology selection for Critical Decision (CD)-1.

DISCUSSION

This discussion presents history and status, findings, and recommendations resulting from the TRA of the WAO and FBSR processes for treating high level waste currently stored in Tank 48 at the Savannah River Site (SRS).

Wet Air Oxidation (WAO) Development History and Status

The Zimpro WAO process (now owned by Siemens Water Technology Corporation) 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. Systems have operated as long as 30 years with minimal maintenance. Only one WAO application has been in radioactive service.

A recent, nonradioactive, industrial application went online in January 2007 to destroy organics for the DoD. 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.[7, 8] The system was tested in a 5 gph pilot plant unit in Rothchild, Wisconsin. 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.

Past work at bench-scale successfully applied WAO to DOE's radioactive waste. Bench-scale WAO was successfully tested at the Hanford Site in the 1990s to destroy organic complexing agents in actual radioactive waste.[9, 10] At 280^{o}C for 1 hour, organics destruction based on total organic carbons for both simulant and radioactive actual waste was > 98%. Nitrite destruction was minimal (< 9%).

In the full-scale radioactive application, 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 principal 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 to 250^{o}C and a pressure of 725 psig. Destruction of EDTA was greater than 95% 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.[11]

Bench-scale testing with nonradioactive simulant of Tank 48H was conducted in 2006.[12, 13, 14] Off-gas and treated simulant 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% at 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.

The WAO Process

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_x, HCl, and low molecular weight short chain oxygenated organics (acetic acid and other carboxylic acids).

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 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.

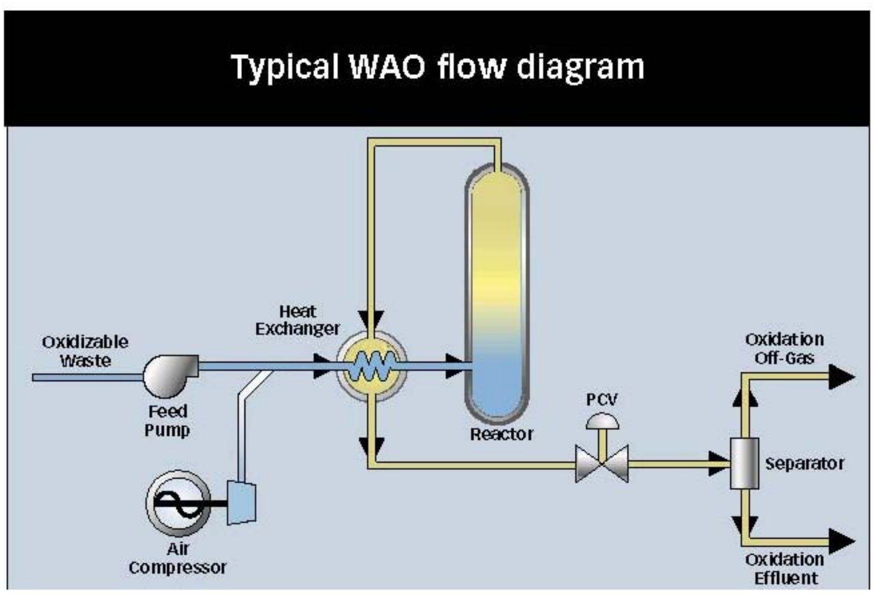

Fig. 1. A schematic of a typical WAO flow diagram.

Fluidized Bed Steam Reforming Development History and Status

In the FBSR 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 radionuclides.

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, C-14, and iodine that are largely volatized.[15] Lessons learned from operation of the Studsvik facility have been documented.[16]

The waste in Tank 48H is high in nitrates, nitrites, and tetraphenylborate (TPB). Pilot plant testing of the Thor Treatment Technologies LLC (THOR) FBSR process using Tank 48H simulant was conducted at the Hazen Research Facility in Golden, Colorado. Tank 48H testing was conducted for the Denitration Mineralization Reformer (DMR), Carbon Reduction Reformer (CRR), Filtration System, and Offgas Treatment System (OGTS) later in 2006. The Final Hazen Report was issued in early 2007.[17]

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.[18, 19, 20] 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.

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). Preconceptual engineering and cost studies, and pilot-scale tests were conducted in 2003 and 2004.[21, 22, 23] 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. 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.

The FBSR Process

The proposed flow diagram for processing of Tank 48H TPB in the 241-96H facility is illustrated in Figure 2. 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.

This Steam Reformer System includes the Denitration and Mineralizing Reformer (DMR), High Temperature Filter (HTF), and Carbon Reduction Reformer (CRR). The functions of the Steam Reformer System are to (a) receive the waste from the Feed Receipt, Preparation, and Feeding System, (b) atomize the waste slurry into the first fluidized bed steam reformer, (c) inject near ambient pressure superheated steam enriched with reactants into the reformers to react the waste with chemicals and 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.

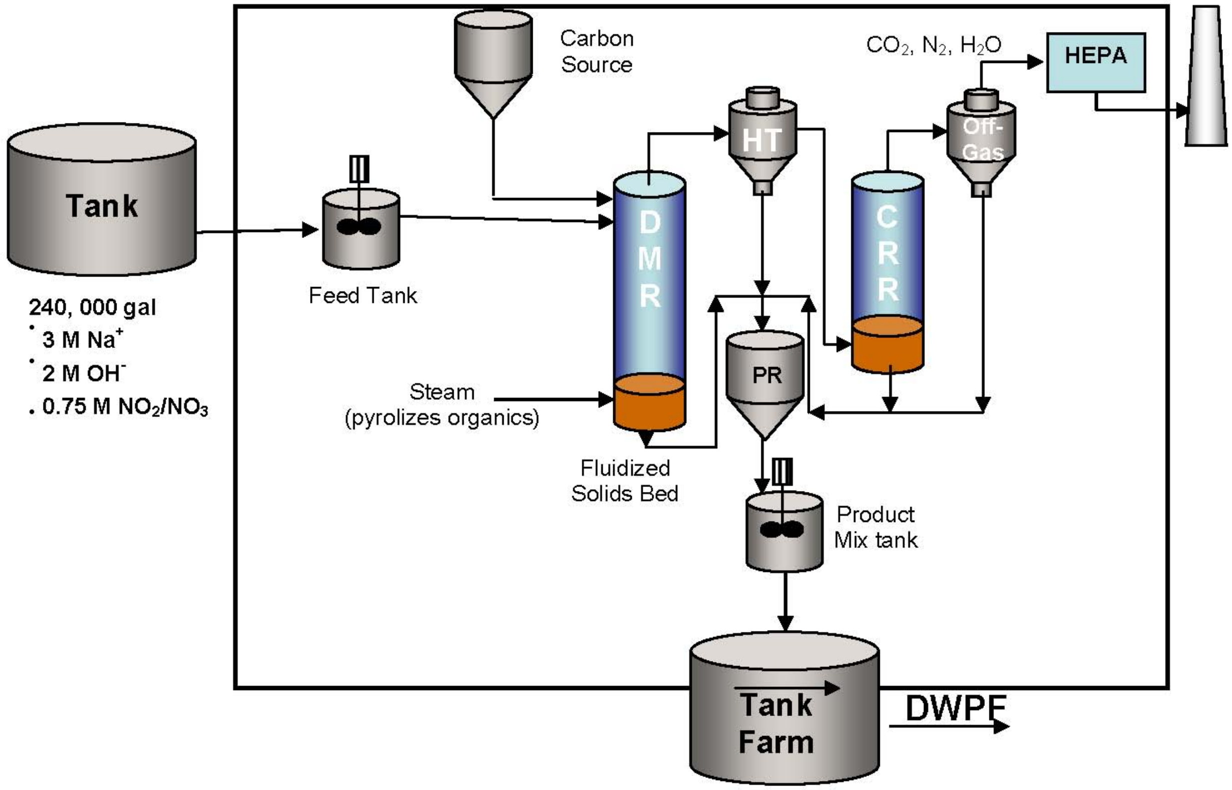

Fig. 2. An illustration of the proposed Tank 48H flowsheet.

The HTF is installed at the offgas outlet of the first reformer (DMR). The function of the filter is to remove entrained solids from the DMR offgas before transferring the offgas to the 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.

The Offgas Treatment System reduces the temperature of the hot offgas received from the CRR vessel, filters out any solids including entrained CRR bed material (alumina) particulates, and removes 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.

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 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. After sufficient cooling in the Product Receiver, process water is added to dissolve and slurry the product while a tank agitator provides mixing. When slurrying and dissolution have been completed, the slurried product is transferred to Tank 51H.

Technology Readiness Assessment - the Process

In 1999, the U.S. Government Accountability Office (GAO) produced an influential report [24] 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) TRA process 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 TRAs in new major programs. Guidance for assessing technology maturity was incorporated into the *Defense Acquisition Guidebook*.[25] 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 TRA process as a method for assessing the level of technology readiness for the Tank 48H treatment technologies.

The TRA process as defined by the DoD consists of three parts: (a) identifying the CTEs, (b) assessing the TRL of each CTE using an established readiness scale, and (c) 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 using the questions in Table I.

Table I. Questions Used to Determine the Critical Technology Elements

Set	Questions
First	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	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.

For those systems determined to be a CTE, the TRL scale used in this assessment is shown in Table II. This scale requires that testing of a prototypical design in a relevant environment be completed before

Table II. 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.
	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.
Basic Technology Research	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.

incorporation of the technology into the final design of the facility. 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 [26] and modified for DOE-EM applications.

TRL Assessment

The Assessment Team was comprised of staff from Pacific Northwest National Laboratory (PNNL) and technical consultants to DOE. 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 and Siemens presented descriptions of the Tank 48H treatment systems, described the technology research and testing results, and participated in a technical support role during the assessment.

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 FBSR and WAO process systems against the two sets of questions described above in Table II and identified the systems listed below as CTEs:

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

The Team completed a TRL assessment for each CTE. Each response to a specific TRL Calculator question was recorded, along with references to the appropriate documents. Then, 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.

Results of the TRA

The TRL for each of the technologies evaluated, including subsystems, is presented in Table III. This table presents the technology/subsystem, TRL rating, and the rationale for the TRL rating. 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 the TRA report [5], 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.

The list of major testing and documentation needs required to reach TRL 6 for WAO and FBSR presented in Table III are provided for comparison purposes as an aid to DOE in selecting the preferred technology for Tank 48H waste treatment. However, 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 the table. Also, the Team believes it would be prudent to continue testing of the backup technology to the extent that resources will permit.

Assessment of WAO and FBSR Advancement Degree of Difficulty

Once the TRL was established for the various WAO and FBSR CTEs, it was necessary to assess what will be required to advance the technology to the TRL required by the project. The advancement degree of difficulty is an approach for defining what is required to move a technology from one TRL to another; it is normally conducted for technologies with TRL less than 6 and defines the testing requirements to reach TRL 6. 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 and FBSR activities are shown in Table IV. The cost estimate for WAO ranges from $4.5 to $9.0 million over a 24 - 36 month period. In comparison, the cost estimate for FBSR ranges from $4.2 to $7.9 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.

Table III. Technology Readiness Level Conclusions for Critical Technology Elements

Critical Technology Element and Description	Technology Readiness Level	Rationale
Supplement Pretreatment Technologies		
Wet Air Oxidation (WAO) Reactor System	3	The Wet Air Oxidation reactor technology was determined to be TRL 3 because continuous testing has not been completed to support the proposed application at Tank 48H.
WAO Offgas Treatment System (OGTS)	2	The OGTS has not been defined. Testing is required to demonstrate the system's ability to capture and recycle particulates and retain Cs-137.
WAO Technology Overall	2	
Fluidized Bed Steam Reforming (FBSR) Steam Reformer System	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. However, no laboratory-scale testing has been conducted with actual Tank 48H waste.
FBSR Offgas Treatment System (OGTS)	4	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 they not been tested using Tank 48H simulated or actual waste.
FBSR Product Handling System	3	The Product Handling System was determined to be a TRL 3 because very little testing has been completed. Transferring solids from dry storage containers to the "wet" atmosphere of the product mixing tank will be a key technical issue.
FBSR Technology Overall	3	

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

Technology	Testing/Documentation Needed	Cost, Dollars in Thousands[a]	Duration, Month[a]
WAO	Autoclave testing with actual Tank 48 waste in SRNL shielded cells	$1,000 - $1,500	9 - 15
	Phase I - Continuous, integrated system testing at the Siemens pilot-scale facility[b]	$2,000 – 3,000 (include $1,000 for simulant)	18 - 24
	Phase II – Conduct integrated pilot-scale testing (including offgas system).	$500 – 2,500	
	Project Documentation (CD-0 / CD-1); see footnote c.	$1,000 - $2,000	6 - 9
	WAO Total	$4,500 - $9,000	24 - 36
FBSR	Laboratory-scale crucible tests with actual Tank 48 waste	$500 – $1,500	6 - 9
	Bench-scale steam reforming tests with actual Tank 48 waste	$1,500 - $2,000	12 - 15
	Additional engineering-scale tests at THOR Hazen facility	$1,200 – 2,800 (includes $500 for simulant)	6 - 12
	Integrated testing of Product Handling System	$1,000 - $1,500	6 - 12
	Project Documentation (CD-0 / CD-1); see footnote c.	$40 - 100	1 - 2
	FBSR Total	$4,200 – 7,900	13 - 17

[a] 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.

[b] 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 to 10 million including all project costs (subcontractors, design reviews, etc.).

[c] Ready to start final design corresponds with CD-2, completion of preliminary design.

CONCLUSIONS AND RECOMMENDATIONS

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 FBSR has a higher overall degree of maturity. The maturity of reformer and off-gas treatment 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 engineering-scale. The Team believes that transferring solids from dry storage containers to the “wet” atmosphere of the product dissolving tank will be a 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 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.

Lessons Learned on 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 of technological maturity 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 modified TRL scoring process are ambiguous and need further clarification (or perhaps deletion) for application to EM projects.
- Some of the programmatic and project-oriented documents are required at very early stages of the technology development programs, i.e., TRL 2. While such programmatic requirements can 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, and testing with nonradioactive simulants is acceptable.

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 48H 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 48H waste processing technologies.

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