Small Column Ion Exchange Technology at Savannah River Site

U.S. Department of Energy
Office of Environmental Management
Office of Technology Innovation and Development

Technology Readiness Assessment Report

November 2011

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ACKNOWLEDGMENTS

The Technology Readiness Assessment (TRA) Team would like to thank Ms. Pat Suggs, Mr. Tom Gutmann, and Mr. Joe Copeland, Department of Energy (DOE) Savannah River Operations Office; Mr. Richard Edwards, Ms. Maria Rios-Armstrong, and Mr. Thomas Huff, Savannah River Remediation, and Dr. Frank Pennebaker and Mr. David Herman, Savannah River National Laboratory, for their exceptional support during this review.

Ms. Suggs was the lead DOE representative responsible for organizing the assessment held on-site by the TRA Team. Mr. Gutmann provided invaluable background information on the program status. Mr. Copeland provided subject matter expertise regarding compliance of the project with the safety requirements defined in DOE-STD-1189, *Integration of Safety in the Design Process*, which was an area of review normally not included in a TRA.

Mr. Edwards and his staff provided responsive support through technical presentations, discussions, and numerous reference documents. Outstanding assistance was provided by Ms. Rios-Armstrong, without whose support, this review would not have been successful. Mr. Huff provided invaluable technical expertise regarding virtually every aspect of the system design. Dr. Pennebaker and Mr. Herman provided extensive technical information related to experimental work for the Small Column Ion Exchange Program in various areas.

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EXECUTIVE SUMMARY

INTRODUCTION

The Small Column Ion Exchange (SCIX) system being developed for deployment at the Savannah River Site (SRS) is a supplementary salt waste processing technology that, if implemented, will augment the baseline Salt Waste Processing Facility (SWPF) capability. An opportunity exists to shorten the SRS radioactive waste system lifecycle by 6 years, and significantly reduce life cycle costs, by accelerating salt processing to earlier completion, simultaneous with sludge vitrification. As described in the Enhanced Tank Waste Strategy, which is part of the Department of Energy (DOE) Office of Environmental Management (EM) *Roadmap – EM Journey to Excellence,* December 16, 2010, the SCIX system, in combination with deployment of a Next Generation Solvent in the SWPF, is projected to provide nearly $3B in cost savings due to schedule acceleration and elimination of "salt waste only" processing in the Defense Waste Processing Facility (DWPF).

The SCIX system salt processing capacity is 2.5 million gallons of salt waste per year to supplement the baseline salt waste processing capability (i.e. SWPF). The system is unique in that it does not require construction of a new facility. Rather, equipment modules are installed inside the tank risers of a Type III tank (Tank 41), which provides both shielding and secondary containment.

The SCIX Program is being suspended beginning October 1, 2011, due to funding constraints. To facilitate restart at the time that budget becomes available, a formal Technology Readiness Assessment (TRA) was conducted to document the technical maturity of the SCIX system and validate the activities remaining to mature the technology to a Technology Readiness Level (TRL) 6.

TECHNOLOGY DESCRIPTION

The SCIX integrated system is comprised of the following primary components: 1) Large Tank Monosodium Titanate (MST) Sorbent Strike, 2) four Rotary Microfilters (RMFs), 3) two Ion Exchange Columns (IXCs) that use Crystalline Silicotitanate (CST) sorbent, 4) one Spent Resin Disposal unit (a.k.a. Grinder), and 5) Common Plant Equipment. Figure ES-1 depicts the primary system components.

The process involves an in-tank strike with MST followed by a filtration step to remove strontium and actinides. The filtration step uses four RMFs developed by the DOE-EM technology program. The Clarified Salt Solution (CSS) is sent through two IXCs in a lead-lag configuration for cesium (Cs) removal. The resultant decontaminated CSS, referred to as Decontaminated Salt Solution, is equivalent to the output of SWPF and is sent to the Saltstone Production Facility (SPF). The MST / solids slurry is collected in the bottom of Tank 41 and transferred to a sludge batch preparation tank (Tank 42 or Tank 51). The loaded CST resin will

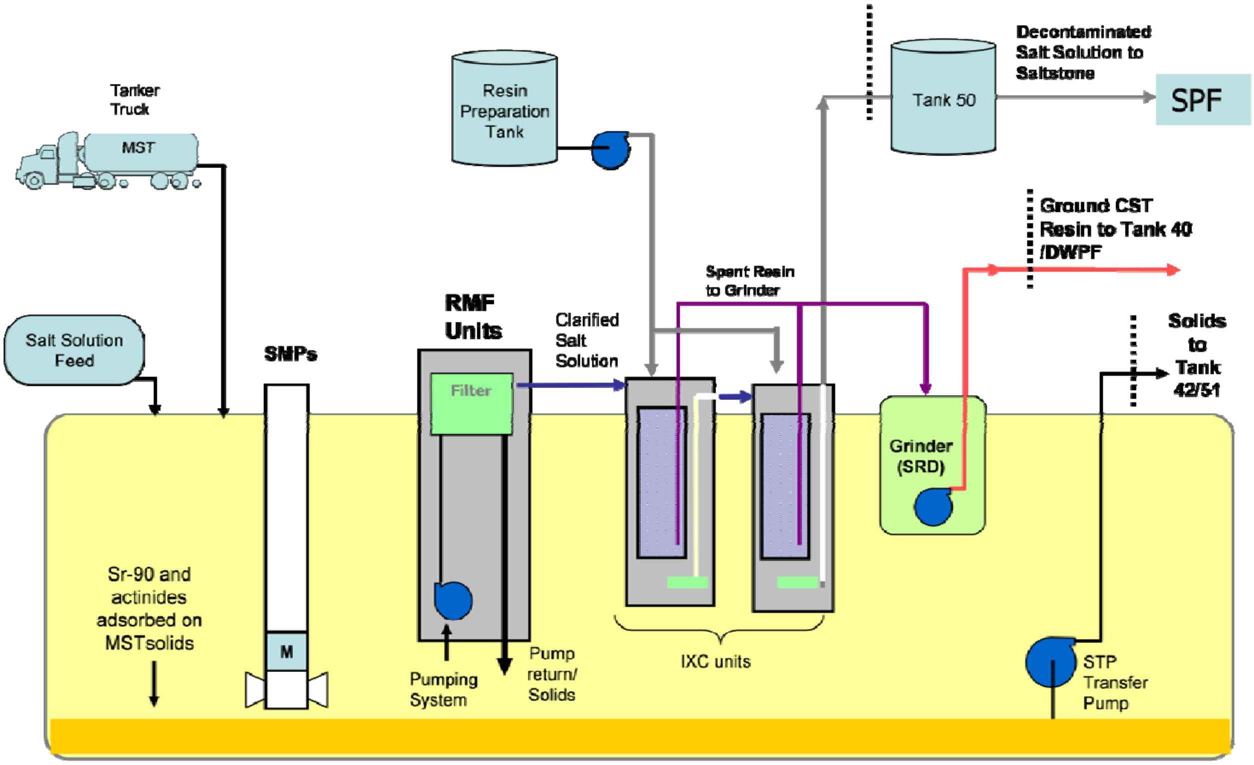

Figure ES-1. SCIX System Modules in a Waste Tank

be sluiced to a grinder to reduce the particle size and transferred to Tank 40 for ultimate disposal at the DWPF. Grinding is necessary to meet transfer line criteria to prevent settling and plugging and to meet DWPF compatibility criteria.

The TRA Team worked with the SCIX Program Team to identify components of the SCIX integrated system that are critical technology elements (CTEs). Four CTEs were identified and evaluated including 1) the Large Tank MST Strike (including the submersible mixer pumps), 2) the RMFs (including the transfer pump), 3) the CST IXCs, and 4) the Grinder.

The MST Strike, CST IXC, and RMFs were all determined to be at a TRL 5. In most cases, the only items required to bring these three CTEs to TRL 6 are as follows:

- Issuance of a final Reliability, Availability, Maintainability, and Inspectability (RAMI) document, a Preliminary Documented Safety Analysis (PDSA) report, and a final Technical Report on Technology,

- Scope, cost, and schedule estimate for technology development and testing required to attain TRL 6,

- Completion of an integrated SCIX system test.

Additional testing on the Cs removal efficiencies and operational parameters and limits for the IXC are also needed to attain TRL 6 for that CTE. Specifically, the engineering scale testing of the Cs removal must be performed, which will likely be accomplished during the integrated testing, as well as definition of specific process limits such as flow rates, sodium concentration, etc.(refer to Questions 20 and 27 of the TRL 6 Calculator).

The Grinder was determined to be at TRL 3. For the Grinder CTE, the only item not completed that resulted in the TRL 3 determination is scale up. A nominal tenth-scale system was tested, but scale-up design and testing was not initiated prior to the decision to suspend the program. Similarly, the only item not completed to attain TRL 5 for the Grinder is the final full scale design, which would result from the scale-up design and testing activities. Thus, completion of these related activities would bring the Grinder CTE to TRL 5, which would bring the entire SCIX integrated system to a TRL 5.

The TRA results concluded that, overall, the SCIX system is at TRL 3. This is primarily due to the specific activities cited above that must be completed to bring the CTEs to TRL 6, as well as the activities required to bring the integrated waste processing system to TRL 6. These include:

- Completion of an integrated SCIX system test (common to all of the CTEs), and

- Identification of and strategy to address single point failures of the system components (i.e., final Operating Plan).

Completion of these activities will result in an overall TRL 6 for the full SCIX integrated system. However, a subset of these activities could be completed to bring the maturity to TRL 5; and the overall status of the SCIX Program to a better point for suspension. This is discussed in more detail below.

RECOMMENDATIONS

The TRA Team offered the following recommendations:

1. At a minimum, the following few, relatively low-cost, activities (as compared to the full set of activities required to attain TRL 6) should be completed.

    - The detailed vendor technology designs should be completed for all CTEs. This would include the scale-up design and testing for the Grinder.

    - Additionally, the interface designs to integrate the CTE components and other equipment into a system could then be finalized and SCIX final design holds released.

- Similarly, completion of these final designs would allow completion of the PDSA.

2. The scope, cost, and schedule estimate should be completed for the technology development and testing required to attain TRL 6, and documented in a revision of the Technology Maturation Plan (TMP).

Implementing these recommendations would better position the program to facilitate a quick and cost effective restart. This is because the original SCIX Team will likely not be available, and thus some key corporate knowledge may be lost. Having the completed full scale design and PDSA would provide the validated documentation to immediately transition to fabrication and integrated testing.

Although not a specific recommendation, the preferred approach would be to bring the system to TRL 6 by completing the integrated testing, which would provide the information and data needed to complete the RAMI analysis, final Technical Report, and Operating Plan. This would provide significant benefit to DOE-EM due to the schedule acceleration and cost savings associated with the SCIX Program and related activities that are part of the overall Enhanced Tank Waste Strategy. However, the TRA Team recognizes that this would be much more costly and thus may not be feasible or warranted under the present SCIX Program status and funding scenario.

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ACRONYMS

ARP	Actinide Removal Process
CEES	Columbia Energy and Environmental Services
CD	Critical Decision
Ci	Curie
CPE	Common Plant Equipment
Cs	Cesium
CSS	Clarified Salt Solution
CSSX	Caustic Side Solvent Extraction
CST	Crystalline Silicotitanate
CTE	Critical Technology Element
DoD	Department of Defense
DOE	U.S. Department of Energy
DOE-EM	DOE Office of Environmental Management
DOE-ORP	DOE Office of River Protection
DOE-SR	DOE Savannah River Operations Office
DSS	Decontaminated Salt Solution
DWPF	Defense Waste Processing Facility
ETR	External Technical Review
FPL	Federal Program Lead
GAO	General Accounting Office
HLW	High-level Waste
INL	Idaho National Laboratory
IX	Ion Exchange
IXC	Ion Exchange Column
LW	Liquid Waste
LWSP	Liquid Waste System Plan
M	Molar
µ	Micron
MCU	Modular Caustic Solvent Side Extraction Unit
Mgal	Million gallons
Mgal/yr	Million gallons per year
mMST	modified Monosodium Titanate
MST	Monosodium Titanate
NASA	National Aeronautics and Space Administration
ORNL	Oak Ridge National Laboratory

ACRONYMS

PDSA	Preliminary Documented Safety Analysis
PNNL	Pacific Northwest National Laboratory
RAMI	Reliability, Availability, Maintainability, and Inspectability
RMF	Rotary Microfilter
SCIX	Small Column Ion Exchange
SE	Strip Effluent
SPF	Saltstone Production Facility
sRF	spherical Resorcinol-Formaldehyde
Sr	Strontium
SRD	Spent Resin Disposal
SRNL	Savannah River National Laboratory
SRR	Savannah River Remediation
SRS	Savannah River Site
STP	Site Treatment Plan
SWPF	Salt Waste Processing Facility
TE	Technology Element
TFA	Tank Focus Area
TMP	Technology Maturation Plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
VSL	Vitreous State Laboratory
WAC	Waste Acceptance Criteria
WPS	Waste Processing System
WRPS	Washington River Protection Solutions

GLOSSARY

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

1 INTRODUCTION

Nuclear material production operations at Savannah River Site (SRS) resulted in a current inventory of approximately 37.1 million gallons (Mgal) of high-level waste (HLW). The HLW is composed of approximately 2.9 Mgal of sludge containing precipitated solids and insoluble waste and 34.2 Mgal of salt solution (supernate) and crystallized salts (saltcake), as shown in Figure 1-1. This waste is being stored, on an interim basis, in 49 underground waste storage tanks in the F- and H-Area Tank Farms. Continued long-term storage of this liquid waste in underground tanks poses an environmental risk.

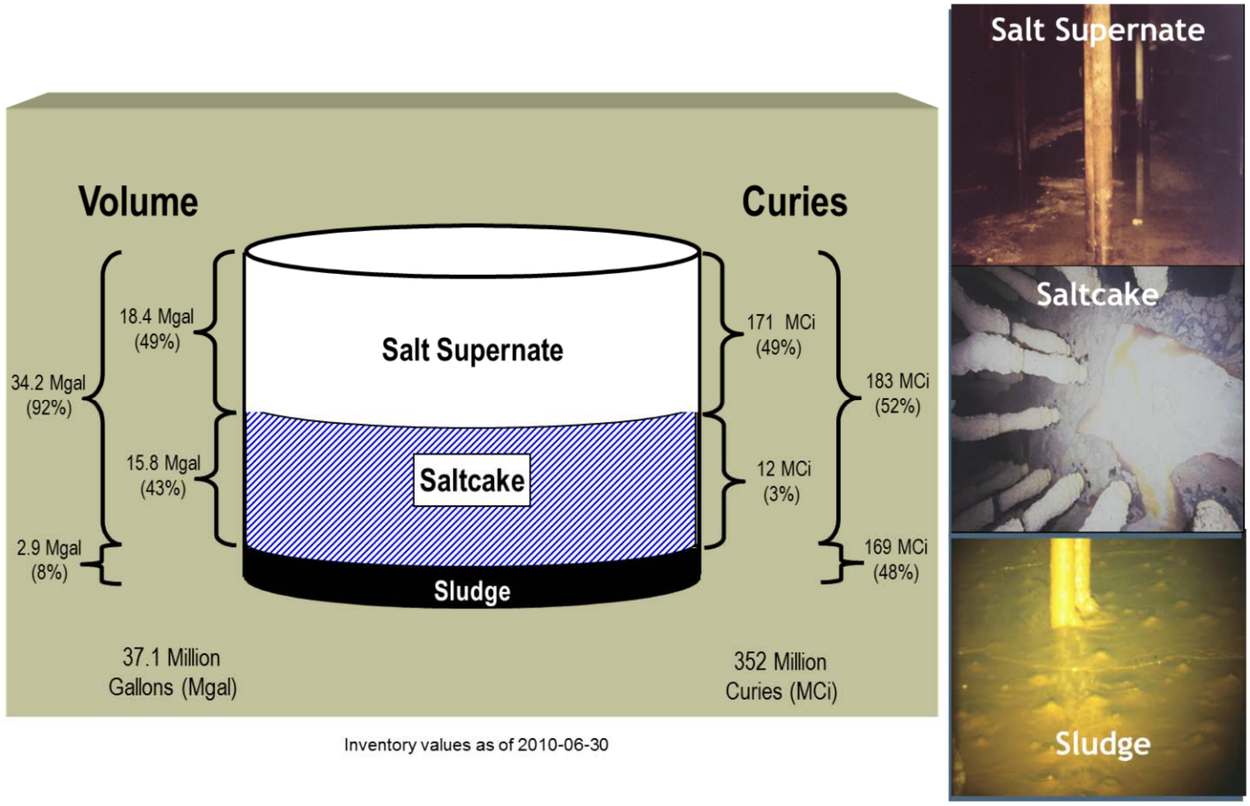

Figure 1-1. SRS Liquid Waste Composite Inventory [1]

The Department of Energy (DOE) Savannah River Operations Office (DOE-SR) is constructing a Salt Waste Processing Facility (SWPF) for the treatment and processing of SRS HLW. The SWPF will remove and concentrate radioactive strontium (Sr), actinides, and cesium (Cs) from the bulk salt waste solutions in the SRS HLW tanks. The sludge and strip effluent (SE) from the SWPF containing concentrated Sr, actinide and Cs wastes will be sent to the SRS Defense Waste Processing Facility (DWPF), where they will be vitrified. The Decontaminated Salt Solution (DSS) that remains after the removal of the highly radioactive constituents will be sent to the

SRS Saltstone Production Facility (SPF) for immobilization in a grout mixture and disposal in grout vaults at SRS [1, 2, 3].

The removal, treatment, and disposal of the highly radioactive contents from HLW storage tanks at SRS is a major effort aimed at reducing the risk profile of DOE. The ability to safely process the salt component of the waste is a crucial prerequisite for completing the high-level waste disposal. Without a suitable method for salt management, DOE will not be able to place the tank waste facilities in a configuration acceptable for safe closure [1, 2, 3].

If SWPF is implemented as the sole salt waste processing capability, Revision 15 of the Liquid Waste System Plan (LWSP) [4] forecasted that DOE would be at risk for not meeting the Site Treatment Plan (STP) [5] commitment to remove all waste from the waste tanks due to delays in processing of salt waste. Assuming the SWPF start-up date of September 2013, operation would not be complete until 2030 at average production rates. This is several years behind the STP schedule. Thus, Revision 15 of the LWSP allowed production of salt-only canisters. Because of the accelerated sludge processing implemented in the LWSP, the bulk of the sludge waste would be removed from the waste tanks and processed by June 2020. Another two years would be required to complete processing the sludge heel in the DWPF feed tank (Tank 40) at a reduced canister rate. Once all sludge has been processed, DWPF would continue to operate to vitrify the Cs loaded SE and the actinide and Sr loaded Monosodium Titanate (MST) streams received from SWPF using revised frit formulae and trim chemicals as needed. During production of these salt-only canisters, the canister waste loading would be limited by the canister heat generation limit of the Glass Waste Storage Building. As a result, two hundred and fifty salt-only canisters were forecasted to be produced per Revision 15 of the LWSP.

The Small Column Ion Exchange (SCIX) Program was proposed because it can provide 2.5 Mgal per year (Mgal/yr) of salt processing capacity to operate in parallel with the SWPF. The combined salt processing capability is sufficient to eliminate salt–only canister production from DWPF and reduce the overall Liquid Waste (LW) lifecycle. The SCIX Program is the end result of technology developments and down-selections for related but different DOE deployments. It is an attractive technology because of its readiness for deployment and modular design. Revision 16 of the LWSP [6] incorporates the SCIX Program into the SRS LW flow sheet, closing the gap between salt and sludge processing. As a result, no salt-only canisters were forecasted to be produced in Revision 16 of the LWSP.

1.1 SMALL COLUMN ION EXCHANGE PROGRAM BACKGROUND

As previously stated, SWPF is the primary planned facility that will remove Cs from Tank Farm salt solutions by the Caustic Side Solvent Extraction (CSSX) process and Sr and actinides by treatment with MST and filtration. Extensive work was done to select the technology for SWPF. Several alternatives were considered for SWPF, including ion exchange in a large column design using Crystalline Silicotitanate (CST) sorbent. This technology was not chosen mainly due to heat concerns in the large column with Cs loaded CST. The detailed analysis of the SWPF alternatives is summarized in the SWPF Environmental Impact Statement [7].

Ion exchange (IX) process technology to treat radioactive liquid waste has been studied and evaluated for many years. IX process technology evaluations to treat nuclear waste were performed at Sandia National Laboratory and Oak Ridge National Laboratory (ORNL) in the 1990s using CST as an ion exchange sorbent. After down selection for SWPF, IX technology still looked promising and continued to be matured within the DOE Office of Environmental Management's (DOE-EM's) Office of Technology Innovation and Development (EM-30) and its predecessor organizations. The greatest technical issue was the heat buildup within a large IX column (IXC). As a result of the ongoing development, a shift from a large column to a small column concept was identified. This concept alleviates the heat buildup issue found in the large columns and supports the method of modular deployment at tank top / tank side for an existing waste tank thus obviating the need to build more shielded facilities. The small column size was modeled by ORNL and by Savannah River National Laboratory (SRNL) to verify the cooling capacity. This modeling is complete, proving that the required cooling capacity is readily achievable. SRNL work continued to refine the design inputs.

The continuing development of the IX technology sponsored by EM included the evaluation of two different resins. CST was specially developed by Texas A&M University with Sandia National Laboratory for the purpose of treating Cs wastes within the DOE complex. CST's high affinity for Cs was an advantage where high decontamination factors were preferred, but also presented the thermal build-up issue previously mentioned. In 2003, a SCIX activity using CST was initiated at SRS to treat low curie salt; however, this effort was terminated due to resources demands for the Modular CSSX Unit (MCU) project. Additional technology development continued for spherical Resorcinol-Formaldehyde (sRF) as an alternative IX media for SRS, as well as for potential application at Hanford.

Several additional restarts of SCIX related activities were implemented under different names throughout the next several years but these were at reduced levels of effort and support. However, the results of the research and development were promising for potential deployments.

In October 2009 during a meeting with DOE-EM, Savannah River Remediation (SRR) proposed to re-start the SCIX Program as a system lifecycle improvement option. DOE-EM accepted the SRR proposal and a team was established to design, fabricate, install, and test the SCIX process. The SCIX Program was established as a Technology Demonstration Operations Activity, and specifically not a project, as defined by DOE Order 413.3A, *Program and Project Management for the Acquisition of Capital Assets* [8].

The SCIX system being developed for deployment at SRS is a supplementary salt waste processing technology that, if implemented, will augment the baseline SWPF capability. An opportunity exists to shorten the SRS radioactive waste system lifecycle by 6 years by accelerating salt processing to earlier completion, simultaneous with sludge vitrification. As described in the Enhanced Tank Waste Strategy, which is part of the DOE-EM *Roadmap – EM Journey to Excellence* [9], the SCIX system, in combination with deployment of a Next Generation Solvent in the SWPF, are projected to provide nearly $3B in cost savings due to schedule acceleration and elimination of "salt waste only" processing in DWPF.

The SCIX system salt processing capacity is 2.5 Mgal/yr to supplement the baseline salt waste processing capability (i.e. SWPF). The system is unique in that it does not require construction of a new facility. Rather, equipment modules are installed inside the tank risers of a Type III tank (Tank 41), which provides both shielding and secondary containment.

The SCIX Program is being suspended beginning October 1, 2011, due to funding constraints. To facilitate restart at the time that budget becomes available, a formal Technology Readiness Assessment (TRA) was conducted to document the technical maturity of the SCIX system and validate the activities remaining to mature the technology to a Technology Readiness Level (TRL) 6. Figure 1-2, excerpted from the *Technology Maturation Plan for the Small Column Ion Exchange Program* (SCIX TMP) [10], shows the IX timeline as described herein.

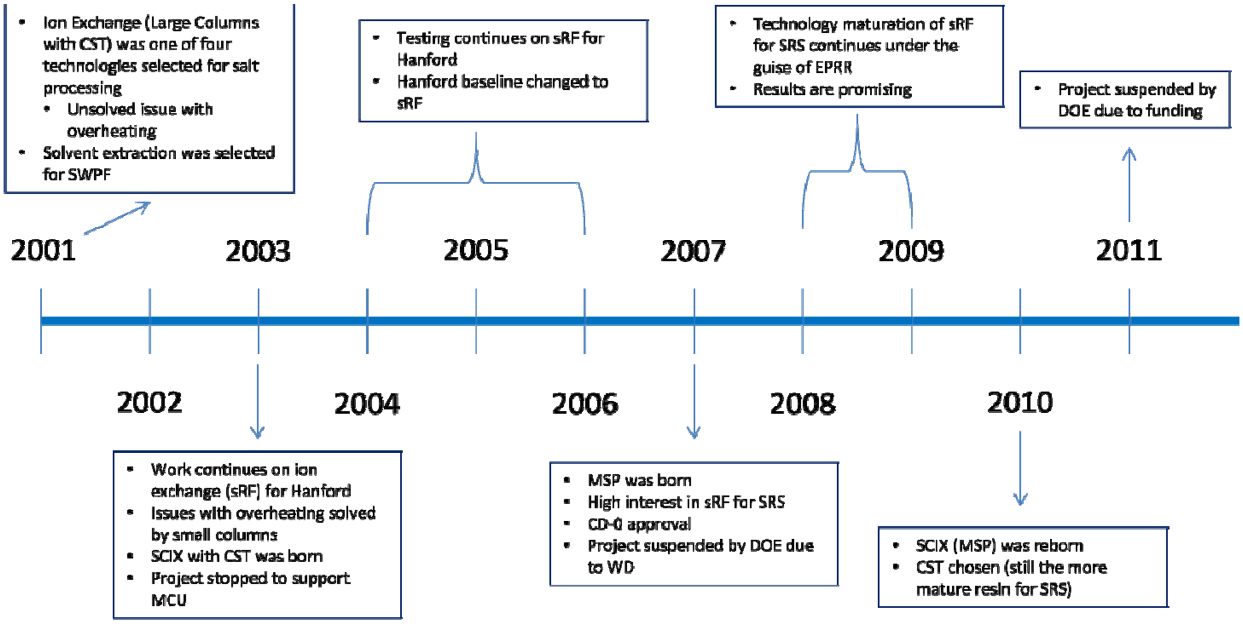

Figure 1-2. Ion Exchange Timeline for SRS

1.2 SMALL COLUMN ION EXCHANGE PROCESS DESCRIPTION

The SCIX integrated system is comprised of the following primary components: 1) Large Tank MST Adsorption, 2) four Rotary Microfilters (RMFs), 3) two IXCs with CST, and 4) one Spent Resin Disposal (a.k.a. Grinder) unit, and 5) the Common Plant Equipment (CPE). The first four components were identified as Critical Technology Elements (CTEs) during the TRA. . This determination process and results are discussed in more detail below. The SCIX integrated system is installed in risers and/or introduced directly into Tank 41. The complete integrated system is depicted in Figure 1.3.

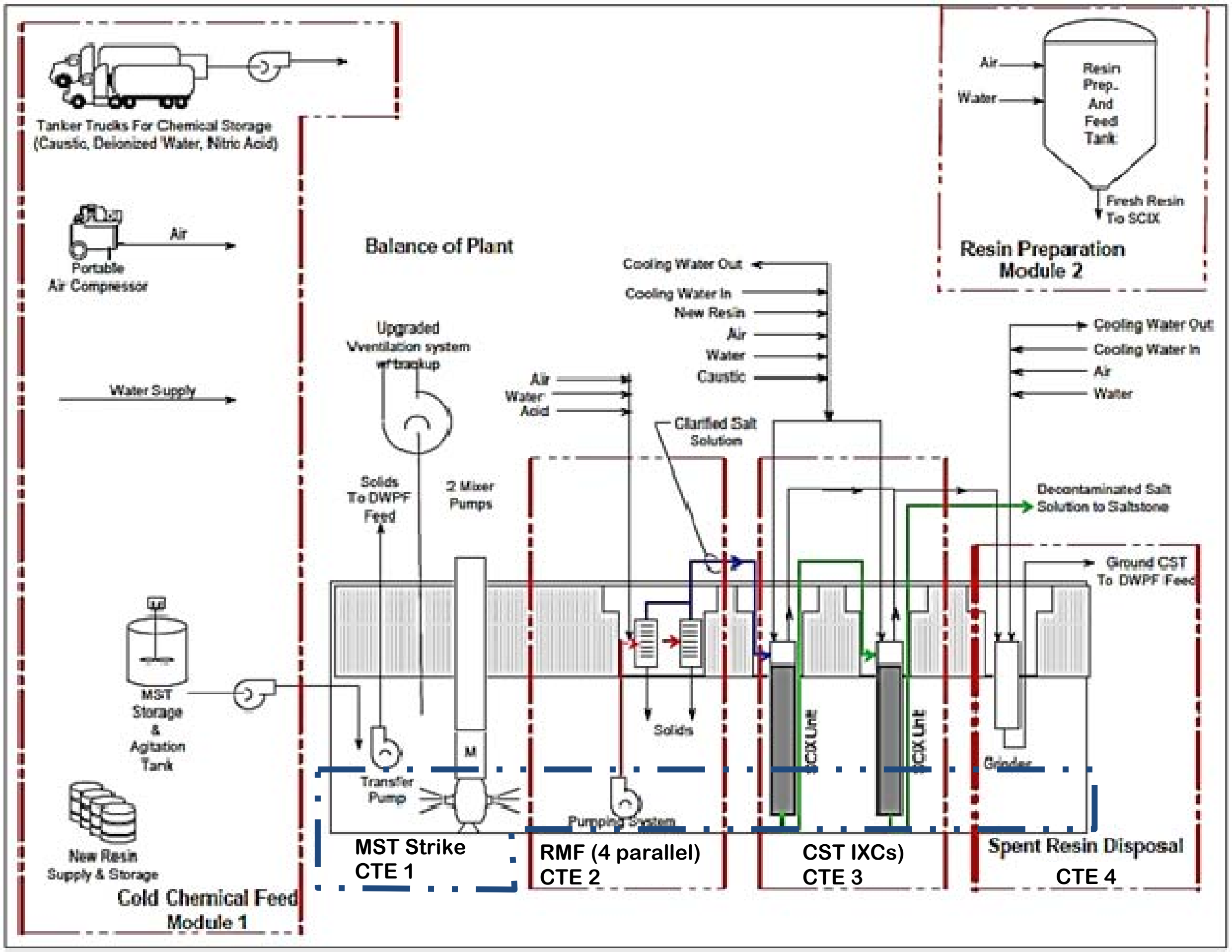

Figure 1-3. Schematic of the Integrated SCIX System showing CTEs

The process involves an in-tank strike with MST to adsorb actinides and Sr in the salt solution. Three submersible mixer pumps are used to ensure mixing of the MST with the salt solution in the tank such that efficient adsorption of the actinides and Sr will occur. The MST / solids slurry is collected in the bottom of the tank and transferred to a sludge batch preparation tank (Tank 42 or Tank 51) for eventual vitrification in DWPF.

The actinide-free salt solution must be filtered prior to passing through the IXCs to remove insoluble solids in the feed stream, which would otherwise foul the IXCs. Furthermore, filtration of the feed to the IXC can help ensure actinides are not present in the SCIX effluent, which is required by the SPF Waste Acceptance Criteria (WAC).

The filtration step uses four RMFs in parallel, which were developed by the DOE-EM technology program. The result is a Clarified Salt Solution (CSS), which is sent through two IXCs packed with CST in a lead-lag configuration for Cs removal. The resulting decontaminated salt solution (DSS) is equivalent to the output of SWPF and is sent to SPF for grouting and eventual disposal in the Saltstone Disposal Facility. CST is a non-elutable sorbent that can only be loaded with Cs one time. Once loaded, the spent media must be removed and the IXC replenished with fresh CST.

Spent CST will be sluiced to the Grinder unit to reduce the particle size and transferred to Tank 40 for eventual immobilization at DWPF. The spent CST must be ground to facilitate the transfer to Tank 40, enable re-suspension of the ground CST for transfer from Tank 40 to DWPF, and to match the approximate particle size distribution of the sludge to minimize stratification within the DWPF process feed tanks.

1.3 SMALL COLUMN ION EXCHANGE TECHNOLOGY READINESS ASSESSMENT OBJECTIVES

The SCIX Program is a Technology Demonstration Operations Activity, and specifically not a project, as defined by DOE Order 413.3A. Nevertheless, this TRA was conducted in compliance with the DOE Guide 413.3-4, *Technology Readiness Assessment Guide* [11], as well as the DOE Office of Environmental Management *Technology Readiness Assessment/Technology Maturation Plan Process Guide* [12]. However, to differentiate the SCIX Program from a formal project, terminology normally associated with a project is not used and similar terms are used, such as a Federal Program Lead (FPL) in lieu of the Federal Project Director, as defined in DOE Order 413. Similarly, any references to Critical Decision (CD) points for the SCIX Program have been eliminated or avoided as part of the TRA documentation.

For this review, CTEs were defined using the prescribed process (see Appendix A). The CTE TRL calculator questions were tailored for assessment of the SCIX integrated system, including the TRL calculators for Waste Processing Systems (WPS), as defined in Appendices B and C, respectively. Additionally, while a TRA does not generally include assessment of the maturity of the safety-related aspects of a technology or system, at the request of DOE-SR, safety-related questions were incorporated into the CTE TRL calculator questions for this TRA.

The FPL and SCIX Program Team informally initiated the TRA process, identified CTEs, and developed the SCIX TMP [10]. An External Technical Review (ETR) of the SCIX Program was conducted in September 2010 [13]. These CTEs were preliminarily reviewed at that time, as well as the TMP. While no specific issues or concerns were identified during the ETR, a more thorough and comprehensive evaluation of the SCIX technology elements (TEs) and determination of the CTEs were completed as part of this assessment. While no new CTEs were identified, the TRA Team did define the MST TE differently. Specifically, the SCIX Program Team had included the large tank MST strike as part of the Common Plant Equipment (CPE) CTE. All of the aspects of the CPE TE were evaluated by the SCIX Program Team, and only the MST strike was determined to be a CTE. The TRA Team evaluated the MST strike and the CPE as separate CTEs. The TRA Team also included a specific TE related to preparation of the CST sorbent due to the importance of this process in ensuring proper characteristics of the CST after loaded into the IXC. The SCIX Program Team evaluated the sorbent preparation a part of the CPE TE. Results are discussed in more detail in Section 3 and Appendix A of this report.

The SCIX Program is being suspended beginning October 1, 2011, due to funding constraints. The primary objective of this TRA was to formally document the technical maturity of the SCIX system and validate the activities remaining to mature the technology to TRL 6. This will facilitate re-start activities once funding becomes available, making it more efficient and cost-effective. This is important because it is very likely that the core SCIX Program Team will not be immediately available to support the re-start effort. Another key objective of the TRA was to support potential deployment of many of the same components of the SCIX system at the Hanford site. The DOE Office of River Protection (DOE-ORP) is planning to deploy a similar system in the Hanford tank farm. The system envisioned for the Hanford deployment uses an elutable sRF resin instead of the CST sorbent. The Grinder unit is not required for the sRF resin; however, many other aspects are similar. Representatives from DOE-ORP observed the TRA, which will help strengthen the transfer of knowledge and lessons-learned between the respective SCIX teams, as well as to provide insight into the assessment process.

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2 TECHNOLOLGY READINESS LEVEL ASSESSMENT PROCESS

2.1 BACKGROUND

A TRA measures technology maturity using the TRL scale that was pioneered by the National Aeronautics and Space Administration (NASA) in the 1980s. In 1999 the General Accounting Office (GAO) recommended that the Department of Defense (DoD) adopt NASA's TRLs as a means of assessing technology maturity prior to transition to final design and operations [14]. In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major programs. Subsequently, the DoD developed detailed guidance for performing TRAs in their *Technology Readiness Assessment (TRA) Deskbook* [15]. Legislation was passed in 2006 specifying that the DoD Milestone Decision Authority must certify to Congress that a technology has been demonstrated in a relevant environment (TRL 6) prior to transition of weapons system technologies to design or to justify any waivers.

In March of 2007, the GAO recommended that DOE adopt the NASA/DoD methodology for evaluating technology maturity [16]. Language supporting the GAO recommendation was incorporated into the U.S. House of Representatives version of the 2008 DOE-EM budget legislation. Prior to that, in 2006-2007, DOE-EM conducted pilot TRAs on a number of projects including Hanford's Waste Treatment Plant, which included multiple TRAs, as well as Savannah River's Tank 48. In March of 2008, DOE-EM issued its *Technology Readiness Assessment (TRA)/Technology Maturation Plan (TMP) Process Guide* [12], which established the TRA process as an integral part of the DOE-EM Project Management's CD Process. Finally, in 2009, the DOE issued a department-wide guidance document for implementing a TRA process titled DOE Guide 413.3-4, *Technology Readiness Assessment Guide* [11]

The TRL scale ranges from 1 (basic principles observed) through 9 (total system successfully used in operations). DOE-EM, DoD, and NASA normally require a TRL 6 for transition of a technology to the Final Design phase of the process.

2.2 DESCRIPTION OF THE TRA PROCESS

"A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies [called Critical Technology Elements (CTEs)] used in systems" [11, 15].

The TRA is an assessment of how far technology development has proceeded. It is not a pass/fail exercise, and is not intended to provide a value judgment of the technology developers or the technology development program. A TRA can:

- Identify the gaps in testing, demonstration, and knowledge of a technology's current readiness level and the information and steps needed to reach the readiness level required for successful inclusion in the project;

- Identify at-risk technologies that need increased management attention or additional resources for technology development; and
- Increase the transparency of management decisions by identifying key technologies that have been demonstrated to work or by highlighting immature or unproven technologies that might result in increased project risk.

The general TRA process as defined in the EM TRA Guide consists of three parts: (1) identifying the CTEs; (2) assessing the TRLs of each CTE using an established readiness scale; and (3) preparing the TRA report. If any of the CTEs are judged to be below the desired level of readiness, the initial TRA is followed by development of a TMP that identifies the additional development required to attain the desired level of readiness. Follow-on TRA(s) are conducted at specific points in the development of the program or project, as necessary. The TRA(s) is conducted by a group of experts that are independent of the project or program under consideration.

The CTE identification process involves breaking the project under evaluation into its component systems and subsystems and determining which of these are essential to program success, and either represent new technologies, are combinations of existing technologies in new or novel ways, or will be used in a new environment. Table 2-1 shows the questions that are used to determine whether or not a specific TE is a CTE. At least one positive response is required in each of the two sets of criteria. Appendix A discusses the results of the CTE determinations made for this TRA.

Table 2-1. Critical Technology element Determination Questions

CTE Determination Questions			
Technology Element:			
Yes	**No**	**Set 1 Criteria**	**Notes**
		• Does the technology directly impact a functional requirement of the process or facility?	
		• 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?	
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	
		• Are there uncertainties in the definition of the end state requirements for this technology?	
		• Do limitations in the understanding of the technology impact the safety of the design?	
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	
		• Is the technology modified?	

CTE Determination Questions			
Technology Element:			
		• Has the technology been repackaged so a new relevant environment is realized?	
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	

The TRL scale used in this assessment is shown in Table 2-2. This scale requires that testing of a prototypical design in a relevant environment be completed before incorporation of the technology into the final design of the facility.

Table 2-2. Technology Readiness Levels used in this Assessment

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot scale, similar (prototypical) system validation in a relevant environment.	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

The testing requirements used in this assessment are compared to the TRLs in Table 2-3. These definitions provide a convenient means to further understand the relationship between the scale of testing, fidelity of testing system, testing environment, and the TRL. This scale requires that for TRL 6, testing must be completed at an engineering or pilot scale, with testing of the system fidelity that is similar to the actual application and with a range of simulated waste and/or limited range of actual waste, if applicable.

Table 2-3. Relationship of Testing Requirements to the TRL

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

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

The assessment of the TRLs is aided by questions based on a TRL Calculator methodology that was originally developed by the U.S. Air Force [15] and modified for DOE-EM applications [11]. The TRL questions used in this assessment are described in more detail in Appendix B.

2.3 SCIX TRA PROCESS DESCRIPTION

The TRA Team was comprised of personnel from DOE EM-31, as well as subject matter experts that provide technical support to DOE-EM, including National Laboratory personnel and independent technical consultants. The TRA Team members were selected based on their individual knowledge of the specific technologies that comprise the SCIX system, as well as the SCIX Program itself. Most of the TRA Team members had participated in the SCIX ETR that was conducted in September 2010. This was beneficial in providing continuity in the reviews such that the TRA process was accelerated yet comprehensive. Additionally, representatives from DOE-ORP and Washington River Protection Solutions (WRPS) participated as observers of the SCIX TRA to provide insights from their experiences as they develop the SCIX system for application at Hanford, as well as to better familiarize themselves with the TRA process, in general. Appendix E includes information on the TRA Team members, as well as the DOE-ORP and WRPS observers.

The SCIX Program Team had conducted an internal, informal TRA for the SCIX system. This included identification of the TEs, determination of the CTEs, and development of a SCIX TMP [10], including completion of the TRL calculator tables with supporting and basis documentation. This provided an excellent starting point for the TRA Team.

The first step completed by the TRA Team was determination of the CTEs. While the SCIX Program Team had already completed this as part of their TRA/TMP process, the TRA Team conducted an independent determination of TEs and selection of CTEs. While the TRA Team organized and evaluated the TEs/CTEs differently, the final selection of CTEs resulted in the same conclusions as those of the SCIX Program Team. This is discussed in more detail in Section 2.4.

Once the CTEs had been validated, the TRA Team conducted due-diligence reviews and evaluations of the testing and design information to validate the input provided by the SCIX Program Team in the TRL calculator tables. In general, the results did not differ significantly from those of the SCIX Program Team. The primary difference is that the SCIX Program Team had conducted separate reviews for the "**T**echnology, technical aspects"; "**M**anufacturing and quality"; and "**P**rogrammatic, customer focus, documentation" components of the TRL calculator; whereas the TRA Team conducted a single assessment that included all of these aspects. Appendix B provides the final TRL results for each CTE.

In addition to the individual CTE assessments, the TRA Team also conducted a review of the integrated SCIX WPS. The WPS assessments are completed for TRL 4 and TRL 6 only, coincident with specific phases of a project (i.e., CD-1 and CD-2, respectively). Although the

SCIX Program is not considered a project, the technology maturation process has been defined and implemented in accordance with those defined for a project, such that the WPS reviews were readily adaptable to the SCIX integrated system. Appendix C provides the final TRL result for the SCIX integrated WPS.

2.4 DETERMINATION OF CTEs

The following definition of a CTE was adopted from the DoD TRA Deskbook [15], and included in both the DOE and EM TRA Guides [11, 12]:

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

The SCIX Program Team had completed an initial determination of the CTEs as part of their internal TRA/TMP process. In general, the CTEs identified by the SCIX Program Team were aligned with the SCIX system modules. Specifically, the SCIX Program is organized into four process modules: IXC module, RMF module, Spent Resin Disposal (SRD) module (a.k.a. the Grinder Unit), and CPE module. The CPE module includes the Cold Chemical Feed, Resin (i.e., CST) Preparation, Balance of Plant (BOP) and Controls, and MST Adsorption. The SCIX Program Team considered the Cold Chemical Feed, CST Preparation, and BOP and Controls as mature components that are routinely accomplished in industry and at DOE facilities. Thus, only the MST Adsorption component of the CPE module was evaluated. While it has been deployed in small tanks, the large tank application at SRS represented a new or novel environment and thus it was determined to be a CTE.

The process for identifying the CTEs for the SCIX system involved a technology system evaluation by the TRA Team members. The TRA Team identified as potential CTEs the technology subsystems/components that are directly involved in processing the tank waste. The TRA Team evaluated the potential CTEs against the two sets of questions presented above in Table 2-1. A system was determined to be a CTE if a "yes" response was provided to at least one of the questions in each of the two sets of criteria.

As part of the due diligence process of the TRA Team, all of the SCIX system components were evaluated, and, based on their functions, the following technologies were identified as individual TEs that warranted evaluation for potential classification as CTEs: 1) Large Tank MST Sorbent Strike, 2) CST Preparation, 3) the remaining CPE, 4) RMF, 5) IXC, and 6) Grinder. The MST strike TE specifically includes the operation and performance of the three submersible mixer pumps. The RMF TE specifically includes the operation and performance of the RMFs and the feed pump that provides the motive force for flow through both the RMF and IXC components.

The evaluation resulted in identification of the same four primary CTEs as determined by the SCIX Program Team, namely 1) Large Tank MST Sorbent Strike, 2) RMF, 3) IXC, and 4) Grinder. Table 2-4 provides a summary of the CTE determinations, indicating the specific questions receiving a "yes" response. The full details of the CTE determination results are included in Appendix C.

Table 2-4. Summary of CTE Determination Results

Criteria	**MST**	**RMF**	**IXC**	**Grinder**
Does the technology directly impact a functional requirement of the process or facility? (Set 1)	**Y**	**Y**	**Y**	**Y**
Is the technology modified? (Set 2)		**Y**	**Y**	
Has the technology been repackaged so a new relevant environment is realized? (Set 2)	**Y**	**Y**	**Y**	**Y**
Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability? (Set 2)	**Y**			

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3 SUMMARY OF THE TECHNOLOGY READINESS LEVEL ASSESSMENT FOR EACH CRITICAL TECHNOLOGY ELEMENT

3.1 LARGE TANK MST SORBENT STRIKE

The Large Tank MST Sorbent Strike CTE was evaluated as a separate technology element, rather than a component of the CPE, as documented in the SCIX TMP [10]. As defined in the context of this TRA, it also includes the operation of the three submersible mixer pumps used to mix the MST / sludge slurry.

3.1.1 Function of the MST Actinide and Sr Removal

The MST is introduced into a waste tank (Tank 41) containing a salt waste solution to sorb actinides and Sr. The MST / salt sludge is then mixed using three submersible mixer pumps to ensure effective sorption kinetics. Actinides and Sr must be removed to ensure that the resulting CSS meets the SPF WAC for these groups of isotopes. Final acceptance to SPF requires further decontamination of Cs, which is accomplished by the CST IXC, a separate CTE discussed in Section 3.3. The MST / sludge slurry will collect in the bottom of Tank 41 and will be remobilized and transferred to a sludge batch preparation tank (Tank 42 or Tank 51) for eventual processing in DWPF.

3.1.2 Description of the MST Actinide Removal System

In the SCIX process, the removal of actinides and Sr from the salt waste is conducted in Tank 41 as shown in Figure 3-1. MST is added to achieve a concentration of 0.4 g MST/liter of salt solution. Mixing is conducted in the large-tank system using three submersible mixer pumps to ensure effective sorption of the actinides and Sr. The TRA Team, like the SCIX Program Team, chose to evaluate these two areas (MST sorption and mixing) as one technology element in our assessment.

MST actinide and Sr removal (sorption and mixing) was determined to be a CTE (see Section 2.4 and Appendix A). The TRL determination for the MST CTE is discussed below and in Appendix B.

3.1.3 Relationship to Other Systems

The scope of the SCIX Program includes several systems and components that provide for receipt of salt waste from HLW tanks, salt waste processing, and disposition of product streams. To aid the SCIX Program in removal and processing of salt waste from HLW tanks, four technologies will be demonstrated and deployed – MST sorption of actinides and Sr (including mixing), rotary micofiltration, CST IX, and spent sorbent grinding. These technologies have been utilized in HLW processing in the past, but not in this specific application or configuration.

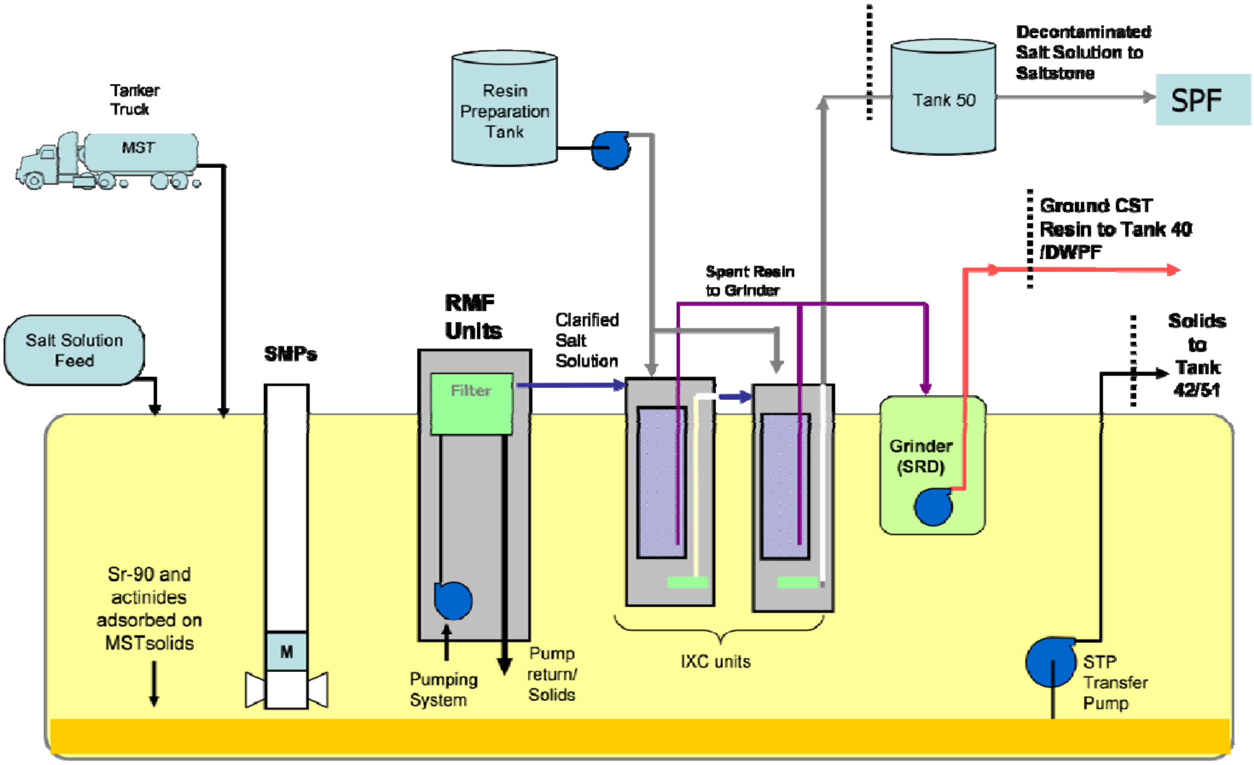

Figure 3-1. Baseline SCIX System Process Diagram.

Prior to processing through the CST IXCs, MST slurry will be mixed with the salt solution to adsorb the Sr and actinides in the salt solution. Then, this MST-laden salt solution must be filtered, prior to passing through the IXCs, to remove the MST and insoluble solids in the feed stream, which would foul the IXCs. Removal of the Sr and actinides is also required to meet the SPF WAC. This resulting product, referred to as CSS, is then fed to the IXCs for Cs removal, which is also required for acceptance at SPF. This final feed stream, which is transferred to SPF for grouting, is referred to as DSS. The MST and insoluble sludge solids will collect in the bottom of Tank 41 for later transfer to Tanks 42 or 51 and ultimate immobilization at DWPF.

The SCIX integrated system will be deployed on a specific HLW tank (Tank 41). However, as part of the overall program planning process, a second tank was identified for potential deployment, as described in the Liquid Waste System Plan, Revision 16 [6]. Upon completion of the salt waste treatment using the SCIX integrated system, the HLW tanks will transition into the final cleaning and residual waste characterization stage.

3.1.4 Development History and Status

The primary processing equipment for the large-tank MST strike is 3 submersible mixer pumps. These pumps have been used for years in several applications at SRS. Savannah River

Remediation has completed a very detailed procurement specification [17] for construction of the mixer pumps needed for the SCIX Program.

For the MST process, an extensive number of laboratory studies [18, 19] have been conducted to determine the influence of mixing and mixing intensity, solution ionic strength, initial actinide and Sr concentrations, temperature, and MST concentration. Extensive testing on simulants has been carried out at laboratory, engineering, and full scale. Actual waste testing at bench scale also has been completed. Models have been developed from the experimental results that allow prediction of actinide and Sr concentrations as a function of contact time with MST. All tests show that actinide and Sr removal with MST will meet processing requirements.

The Actinide Removal Process (ARP) began production operations with actual waste in April 2008. In the ARP process, there are two 5,000 gallon strike tanks with a working volume of 3,800 gallons each.

A procurement specification has been developed for MST [20]. MST from Optima and Harrell has been verified to meet the required specification. MST from both Optima and Harrell has been used in production operations in ARP.

3.1.5 Relevant Environment

The relevant environment includes processing actual HLW salt solutions inside a 1.3 million gallon waste tank. The salt solution contains 5-6 Molar (M) total sodium including caustic, dissolved aluminum, and nitrate salts.

3.1.6 Comparison of the Relevant Environment and the Demonstrated Environment

The MST actinide and Sr sorption process has been successfully demonstrated on actual tank waste at laboratory and bench scale, on multiple simulants at engineering scale, and on actual waste in the ARP. Simulants used in testing were high fidelity, multi-component solutions that were based on actual waste analyses.

3.1.7 Technology Readiness Level Determination

The MST CTE (MST sorption and mixing with 3 submersible mixer pumps) was determined to be at TRL 5. Numerous laboratory scale tests with simulants and actual wastes and full scale tests with a range of simulants using prototypical equipment have been completed and are consistent. However, the final technology report on testing and development has not been completed. Also, the integrated testing is a major activity that has not been started. All required programmatic documents for TRL 6 have not been completed including a performance baseline (cost and schedule), Preliminary Design Safety Analysis (PDSA), final design drawings, and a Reliability, Availability, Maintainability, and Inspectability (RAMI) report.

3.2 ROTARY MICROFILTER

The RMF CTE includes the four RMF units as well as the feed pump that provides the primary motive force for moving the salt solution from the tank level through the RMFs, into the IXC, and to Tank 50.

3.2.1 Function of the RMF

The function of the RMF system is to separate liquids drawn from the waste tank into a solids concentrate that is returned to the waste tank. The resulting clarified salt solution (CSS) is then transferred to the IXCs for Cs removal.

3.2.2 Description of the RMF

Each RMF unit contains a series of flat, round, 0.5-micron (µ) filter element disks set on a hollow rotating shaft inside a stationary cylindrical pressure vessel. Salt solution enters the element chamber under pressure, is distributed across the element surface, and is forced through the element. The filtrate (CSS) is collected in the hollow shaft and is discharged to the IXCs. Solids and excess unfiltered solution are continuously returned to Tank 41. Stationary disks oppose the rotating element disks and provide a means for prohibiting fluid rotation. The rotation of the elements near the stationary disks provides a large amount of turbulence at the element surface. Centrifugal force acts to carry away the solids, minimizing the deposition and obviating the need for a back pulse system. A connection for adding acid or other chemicals to clean/dissolve debris from a plugged element is also included. Figure 3-2 [22] shows a schematic of the internal configuration of the RMF unit.

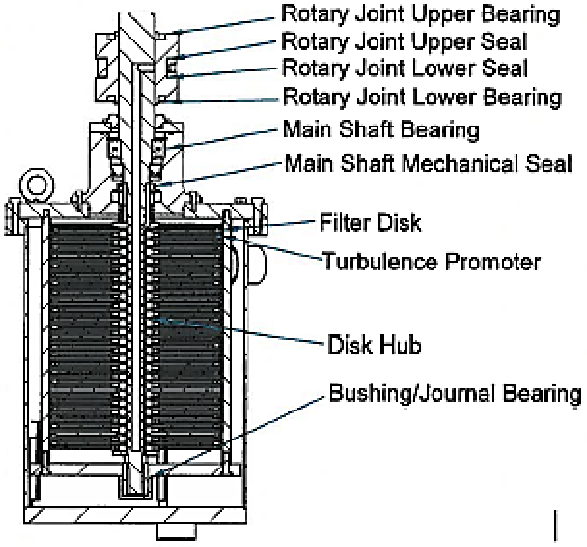

Figure 3-2. Rotary Filter Unit Diagram.

The process tank riser that contains the RMF component has a stainless steel liner/shroud assembly inserted in the riser to protect the waste tank components from the effects of contact with nitric acid. The in-tank shroud has louvers cut into it that direct any free draining nitric acid away from tank components and vents the shroud to the tank vapor space. The RMFs and associated piping and valves are located inside the RMF unit. The unit components are constructed of stainless steel and chemical resistant materials, well shielded for radiation reduction, and are designed to mount inside a process tank riser, and be free draining into the process tank via the louvered shroud.

The following description is taken from the Preliminary Consolidated Hazards Analysis document [21]. The RMF System will be installed in a robust riser of the process tank and consists of a pumping system, RMF units and piping to transfer the filter effluent (the CSS) to the IXCs. The transfer lines from the RMF units to the IXCs will be above ground and utilize secondary containment and shielding as appropriate. The RMF pumping system will utilize one submersible centrifugal pump feeding four RMF units connected in parallel and installed in a riser of the process tank. The submersible RMF feed pump provides the motive force for transferring the raw salt solution from Tank 41 to the RMF units, forcing the raw salt solution through the RMF housing, transferring the CSS from the RMFs to the IXCs, pumping the CSS through the IXC resin beds, and pumping the IXC effluent (DSS) to Tank 50. Figure 3-3 [23] shows the RMF system with the riser/tank top mounted configuration.

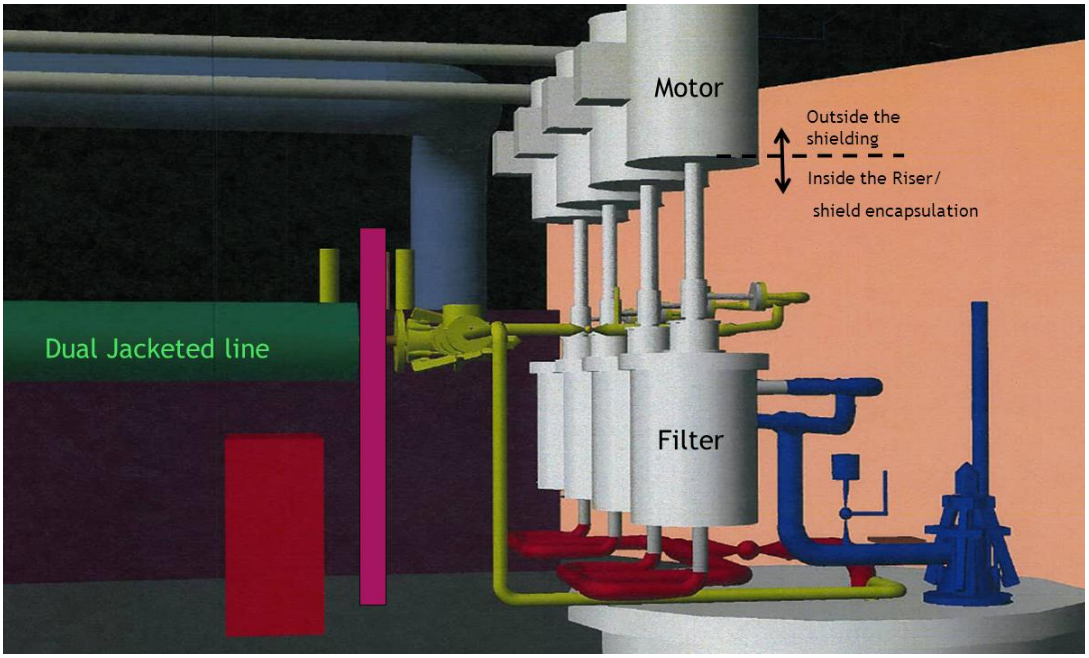

Figure 3-3. Representation of Rotary Microfilter System with Four Pack of Filters,

3.2.3 Relationship to Other Systems

The RMF System receives salt solution from Tank 41, filters it to remove MST and sludge solids, and passes it to the CST IXCs. It is mounted in a riser on the top of Tank 41.

3.2.4 Development History and Status

The SpinTek RMF used in the SCIX Program has been developed in partnership with DOE-EM for the purpose of deployment in radioactive service in the DOE complex. Testing has been completed on single disk laboratory scale [24], three disk pilot scale [25], and full scale, twenty five disk filter units [26, 27]. Thousand-hour tests using twenty five disk units with simulants have also been conducted at full scale [28, 29]. Figure 3-4 [29] shows the full scale, 25-disk unit used in these test activities.

Figure 3-4. Full scale, 25-disk Filter used in test activities

3.2.5 Relevant Environment

The RMF system processes a high radiation salt solution. The pump, RMF units, and associated piping are exposed to high levels of radiation. The motors and structural components on the tank top are outside the riser in a relatively low radiation environment. Full specification of the environment can be found in the *Task Requirements and Criteria Small Column Ion Exchange Program* document [30] and procurement specification for the RMF assembly [31].

3.2.6 Comparison of the Relevant Environment and the Demonstrated Environment

The relative and demonstrated environments are the same. Full scale, twenty five disk RMF units have processed a range of non-radioactive simulants [30]. SRS salt solution has been successfully processed using a single disk unit [24].

3.2.7 Technology Readiness Level Determination

The RMF System has attained TRL 5. A procurement specification for an RMF unit, which included the 1000-hour testing, was developed and awarded [32]. A second procurement specification for a complete RMF assembly has also been developed, although it was not awarded [31]. However, the final technology report on testing and development has not been completed. Also, the integrated testing is a major activity that has not been started. All required programmatic documents for TRL 6 have not been completed including a PDSA, performance baseline (cost and schedule), final design drawings, and RAMI report.

3.3 ION EXCHANGE COLUMN WITH CRYSTALLINE SILICOTITANATE

The IXC with CST is the heart of the SCIX system, and the primary CTE from which the SCIX name is derived. The challenges with heat management in earlier large column designs were the driver for conception and development of this modular, small column, at-tank approach.

3.3.1 Function of the Ion Exchange Column

The function of the IXC is to remove ^{137}Cs from the clarified salt solution that is fed from the rotary microfilter (RMF). The ^{137}Cs-decontaminated salt solution must meet the SPF WAC of ≤ 45 nCi ^{137}Cs/g [33], but a target of ≤ 6 nCi ^{137}Cs/g has been set based on SRS discussions with regulators. The IXC system must also be capable of sluicing the loaded CST to the grinder, nominally in half column volumes at a time.

3.3.2 Description of the Ion Exchange Column

The IXC CTE includes the ion exchange media (engineered form of CST known as IONSIV® IE-911CW), two ion exchange columns in series, piping to transfer the CSS between the two ion exchange columns, and the DSS from the lag column unit to Tank 50, and all process connections required for operation and maintenance of the IXCs [30]. The CSS (i.e., the effluent from the RMF CTE) shall flow through two ion exchange columns, operating in series, to remove ^{137}Cs from the waste stream. The ion exchange effluent (DSS) shall flow to Tank 50. The baseline ion exchange media to be used in the IXCs is CST. CST exchange media is a once through material that cannot be regenerated. Once fully loaded with ^{137}Cs, the spent CST resin must be sluiced from the column and transferred to the grinder to reduce the particle size. The ion exchange column will be equipped with two sluicing lines at different heights to allow sluicing half a batch volume at a time, or the whole batch, depending on the grinder capacity. The ^{137}Cs-loaded resin and any liquid will be sluiced from the ion exchange column to the grinder using Inhibited Water (IW). During use, the ^{137}Cs-loaded CST material generates heat requiring the ion exchange column to be cooled.

3.3.3 Relationship of the Ion Exchange Column to Other Systems

The IXC component interfaces with the RMF CTE and the SRD (Grinder) Unit CTE. Initially, the IXC interfaces with the CST preparation vessel, where the material is pretreated to remove fines and is caustic washed to remove impurities before transfer into the column. The IXC receives clarified feed from the RMF and transfers the ^{137}Cs-decontaminated solution to Tank 50. The loaded CST material is sluiced from the column to the grinder so that the material can be size-reduced as required.

3.3.4 Development History and Status

Crystalline silicotitanate was developed in the early 1990s by researchers at Sandia National Laboratory and Texas A&M University. The early history of the development of this non-elutable inorganic ion exchange material was described by Miller *et al.* [34]. In the late 1990s, an engineered form of CST (marketed by UOP under the trade name IONSIV® IE-911) was used to remove ^{137}Cs from liquid wastes stored in the Melton Valley Storage Tanks at the ORNL [35]. During the operational campaign at ORNL, ~270,000 gallons of waste were processed, with 7700 Ci of ^{137}Cs being removed.

Following the success of the CST application at ORNL, IE-911 was investigated as a possible technology for ^{137}Cs separation in the SWPF [36]. Despite adequate ^{137}Cs separation performance, CST was not selected for application in the SWPF, mainly because of safety reasons based on the heat generated in loading 5-foot diameter columns with ^{137}Cs, and the possibility of the column plugging when loaded with millions of curies of ^{137}Cs. Plugging attributed to Al/Si solids precipitation was observed during tests with actual waste. For the SCIX application, these issues are overcome by using smaller ion exchange columns with one central and four outer cooling loops.

The ability of IE-911 to separate ^{137}Cs was investigated with actual SRS tank waste solution in the late 1990s [37]. Liquid from SRS Tank 44F was used in the testing because of its high salt content (15 M Na) and high ^{137}Cs concentration (1.26 Ci/L). The as-received waste sample was diluted to 5.4 M Na before ion exchange processing. To achieve the desired Cs concentration in the feed solution, non-radioactive cesium nitrate was added to yield a total Cs concentration of 0.35 M. The feed solution was treated with MST to remove actinides and strontium before processing through the IE-911 column. Seventy-five liters of the diluted Tank 44F liquid was processed through a 1.5-cm diameter by 160-cm long IE-911 column. Excellent separation of ^{137}Cs was achieved (> 99.999%), and the decontaminated salt solution met the acceptance requirements for the SPF. Thermal modeling has been performed to evaluate the safety of the small-column design [38, 39]. Figure 3-5 illustrates the cross-section of the column used in the thermal modeling calculations.

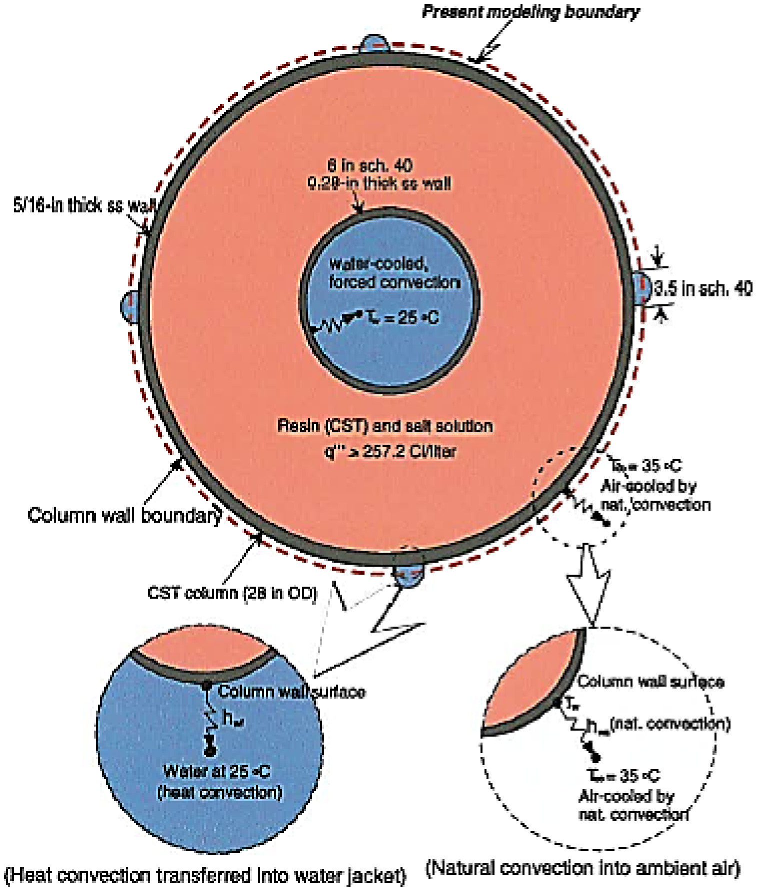

Figure 3-5. Cross-section of the CST ion exchange column used in thermal modeling studies

The thermal modeling results indicate that suspension of flow through a fully-loaded column (at an ambient temperature of 35 °C) would result in a maximum temperature of 63°C, provided active cooling is maintained on the column. Loss of active cooling under the stop flow condition could lead to temperatures of 156 °C; in this case the temperature would remain at the boiling point of the feed salt solution (130 °C) until all the liquid had evaporated from the column. The dried column could reach a peak temperature of 258 °C. In addition, off-normal cases in which the CST material is dropped to the bottom of the tank was also examined (Figure 3-6). In neither the case where the 450 gallons of fully-loaded CST is arranged in a hemispherical pile, nor in the case where it is evenly distributed across the bottom of the tank, would the at-wall temperature be expected to exceed the control limit of 100 °C.

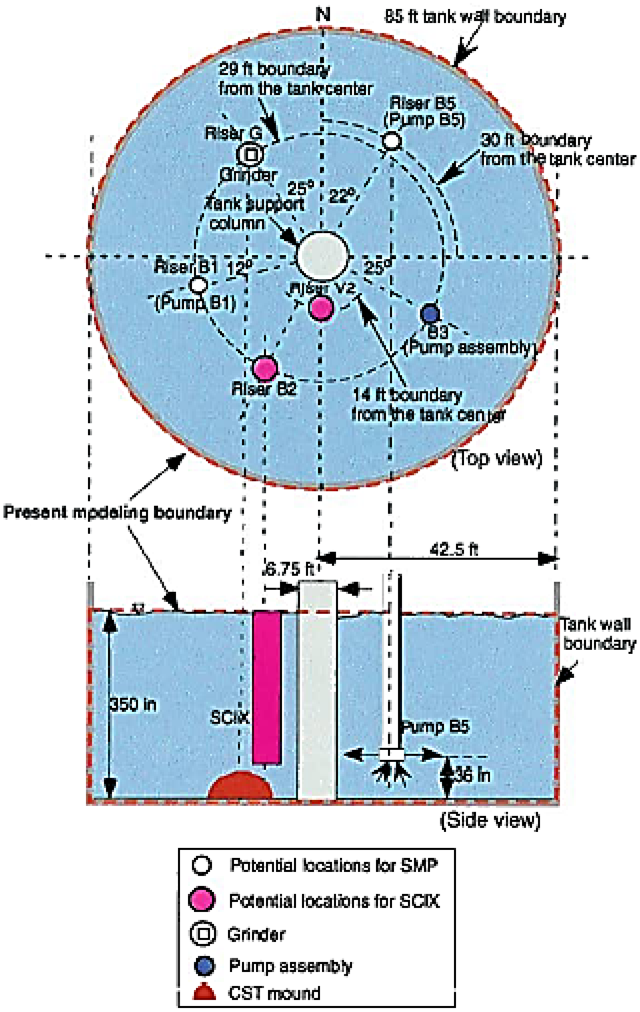

Figure 3-6. Conditions for thermal modeling of loaded CST ion exchange material should it be dumped to the bottom of Tank 41

Work was conducted at the Vitreous State Laboratory (VSL) of The Catholic University of America to test the sluicing function of the ion exchange column [40]. These tests were designed to: a) establish that sluicing can be done for the existing column design, b) determine the air/water pressure conditions required for sluicing and establish the optimal conditions to do the sluicing under controlled conditions with minimal amounts of water used for transport, and c) determine degree of control for partial column sluicing. The tests were performed at essentially full scale. Figure 3-7 shows the column used in the sluicing experiments. The results of the testing showed that, based on the existing column design, the ion exchange material can be sluiced with water at 35 to 45 psi. The column can also be sluiced with air, but care must be taken to prevent dewatering of the slurry in the vertical sluice discharge piping, which can lead to clogging. Water sluicing of an entire column required approximately one additional volume of added water to sluice the entire bed contents.

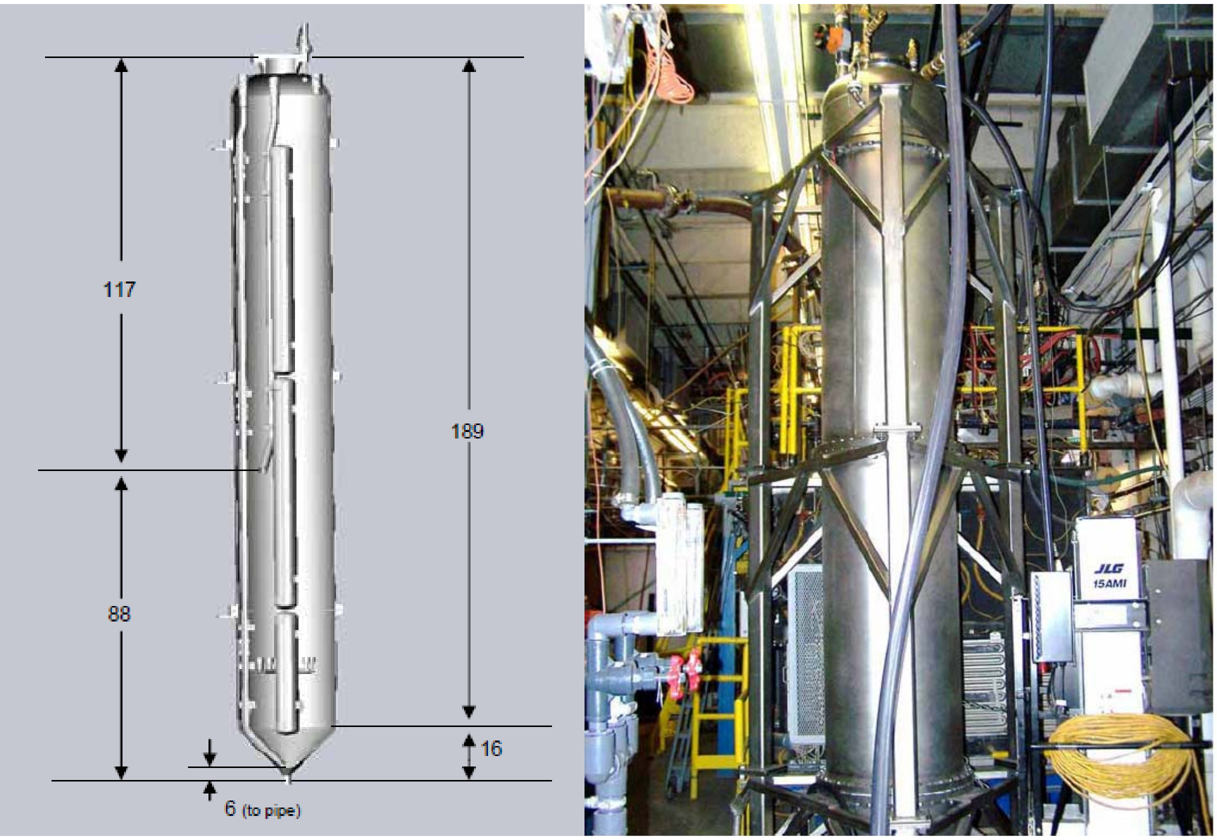

Figure 3-7. Full-scale IXC used for ion exchanger sluicing tests. (left, Schematic with dimension in inches; right, photograph of the column installed at VSL)

More recently, full-scale hydraulic and sluicing tests were conducted by Columbia Energy and Environmental Services (CEES) [41]. The results of this study were consistent with the earlier work conducted at VSL, indicating that the zeolite used as a surrogate for IE-911 could be readily removed from the column. This work also demonstrated the need to remove fines from the column so that the column can be operated within the desired pressure drop range. Figure 3-8 represents selected photographs of column components after post-test disassembly of the IXC at CEES. It should be noted that both the VSL and the CEES testing used a natural zeolite as a stand-in for IE-911 and that neither test actually examined the ^{137}Cs removal performance.

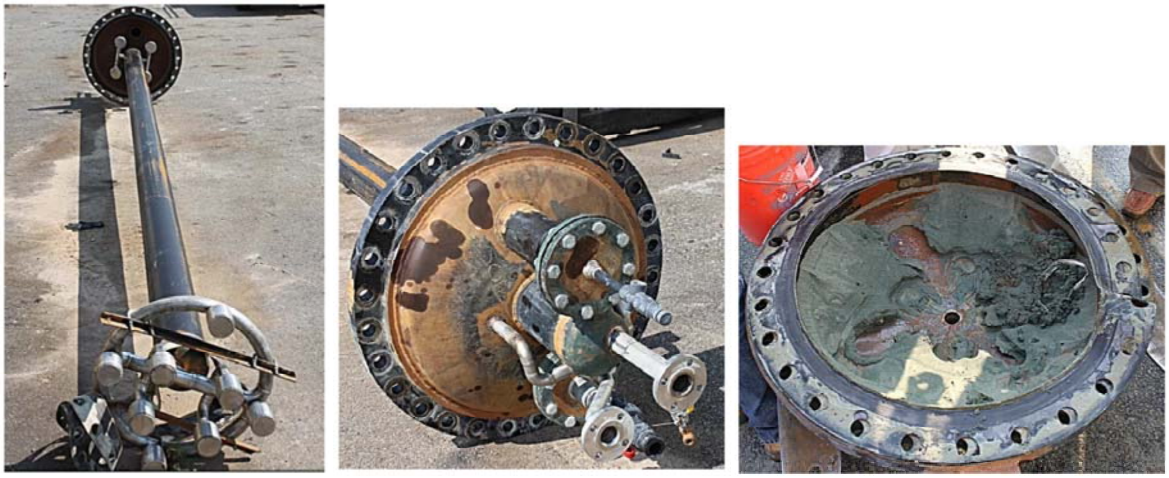

***Figure 3-8* Selected photos from the full-scale hydraulic and sluicing tests performed at CEES. (left, column internals; middle, connections on the top head of the IXC; right, media remaining in the bottom of the column after sluicing)**

3.3.5 Relevant Environment

The IXC system will treat solutions with ^{137}Cs concentration as high as 2.63 Ci/gal, specific gravity of 1.0 to 1.5, viscosity of 1 to 5 CP, and pH 12 to 14 [42]. The solution temperatures will range from 20 to 40 °C. The system is operated in a remote environment by a distributed control system.

3.3.6 Comparison of the Relevant Environment to the Demonstrated Environment

A laboratory-scale test was conducted using CST to separate ^{137}Cs from 75 L of diluted actual waste from SRS Tank 44F [36]. The column dimensions were 1.5-cm diameter by 160-cm long. The treated salt solution met the SPF acceptance specification g. Cs loading on the column was ~375 Ci/L.

The full-scale tests at VSL and CEES were performed in a simulated environment using a simulant for the IE-911 ion exchange material (the natural zeolite clinoptilolite). The fidelity of these tests can only be categorized as matching pieces of the final application, since the actual ion exchange performance (*i.e.,* the ability to remove Cs from a high salt solution) was not examined, nor was actual IE-911 used in the tests.

3.3.7 Technology Readiness Level Determination

The IXC CTE is assigned TRL 5. Extensive testing of the IE-911 ion exchange material has been completed, with a range of simulants, as well as actual SRS tank waste. Scale-up of IX processes is well understood. Features have been designed into the ion exchange column to control heat buildup and these features have been examined by thermal modeling. Full-scale sluicing of the ion exchange media (using clinoptilolite as a surrogate for IE-911) has been demonstrated. The primary actions to be taken to move the IXC to TRL 6 include: a) issuing a final RAMI document and PDSA, b) completion of a performance baseline including total program scope, schedule, and cost, c) completion of an integrated SCIX system test, and d) issuing the final Technical Report on Technology.

3.4 SPENT RESIN DISPOSAL (GRINDER UNIT)

For purposes of this discussion, the SRD module will be referred to as the Grinder Unit. The grinder technology selected for the SCIX system is an immersion mill design. It was selected after comparative testing of multiple technologies. In addition, work has been completed to ensure material flow and determine grinder equipment configuration and cycles. [40, 43] A key benefit of the immersion mill is that it eliminates the need for the ancillary equipment and connections (i.e. transfer pumps, valves, hoses, mechanical seals, etc.), which reduces processing time, as well as maintenance needs. Additionally, this type of mill helps eliminate phenomenon such as hydraulic media packing, floating of the charge, and the effects of seal features. Informative discussions regarding the benefits of the immersion mill technology, and comparison with other types of media-based mills (i.e. ball mills), can be found at www.hockmeyer.com.

3.4.1 Function of the Grinder Unit

The Cs-loaded CST from the IXC is sluiced into the Grinder Unit for size reduction to facilitate eventual transfer to DWPF. Its primary function is to grind the CST into a particle size distribution that is similar to the sludge being fed to the DWPF. This will ensure that the ground CST/sludge mixture does not stratify or segregate in the various DWPF process tanks, providing a homogeneous feed. Earlier work at SRNL has shown that CST can be ground to a size small enough to be suitable for processing at DWPF [43].

3.4.2 Description of the Grinder Unit

The overall flow-sheet for the SCIX system is shown in Figure 3-1. The CST sorbent is loaded until breakthrough on the lead column and then the column is taken out of service and sluiced to the grinder. The CST is ground until it meets the particle size acceptance criteria then it is pumped to Tank 40 and blended with sludge in preparation for feed to the DWPF, where it is incorporated into a glass matrix for final disposal.

Figure 3-9 shows a schematic of the basic internal configuration of an immersion mill. The type of immersion mill grinder selected for the SCIX system is a Hockmeyer design. It uses a circulation milling approach by rapidly pumping the slurry through the media field multiple times. This technology has been demonstrated to operate more rapidly and efficiently than conventional ball mills (e.g., basket type, horizontal, and vertical).

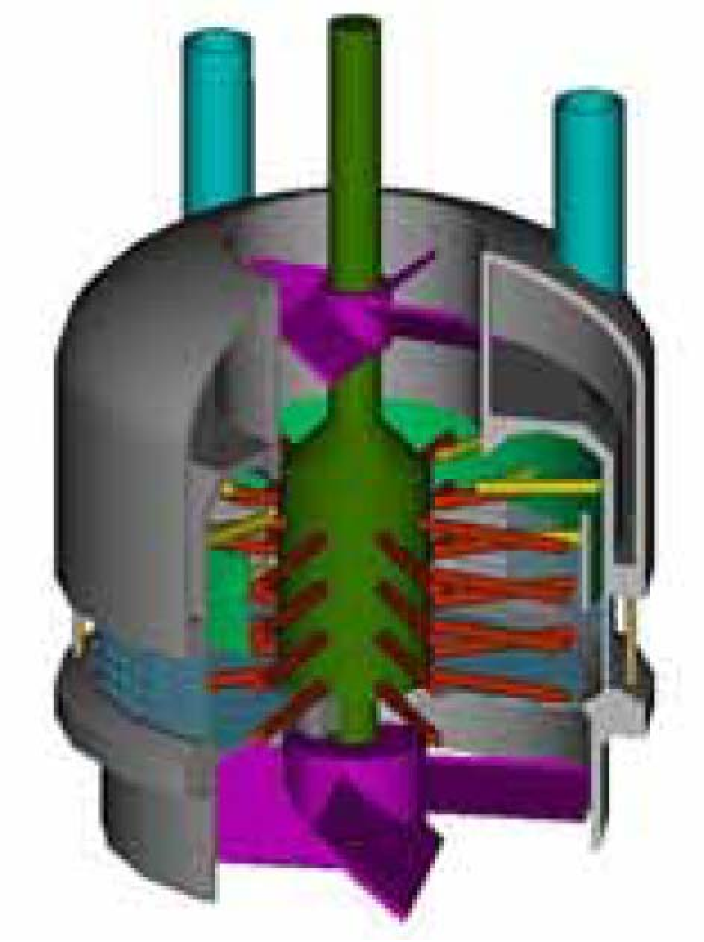

Figure 3-9*. Representation of Immersion Mill showing the rotating shaft with pins that mobilize the grinding media and the CST. The mill rests in a tank with screens the size of the final particle size. The mixing impeller circulates the bed.*

The immersion mill consists of an internal grinding area where the cesium loaded CST is pulled into the grinding area by the propeller. The CST is ground with small hard beads. Selection of the media material and size is based on the characteristics of the material being size reduced, and is key to the efficiency of the process. The mill is on a shaft which is lowered into the tank of the material to be ground. Metal pegs on the shaft rotate through the media and past stationary pegs in the grinding tank as shown in the figure. This action agitates the media to promote efficient grinding. One or two propellers, depending on application, are attached to the rotating shaft on the top and bottom of the tank. This establishes circulation cells that mix the material being ground while continually cycling it through the mill. This technology has been used previously at SRS on Tank 7 to grind zeolite.

Figure 3-10 shows the CST during grinding. The initial feed is on the order of 300 to 600-µ. After the grinding the average particle size is between 5 and 20 microns. The immersion mill technology has been demonstrated to be a reliable and effective technology.

Figure 3-10. Slurry of ground CST at 40% solids. The process will be operated at 20% solids for transport ease. The slurry is pumpable to Tank 40

3.4.3 Relationship to Other Systems

The Grinder Unit is the last processing step prior to transfer of the ground CST to Tank 40 where it is mixed with sludge to make feed to the DWPF. The IXC is taken off line when the sorbent is spent, and the sorbent is sluiced into the tank, or bucket, in which the Grinder Unit is installed. The material is continuously recirculated through the mill with the propeller(s) until the required particle size range is achieved. The material is fluid at this time and is batch transferred via eduction from the Grinder Unit bucket to Tank 40.

The grinder operates with sorbent fully loaded with Cs, and the gamma dose is quite high. The grinder is all metal, and is not impacted by the radiation to the extent polymers and organics would be, but this is an area that will be further investigated to ensure reliable remote operation and maintenance.

3.4.4 Development History and Status

Grinders of various types have been used in several DOE applications. The inline disperser was used to treat sludge and zeolite from the tanks at West Valley, New York. The immersion mill was used to treat the zeolite from Tank 7 at Savannah River. For the SCIX application these technologies were investigated, as well as a sonication size reduction system. Sonication is a newer technology that has shown promising results, which is why it was also selected for testing. The details of each are fully described in Mohr, et al [44], including the testing and performance results. After evaluation of the test results, the SCIX Program team selected the immersion mill (ball mill) as the preferred technology and has written the specifications for that technology [40, 42, 44]. Specifically, a Hockmeyer-based design was specified.

Hockmeyer introduced the immersion mill technology in the 1990's. Development has continued and a wide range of grinder units providing an array of capacities and size reduction capabilities (e.g., as small as 50 nanometer range) has been developed and deployed for commercial and Federal applications. Hockmeyer immersion mills are used in a wide variety of commercial applications, including paint manufacturing, pharmaceuticals, food processing, ink manufacturing, agricultural products, cosmetics production, and many more. Immersion mills as large as 1000 to 2000 gallon capacity units have been developed and are commercially available. The capacity requirement for the SCIX Grinder Unit is approximately 220 to 440 gallons (i.e., nominally half of an IXC volume to a full column volume). The final design will determine the tank volume and size of the grinder. Hockmeyer has a commercially available unit that has a rated capacity of 250 to 500 gallons. Although this particular unit has not been demonstrated to achieve the required particle size distribution, it illustrates that, while scale-up will require testing and validation, it is a process that is well known to experts in the industry.

3.4.5 Relevant Environment

The grinder is exposed to the highest radiation field in the process. This high radiation field impacts the shielding and containment design. Additionally, all operations, monitoring, and maintenance will be performed remotely.

3.4.6 Comparison of the Relevant Environment and the Demonstrated Environment

The grinding was performed in commercial equipment at the vendor site. Both CST and zeolite were used as feed. Zeolite has similar characteristics as CST, and is much less expensive. Sandia has characterized the CST in some detail [45]. The CST has been extensively evaluated by DOE-EM for decades and it is well understood.

While Cs-loaded CST has not been specifically demonstrated, prior activities to retrieve and grind Cs-loaded zeolite at SRS, West Valley, and Oak Ridge were successful completed. Savannah River Site has extensive experience in handling and treating materials in a high radiation environment. However, details of other key remote operations, such as media change-out (if required), grinder removal, maintenance/repair, and disposition must be finalized and demonstrated.

3.4.7 Technology Readiness Level Determination

Grinding is widely used for a variety of materials and has been successfully piloted with CST and surrogate sorbents for this program. However, in TRL 4 determination, question 21 states "Scaling documents and design of technology have been completed". In discussions with the engineering staff, this was noted as not being accomplished. Specifically, the detailed full scale vendor designs are yet to be completed. The reason for the need to do additional testing is the propeller mixing of this type material at this volume has not been previously demonstrated. The vendor would not complete design or quote a unit until this demonstration is successfully completed. Discussions were held with vendors to review the ability to scale from current testing to full scale. This involves a scale-up of approximately a factor of ten. Scale-up will involve determining the appropriate configuration of the mill internals to ensure the target particle size distribution is achieved, while not allowing excessive hold-up in the unit. The characteristics of the grinding media, such as size, quantity, and material, must be selected and validated to achieve the desired results.

This testing was planned to be conducted during FY2011; however, it was not completed prior to the decision to suspend the SCIX Program due to funding constraints. Completion of the scale-up testing, design validation, and documentation will satisfy the open items from the TRL 4 and TRL 5 calculator tables, resulting in an overall maturity of TRL 5 for this CTE. However, until this is completed, the Grinder Unit CTE is at TRL 3.

3.5 INTEGRATED WASTE PROCESSING SYSTEM

The SCIX system is a relatively simple flow sheet with a limited number of components. Integration of these systems will be readily accomplished once the full scale detailed vendor designs have been completed for all of the CTEs. Completion of these will allow the actual component interface designs to be completed such that a full scale integrated system can be designed, constructed, and tested. This is the primary activity that must be accomplished to attain TRL 6 for the SCIX WPS. Identification and development of a mitigation strategy for single point failures in the WPS is also required. This can be readily accomplished by finalizing the Operations Plan, which has been drafted but not finalized. See Appendix C.

Key interfaces with other CPE and process facilities, such as transfer to other tanks, compatibility with DWPF, and acceptability to the SPF WAC have been addressed appropriately, primarily due to the preceding efforts related to SWPF and MCU.

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4 CONCLUSIONS, OBSERVATIONS AND RECOMMENDATIONS

The SCIX Program Team has done an outstanding job of implementing the TRA/TMP process. Their efforts in developing a TMP have resulted in a focused and effective technology development program that has accelerated advancement of the technical maturity of the SCIX components and integrated system. The TRA Team, which includes most of the participants from the ETR conducted in September 2010, were extremely impressed with the amount and quality of work completed by the SCIX Program Team during the past year. The following conclusions, observations, and recommendations are offered.

4.1 CONCLUSIONS AND OBSERVATIONS

The SCIX system designs for the CTEs, as well as the integrated system, are comprehensive and appear to address all of the technical needs and programmatic requirements regarding processing capabilities. This is primarily due to the SCIX Program Team efforts to develop and implement a well-designed technology maturation strategy. The TRA Team did not find any individual CTEs or the integrated WPS that represent significant or unacceptable technical risk to the program mission.

A significant amount of work has been accomplished in a relatively short period of time by the SCIX Program Team. Testing and design have been completed at full or pilot scale for all CTEs, as well as most of the TEs. This has included testing with nonradioactive, representative simulants, as well as substantial testing with actual radioactive waste at laboratory and bench scale.

The SCIX Program is being suspended on September 30, 2011 due to funding constraints. This will result in disbanding of the SCIX Program Team, and thus potential loss of significant corporate knowledge related to the development history and technical status of the SCIX components and integrated system. The timing of this decision relative to the current phase of the SCIX Program is unfortunate and not amenable to an efficient restart if/when budget becomes available again. While a set of actions have been identified that are necessary to bring the SCIX Program to TRL 6, a subset of activities, which are considered to be relatively low cost and short duration, could be completed that would position the SCIX Program for a much more effective restart. These specific activities are discussed in more detail below in the recommendations.

While the TRA Team determined an overall maturity for the SCIX Program of TRL 3, that rating was based on the technical maturity of only one CTE, the Grinder Unit. If the scale-up testing had been conducted, the Grinder CTE would be at TRL 4. The logical progression of that activity would result in a full scale detailed vendor design, which would bring the Grinder CTE to TRL 5, and thus the entire SCIX Program would be TRL 5, based on the maturity of the CTEs. However, the integrated WPS for the SCIX Program was determined to be TRL 4. The SCIX system did not achieve TRL 6 because of two key activities:

- Documentation of the strategy to address single point failures (i.e. Operating Plan), and

- Completion of the integrated testing, which is a common for all CTEs to attain TRL 6.

In discussion with the SCIX Program Team, an Operating Plan has been drafted but not completed and thus not available as a reference that could be used as a basis or justification.

Generally, the overall TRL of a technology is based on the lowest TRL of an individual CTE or the integrated WPS. However, the WPS TRL calculators are specific to a formal project, as defined by DOE Order 413.3A [8]. The calculator tables have only been established for TRL 4 and TRL 6, which coincide with CD-1 and CD-2, respectively. Thus, no calculator table exists for TRL 5, which may be more appropriate for a program such as SCIX. This apparent gap in the TRA process is planned to be addressed in upcoming revisions to the EM TRA/TMP Guide [12].

4.2 RECOMMENDATIONS

The TRA Team developed the following recommendations based on the results of the assessment:

1. At a minimum, the following few activities should be completed. These are considered to be relatively low cost when compared to the full set of activities required to attain TRL 6, particularly the integrated testing.

    - The detailed vendor technology designs should be completed for all CTEs. This would include the scale-up design and testing for the Grinder.

    - Additionally, the interface designs to integrate the CTE components and other equipment into a system could then be finalized and SCIX final design holds released.

    - Similarly, completion of these final designs would allow completion of the PDSA.

2. A detailed scope, cost, and schedule estimate should be completed for the technology development and testing required to attain TRL 6, and documented in a revision of the TMP.

Implementing these recommendations would better position the program to facilitate a quick and cost effective restart. This is because the original SCIX Team will likely not be available, and thus some key corporate knowledge may be lost. Having the completed full scale design and PDSA would provide the validated documentation to immediately transition to fabrication and integrated testing, thus providing a much more efficient restart once funding becomes available to do so.

It should be noted that, with the exception of completing the scale-up testing and full scale vendor design for the Grinder CTE, the entire SCIX Program, including all CTEs and the integrated WPS, could attain TRL 6 with completion of the following actions:

- Issuance of a final RAMI document, PDSA, a final Technical Report on Technology, and a final Operating Plan that addresses single point failures;
- Completion of a performance baseline including total program scope, schedule, and cost; and,
- Completion of full scale integrated testing of the SCIX system.

Although not a specific recommendation, the preferred approach would be to bring the system to TRL 6 by completing the integrated testing, which would provide the information and data needed to complete the RAMI analysis, final Technical Report, and Operating Plan. The integrated testing represents the most costly and schedule intensive activity necessary to achieve the TRL 6; however, it is necessary because completion of all of the remaining activities is contingent on the results of the integrated testing. This would provide significant benefit to DOE-EM due to the schedule acceleration and cost savings associated with the SCIX Program and related activities that are part of the overall Enhanced Tank Waste Strategy. Nevertheless, the TRA Team recognizes that this would be much more costly and thus may not be feasible or warranted under the present SCIX Program status and funding scenario.

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5 LESSONS LEARNED AND CONTINUOUS PROCESS IMPROVEMENT

The SCIX TRA was considered a successful and beneficial review, for both the TRA Team and the SCIX Program Team. Several factors led to this, which should be considered in future assessments of this type. First, the TRA Team membership was constituted almost entirely of individuals that had participated on the SCIX ETR that was conducted during September 2010. This provided excellent continuity between the two reviews and also accelerated the process of understanding the current technical status of the SCIX Program. For example, specific recommendations from the ETR Team were readily recognized where they had been incorporated into the SCIX Program planning. As a result, the onsite review was more efficient and required less time from the technical experts supporting the SCIX Program.

Second, the SCIX Program Team had fully embraced the TRA/TMP concept and adopted it into their planning and strategy development, prior to any formal external reviews or assessments. This significantly improved the overall process and resulted in more benefit to the program. It also reduced the time, and thus the cost, for the TRA.

Finally, due to the decision to suspend the SCIX Program, the major justifications for conducting the TRA were: 1) to formally document the maturity of the system and to identify the specific activities remaining to bring the system to TRL 6, positioning DOE-SR for a much more efficient restart, and 2) to provide information that would be beneficial to other potential deployments. The first objective was clearly met as evidenced by the TRA Team recommendations. In addressing the second objective, DOE-ORP and WRPS personnel, who are involved with the potential SCIX deployment at Hanford, participated as observers of the SCIX TRA. Their involvement added to the overall benefit to DOE-EM in that not only did they identify specific data needs and operational parameters that are common, but also areas in which the systems differ. This will help focus the technology development and testing efforts on the highest priority needs, potentially reducing cost and accelerating the schedule. Future TRAs and ETRs should include, as appropriate, involvement of technical staff from sites that represent additional technology deployments, either planned or potential.

In addition to the positive outcomes of this TRA, some areas of improvement were also identified. First, as mentioned above, the EM TRA/TMP Guide is specific to projects, as defined in DOE Order 413.3A. It is generally adaptable to a Technology Demonstration Operations Activity such as the SCIX Program; however, the TRA/TMP Guide should be expanded to specifically include these “non-413” types of activities. For example, the integrated WPS calculator tables need to be expanded to include TRL 5, such that they are not solely aligned with CD-1 and CD-2 project phases, or exclusions should be provided in the text of the document that differentiate formal projects from Technology Demonstration Operations Activities. Second, some of the wording of the CTE TRL calculator questions are also specific to projects and should be revised to accommodate different types of activities, or separate tables should be developed for “non-413” activities. Finally, the wording of some of the CTE determination and TRL calculator questions is ambiguous and can lead to misinterpretations. The language in the

TRA/TMP Guide should be strengthened to ensure that both TRA teams and the project/program teams recognize that the tables and questions provided are examples and not the only acceptable questions. Specifically, the questions should be customized such that they are better aligned with the mission and needs of the project or program being assessed.

Finally, the SCIX Program was a fast-paced effort that was on schedule to be deployed in a matter of months. As a result, an initial external TRA was not completed. The SCIX Program Team did an outstanding job of conducting an internal TRA and consequently developing and implementing a TMP; however, some key findings resulted from the earlier ETR, which were not included in their original TMP. This occurred because in the process of working with the FPL to develop the ETR Charter, a specific request was made to conduct a cursory evaluation of the technical maturity of the SCIX system. Several members of the ETR Team were also familiar with the TRA process and were able to provide appropriate technical maturity-related recommendations. Fortunately, in this case, no significant technical issues were identified and the SCIX Program was able to incorporate the recommendations and move forward at the accelerated pace. In the future, the ETR and TRA processes need to be planned into the project or program strategy, as appropriate, from the outset and scope creep and “morphing” between ETRs and TRAs should be avoided.

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APPENDIX A. DETERMINATION & VALIDATION OF CRITICAL TECHNOLOGY ELEMENTS

Table A-1
Large Tank Monosodium Titanate Sorbent Strike CTE Questions

Technology Element:

Yes	**No**	**Set 1 Criteria**	**Notes**
		• Does the technology directly impact a functional requirement of the process or facility?	Yes
		• 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?	No
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	No
		• Are there uncertainties in the definition of the end state requirements for this technology?	No
		• Do limitations in the understanding of the technology impact the safety of the design?	No
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	No
		• Is the technology modified?	No
		• Has the technology been repackaged so a new relevant environment is realized?	Yes, deployment in a large tank, to include suspension and re-suspension using Submersible Mixing Pumps, achieving appropriate residence time, transfer to Rotary Microfilters using in-tank pumps.
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Yes, deployment in a large tank, to include suspension and re-suspension using Submersible Mixing Pumps, achieving appropriate residence time, transfer to Rotary Microfilters using in-tank pumps.

Table A-2
Rotary Microfilter CTE Questions

Technology Element:

Yes	No	Set 1 Criteria	Notes
		• Does the technology directly impact a functional requirement of the process or facility?	Yes
		• 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?	No
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	No
		• Are there uncertainties in the definition of the end state requirements for this technology?	No
		• Do limitations in the understanding of the technology impact the safety of the design?	No
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	No
		• Is the technology modified?	Yes
		• Has the technology been repackaged so a new relevant environment is realized?	Yes
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	No, system design is new for this application (i.e. four units ganged and working simultaneously)

Table A-3
Crystalline Silicotitanate Sorbent Preparation CTE Questions

Technology Element:

Yes	**No**	**Set 1 Criteria**	**Notes**
		• Does the technology directly impact a functional requirement of the process or facility?	Yes
		• 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?	No
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	No
		• Are there uncertainties in the definition of the end state requirements for this technology?	No
		• Do limitations in the understanding of the technology impact the safety of the design?	No
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	No
		• Is the technology modified?	No
		• Has the technology been repackaged so a new relevant environment is realized?	No
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	No

Table A-4
Ion Exchange Column CTE Questions

Technology Element:			
Yes	**No**	**Set 1 Criteria**	**Notes**
		• Does the technology directly impact a functional requirement of the process or facility?	Yes
		• 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?	No
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	No
		• Are there uncertainties in the definition of the end state requirements for this technology?	No
		• Do limitations in the understanding of the technology impact the safety of the design?	No
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	No
		• Is the technology modified?	Yes
		• Has the technology been repackaged so a new relevant environment is realized?	Yes
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	No

Table A-5
Spent Resin Disposal (Grinder) CTE Questions

Technology Element:

Yes	**No**	**Set 1 Criteria**	**Notes**
		• Does the technology directly impact a functional requirement of the process or facility?	Yes
		• 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?	No
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	No
		• Are there uncertainties in the definition of the end state requirements for this technology?	No
		• Do limitations in the understanding of the technology impact the safety of the design?	No
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	No
		• Is the technology modified?	No
		• Has the technology been repackaged so a new relevant environment is realized?	Yes
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	No

Table A-6
Common Plant Equipment CTE Questions

Technology Element:			
Yes	**No**	**Set 1 Criteria**	**Notes**
		• Does the technology directly impact a functional requirement of the process or facility?	Yes
		• 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?	No
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	No
		• Are there uncertainties in the definition of the end state requirements for this technology?	No
		• Do limitations in the understanding of the technology impact the safety of the design?	No
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	No
		• Is the technology modified?	No
		• Has the technology been repackaged so a new relevant environment is realized?	No
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	No

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APPENDIX B. TECHNOLOGY READINESS LEVEL CALCULATORS AS MODIFIED FOR THE DOE OFFICE OF ENVIRONMENTAL MANAGEMENT

(NOTE: The references listed in Tables B-1 through B-11 are not the same as the list of references for the main body of the report, shown in Section 6. The references that correspond to this section are listed in Appendix D.)

Table B-1
TRL 5 Questions for Critical Technology Elements

CTE: Large Tank MST Sorbent Strike

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	1. The relationships between major system and sub-system parameters are understood on a laboratory scale.	Ref. 33, 105, 108
T	Y	2. Plant size components available for testing	Ref. 10
T	Y	3. System interface requirements known (How would system be integrated into the plant?)	Ref. 14, 87
P	Y	4. Preliminary design engineering has begun	ARP is an operational facility using MST to absorb Sr and actinides. SMPs operational in waste tanks. Ref. 26, 125
T	Y	5. Requirements for technology verification established, to include testing and validation of safety functions.	Ref. 114, 80
T	Y	6. Interfaces between components/subsystems in testing are realistic (bench top with realistic interfaces)	Ref. 45, 48, 52, 53, 59, 62, 61, 58, 1
M	Y	7. Prototypes of equipment system components have been created (know how to make equipment)	Ref. 26
M	Y	8. Manufacturing techniques have been defined to the point where largest problems defined	Ref. 26
M	Y	9. Availability and reliability (RAMI) target levels identified	Ref. 87
T	Y	10. Laboratory environment for testing modified to approximate operational environment; to include testing and validation of safety functions.	Ref. 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	11. Component integration issues and requirements identified	Ref. 14, 87
P	Y	12. Detailed 3D design drawings and P&IDs have been completed to support specification of a prototypic engineering-scale testing system	ARP is an operational facility using MST to absorb Sr and actinides. SMPs operational in waste tanks. Ref. 26, 125
T	Y	13. Requirements definition with performance thresholds and objectives established for final plant design	Ref. 87, 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
P	Y	14. Preliminary technology feasibility engineering report completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 20
T	Y	15. Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Ref. 119, 121, 100

Table B-1
TRL 5 Questions for Critical Technology Elements

CTE: Large Tank MST Sorbent Strike

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	16. Formal control of all components to be used in final prototypical test system	Ref. 114, 26
P	Y	17. Configuration management plan in place	Ref. 9
T	Y	18. The range of all relevant physical and chemical properties has been determined (to the extent possible)	Ref. 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	19. Simulants have been developed that cover the full range of waste properties	Ref. 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	20. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes	Ref. 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	21. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Ref. 110, 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	22. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed - results validate design	Ref. 47, 46, 63, 66
T	Y	23. Test results for simulants and real waste are consistent	Ref. 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	24. Laboratory to engineering scale scale-up issues are understood and resolved; to include testing and validation of safety functions.	Ref. 91, 115, 40, 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	25. Limits for all process variables/parameters and safety controls are being refined	Ref. 91, 115, 40
P	Y	26. Test plan documents for prototypical engineering-scale tests completed	ARP is an operational facility using MST to absorb Sr and actinides
P	Y	27. Risk management plan documented; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 126
P	Y	28. Test plan for prototypical lab-scale tests executed – results validate design; to include testing and validation of safety functions.	Ref. 72, 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
P	Y	29. Finalization of hazardous material forms and inventories, completion of process hazard analysis, and identification of system/components level safety controls at the appropriate preliminary design phase.	Ref. 91, 115, 40, 128, 129

Table B-2
TRL 6 Questions for Critical Technology Elements

CTE: Large Tank MST Sorbent Strike

T/P/M	Y/N	Criteria	Basis and Supporting Documents
T	Y	1. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	Ref. 87
M/P	N	2. Availability and reliability (RAMI) levels established	Ref. 8 Conduct RAMI Analysis
P	N	3. Preliminary design drawings for final plant system are complete; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process*	Complete Vendor Design
T	Y	4. Operating environment for final system known	Ref. 87, 14
P	N	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 8 Conduct RAMI Analysis
P	N	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	The SCIX Program will be suspended effective October 2011. Baseline through final design is complete; baseline will be reset upon program restart.
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 71, 124
P	Y	8. Operational requirements document available; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 87, 128, 129
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 30, 94
T	Y	10. System technical interfaces defined	Ref. 87
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 99
P	Y	12. Analysis of project timing ensures technology will be available when required	Program schedule tracks activities required to ensure viability of program execution
P	Y	13. Have established an interface control process	Ref. 7
P	Y	14. Acquisition program milestones established for start of final design (CD-2)	Operations Activity does not have critical decisions. Procurement strategy has been identified.
M	Y	15. Critical manufacturing processes prototyped	ARP is an operational facility using MST to absorb Sr and actinides. SMPs operational in waste tanks.

Table B-2
TRL 6 Questions for Critical Technology Elements

CTE: Large Tank MST Sorbent Strike

T/P/M	Y/N	Criteria	Basis and Supporting Documents
M	Y	16. Most pre-production hardware is available to support fabrication of the system	ARP is an operational facility using MST to absorb Sr and actinides. SMPs operational in waste tanks. Ref. 26
T	Y	17. Engineering feasibility fully demonstrated	Ref. 99, 43
M	Y	18. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	ARP is an operational facility using MST to absorb Sr and actinides. SMPs operational in waste tanks. Ref. 26, 125
P	Y	19. Technology "system" design specification complete and ready for detailed design	Ref. 20
T	Y	20. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 124
P	Y	21. Formal configuration management program defined to control change process	Ref. 9
P	N	22. Final Technical Report on Technology completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Issue Final Technical Report on Technology
M	Y	23. Process and tooling are mature to support fabrication of components/system	ARP is an operational facility using MST to absorb Sr and actinides. SMPs operational in waste tanks. Ref. 26, 125
T	Y	24. Engineering-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Ref. 124
T	Y	25. Engineering to full-scale scale-up issues are understood and resolved	Ref. 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	26. Laboratory and engineering-scale experiments are consistent	Ref. 98, 47, 46, 63, 66, 54, 55, 64, 69, 57, 65
T	Y	27. Limits for all process variables/parameters and safety controls are defined	Ref. 124, 91, 115, 40
M	Y	28. Production demonstrations are complete (at least one time)	ARP is an operational facility using MST to absorb Sr and actinides. SMPs operational in waste tanks. Ref. 26, 125
P	N	29. Integration demonstrations have been completed (e.g. construction of testing system); to include testing and validation of safety functions.	Must complete Integrated Test

Table B-2
TRL 6 Questions for Critical Technology Elements

CTE: Large Tank MST Sorbent Strike

T/P/M	Y/N	Criteria	Basis and Supporting Documents
P	N	30. Finalization of hazardous material forms and inventories; completion of process hazard analysis, identification of system/components level safety controls at the appropriate preliminary/final design phase.	Ref. 40, 128, 129 Issue Preliminary Documented Safety Analysis

Table B-3
TRL 5 Questions for Critical Technology Elements

CTE: Rotary Microfilter

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	1. The relationships between major system and sub-system parameters are understood on a laboratory scale.	Ref. 106, 44, 95
T	Y	2. Plant size components available for testing	Full scale testing has been carried out Ref. 127, 24, 50, 56
T	Y	3. System interface requirements known (How would system be integrated into the plant?)	Ref. 85, 14, 92, 87
P	Y	4. Preliminary design engineering has begun	Full scale RMF units have been produced Ref. 68
T	Y	5. Requirements for technology verification established, to include testing and validation of safety functions.	Safety function is passive containment outside the primary pressure boundary; will be verified during testing in support of TRL7. Ref. 93
T	Y	6. Interfaces between components/subsystems in testing are realistic (bench top with realistic interfaces)	Ref. 44
M	Y	7. Prototypes of equipment system components have been created (know how to make equipment)	Full scale RMF units have been produced Ref. 127, 24
M	Y	8. Manufacturing techniques have been defined to the point where largest problems defined	Full scale RMF units have been produced Ref. 50, 56
M	Y	9. Availability and reliability (RAMI) target levels identified	Ref. 87
T	Y	10. Laboratory environment for testing modified to approximate operational environment; to include testing and validation of safety functions.	Ref. 44 Safety function is passive containment outside the primary pressure boundary; will be verified during testing in support of TRL7.

Table B-3
TRL 5 Questions for Critical Technology Elements

CTE: Rotary Microfilter

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	11. Component integration issues and requirements identified	Ref. 44, 85, 87
P	Y	12. Detailed 3D design drawings and P&IDs have been completed to support specification of a prototypic engineering-scale testing system	Ref. 95, 44
T	Y	13. Requirements definition with performance thresholds and objectives established for final plant design	Ref. 87, 37
P	Y	14. Preliminary technology feasibility engineering report completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 17
T	Y	15. Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Full scale RMF testing completed Ref. 95, 44, 50, 56
T	Y	16. Formal control of all components to be used in final prototypical test system	Ref. 127
P	Y	17. Configuration management plan in place	Ref. 9
T	Y	18. The range of all relevant physical and chemical properties has been determined (to the extent possible)	Ref. 44, 14, 67
T	Y	19. Simulants have been developed that cover the full range of waste properties	Ref. 44, 14, 67
T	Y	20. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes	Ref. 44, 106
T	Y	21. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Ref. 95, 44, 67, 50, 56
T	Y	22. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed - results validate design	Ref. 106
T	Y	23. Test results for simulants and real waste are consistent	Ref. 106, 44
T	Y	24. Laboratory to engineering scale scale-up issues are understood and resolved; to include testing and validation of safety functions.	Full scale tests have been conducted Safety function is passive containment outside the primary pressure boundary; will be verified during testing in support of TRL7. Ref. 44, 50, 56
T	Y	25. Limits for all process variables/parameters and safety controls are being refined	Ref. 91, 115, 40

Table B-3
TRL 5 Questions for Critical Technology Elements

CTE: Rotary Microfilter

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P	Y	26. Test plan documents for prototypical engineering-scale tests completed	Full scale testing completed Ref. 127, 50, 56
P	Y	27. Risk management plan documented; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 126
P	Y	28. Test plan for prototypical lab-scale tests executed – results validate design; to include testing and validation of safety functions.	Safety function is passive containment outside the primary pressure boundary; will be verified during testing in support of TRL7. Ref. 95
P	Y	29. Finalization of hazardous material forms and inventories, completion of process hazard analysis, and identification of system/components level safety controls at the appropriate preliminary design phase.	Ref. 91, 115, 40, 128, 129

Table B-4
TRL 6 Questions for Critical Technology Elements

CTE: Rotary Microfilter

T/P/M	Y/N	Criteria	Basis and Supporting Documents
T	Y	1. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	Ref. 87, 23
M/P	N	2. Availability and reliability (RAMI) levels established	Final RAMI document not yet produced. Ref. 8
P	Y	3. Preliminary design drawings for final plant system are complete; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process*	System ordered Procurement Specification Ref. 27
T	Y	4. Operating environment for final system known	Ref. 87
P	N	5. Collection of actual maintainability, reliability, and supportability data has been started	Final RAMI document has not yet been produced Ref. 8, 50, 66
P	N	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	The SCIX Program will be suspended effective October 2011. Baseline through final design is complete; baseline will be reset upon program restart.

Table B-4
TRL 6 Questions for Critical Technology Elements

CTE: Rotary Microfilter

T/P/M	Y/N	Criteria	Basis and Supporting Documents
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Variable limits for solids concentration, vibration, temperature, pressure, and flow rate can be found in procurement specification Ref. 27 Safety controls are specified in Ref. 115 and Ref. 40, Ref. 23, 17
P	Y	8. Operational requirements document available; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 87, 128, 129
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 44
T	Y	10. System technical interfaces defined	Ref. 87
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 44
P	Y	12. Analysis of project timing ensures technology will be available when required	Program schedule tracks activities required to ensure viability of program execution so far. Future of program is uncertain.
P	Y	13. Have established an interface control process	Ref. 7
P	NA	14. Acquisition program milestones established for start of final design (CD-2)	Operations Activity does not have critical decisions. Procurement strategy has been identified.
M	Y	15. Critical manufacturing processes prototyped	Full scale RMF unit has been produced Ref. 50, 56
M	Y	16. Most pre-production hardware is available to support fabrication of the system	Full scale RMF units have been produced Ref. 50, 56
T	Y	17. Engineering feasibility fully demonstrated	Ref. 44, 50, 56, 67
M	Y	18. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Full scale RMF units have been produced Ref. 50, 56
P	Y	19. Technology "system" design specification complete and ready for detailed design	Ref. 17
T	Y	20. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 44, 67, 50, 56
P	Y	21. Formal configuration management program defined to control change process	Ref. 9
P	N	22. Final Technical Report on Technology completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Final Technical Report on Technology has not been issued

Table B-4
TRL 6 Questions for Critical Technology Elements

CTE: Rotary Microfilter

T/P/M	Y/N	Criteria	Basis and Supporting Documents
M	Y	23. Process and tooling are mature to support fabrication of components/system	Full scale RMF has been fabricated Ref, 50, 56
T	Y	24. Engineering-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Ref. 44, 67, 50, 56
T	Y	25. Engineering to full-scale scale-up issues are understood and resolved	Full scale (25 disk) RMF has been produced and tested Ref. 44, 67, 68, 83, 50, 56
T	Y	26. Laboratory and engineering-scale experiments are consistent	Ref. 4, 109, 111, 44, 50, 56, 67
T	N	27. Limits for all process variables/parameters and safety controls are defined	Variable limits for solids concentration, vibration, temperature, pressure, and flow rate can be found in procurement specification Ref. 27, Safety controls are specified in Ref. 115 and Ref. 40, but the final limits await completion of the final PDSA. Ref. 23, 87, 91, 17
M	Y	28. Production demonstrations are complete (at least one time)	Full scale, 25 disk RMFs have been produced and tested. Ref. 44, 50, 56, 67
P	N	29. Integration demonstrations have been completed (e.g. construction of testing system); to include testing and validation of safety functions.	Fully integrated SCIX system has not been tested Individual RMF has been tested at full scale for ~ 1500 hrs. Process control of two RMFs operating in parallel has been demonstrated. Ref. 44, 67
P	N	30. Finalization of hazardous material forms and inventories; completion of process hazard analysis, identification of system/components level safety controls at the appropriate preliminary/final design phase.	Ref. 40, 128, 129 Preliminary Documented Safety Analysis (PDSA) has not yet been prepared

Table B-5
TRL 5 Questions for Critical Technology Elements

CTE: Ion Exchange Columns with CST

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	1. The relationships between major system and sub-system parameters are understood on a laboratory scale.	Ref: 18, 28, 62, 90
T	Y	2. Plant size components available for testing	Received 4 Vendor Responses to Request for Proposal. These are business sensitive and cannot be directly referenced.
T	Y	3. System interface requirements known (How would system be integrated into the plant?)	Ref. 112, 15, 87
P	Y	4. Preliminary design engineering has begun	Ref. 90, 3
T	Y	5. Requirements for technology verification established, to include testing and validation of safety functions.	Ref. 28, 18
T	Y	6. Interfaces between components/subsystems in testing are realistic (bench top with realistic interfaces)	Ref. 97
M	Y	7. Prototypes of equipment system components have been created (know how to make equipment)	Ref. 32, 35, 97
M	Y	8. Manufacturing techniques have been defined to the point where largest problems defined	Components are standard piping / pressure vessels; no special manufacturing techniques required. CST has been manufactured. Ref. 86
M	Y	9. Availability and reliability (RAMI) target levels identified	Ref. 87
T	Y	10. Laboratory environment for testing modified to approximate operational environment; to include testing and validation of safety functions.	Ref. 120, 101, 34, 32
T	Y	11. Component integration issues and requirements identified	Ref. 36, 18
P	Y	12. Detailed 3D design drawings and P&IDs have been completed to support specification of a prototypic engineering-scale testing system	Ref. 90, 3
T	Y	13. Requirements definition with performance thresholds and objectives established for final plant design	Ref. 87
P	Y	14. Preliminary technology feasibility engineering report completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 5, 115, 18
T	Y	15. Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Ref. 32, 35, 31
T	Y	16. Formal control of all components to be used in final prototypical test system	Ref. 28
P	Y	17. Configuration management plan in place	Ref. 9

Table B-5
TRL 5 Questions for Critical Technology Elements

CTE: Ion Exchange Columns with CST

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	18. The range of all relevant physical and chemical properties has been determined (to the extent possible)	Ref. 11, 12. 107, 96, 60, 32, 97
T	Y	19. Simulants have been developed that cover the full range of waste properties	Ref. 118, 116, 122, 103, 97
T	Y	20. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes	Ref. 11, 122
T	Y	21. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Ref. 117, 122
T	Y	22. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed - results validate design	Ref. 122
T	Y	23. Test results for simulants and real waste are consistent	Ref. 122 (Figure 12)
T	Y	24. Laboratory to engineering scale scale-up issues are understood and resolved; to include testing and validation of safety functions.	Ref. 32, 35, 18, 73, 48, 52, 53, 59, 62, 61, 58, 54, 63, 66, 55, 64, 69, 49, 70, 51, 57, 65, 97, 123, 90
T	Y	25. Limits for all process variables/parameters and safety controls are being refined	Ref. 91, 115, 40
P	Y	26. Test plan documents for prototypical engineering-scale tests completed	Ref. 32, 89, 2
P	Y	27. Risk management plan documented; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 126
P	Y	28. Test plan for prototypical lab-scale tests executed – results validate design; to include testing and validation of safety functions.	Ref. 97
P	Y	29. Finalization of hazardous material forms and inventories, completion of process hazard analysis, and identification of system/components level safety controls at the appropriate preliminary design phase.	Ref. 91, 115, 40, 15, 128, 129

Table B-6
TRL 6 Questions for Critical Technology Elements

CTE: Ion Exchange Columns with CST

T/P/M	Y/N	Criteria	Basis and Supporting Documents

Table B-6
TRL 6 Questions for Critical Technology Elements

CTE: Ion Exchange Columns with CST

T/P/M	Y/N	Criteria	Basis and Supporting Documents
T	Y	1. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	Ref. 96, 60
M/P	Y	2. Availability and reliability (RAMI) levels established	Ref. 87
P	N	3. Preliminary design drawings for final plant system are complete; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process*	Complete Vendor Design
T	Y	4. Operating environment for final system known	Ref. 15, 87
P	N	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 8 Conduct RAMI Analysis
P	N	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	The SCIX Program will be suspended effective October 2011. Baseline through final design is complete; baseline will be reset upon program restart.
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 18
P	Y	8. Operational requirements document available; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 87, 128, 129
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 40
T	Y	10. System technical interfaces defined	Ref. 87
T	N	11. Component integration demonstrated at an engineering scale	The integrated demonstration must be performed.
P	Y	12. Analysis of project timing ensures technology will be available when required	Ref. 76
P	Y	13. Have established an interface control process	Ref. 7
P	Y	14. Acquisition program milestones established for start of final design (CD-2)	Operations Activity does not have critical decisions. Procurement strategy has been identified.
M	Y	15. Critical manufacturing processes prototyped	Ref. 86, 90, 3
M	Y	16. Most pre-production hardware is available to support fabrication of the system	Received EOI response from four vendors
T	Y	17. Engineering feasibility fully demonstrated	Ref. 32, 35
M	Y	18. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Received EOI response from four vendors
P	Y	19. Technology ”system” design specification complete and ready for detailed design	Ref. 18

Table B-6
TRL 6 Questions for Critical Technology Elements

CTE: Ion Exchange Columns with CST

T/P/M	Y/N	Criteria	Basis and Supporting Documents
T	N	20. Engineering-scale system is high-fidelity functional prototype of operational system	Prototyping of sluicing with zeolite has been completed, but engineering scale testing of the Cs removal efficiency of the CST has not. This would most likely be accomplished in the integrated test. Ref. 90
P	Y	21. Formal configuration management program defined to control change process	Ref. 9
P	N	22. Final Technical Report on Technology completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Issue Final Technical Report on Technology
M	Y	23. Process and tooling are mature to support fabrication of components/system	Ref. 86, 90, 3
T	N	24. Engineering-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Need to perform integrated test.
T	Y	25. Engineering to full-scale scale-up issues are understood and resolved	Ref. 49, 70, 51
T	Y	26. Laboratory and engineering-scale experiments are consistent	Ref. 104
T	N	27. Limits for all process variables/parameters and safety controls are defined	Ref. 40, 18 Specific process limits and safety controls still need to be defined for the IX process (e.g., flow rates, Na concentration, etc.).
M	Y	28. Production demonstrations are complete (at least one time)	Production of CST has been demonstrated.
P	N	29. Integration demonstrations have been completed (e.g. construction of testing system); to include testing and validation of safety functions.	Complete Integrated Test
P	N	30. Finalization of hazardous material forms and inventories; completion of process hazard analysis, identification of system/components level safety controls at the appropriate preliminary/final design phase.	Ref. 40, 128, 129 Issue Preliminary Documented Safety Analysis

Table B-7
TRL 3 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation

Table B-7
TRL 3 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P	Y	1. Some key process and safety requirements are identified; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process..*	Ref. 91, 115, 40, 128, 129
P	Y	2. Key process parameters/variables and associated hazards have begun to be identified; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process..*	Ref. 91, 115, 40, 128, 129
T	Y	3. Predictions of elements of technology capability validated by analytical studies	Ref. 102
P	Y	4. The basic science has been validated at the laboratory scale	Ref. 38, 102
T	N/A	5. Science known to extent that mathematical and/or computer models and simulations are possible	Modeling and Simulation not used for this CTE
P	Y	6. Preliminary system performance characteristics and measures have been identified and estimated	Ref. 87
T	N/A	7. Predictions of elements of technology capability validated by Modeling and Simulation (M&S)	Modeling and Simulation not used for this CTE
T	Y	8. Basic laboratory research equipment used to verify physical principles	Ref. 102
T	Y	9. Predictions of elements of technology capability validated by laboratory experiments	Ref. 102
P	Y	10. Customer representative identified to work with development team	Program Team Table Ref. 75
P	Y	11. Customer participates in requirements generation	Ref. 74, 75
P	Y	12. Requirements tracking system defined to manage requirements creep	Ref. 81
M		13. Design techniques have been identified/developed	Ref. 6
T	Y	14. Paper studies indicate that system components ought to work together	Ref. 113, 38
P	Y	15. Customer identifies technology need date.	Ref. 13
T	Y	16. Performance metrics for the system are established (What must it do)	Ref. 87
P	Y	17. Scaling studies have been started	Ref. 102, 113
M	Y	18. Current manufacturability concepts assessed	A commercial unit will be adapted
M	Y	19. Sources of key components for laboratory testing identified	Ref. 38

Table B-7
TRL 3 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	20. Scientific feasibility fully demonstrated	Ref. 102, 38
T	Y	21. Analysis of present state of the art shows that technology fills a need	Ref. 102, 38
P	Y	22. Risk areas identified in general terms	Ref. 126
P	Y	23. Risk mitigation strategies identified	Ref. 126
P	Y	24. Rudimentary best value analysis performed for operations	Ref. 126
T	Y	25. Key physical and chemical properties have been characterized for a number of waste samples	Ref. 89, 39
T	Y	26. A simulant has been developed that approximates key waste properties	Ref. 102, 89
T	Y	27. Laboratory scale tests on a simulant have been completed	Ref. 102
T	Y	28. Specific waste(s) and waste site(s) has (have) been defined	Ref. 87
T	Y	29. The individual system components have been tested at the laboratory scale	Ref. 102, 113, 38

Table B-8
TRL 4 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	1. Key process variables/parameters been fully identified and preliminary hazard evaluations have been performed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 91, 115, 40, 128, 129
M	Y	2. Laboratory components tested are surrogates for system components	Ref. 113, 88
T	Y	3. Individual components tested in laboratory~~/~~or by supplier	Ref. 102, 113, 88
T	Y	4. Subsystems composed of multiple components tested at lab scale using simulants	Ref. 113, 88
T	N/A	5. Modeling & Simulation used to simulate some components and interfaces between components	Modeling and simulation not used for this CTE
P	Y	6. Overall system requirements for end user's application are known and documented	Ref. 87
P	Y	7. System performance metrics measuring requirements have been established	Ref. 87
P	Y	8. Laboratory testing requirements derived from system requirements are established	Ref. 89
T	Y	9. Laboratory experiments with available components show that they work together	Ref. 113, 88
T	Y	10. Analysis completed to establish component compatibility (Do components work together)	Ref. 113, 88
P	Y	11. Science and Technology Demonstration exit criteria established (S&T targets understood, documented, and agreed to by sponsor)	Exit criterion is achieving a TRL 6 as documented in this Technology Maturation Plan.
T	Y	12. Technology demonstrates basic functionality in simulated environment	Ref. 113
M	Y	13. Scalable technology prototypes have been produced (Can components be made bigger than lab scale)	Ref. 113, 88
P	Y	14. Draft conceptual designs have been documented (system description, process flow diagrams, general arrangement drawings, and material balance)	Ref. 19, 22
M	Y	15. Equipment scale-up relationships are understood/accounted for in technology development program	Ref. 88
T	Y	16. Controlled laboratory environment used in testing	Ref. 113, 88
P	Y	17. Initial cost drivers identified	Completed cost analysis of scope of work
T	Y	18. Integration studies have been started	Ref. 113, 88

Table B-8
TRL 4 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P	Y	19. Formal risk management program initiated	Ref. 126
M	Y	20. Key manufacturing processes for equipment systems identified	Received 1 Vendor Response to Request for Proposal
P	N	21. Scaling documents and designs of technology have been completed	Complete Vendor Design
P/T	Y	22. Functional process description developed. (Systems/subsystems identified)	Ref. 87
T	Y	23. Low fidelity technology "system" integration and engineering completed in a lab environment	Ref. 102, 113, 88
T	N/A	24. Key physical and chemical properties have been characterized for a range of wastes	This CTE applies to grinding of CST. Input material properties are not variable relative to grindability.
T	Y	25. A limited number of simulants have been developed that approximate the range of waste properties	Ref. 89
T	Y	26. Laboratory-scale tests on a limited range of simulants and real waste have been completed	Ref. 102, 113, 88
T	Y	27. Process/parameter limits and safety control strategies are being explored	Ref. 91, 115, 40
T	Y	28. Test plan documents for prototypical lab-scale tests completed	Ref. 102, 113, 89
P	Y	29. Technology availability dates established	Received 1 Vendor Response to Request for Proposal

Table B-9
TRL 5 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	30. The relationships between major system and sub-system parameters are understood on a laboratory scale.	Ref. 102, 113, 88
T	Y	31. Plant size components available for testing	Ref. 113, 88
T	Y	32. System interface requirements known (How would system be integrated into the plant?)	Ref. 113, 88
P	N	33. Preliminary design engineering has begun	Complete Vendor Design
T	Y	34. Requirements for technology verification established, to include testing and validation of safety functions.	Ref. 89
T	Y	35. Interfaces between components/subsystems in testing are realistic (bench top with realistic interfaces)	Ref. 113, 88

Table B-9
TRL 5 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
M	Y	36. Prototypes of equipment system components have been created (know how to make equipment)	Both technologies being considered
M	Y	37. Manufacturing techniques have been defined to the point where largest problems defined	Technology is adapting commercial equipment. Both technologies under consideration have been built at full scale for similar applications
M	Y	38. Availability and reliability (RAMI) target levels identified	Ref. 87
T	N	39. Laboratory environment for testing modified to approximate operational environment; to include testing and validation of safety functions.	Safety function is pressure boundary. Will be validated in full scale unit during vendor qualification testing. See Question 4.
T	Y	40. Component integration issues and requirements identified	Ref. 89
P	Y	41. Detailed 3D design drawings and P&IDs have been completed to support specification of a prototypic engineering-scale testing system	Ref. 113, 88
T	Y	42. Requirements definition with performance thresholds and objectives established for final plant design	Ref. 87
P	Y	43. Preliminary technology feasibility engineering report completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 113, 19
T	Y	44. Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Ref. 113, 88
T	Y	45. Formal control of all components to be used in final prototypical test system	Ref. 113, 29
P	Y	46. Configuration management plan in place	Ref. 9
T	Y	47. The range of all relevant physical and chemical properties has been determined (to the extent possible)	Ref. 39
T	Y	48. Simulants have been developed that cover the full range of waste properties	Ref. 89
T	Y	49. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes	Ref. 89
T	Y	50. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Ref. 113, 88
T	Y	51. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed - results validate design	Ref. 113, 88

Table B-9
TRL 5 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	52. Test results for simulants and real waste are consistent	Ref. 113, 88
T	Y	53. Laboratory to engineering scale scale-up issues are understood and resolved; to include testing and validation of safety functions.	Ref. 113, 88
T	Y	54. Limits for all process variables/parameters and safety controls are being refined	Ref. 91, 115,40, 113, 88
P	Y	55. Test plan documents for prototypical engineering-scale tests completed	Ref. 113, 88 Safety function is passive pressure boundary. Function will be validated on production unit.
P	Y	56. Risk management plan documented; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 126
P	Y	57. Test plan for prototypical lab-scale tests executed – results validate design; to include testing and validation of safety functions.	Ref 113, 88 Safety function is passive pressure boundary. Function will be validated on production unit.
P	Y	58. Finalization of hazardous material forms and inventories, completion of process hazard analysis, and identification of system/components level safety controls at the appropriate preliminary design phase.	Ref. 91, 115, 40, 128, 129

Table B-10
TRL 6 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documents
T	Y	31. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	Ref. 90
M/P	N	32. Availability and reliability (RAMI) levels established	Ref. 8 Conduct RAMI Analysis
P	N	33. Preliminary design drawings for final plant system are complete; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process*	Complete Vendor Design
T	Y	34. Operating environment for final system known	Ref. 15, 87

Table B-10
TRL 6 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documents
P	N	35. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 8 Conduct RAMI Analysis
P	N	36. Performance Baseline (including total project cost, schedule, and scope) has been completed	The SCIX Program will be suspended effective October 2011. Baseline through final design is complete; baseline will be reset upon program restart.
T	N	37. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 19, 90
P	Y	38. Operational requirements document available; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Ref. 87, 128, 129
P	Y	39. Off-normal operating responses determined for engineering scale system	Tank 7 operating experience
T	Y	40. System technical interfaces defined	Ref. 87
T	Y	41. Component integration demonstrated at an engineering scale	Ref. 113, 88
P	Y	42. Analysis of project timing ensures technology will be available when required	Program schedule tracks activities required to ensure viability of program execution
P	Y	43. Have established an interface control process	Ref. 7
P	N/A	44. Acquisition program milestones established for start of final design (CD-2)	Operations Activity not subject to critical decisions. Procurement strategy has been identified.
M	N	45. Critical manufacturing processes prototyped	No critical (non-standard) manufacturing processes identified. Final manufacturing will be part of procurement. Complete Vendor Fabrication
M	Y	46. Most pre-production hardware is available to support fabrication of the system	Modification of commercially available grinder planned
T	Y	47. Engineering feasibility fully demonstrated	Ref. 113, 88
M	N	48. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Received 1 Vendor Response to Request for Proposal
P	Y	49. Technology "system" design specification complete and ready for detailed design	Ref. 19
T	Y	50. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 113, 88
P	Y	51. Formal configuration management program defined to control change process	Ref. 9

Table B-10
TRL 6 Questions for Critical Technology Elements

CTE: Spent Resin Disposal (Grinder Unit)

T/P/M	Y/N	Criteria	Basis and Supporting Documents
P	N	52. Final Technical Report on Technology completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Issue Final Technical Report on Technology
M	N	53. Process and tooling are mature to support fabrication of components/system	No unusual tooling requirements expected. Final manufacturing will be part of procurement. Complete Vendor Fabrication
T	Y	54. Engineering-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	Ref. 113, 88
T	Y	55. Engineering to full-scale scale-up issues are understood and resolved	Ref. 113, 88
T	Y	56. Laboratory and engineering-scale experiments are consistent	Ref. 113, 88
T	Y	57. Limits for all process variables/parameters and safety controls are defined	Ref. 91, 115, 40, 19
M	N	58. Production demonstrations are complete (at least one time)	Complete Integrated Test
P	N	59. Integration demonstrations have been completed (e.g. construction of testing system); to include testing and validation of safety functions.	Issue Final Technical Report on Technology Full size grinder has not been designed or tested, must be done as part of integrated demonstration.
P	N	60. Finalization of hazardous material forms and inventories; completion of process hazard analysis, identification of system/components level safety controls at the appropriate preliminary/final design phase.	Ref. 40, 128, 129 Issue Preliminary Documented Safety Analysis

APPENDIX C. TECHNOLOGY READINESS LEVEL SUMMARY FOR THE SCIX INTEGRATED WASTE PROCESSING SYSTEM

(NOTE: The references listed in Tables C-1 and C-2 are not the same as the list of references for the main body of the report, shown in Section 6. The references that correspond to this section are listed in Appendix D.)

Table C-1
TRL 4 Questions for the Waste Processing System (WPS)

WPS: Small Column Ion Exchange (SCIX) Program

	Y/N	**Questions**	**Basis and Supporting Documents**
Processing	Y	1. Is the WPS, as it appears in the conceptual design, intended to accept the full range of wastes to be processed?	Ref. 60, 82, 40
	Y	2. Is the WPS capable of meeting targets for startup and completion of waste processing?	Ref. 5, 76, 22
	Y	3. Have the target operational and performance requirements for the WPS been determined?	Ref. 87, 76, 78
	Y	4. Have all TEs that require an increase or change in capability been identified as CTEs?	Ref. 79
	Y	5. Has WPS process flow been modeled?	Ref. 76, 60, 15, 14, 22
	Y	6. Have WPS single point failures been identified?	Ref. 8, 40
	Y	7. Can TEs be sized to meet WPS throughput requirements?	Ref. 87, 76, 28, 29, 27, 26, 25, 44, 21
	Y	8. Have all new or novel operating modes of the WPS been modeled and/or tested at lab scale?	Ref. 80 [Ref. 80, the TMP, documents all tests and modeling performed.]
	N/A	9. Have all recycle streams been identified and included in the conceptual design process flow models?	There are no recycle streams in the SCIX system.
	Y	10. Have the key safety aspects of the WPS related to processing been identified?	Ref. 40, 128, 129
	Y	11. Are appropriate measures in place to ensure safe operation of the processing activities?	Ref. 40, 87, 128, 129
Disposal Note that in this context "disposal" is defined as disposition of the waste streams to DWPF and SPF	Y	12. Will the WPS produce a product or products that can be dispositioned?	Ref. 5, 15, 14, 45, 62, 61, 58, 60, 82, 87, 76
	Y	13. Are all WPS waste streams identified and characterized to the extent necessary for conceptual design?	Ref. 77, 76, 40
	Y	14. Can all WPS waste streams, including, process liquids, off gases, and solids identified in the conceptual design be treated and disposed?	Ref. 42, 41, 62, 61, 58, 45, 60
	Y	15. Will the waste streams meet the waste acceptance criteria of the proposed disposition facilities/sites?	Ref. 62, 61, 58, 60, 1, 40
	Y	16. Have the disposition facilities/site been contacted to ensure that the waste forms are compatible with facility/site **operations, procedures, and regulations**?	Ref. 78, 7
	Y	17. Have the key safety aspects of the WPS related to disposal been identified?	Ref. 1, 16, 30, 40, 94, 120, 128, 129
	Y	18. Are appropriate measures in place to ensure safe operation of the disposal activities?	Ref. 1, 16, 30, 40, 94, 120, 128, 129

Table C-1
TRL 4 Questions for the Waste Processing System (WPS)

WPS: Small Column Ion Exchange (SCIX) Program

	Y/N	**Questions**	**Basis and Supporting Documents**
Interfaces	Y	19. New or novel interfaces among WPS systems have been identified as CTEs?	Ref. 7, 79, 87
	Y	20. Are all WPS technology interfaces and dependencies determined and understood at the conceptual level?	Ref. 7, 87
	Y	21. Can all WPS components be successfully mated?	Ref. 87, 18, 20, 17, 19
	Y	22. Are the processing modes of the TEs (e.g., batch, continuous) compatible?	Ref. 76, 22
	Y	23. Have the key safety aspects of the WPS related to interfaces with other systems and components been identified?	Ref. 1, 16, 40, 84, 94, 120, 128, 129
	Y	24. Are appropriate measures in place to ensure safe operation of the interface activities?	Ref. 1, 16, 40, 84, 94, 120, 128, 129

Table C-2
TRL 6 Questions for the Waste Processing System (WPS)

WPS: Small Column Ion Exchange (SCIX) Program

	Y/N	**Questions**	**Basis and Supporting Documents**
Processing	Y	1. Have all TEs that require an increase or change in capability been identified as CTEs?	Ref. 79
	Y	2. Can the WPS accept the full range of wastes to be processed?	Ref. 60, 82, 40
	Y	3. Is the WPS capable of meeting targets for startup and completion of waste processing?	Ref. 5, 76, 22
	Y	4. Have the target operational and performance requirements for the WPS been determined?	Ref. 87, 76, 78
	N	5. Have major sections of the WPS and their interfaces been modeled and/or piloted?	Ref. 76, 60, 15, 14 Full scale integrated testing has not been completed.
	Y	6. Has WPS data collection and data flow been modeled/tested?	Ref. 84
	Y	7. Has WPS process flow and process control been modeled/tested?	Ref. 76, 60, 15, 14, 68, 83
	Y	8. Have WPS single point failures been identified?	Ref. 8, 40 An Operations Plan has been drafted but not finalized so it is not included as a formal reference but was discussed in detail by the SCIX Team during the TRA.

Table C-2
TRL 6 Questions for the Waste Processing System (WPS)

WPS: Small Column Ion Exchange (SCIX) Program

	Y/N	Questions	Basis and Supporting Documents
	Y	9. Can TEs be sized to meet WPS throughput requirements?	Ref. 87, 76, 28, 29, 27, 26, 25, 44, 21
	Y	10. Have all new or novel operating modes of the WPS been modeled and/or piloted?	Ref. 80 [Ref. 80, the TMP, documents all tests and modeling performed.]
	N/A	11. Are all recycle streams fully characterized?	There are no recycle streams in the SCIX system.
	N/A	12. Are all WPS recycle streams included in process models?	There are no recycle streams in the SCIX system.
	Y	13. Have the key safety aspects of the WPS related to processing been identified?	Ref. 40, 128, 129
	Y	14. Are appropriate measures in place to ensure safe operation of the processing activities?	Ref. 40, 87, 128, 129
	Y	15. Is the appropriate documentation in place that adequately describes the safety features related to processing, and their functions in the overall integrated WPS?	Ref. 40, 128, 129
Disposal Note that in this context "disposal" is defined as disposition of the waste streams to DWPF and SPF	Y	16. Will the WPS produce a product or products that can be dispositioned?	Ref. 5, 15, 14, 45, 62, 61, 58, 60, 82, 87, 76
	Y	17. Are all WPS waste streams identified?	Ref. 77, 76, 40
	Y	18. Have the waste streams produced by the WPS been fully characterized?	Ref. 77, 76, 40
	Y	19. Has a disposition path been determined for each waste stream, including, process liquids, off gases, and solids?	Ref. 42, 41, 62, 61, 58, 45, 60
	Y	20. Will the waste forms meet the waste acceptance criteria of the proposed disposition facilities?	Ref. 62, 61, 58, 60, 40, 1
	Y	21. Have the disposition facilities/sites been contacted to ensure that the waste streams are compatible with disposal facility/site **operations, procedures, and regulations**?	Ref. 78, 7
	Y	22. Have the key safety aspects of the WPS related to disposal been identified?	Ref. 1, 16, 30, 40, 94, 120, 128, 129
	Y	23. Are appropriate measures in place to ensure safe operation of the disposal activities?	Ref. 1, 16 30, 40, 94, 120, 128, 129
	Y	24. Is the appropriate documentation in place that adequately describes the safety features related to disposal, and their functions in the overall integrated WPS?	Ref. 1, 16, 40, 84, 94, 120, 128, 129
Interfaces	Y	25. Are all WPS technology interfaces and dependencies determined and understood?	Rf. 7, 87

Table C-2
TRL 6 Questions for the Waste Processing System (WPS)

WPS: Small Column Ion Exchange (SCIX) Program

	Y/N	**Questions**	**Basis and Supporting Documents**
	Y	26. New or novel interfaces among WPS systems have been identified as CTEs?	Ref. 7, 79, 87
	N	27. Have all WPS TE interfaces been modeled or piloted?	Ref. 80 [Ref. 80, the TMP, documents all tests and modeling performed.] Full scale designs are not completed for all CTEs so interface designs are not complete. Additionally, the integrated testing must be completed to validate the interfaces.
	Y	28. Are the processing modes of the TEs (e.g., batch, continuous) compatible?	Ref. 76
	Y	29. Have the key safety aspects of the WPS related to the interfaces with other systems and components been identified?	Ref. 1, 16, 40, 84, 94, 120, 128, 129
	Y	30. Are appropriate measures in place to ensure safe operation of the interface activities?	Ref. 1, 16, 40, 84, 94, 120, 128, 129
	Y	31. Is the appropriate documentation in place that adequately describes the safety features related to the interfaces, and their functions in the overall integrated WPS?	Ref. 1, 16, 40, 84, 94, 120, 128, 129

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APPENDIX D. LISTING OF REFERENCE DOCUMENTS FOR TRL DETERMINATION

	REFERENCE	MST	RMF	IXC	SRD	WPS
1	CBU-WSE-2005-00276, Recommended Waste Acceptance Criteria (WAC) for Transfers from the Salt Waste Processing Facility (SWPF) to the Defense Waste Processing Facility (DWPF) and Saltstone Production Facility (SPF)	X				X
2	CEES-0864, SCIX Ion Exchange Column Performance Demonstration Procedure, Columbia Energy and Environmental Services			X		
3	CEES-0877, Rev. 0, “Small Column Ion Exchange Demonstration Report”, Columbia Energy and Environmental Services, September 26, 2011			X		
4	Centrifugal Membrane Filtration Final Report, Contract DE-AC21-96MC33136 8/4/99		X			
5	G-ADS-H-00014, Liquid Waste Operations Enhanced Processes for Radionuclide Removal (EPRR) Systems Engineering Evaluation (SEE)			X		X
6	G-ESR-H-00152, Small Column Ion Exchange Engineering Execution Plan				X	
7	G-ESR-H-00173, Interface Control Document – Small Column Ion Exchange Program	X	X	X	X	X
8	G-ESR-H-00174, Reliability, Availability, Maintainability and Inspectability Study – Small Column Ion Exchange Program	X	X	X	X	X
9	G-TRT-H-00023, Configuration Management Plan – Small Column Ion Exchange Program	X	X	X	X	
10	ICEM2009-16174, Separation of Fission Products and Actinides from Savannah River Site High-Level Nuclear Wastes [Proceedings of The 12th International Conference on Environmental Remediation and Radioactive Waste Management ICEM2009, October 11 – 15, 2009, Liverpool, UK]	X				
11	Ind. Eng. Chem. Res., Vol. 35, No. 11, pp. 4246-4256, Ion Exchange of Group 1 Metals by Hydrous Crystalline Silicotitanate			X		
12	Ind. Eng. Chem. Res., Vol. 36, No. 6, pp. 2427-2434, Modeling Multicomponent Ion Exchange Equilibrium Utilizing Hydrous Crystalline Silicotitanates by a Multiple Interactive Ion Exchange Site Model			X		
13	Letter to James French from Terrel Spears Subject: Agreement on Key Input Bases and Assumptions for Small Column Ion Exchange (SCIX) and Z Area Fluidized Bed Steam Reformer (ZFBSR) Projects (Your letter SRR-2009-00035, 12/18/09) 01/04/10				X	
14	LWO-LWE-2007-00174, Preliminary Modular Salt Processing Flowsheet for Addition of Modified Monosodium Titanate and Operation of the Rotary Microfilter	X	X			
15	LWO-LWE-2007-00178, Preliminary Flowsheet for Crystalline Silicotitanate Small Column Ion-Exchange Processing of Tanks 1, 2, 3, 37, and 41 Dissolved Salts			X	X	X
16	Manual 1S, SRS Waste Acceptance Criteria Manual					X
17	M-CDP-H-00044, Conceptual Design Package for Small Column Ion Exchange Program Rotary Microfilter Component		X			X
18	M-CDP-H-00045, Conceptual Design Package for Small Column Ion Exchange Program Ion Exchange Column Component			X		X
19	M-CDP-H-00046, Conceptual Design Package for Small Column Ion Exchange Program Spent Resin Disposal Component				X	X
20	M-CDP-H-00047, Conceptual Design Package for Small Column Ion Exchange Program Common Plant Equipment Component	X				X
21	M-CLC-H-03038, Hydraulic Evaluation of Process Feed Pump, WTE-P-351, Transfer Salt Solution from Tank 41H (241-941H) Through RMFs then Through INEXs, and to Tank 50H (241-950H)					X

	REFERENCE	MST	RMF	IXC	SRD	WPS
22	M-M5-H-08651, Liquid Waste Operations Small Column Ion Exchange Program Waste Tank 41H Primary Process Flow Diagram				X	X
23	M-M6-H-SK001, Waste Tank 41H Riser H Rotary Microfilter System Piping and Instrumentation Diagram		X			
24	M-SPP-A-00102, Rotary Filtration System		X			
25	M-SPP-H-00472, Submersible Transfer Pump Assembly Procurement Specification					X
26	M-SPP-H-00495, Submersible Mixer Pump Procurement Specification	X				X
27	M-SPP-H-00508, Rotary Micro Filter Procurement Specification		X			X
28	M-SPP-H-00512, SCIX Ion Exchange Column (IXC) Procurement Specification			X		X
29	M-SPP-H-00513, SCIX Spent Resin Disposal Unit (SRD) Procurement Specification				X	X
30	N-NCS-H-00192, Nuclear Criticality Safety Evaluation: Actinide Removal Process and Modular CSSX Unit	X				X
31	ORNL/TM-13503, Cesium Removal Demonstration Utilizing Crystalline Silicotitanate Sorbent for Processing Melton Valley Storage Tank Supernate: Final Report			X		
32	ORNL/TM-1999/103, Hydraulic Performance and Gas Behavior of a Tall Crystalline Silicotitanate Ion–Exchange Column			X		
33	ORNL/TM-1999/166, Resuspension and Settling of Monosodium Titanate and Sludge in Supernate Simulant for the Savannah River Site	X				
34	ORNL/TM-2000/362, Study of Potential Impact of Gamma-Induced Radiolytic Gases on Loading of Cesium onto Crystalline Silicotitanate			X		
35	ORNL/TM-2001/129, Wastewater Triad Project: Final Summary Report			X		
36	PER/ORNL/SCIX-006, Statement of Work (SOW) for ORNL – Small Column Ion Exchange (SCIX)			X		
37	P-SOW-H-00008, Small Column Ion Exchange Program Scope of Work		X			
38	RPT-5539-ME-0003, Defense Waste Processing Facility (DWPF) Grinder Evaluation Report				X	
39	SAND 2001-0999, Characterization of UOP IONSIV IE-911				X	
40	S-CHA-H-00010, Preliminary Consolidated Hazards Analysis for Small Column Ion Exchange Program [Post-1189]	X	X	X	X	X
41	SRNL-L2200-2010-00009, Air Dispersion Modeling for the SRS Title V Permit Renewal					X
42	SRNL-L2200-2011-00027, Assessment of Occupational Exposure to Chemical Dispersion from H Tank Farm Tank 41					X
43	SRNL-STI-2008-00446, ISDP Salt Batch #2 Supernate Qualification	X				
44	SRNL-STI-2009-00183, Testing of a Full-Scale Rotary Microfilter for the Enhanced Process for Radionuclides Removal		X			X
45	SRNL-STI-2010-00297, Paper Study Evaluations of the Introduction of Small Column Ion Exchange (SCIX) Waste Streams to the Defense Waste Processing Facility	X				X
46	SRNL-STI-2010-00438, Review of Experimental Studies Investigating the Rate of Strontium and Actinide Adsorption by Monosodium Titanate	X				
47	SRNL-STI-2010-00534, Review of Actinide and Strontium Loading Data for MST and mMST	X				

	REFERENCE	MST	RMF	IXC	SRD	WPS
48	SRNL-STI-2010-00566, Impacts of Small Column Ion Exchange Streams on DWPF Glass Formulation: KT01, KT02, KT03, and KT04-Series Glass Compositions	X		X		
49	SRNL-STI-2010-00570, Thermal Modeling of CST Media in the Small Column Ion Exchange Project			X		
50	SRNL-STI-2010-00591, Rotary Filter 1000 Hour Test		X			
51	SRNL-STI-2010-00682, The Hydrothermal Reactions of Monosodium Titanate (MST), Crystalline Silicotitanate (CST) and Sludge in the Modular Salt Process (MSP): A Literature Survey			X		
52	SRNL-STI-2010-00687, Impacts of Small Column Ion Exchange Streams on DWPF Glass Formulation: KT05 and KT06-Series Glass Compositions	X		X		
53	SRNL-STI-2010-00759, Impacts of Small Column Ion Exchange Streams on DWPF Glass Formulation: KT07-Series Glass Compositions	X		X		
54	SRNL-STI-2010-00792, Scaling Solid Resuspension and Sorption for the Small Column Ion Exchange (SCIX) Processing Tank	X		X		
55	SRNL-STI-2010-00793, Investigating Suspension of MST Slurries in a Pilot-Scale Waste Tank	X		X		
56	SRNL-STI-2011-00008, Rotary Filter 1000 Hour Sludge Washing Test		X			
57	SRNL-STI-2011-00054, Rheology of Settled Solids in the Small Column Ion Exchange (SCIX) Process	X		X		
58	SRNL-STI-2011-00075, SCIX Impact on DWPF CPC	X		X		X
59	SRNL-STI-2011-00178, Impacts of Small Column Ion Exchange Streams on DWPF Glass Formulation: KT08, KT09, and KT10-Series Glass Compositions	X		X		
60	SRNL-STI-2011-00181, Modeling CST Ion-Exchange for Cesium Removal from SCIX Batches 1 – 4			X		X
61	SRNL-STI-2011-00185, Impact of Small Column Ion Exchange Streams on DWPF Glass Formulation: Melt Rate Studies	X		X		X
62	SRNL-STI-2011-00198, Summary Report on Potential Impacts of Small Column Ion Exchange on DWPF Glass Formulation	X		X		X
63	SRNL-STI-2011-00215, Strontium and Actinide Sorption by MST and mMST Under Conditions Relevant to the Small Column Ion-Exchange (SCIX) Process	X		X		
64	SRNL-STI-2011-00250, Investigating Suspension of MST, CST, and Simulated Sludge Slurries in a Pilot-Scale Waste Tank	X		X		
65	SRNL-STI-2011-00311, Rheology of Settled Solids in the Small Column Ion Exchange (SCIX) Process	X		X		
66	SRNL-STI-2011-00340, Desorption of Sorbates from MST, mMST, and CST Under Various Conditions	X		X		
67	SRNL-STI-2011-00396, Rotary Filter Fines Testing for Small Column Ion Exchange		X			
68	SRNL-STI-2011-00466, Testing of the Dual Rotary Filter System		X			X
69	SRNL-STI-2011-00453, Pilot-Scale Testing of the Suspension of MST, CST, and Simulated Sludge Slurries in a Sludge Tank	X		X		
70	SRNL-STI-2011-00502, Three-Dimensional Thermal Modeling Analysis of CST Media for the Small Column Ion Exchange Project			X		
71	SRNL-TR-2008-00301, Impact of Reduced quantities of Monosodium Titanate on the Actinide Removal Process Facility	X				

	REFERENCE	MST	RMF	IXC	SRD	WPS
72	SRNL-TR-2010-00133, Annotated Bibliography of Technical Documents Pertaining to Strontium and Actinide Separations from High-Level Nuclear Waste Solutions	X				
73	SRNL-TR-2010-00277, Literature Review of Maximum Loading of Radionuclides on Crystalline Silicotitanate			X		
74	SRR-2009-00035, Letter to Terrel Spears from James French Subject: Agreement on Key Input Bases and Assumptions for Small Column Ion Exchange (SCIX) and Z Area Fluidized Bed Steam Reformer (ZFBSR) Projects 12/18/2009				X	
75	SRR-LWE-2010-00155, Small Column Ion Exchange Safety Design Integration Team Charter				X	
76	SRR-LWP-2009-00001, Liquid Waste System Plan, Rev. 16					X
77	SRR-LWP-2010-00070, Salt Batch Plan-2010 in Support of System Plan R-16					X
78	SRR-SCIX-2010-00001, Small Column Ion Exchange Program Customer Expectations					X
79	SRR-SCIX-2010-00007, Technology Maturation Strategy for the Small Column Ion Exchange Program					X
80	SRR-SCIX-2010-00026, Technology Maturation Plan for the Small Column Ion Exchange Program	X				X
81	SRR-SCIX-2010-00044, Rev. 1, SCIX Design Compliance Matrix				X	
82	SRR-SCIX-2010-00050, Sampling and Qualification Strategy for the Small Column Ion Exchange Program					X
83	SRR-SCIX-2011-00085, Process Control Development and Testing for the Dual Rotary Micro Filter System		X			X
84	SRR-SPT-2010-00052, Control and Automation Strategy for Small Column Ion Exchange (SCIX)					X
85	TTI Drawing Numbers 1760-M-400 through 421, Pump Module		X			
86	US Patent 6,479,427 B1, Silico-Titanates and the Methods of Making and Using			X		
87	U-TC-H-00012, Task Requirements and Criteria – Small Column Ion Exchange Program	X	X	X	X	X
88	VSL-10S2100-1, Data Summary Report – Small Column Ion Exchange (SCIX) Grinder Testing				X	
89	VSL-10T2100-1, Test Plan Small Column Ion Exchange (SCIX) Grinder and Sluicing Testing			X	X	
90	VSL-11R2100-1, Final Report – Small Column Ion Exchange (SCIX) Grinding, Pumping, and Sluicing Testing			X	X	
91	WSMS-OR-04-0002, Consolidated Hazards Analysis for the Small Column Ion Exchange System [Pre-1189]	X	X	X	X	
92	WSRC-RP-2004-00234, Impact of a Rotary Microfilter on the Savannah River Site High Level Waste System		X			
93	WSRC-RP-2006-00493, Task Technical and Quality Assurance Plan for the Testing of the Full-Scale Rotary Microfilter		X			
94	WSRC-SA-2002-00007, Concentration, Storage, and Transfer Facilities Documented Safety Analysis	X				X
95	WSRC-STI-2006-00073, Testing and Evaluation of the Modified Design of the 25-Disk Rotary Microfilter		X			

	REFERENCE	MST	RMF	IXC	SRD	WPS
96	WSRC-STI-2007-00315, Modeling of Ion-Exchange for Cesium Removal from Dissolved Saltcake in SRS Tanks 1-3, 37 and 41			X		
97	WSRC-STI-2007-00609, Literature reviews to Support Ion Exchange Technology Selection for Modular Salt Processing			X		
98	WSRC-STI-2008-00068, Batch Testing of the Actinide Removal Process (ARP) and ESS (Extract, Scrub, and Strip) of Tank 25F Dissolved Salt Cake	X				
99	WSRC-STI-2008-00117, Tank 49H Salt Batch Supernate Qualification for ARP / MCU	X				
100	WSRC-TR-2000-00142, Phase V Simulant Testing of Monosodium Titanate Adsorption Kinetics	X				
101	WSRC-TR-2000-00177, Gas Generation and Bubble Formation Model for CST Ion Exchange Columns			X		
102	WSRC-TR-2000-00350, CST Particle Size Reduction Tests				X	
103	WSRC-TR-2000-00394, Results of Sorption / Desorption Experiments with IONSIV IE-911 Crystalline Silicotitanate			X		
104	WSRC-TR-2001-00400, Preliminary Ion Exchange Modeling for Removal of Cesium from Hanford Waste Using Hydrous Crystalline Silicotitanate Material - Section 9.2			X		
105	WSRC-TR-2001-00413, Flocculating, Settling and Decanting for the Removal of Monosodium Titanate and Simulated High-Level Waste Sludge from Simulated Salt Supernate	X				
106	WSRC-TR-2003-00030, Testing of the SpinTek Rotary Microfilter Using Actual Waste		X			
107	WSRC-TR-2003-00430, Small Column Ion Exchange Analysis for Removal of Cesium from SRS Low Curie Salt Solutions Using Crystalline Silicotitanate (CST) Resin			X		
108	WSRC-TR-2003-00471, MST / Sludge Agitation Studies for Actinide Removal Process and DWPF	X				
109	WSRC-TR-2004-00047, Pilot-scale Testing of a Rotary Microfilter with Irradiated Filter Disks and Simulated SRS Waste		X			
110	WSRC-TR-2004-00145, Monosodium Titanate Multi-Strike Testing	X				
111	WSRC-TR-2004-00194, Pilot-scale Testing of a Rotary Microfilter with Irradiated Filter Disks and Simulated SRS Waste		X			
112	WSRC-TR-2005-00034, High Level Waste System Impacts from Small Column Ion Exchange Implementation			X		
113	WSRC-TR-2005-00282, Confirmation of Small Column Ion exchange Crystalline Silicotitanate (CST) Grinder Configuration and Estimation of Treatment Cycle				X	
114	WSRC-TR-2006-00039, Development of Monosodium Titanate (MST) Purchase Specifications	X				
115	WSRC-TR-2007-00347, Preliminary Consolidated Hazard Analysis for Small Column Ion Exchange Process in Support of Modular Salt Processing [Pre-1189]	X	X	X	X	
116	WSRC-TR-97-00016, Examination of Crystalline Silicotitanate and Applicability in Removal of Cesium from SRS High Level Waste			X		
117	WSRC-TR-98-00396, Modeling of Crystalline Silicotitanate Ion Exchange Columns Using Experimental Data from SRS Simulated Waste			X		
118	WSRC-TR-99-00116, Preparation of Simulated Waste Solutions			X		

	REFERENCE	MST	RMF	IXC	SRD	WPS
119	WSRC-TR-99-00134, Final Report on Phase III Testing of Monosodium Titanate Adsorption Kinetics	X				
120	WSRC-TR-99-00285, Radiolytic Gas Generation in Crystalline Silicotitanate Slurries			X		X
121	WSRC-TR-99-00286, Phase IV Testing of Monosodium Titanate Adsorption with Radioactive Waste	X				
122	WSRC-TR-99-00308, Cesium Removal from Savannah River Site Radioactive Waste Using Crystalline Silicotitanate (Ionsiv IE911)			X		
123	X-CLC-H-00885, Evaluation of Venting Requirements for the Ion Exchange Column and Rotary Microfilter Shroud in Tank 41			X		
124	X-ESR-H-00120, Evaluation of ISDP Batch 1 Qualification Compliance to 512-S, DWPF, Tank Farm, and Saltstone WAC	X				X
125	X-SPP-H-00012, Specification for Procurement of 15% Monosodium Titanate (MST)	X				
126	Y-RAR-H-00081, Small Column Ion Exchange Program Risk and Opportunity Analysis Report	X	X	X	X	
127	M-SPP-A-00110, Rotary Filtration System		X			
128	U-TRT-H-0009, Small Column Ion Exchange Conceptual Design Safety Report, Rev. 1, June 2011	X	X	X	X	X
129	WDED-11-33, Conceptual Safety Validation Report for the Small Column Ion Exchange Conceptual Safety Design Report, Rev. 0, August 2011	X	X	X	X	X

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APPENDIX E. SMALL COLUMN ION EXCHANGE PROGRAM TRA TEAM MEMBERS AND OBSERVERS

Hoyt Johnson.

Mr. Johnson is the lead for Technical Readiness Assessments and External Technical Reviews in the Office of Technology Innovation and Development within the Office of Environmental Management (EM). He has served as a member of various review teams which include a technical readiness assessment of the Calcine Disposition Project at the Idaho National Laboratory (INL), a Construction Project Review of the Salt Waste Processing Facility(SWPF) at the Savannah River Site (SRS), an independent review of Tank 48H technology alternatives at SRS and as the EM headquarters lead for the SWPF 30% design review. Mr. Johnson is the Technical Standards Manager for the Office of Environmental Management and is a subcommittee member of the International Standards Organization (ISO) Technical Committee 20 charged with developing a standardized definition of technology readiness levels and their criteria of assessment. In addition, he has over 37 years of experience in nuclear related work including over twenty years of field experience in the design, construction, testing, operation and maintenance of complex plant components systems and structures at three nuclear sites. Mr. Johnson holds a B.S. in Metallurgical Engineering from Virginia Tech and a MBA from the Florida Institute of Technology. He is a registered Professional Engineer in the state of Virginia.

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Jay Roach.

Mr. Roach received his B.S. degree in Mechanical Engineering from the University of Texas at Arlington, his M.S. degree in Mechanical Engineering from the University of Idaho, and is currently completing his Ph.D. degree in Mechanical Engineering from the University of Idaho. Mr. Roach's doctoral research was related to cold crucible induction melter systems for immobilization of high level radioactive waste. Currently, Mr. Roach owns his own technical consulting firm and provides subject matter expertise to the U.S. Department of Energy Office of Environmental Management (DOE-EM), and specifically the Office of Technology Innovation and Development (EM-30). Mr. Roach provides technical expertise across all areas of the EM-30 program, including Tank Waste Processing, Soil and Groundwater Remediation, Nuclear Materials Disposition, and Deactivation and Decommissioning. In addition, he provides technical support to development and implementation of the EM International Program for collaborative research and development opportunities with foreign governments, including United Kingdom, Russia, and Canada. Mr. Roach has been a team member and/or led multiple reviews and assessments for EM-30, including the U-233 Downblend Project at Oak Ridge, and the initial External Technical Review of the Small Column Exchange Program at Savannah River Site. Prior to this, Mr. Roach worked at the Idaho National Laboratory (INL) for almost 20 years, where he was involved in developing the initial roadmaps for treatment and disposition of the waste inventories located at the Idaho site. During this time, Mr. Roach served as a Waste Type Manager in the DOE Mixed Waste Focus Area, which was a national program to develop, demonstrate, and deploy treatment technologies for the DOE complex's radioactive waste streams that also contain regulated hazardous constituents. He also represented the INL on the Tanks Focus Area, which was another national program that addressed the challenges with treatment and disposition of the high level tank waste, including the Idaho Calcine and Sodium Bearing Waste. During the last eight years at the INL, Mr. Roach managed an organization of approximately 30 scientists and engineers conducting research and development in technologies and systems related to environmental, energy, and security challenges.

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Dr. Harry Harmon

Since retiring on January 1, 2008, Dr. Harmon is providing management and technical consulting to the Department of Energy (DOE) and its contractors including assessments such as technology readiness assessments, independent project reviews, and technology development program reviews. Previously, Dr. Harmon served seven years as a Senior Program Manager for Pacific Northwest National Laboratory (PNNL) where he served as the Salt Processing Technology Development Manager at the DOE Savannah River Site. Prior to joining PNNL, he worked in the private sector as Senior Program Manager for NUKEM and Vice President of Tank Waste Programs at M4 Environmental Management, Inc. Dr. Harmon also served at STS and Hanford in key senior management positions. At SRS, Dr. Harmon provided expert technical advice and management of technology development for high-level waste program for the Westinghouse Savannah River Company. As the Vice President of the Tank Waste Remediation System Division of Westinghouse Savannah River Company, he managed the overall system required to safely manage the waste tanks and process the waste for final disposal. During that time, his organization made significant progress on mitigation and remediation of the high visibility Hanford waste tank safety issues. In previous years at SRS with Westinghouse and Dupont, he held several management positions in Savannah River Laboratory where he directed process and equipment research and development in nuclear fuel reprocessing actinide processing, waste management, and environmental restoration. His technical expertise is in waste management, nuclear fuel reprocessing, separations chemistry and engineering, and developing and implementing technology in these areas.

Dr. Harmon is a member of the American Chemical Society and Sigma Xi. He has participated in a number of independent reviews for the National Research Council, U.S. DOE, and DOE contractors and has also written a collection of articles and publications on the subjects of actinide chemistry, nuclear fuel reprocessing, and high level waste management. Dr. Harmon earned a B.S. degree in Chemistry in 1968 from Carson-Newman College, Jefferson City, Tennessee, and a PhD. in Inorganic and Nuclear Chemistry in 1971 from the University of Tennessee in Knoxville. He currently serves on the Board of Visitors of the Chemistry Department at the University of Tennessee.

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Dr. Gregg Lumetta

Dr. Gregg Lumetta is currently a Staff Scientist in the Radiochemical Sciences and Engineering Group at the Pacific Northwest National Laboratory (PNNL) and has more than 20 years of experience in the field of radiochemical separations. His research interests include the study of solvent-extraction and ion-exchange systems, especially regarding radiochemical separations, the treatment of waste streams, radiological decontamination, and hydrometallurgy. He has served as the focus area lead for the Transuranic Recycle Technology Focus Area of PNNL's Sustainable Nuclear Power Initiative, PNNL technical lead for the Department of Homeland Security Threat Awareness and Characterization Thrust Area, and managed the Separations and Radiochemistry Team in the Radiochemical Processing Laboratory from 1999 to 2003. He led efforts in developing and testing of the Hanford baseline sludge pretreatment process, including caustic and oxidative leaching.

Dr. Lumetta received a B.S. in chemistry and a Ph.D. in inorganic chemistry from the University of Missouri—St. Louis. He has authored or co-authored 54 papers in peer-reviewed journals, 51 publicly released reports, 17 papers in conference proceedings, 72 conference presentations, and 1 book chapter. He has served as editor for three technical books. Dr. Lumetta is a Fellow of the American Chemical Society and a member of Phi Kappa Phi.

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Dr. Herbert Sutter

Dr. Sutter holds an A.B. in Chemistry from Hamilton College, a Ph.D. in Physical Chemistry from Brown University and a Post-Doctoral Theoretical Chemistry from Cambridge University, UK. He has more than thirty years of experience in the fields of separations science, high and low level radioactive waste treatment, waste water treatment, vitrification, and analytical chemistry. For the past nineteen years he has provided technical and programmatic support to the DOE Office of Environmental Management (EM). Dr. Sutter has provided technical assistance to the DOE programs at Hanford, Savannah River, and other sites in: (1) separation technologies; (2) technology development; (3) high level waste disposal; (4) nuclear waste characterization; (5) vitrification; and (6) analytical laboratory management. From 2007 through the present Dr. Sutter has supported the EM Office of Project Recovery working on technology aspects of Hanford's Waste Treatment Plant. During that time he helped develop the EM Technology Readiness Assessment (TRA)/Technology Maturation Plan (TMP) Process Guide (March 2008). From 2005 to 2006, Dr. Sutter assisted EM in the development of a long-term, complex-wide Project Plan for Technology Development and Demonstration. From 2002-2004, he was a senior scientist for Kenneth T. Lang Associates, Inc. and provided support to EM in several areas including the evaluation of HLW vitrification technologies at Hanford and pretreatment and separation technologies at Savannah River. He has also been a consultant to private industry on separation technologies. From 1990-2002, as a scientist for Science Applications International Corporation, he supported EM in the areas of nuclear waste treatment and characterization and analytical chemistry. From 1982-1990, Dr. Sutter was Vice President and Chief Scientist at Duratek Corporation and responsible for technical direction of all research and development and commercialization programs in ion exchange, filtration and separation techniques. Relevant experience includes: waste water treatment, bench and pilot testing, and waste treatment studies. Dr. Sutter has authored or co-authored over 30 journal articles and technical reports and is a member of the American Chemical Society and the American Nuclear Society.

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Phil McGinnis.

Phil McGinnis is currently a staff member at Oak Ridge National Laboratory with 35 years of experience at Oak Ridge, and is retiring September 2011. He has degrees in Chemical Engineering and is a professional engineer in Tennessee. Phil was the Tanks Focus Area Technical Integration Manager for the Tanks Focus Area from 1992 through 2002. He is the programmatic lead for EM Technology Activities for Oak Ridge, and serves as the representative from Oak Ridge National Lab to the National Laboratory Advisory Group that works closely with DOE-EM. Phil has been involved in providing technology for all of the EM activities over the past 15 years. He has worked closely with the treatment of Fernald retrieval and processing waste streams and with the treatment of U233 in Oak Ridge. He is one of the authors of the recent DOE EM Technical Evaluation for Transforming the Tank Waste System- Tank Waste System Integrated Project Team Final Report. During the time frame of support to TFA, he developed a strong understanding of the needs of all of the EM sites for technology and provided support to Savannah River on several projects. Phil has served as a reviewer on expert panels for DOE-EM and is participating in the Technology Readiness Review for this project, for the U233 project at Oak Ridge, for INL Hot Isostatic Press evaluation, and Nickel Decontamination evaluation.

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