Savannah River Site Salt Waste Processing Facility Technology Readiness Assessment Report

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Prepared by the
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Executive Summary

Background

The purpose of this assessment was to determine the technology maturity level of the technologies planned for use in the Salt Waste Processing Facility (SWPF) being constructed at DOE's Savannah River Site (SRS).

The U.S Department of Energy (DOE), Savannah River Operation Office (SR) is constructing SWPF for the treatment and processing of SRS High Level Waste (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 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.

Three consecutive basic unit operations are employed to treat salt waste at the SWPF: Alpha Strike Process (ASP), Caustic-side Solvent Extraction (CSSX), and Alpha Finishing Process (AFP). (See Figure ES-1.Note: MST, APA and CFF are subsystems of both ASP and AFP unit processes.)

SWPF PROCESSING

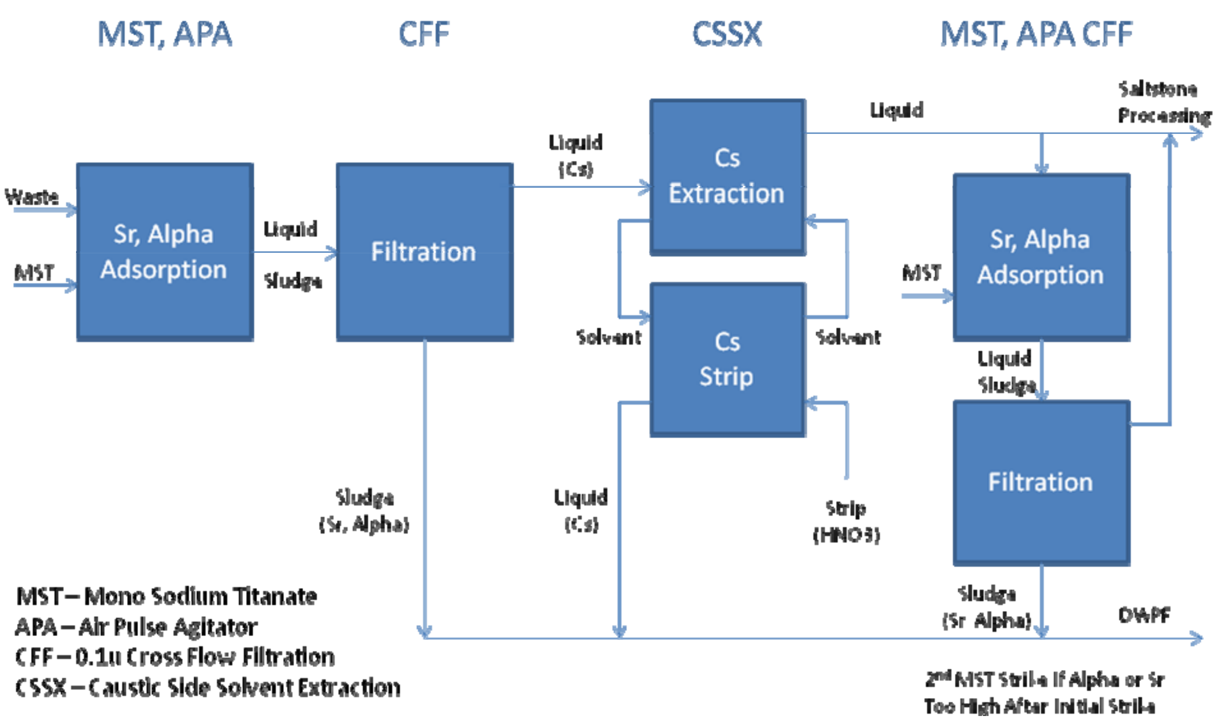

Figure ES-1

The methodology used for this Technology Readiness Assessment (TRA) is based on detailed guidance for conducting TRAs contained in the DOE Office of Environmental Management *Technology Readiness Assessment (TRA)/Technology Maturation Plan (TMP) Process Guide*[1].

The TRA consists of three parts:

- Determination of the Critical Technology Elements (CTEs) for each of the candidate processes. CTEs are those elements (such as subsystems) of an overall process that are essential to its success, are new, or are being applied in new or novel ways or in new environments.
- Evaluation of the Technology Readiness Levels (TRLs) of each CTE against the technology readiness scale developed by NASA and adapted by DOE-EM for waste processing. The DOE- EM process uses a detailed set of questions for each TRL.
- Definition of the technology testing or engineering work necessary to bring immature technologies to the appropriate maturity levels.

The Assessment Team identified five major SWPF systems. Four of these systems were divided into 10 subsystems giving eleven Technology Elements (TEs) that were evaluated as potential CTEs. Seven of the TEs were determined to be CTEs. Table ES-1 displays the SWPF systems and subsystems (TEs). TEs determined to be CTEs are high-lighted. Process Integration was also determined to be a CTE.

Table ES-1. SWPF Systems and Subsystems (TEs)

Systems				
Feed Adjustment	Actinide/Sr Removal	CSSX	Product Handling	Analytical Laboratory
Subsystems (TEs)				
Al Chemistry	MST Performance	CSSX Chemistry	Strip Effluent	
	Cross Flow Filter	Centrifugal Contactors	MST/Sludge	
	Air Pulse Agitator	Solvent Recovery	DSS	

The specific responses to each of the TRL questions for each CTE evaluated in this TRA are presented in Appendix B. The TRL determination for each of the technologies evaluated, including subsystems, is presented in Section 3.

Conclusions, Observations, and Recommendations

Based on interactions with DOE and Parsons SWPF project personnel and on review of extensive documentation during the course of this assessment, the TRA Team has reached the following general conclusions:

- All SWPF Critical Technology Elements satisfy the requirements of Technology Readiness Level (TRL) 6 and are ready for insertion into detailed design. Availability of the full-scale plant for cold commissioning is required for advancement to TRL 7.
- DOE and Parsons have conducted a very thorough technology development and large-scale testing program.

The Team makes the following observations and recommendations.

1. Continued Study of Operating Limits to Prevent and/or Minimize Solids Formation in Feed Adjustment and Solvent Extraction

Observation: Parsons' has made significant progress in assimilating existing data, conducting additional tests, and modeling applications to develop a much improved understanding of precipitation of aluminum-containing solids in the SWPF processes. Its latest report (02-700-00654, *Milestone Progress Report for CSSX Dispersion (Emulsion) Task,*) included recommendations for future laboratory and full-scale CSSX studies. The recommendations address enhanced feed stability, preventing solids formation in CSSX contactors, and alternative contactor flushing approaches. The TRA Team endorses these recommendations and believes that the results will bring significant benefits in refining optimum process conditions well before startup testing.

Recommendation: SWPF project management should ensure that adequate priority is provided to complete the studies recommended in Parsons' report 02-700-00654.

2. Impact of Dissolving Aluminum in Tank Farm Sludge on SWPF Feed Chemistry

Observation: SRS is planning to utilize aluminum dissolution in the Tank Farm to reduce the aluminum concentration in feed to DWPF and, thereby, reduce the number of canisters that must be produced at DWPF. While reducing canisters has significant cost savings, it is not clear to the Team that the impact of the additional aluminum coming to SWPF has been assessed. Recent SWPF studies have recommended a reduction of aluminum concentration (<0.5 Molar) as well as increased hydroxide concentration in SWPF feed. These changes are required for SWPF feed stability and prevention of solids formation downstream in the centrifugal contactors. The recommended lower aluminum concentrations and higher hydroxide concentrations would appear to increase the volume of feed to be processed in SWPF. Furthermore, if precipitation is difficult to prevent in SWPF due to the increased aluminum input, some aluminum-containing solids could be filtered out in the ASP and sent to DWPF with the MST/sludge stream.

Recommendation: An integrated Liquid Waste Systems Model should evaluate the impacts on SWPF and the entire Liquid Waste System of the aluminum in sludge being diverted from the DWPF feed to the SWPF feed.

3. Interaction between SWPF project and Integrated Salt Disposition project

Observation: SRS currently has another project, the Integrated Salt Disposition Project (ISDP), which is successfully utilizing most of the processes that will be employed at the SWPF. The ISDP's Actinide Removal Process (ARP) and Modular Caustic Solvent Side Extraction Unit (MCU) have successfully demonstrated removal of radioactive constituents from salt waste. The TRA team endorses the existing interaction between the ISDP Project and SWPF Project, but feels that both projects would benefit from enhanced interaction.

Recommendation: The interaction and communication between the two projects should continue and be enhanced as much as possible in the future in order to maximize the benefit of current ISDP operating experience. Exchange of personnel between the two projects should be considered.

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Acronyms and Abbreviations

AFF	Alpha Finishing Facility
AFP	Alpha Finishing Process
Al	Aluminum
ANL	Argonne National Laboratory
APA	Air Pulse Agitator
ARP	Actinide Removal Process
ASME	American Society of Mechanical Engineers
ASP	Alpha Strike Process
AST-A	Alpha Sorption Tank-A
BOBCalixC6	Calix[4]arene-bis(tert-octylbenzo-crown-6
BPF	Barnwell Processing Facility
CDCSS	Cs-depleted CSS
CFF	Cross Flow Filtration
CINC	Costner Industries Nevada Corporation
CIP	Clean-in-place
Cs	Cesium
CSS	Clarified Salt Solution
CSSE	Cesium Strip Effluent solution
CSSX	Caustic-side Solvent Extraction
CTE	Critical Technology Element
DCS	Distributed Control System
DHTSS	DSS Hold Tank
DoD	Department of Defense
DOE	U.S. Department of Energy
DOE-EM	Department of Energy, Office of Environmental Management
DSS	Decontaminated Salt Solution
DWPF	Defense Waste Processing Facility
EPC	Engineering, Procurement, and Construction
FFT-A	Filter Feed Tank-A
FFT-B	Filter Feed Tank-B
FST	Full-Scale Test
GAO	General Accounting Office
gpm	Gallon per Minute
$H_2C_2O_4$	Oxalic Acid
HEPA	High-Efficiency Particulate Air
HLW	High-level Waste

HNO_3	Nitric Acid
HTF	H-Tank Farm
ICDs	Interface Control Documents
INEEL	Idaho National Engineering and Environmental Laboratory
ISDP	Integrated Salt Disposition Project
ISDP/ARP	Integrated Salt Disposition Project, Actinide Removal Process
K	Potassium
LPPP	Low Point Pump Pit
LWO	Liquid Waste Operation
M	Molar
m	Micron
M&O	Management and Operating
MCU	Modular Caustic Solvent Side Extraction Unit
Mgal	Million gallons
Mgal/yr	Million gallon per year
MST	Monosodium Titanate
MSTT	MST/Sludge Transfer Tank
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
Na	Sodium
Na^+	Sodium ion
NaOH	Sodium Hydroxide
O/A	Organic to Aqueous
ORNL	Oak Ridge National Laboratory
PMVS	Pulse Mixer Ventilation System
PNNL	Pacific Northwest National Laboratory
PPT	Precipitate Pump Tank
PVVS	Process Vessel Ventilation System
RAM	Reliability, Availability, and Maintainability
SCCs	Structure, Systems and Components
SFP	Solvent Feed Pump
SHT	Solvent Hold Tank
Si	Silicon
SPF	Saltstone Production Facility
SR	Savannah River Operations Office
Sr	Strontium
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SSFT	Salt Solution Feed Tank
SSRT	Sludge Solids Receipt Tank

SWPF	Salt Waste Processing Facility
TEs	Technology Element
TFA	Tank Focus Area
TMP	Technology Maturation Plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TU	Tank Utilization
VFD	Variable Frequency drive
WAC	Waste Acceptance Criteria
WTE	Waste Transfer Enclosure
WTP	Waste Treatment Plant
WWHT	Waste Water Hold Tank

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Glossary

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

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1 Introduction

Nuclear material production operations at Savannah River Site (SRS) resulted in the generation of approximately 37 million gallons (Mgal) of High-level waste (HLW). The HLW is composed of approximately 3.0 Mgal of sludge containing precipitated solids and insoluble waste and 33.5 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. [1, 2]

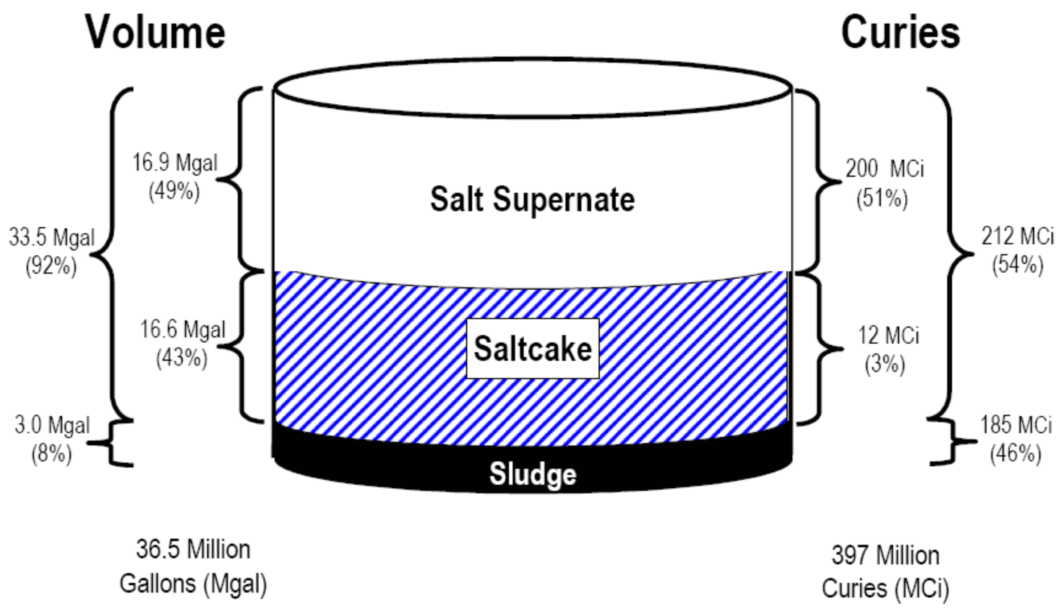

Figure 1-1. SRS Liquid Waste Composite Inventory[1]

The U.S Department of Energy (DOE), Savannah River Operation Office (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 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]

1.1 SWPF Background

Upon completion of conceptual design for the baseline 1.0 million gallon per year (Mgal/yr) facility, SR directed both SWPF EPC Contractors to complete Conceptual Designs for the SWPF, based on a nominal capacity of 3.0 Mgal/yr. In order to meet the required nominal throughput, given the revised assumptions, the instantaneous throughput for the SWPF was required to be ≥ 4.95 Mgal/yr. DOE and the EPC critically reviewed the Actinide Removal Process (ARP) and Caustic-Side Solvent Extraction (CSSX) Process Conceptual Design in view of results from Monosodium Titanate (MST) and filtration performance tests completed after Conceptual Design and CSSX pilot-scale tests. Changes to key design assumptions and the addition of an Alpha Finishing Process (AFP) resulted in a significant increase in predicted plant throughput capability. This improved design was called the SWPF Enhanced Conceptual Design. [2]

The minimum throughput required by the SWPF Contract (DE-AC09-02SR222102)[4] is 3.75 Mgal/yr, based on an availability of 75% and an instantaneous throughput of 5.0 Mgal/yr. The current plant final design baseline provides the ability to process batches of waste feed of 23,200 gallons each in approximately 21.6 hours. This results in an instantaneous maximum capacity of 9.4 Mgal/yr. Nominal throughput for the SWPF is defined as the minimum sustained average throughput that can be expected over the life of the plant, after accounting for SWPF unavailability due to forced shutdowns or scheduled outages (availability). Assuming a minimum availability of 75%, the nominal throughput for the SWPF is:

Nominal Throughput = Design Throughput x SWPF Availability

$$\text{Nominal Throughput} = 9.4 \text{ Mgal/yr} \times 0.75 = 7.0 \text{ Mgal/yr.}$$

This exceeds the SWPF contract[4] requirement of 3.75 Mgal/yr. The actual facility throughput will also be affected by interfacing facilities (primarily H-Area Tank Farm, DWPF, and SPF). However, managing these interfaces falls under the auspices of the Liquid Waste Operations (LWO) Contractor and Site Management and Operating (M&O) Contractor, in cooperation with the EPC and direction from DOE.[2]

1.2 SWPF Process Description

Three consecutive basic unit operations are employed to treat salt waste at the SWPF: Alpha Strike Process (ASP), Caustic-side Solvent Extraction (CSSX), and Alpha Finishing Process (AFP). (See Figure 1-2.) These processes separate the radioactive elements (primarily actinides, Sr, and Cs) from the bulk salt waste and concentrate them into a relatively small volume. This small volume is then transferred to the Defense Waste Processing Facility (DWPF) for vitrification. The remaining bulk salt waste contains only low levels of radioactive materials and is sent to the Saltstone Processing Facility (SPF) for incorporation into grout.[2] The following section gives a brief description of each major process used in the SWPF.

1.2.1 Alpha Strike Process

The Alpha Strike Process is a batch process where the SWPF feed is chemically adjusted and MST added. The MST adsorbs the Sr and actinides, and the resulting MST slurry is filtered to produce a concentrated MST/sludge slurry and a Clarified Salt Solution (CSS) filtrate. The concentrated MST/sludge slurry is washed to reduce the sodium ion (Na^+) concentration and transferred to the DWPF for vitrification while the CSS is routed to the CSSX process.[2, 3]

1.2.2 Caustic-Side Solvent Extraction

The second SWPF process, the CSSX, is a continuous flow process that uses 36 contactor stages for extraction, scrubbing, stripping, and washing of aqueous and organic streams. The Cs is removed by contacting the CSS (aqueous phase) with an organic solvent in the extraction stage contactors. The Cs-depleted aqueous outlet stream is sent to the AFP for analysis. If the Sr/actinide concentration in the CSS from the CSSX is sufficiently low, the aqueous raffinate from the extraction stages is sent to the SPF to be solidified with a cementitious grout mixture. If the Sr/actinide concentration in the CSS is excessive, the aqueous raffinate from the extraction stages (referred to as Cs-depleted CSS [CDCSS]) is sent to the AFP for an additional MST strike. Following extraction, the Cs-rich solvent is scrubbed to remove impurities (primarily sodium and potassium). The solvent is then contacted with a dilute nitric acid strip solution in the stripping stages, where the Cs is transferred to the aqueous strip effluent. The strip effluent, which contains a high Cs concentration, is sent to the DWPF for vitrification.[2, 3]

1.2.3 Alpha Finishing Process

The AFP, located downstream of the CSSX, is the third SWPF processing stage. When the SWPF is operating in a single-strike mode, DSS from the CSSX is sent to the AFP for confirmatory sampling prior to transfer to the SPF. However, if the Sr/actinide content of the waste feed is excessive so that a single MST strike cannot reduce the concentrations to where the CDCSS meets the Saltstone Waste Acceptance Criteria (WAC), the CDCS will be sent to the AFP for a second MST strike. Because the CDCSS contains a limited Cs concentration, the process equipment in the Alpha Finishing Facility (AFF) can be operated and maintained without the extensive shielding and remote handling provisions required in the ASP.[2, 3]

1.3 TRA Objectives

The SWPF project has not had any prior TRAs conducted on any of its technologies. At the time of this TRA, the SWPF project had recently completed a 90% design review and received CD-3 approval. The SWPF Federal Project Director requested that a TRA be performed to assure that the technologies planned for the SWPF are adequate and have been matured to the appropriate technology levels.[5] The purpose of this TRA was to evaluate the technologies used in treatment processes of SWPF in accordance with the Technology Readiness Assessment (TRA)/Technology Maturation Plan (TMP) Process Guide.[6] This TRA was intended to:

- Identify critical technology elements (CTE).
- Determine the Technology Readiness Level (TRL) associated with each CTE.
- Determine the degree of difficulty (measured by cost and schedule) in improving the maturity level of any of the technologies that have not reached the appropriate level (TRL 6).

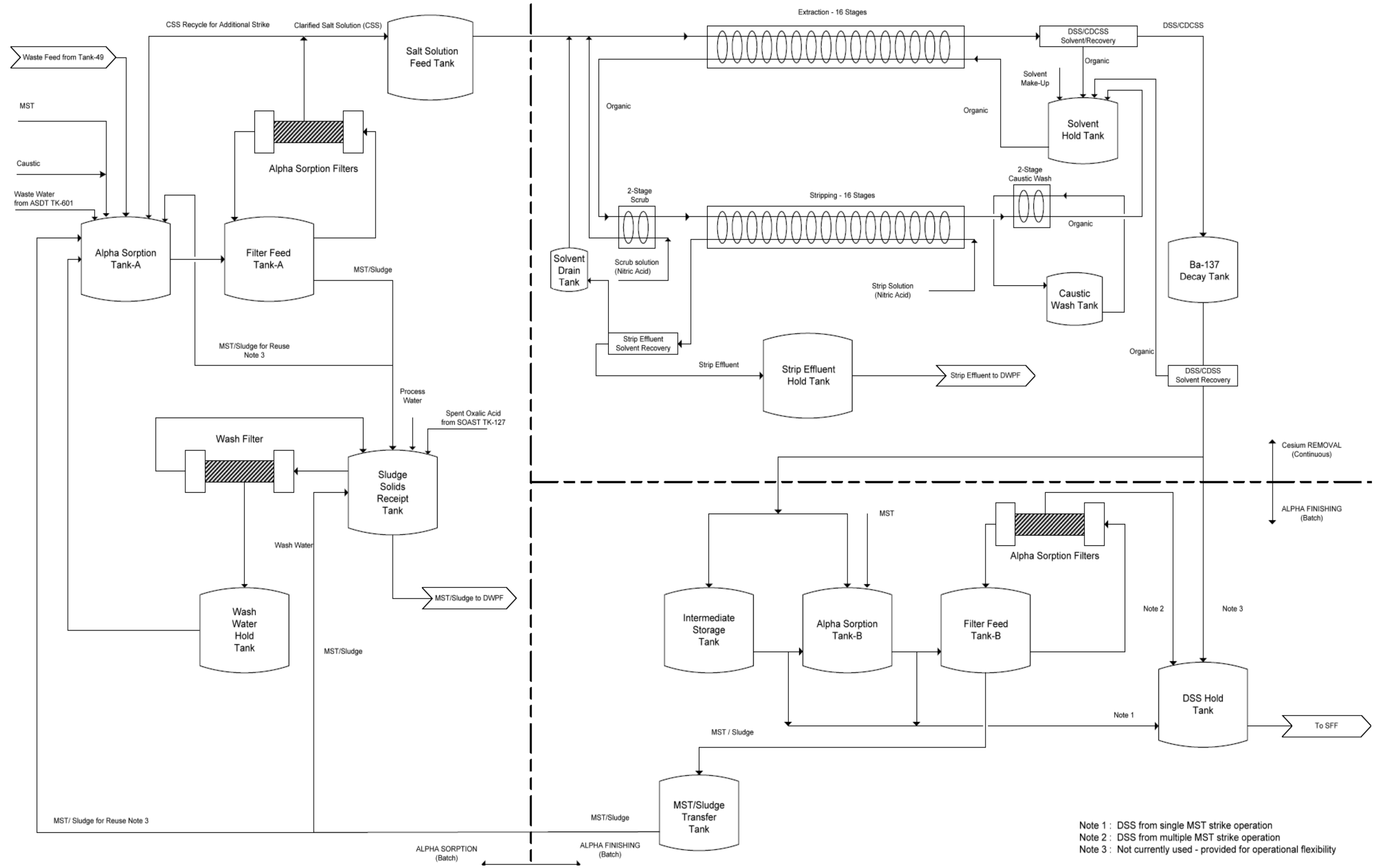

Figure 1-2. Salt Waste Processing Facility Process Flow Diagram

2 Technology Readiness Assessment

2.1 Background

A TRA measures technology maturity using the Technology Readiness Level (TRL) scale that was pioneered by the 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.[7] 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*.[8] Recent legislation (2006) has specified 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 justify any waivers.

In March of 2007 the GAO recommended that DOE adopt the NASA/DoD methodology for evaluating technology maturity.[9] Language supporting the GAO recommendation was incorporated in the House version of the 2008 Department of Energy, Office of Environmental Management (DOE-EM) budget legislation. In 2006-2007, EM conducted pilot TRAs on a number of projects including Hanford's Waste Treatment Plant, Savannah River's Tank 48, and Hanford's K-Basins. In March of 2008 EM issued its *Technology Readiness Assessment (TRA)/Technology Maturation Plan (TMP) Process Guide* which established the TRA process as an integral part of EM Project Management's Critical Decision Process.[6]

The TRL scale ranges from 1 (basic principles observed) through 9 (total system used successfully in project operations). DOE-EM, DoD, and NASA normally require a TRL of 6 for incorporation of a technology into the detailed design process.

2.2 Description of 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."[6, 8]

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 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 TRA is followed by development of a Technology Maturation Plan that identifies the additional development required to attain the desired level of readiness. The process is carried out by a group of experts that are independent of the project under consideration.

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

The TRL scale used in this assessment is shown in Table 2.1. This scale requires that testing of a prototypical design in a relevant environment be completed before incorporation of the technology into the final design of the facility.

The testing requirements used in this assessment are compared to the TRLs in Table 2.2. These definitions provide a convenient means to further understand the relationship between the scale of testing, fidelity of testing system, testing environment, and the TRL. This scale requires that for TRL 6, testing must be completed at an engineering or pilot scale, with testing of the system fidelity that is similar to the actual application and with a range of simulated waste and/or limited range of actual waste, if applicable.

The assessment of the TRLs was aided by questions based on a TRL Calculator methodology that was originally developed by the U.S. Air Force[8] and modified for DOE-EM applications.[6] The TRL questions used in this assessment are described in more detail in Appendix B.

Table 2-1 Technology Readiness Levels

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot scale, similar (prototypical) system validation in a relevant environment.	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
Basic Technology Research	**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.
	TRL 1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

Table 2-2 TRL Scale, Fidelity, and Environment Definitions

Scale	
Full Plant Scale	Matches final application
Engineering Scale[1]	Typical (1/10 < system < Full Scale)
Laboratory/Bench[1]	< 1/10 Full Scale
System Fidelity	
Identical System Configuration	-matches final application in all respects
Similar Systems Configuration	-matches final application in almost all respects
Pieces	-system matches a piece or pieces of the final application
Paper	-system exists on paper (i.e., no hardware system)
Environment (Waste)	
Operational (Full Range)	Full range of actual waste
Operational (Limited Range)	Limited range of actual waste
Relevant	Simulants plus a limited range of actual wastes
Simulated	Range of simulants
[1] The Engineering Scale and Laboratory/Bench scale may vary based on engineering judgment.	

2.3 TRL Assessment Process Description

The Assessment Team was comprised of staff from the DOE EM-21 and technical consultants to DOE. See Appendix D for identification of the Assessment Team and supporting contractor and vendor personnel. The Assessment Team members have extensive experience on related nuclear waste treatment technologies. The Parsons engineering staff and Liquid Waste Operations personnel presented descriptions of the Salt Waste Process Facility treatment systems, described the technology research and testing results, and participated in the completion of the responses to the individual TRL questions. Each response to a specific TRL question was recorded, along with references to the appropriate documents.

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

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

2.4 Determination of CTEs

The process for identifying the CTEs for the facilities involved a technology system evaluation by the treatment subject matter experts on the Assessment Team. The Assessment Team identified as potential CTEs the technology subsystems that are directly involved in processing the tank waste. The Team evaluated the potential CTEs against the two sets of questions presented in Table 2-3. 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.

Table 2-3. Critical Technology Element Questions

Set 1 - Criteria	Yes	No
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		
• Is the technology modified?		
• 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?		

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3 Summary of the Technology Readiness Assessment

3.1 Determination of SWPF CTEs

The Assessment Team identified five major SWPF systems. Four of these systems were divided into 10 subsystems giving eleven Technology Elements (TEs) that were evaluated against the two sets of questions presented in Table 2-3. The results of the CTE evaluations are presented in Appendix A. Seven of the TEs were determined to be CTEs. Table 3-1 displays the SWPF systems and subsystems (TEs). TEs determined to be CTEs are high-lighted. Process Integration was also determined to be a CTE.

Table 3-1. SWPF Systems and Subsystems (TEs)

Systems				
Feed Adjustment	Actinide/Sr Removal	CSSX	Product Handling	Analytical Laboratory
Subsystems (TEs)				
Al Chemistry	MST Performance	CSSX Chemistry	Strip Effluent	
	Cross Flow Filter	Centrifugal Contactors	MST/Sludge	
	Air Pulse Agitator	Solvent Recovery	DSS	

3.2 Feed Adjustment - Al Chemistry

3.2.1 Function of Feed Adjustment

The function of Feed Adjustment is to receive waste transfers from the SRS Tank Farms and to make chemical adjustments required for feed stability and processing. Control of aluminum chemistry to prevent or minimize solids formation is a key requirement.

3.2.2 Description of Feed Adjustment

At the Tank Farms, waste removed from individual liquid radioactive waste tanks will be staged as macro-batches in Tank 49. A macro-batch will be subdivided into mini-batches (23,200 gal) for transfer and treatment in the SWPF. The macro-batch will provide a large volume of consistent composition waste to facilitate reproducibility and optimization of operations in the SWPF. Each macro-batch will be blended, mixed, and sampled. If the macro-batch sample results meet SWPF feed specifications, the macro-batch can be qualified for transfer to the SWPF. The contents of Tank 49 will be mixed to ensure that solids are evenly distributed prior to batch transfer to the SWPF. The Tank Farm waste feed preparation operations, including transfer between tanks, chemical adjustments, blending and mixing, and sampling and analysis, will be performed by the Site LWO and M&O.[2, 3]

The feed in Tank 49 will be required to conform to the SWPF Feed WAC prior to transfer to the SWPF. Sample results from source tanks may be used in the waste feed evaluation to qualify a macro-batch in Tank 49. Feed transfer to the SWPF will be performed in accordance with a transfer procedure, as specified in *SWPF Waste Transfer Interface Control Document*[10] and approved waste transfer operating procedures for the H-Area Tank Farm, S-Area DWPF, and J-Area SWPF.

Some macro-batches are expected to contain high Sr/actinide concentrations and will require multiple MST strikes. Because transfer of a new batch of waste from the source tanks to Tank 49 may take several days (during which time two or more SWPF feed batches may be processed), there will be a point in time during a macro-batch transfer at which Tank 49 Sr/actinide concentration will change enough to require a transition in SWPF operations from single-strike to multi-strike or from multi-strike to single-strike operation. In order to identify when this transition should be made, Tank 49, the SWPF Alpha Sorption Tank-A (AST-A), or the SWPF Salt Solution Feed Tank (SSFT) will be sampled periodically, as outlined in the *SWPF Analytical Laboratory Design Requirements*.[11]

3.2.3 Relationship to Other Systems

The SWPF feed will be transferred from Tank 49.[10] Feed will be transferred to the SWPF at a nominal flow rate of 130 gallons per minute (gpm) and temperature of 77 ± 10 degrees Fahrenheit (°F). Feed will be received at the SWPF in mini-batch (referred to as a "batch" throughout the remainder of this section) transfers of approximately 23,200 gallons each. This is the batch size necessary to meet the design throughput requirements, given an overall AST-A cycle time of approximately 21.6 hours for single-strike operation. AST-A, Filter Feed Tank-A (FFT-A), and the Alpha Sorption Filters have been sized based on this cycle time and batch volume.

3.2.4 Development History and Status

Lab-scale simulant and actual waste feed stability studies[12, 13] were conducted to investigate supersaturation with respect to aluminum and precipitation caused by heating or seeding with gibbsite crystals.

The feed solution for the Cross flow filter(CFF) large-scale test[14] was prepared from MST and simulated sludge in an aqueous solution of 2.8 Molar (M) sodium hydroxide (NaOH) and 2.8M sodium nitrate (NaNO3). Simulated sludge for the test included aluminum, iron, manganese, sodium (Na), and potassium solids. The CFF test unit included a single filter nearly identical in size to the proposed full-scale SWPF filters, along with support equipment to provide prototypical flows and pressures. For most tests, the solution was filtered until the concentration had increased to 7 wt% solids. The testing demonstrated the constructability and operability of the CFF and determined the optimum flow rates, operating pressures, filtrate-flow control, and cycle timing for filter back pulse and chemical cleaning.[14]

The CSSX Full-Scale Test (FST) [15] used a high-fidelity simulated SWPF waste and actual CSSX solvent. The simulated salt feed solution was recycled within the system for both the testing performed in San Diego and that performed at the Barnwell Processing Facility (BPF). During testing conducted at the BPF (prototypic of SWPF operations), the simulant was diluted during operation by the addition of the spent scrub solution leaving the scrub contactors. The normal simulant-to-scrub feed flow ratio was 15:1. This dilution resulted in the need to periodically discharge the volume accumulated from scrub addition by transfer to the DSS Waste Tank and made it necessary to reconstitute the scrub-diluted simulant to original simulant component concentrations. Solids formed in the feed tank and also were observed in the contactor stages. Further tests were recommended to investigate operational strategies to limit or eliminate the formation of solids and/or solids dispersions that were observed during this test.[15]

In response to the above recommendation, laboratory analyses of CSSX solids and dispersions samples and modeling predictions were conducted.[16] The results provided substantial information on the nature and compositions of CSSX solids and dispersions, circumstances and operational conditions that can promote the formation of solids and dispersions, means of suppressing or preventing precipitate formations, and identification methods to mitigate/dissolve the solids or dispersions, if they form. Based on these results, it was recommended that the maximum CSSX normal operating limits/conditions for Aluminum (Al) and Silicon (Si) in SWPF feed be re-evaluated. It also was recommended that the SWPF feed have the following concentration limits: Al $\leq$ 0.25M, OH $\geq$ 2.0M, and Si $\leq$ 0.03M. The SWPF Waste Acceptance Criteria document has been revised to incorporate this recommendation.[17] Also, initial operations of the SRS Integrated Salt Disposition Project (ISDP) have shown the need for addition of sodium hydroxide to the tank waste feed to reduce aluminum concentration and prevent precipitation of aluminum-containing solids.[18]

3.2.5 Relevant Environment

Feed adjustment will be carried out in a highly radioactive environment. Radioactivity is dominated by up to 5.25 Ci/gal of Cs-137. Feed solutions will contain high concentrations of dissolved salts (6.4 M sodium), very strong caustic (from 0.5 M to several molar hydroxide), significant aluminate concentrations, and low concentrations of suspended solids.[2, 3]

3.2.6 Comparison of the Relevant Environmental and the Demonstrated Environment

Laboratory-scale feed stability studies[13] were conducted with six SRS radioactive waste samples. The samples were tested for supersaturation of aluminum and for precipitation of aluminosilicates by heating the solutions to accelerate solids formation. Also, feed preparation and feed adjustment activities were conducted in support of numerous process tests. Several bench-scale CSSX flowsheet tests were conducted with actual radioactive waste that had been chemically adjusted and filtered prior to processing in the 2-cm centrifugal contactors.[19-24] Finally, large-scale tests of air pulse agitators[14], cross-flow filters[14], and centrifugal contactors[15] were conducted using multi-component simulants that were formulated based on actual waste compositions. Each of the large-scale tests was begun by receiving vendor prepared simulants and feed adjustment as required.

3.2.7 Technology Readiness Level Determination

The Feed Adjustment System was determined to be TRL 6 because of the range of laboratory- and bench-scale tests with actual waste and particularly by the large-scale equipment tests that involved batches of SWPF feed simulant. In addition, a recent study[16] of solids and emulsions in the CSSX process substantially extended the knowledge base on aluminum chemistry in SWPF feed and CSSX unit operations. This study led to changes in the SWPF feed specifications for aluminum, hydroxide, and Si.

All required project documents for TRL 5 and 6 have been completed including performance baseline and final design drawings (CD-3 approved), RAMI levels, operating requirements document, interface control documents, configuration management plan, and final test reports. Tables B-1 and B-2 in Appendix B capture the result of the TRL 5 and TRL 6 evaluations.

3.3 Actinide/Sr Removal

The removal of actinides and strontium (Sr) from the salt waste takes place in two systems, the Alpha Strike Process (ASP) System and the Alpha Finishing Process (AFP) System, as shown in Figure 1-2. The ASP/AFP systems contain three major technology elements (TEs); absorption of the actinides/Sr on Monosodium Titanate (MST), filtration of the MST/sludge/salt solution using cross flow filters (CFF), and mixing of the MST/sludge/salt solution in the various tanks contained in the ASP system using Air Pulse Agitators (APAs).

CFF and APA were determined to be CTEs (see Section 2.4 and Appendix B). Their technology readiness assessments can be found below in Sections 3.3.1 and 3.3.2 and Appendix B. MST absorption was determined not to be a CTE based on its successful demonstrations on a variety of actual wastes and simulants at laboratory and bench scales[25-36] and in the SRS Integrated Salt Disposition Project, Actinide Removal Process (ISDP/ARP).[18]

3.3.1 Cross Flow Filtration (CFF)

3.3.1.1. Function of the CFF

The SWPF uses CFF to concentrate the MST/sludge slurry to approximately 5 weight percent (wt %).

3.3.1.2. Description of the CFF System

As shown in Figure 1-2, three sets of cross flow filters are employed in the SWPF; the ASP Alpha Sorption filters, the ASP Wash filters, and the AFP Alpha Sorption filters. Descriptions of each drawn from the Process Basis of Design document[2] are as follows.

ASP Alpha Sorption filters
Two filtration circuits, each designed for 50% of the required capacity, are normally in service, with a third isolated and maintained in standby. A two-pump system consisting of a feed pump and a recirculation pump is employed for each ASP Alpha Sorption filter circuit. The Filter Feed/Solids Transfer Pumps provide positive pressure to the suction of the associated Filter Recirculation Pump. Cross-flow through the ASP Alpha Sorption Filters is provided by the Filter Recirculation Pumps which maintain a high flow velocity (nominally 9-13 ft/s) through the cross-flow filter tubes. Most of the slurry exiting the filter is re-circulated back to the recirculation pump suction. A bleed-back flow is returned to the filter feed tank in order to prevent excessive concentration of solids in the filter loop.

The filters contain parallel one-half-inch-diameter tubes fabricated from sintered stainless steel that have a pore size of 0.1 micron (μ). The filters are sized such that two filters operating in parallel can produce filtrate at the design filtrate flow rate of 21.5 gal/min, assuming an average filtrate flux rate of 0.06 gal/min per square foot. This filtration rate corresponds to a filtration cycle time of approximately 21.6 hours, which matches the AST cycle time and corresponds to a design processing rate of 9.4 Mgal/yr.

The filters are designed so that the filter tube bundle is self-draining and vertically removable. Each filter can be back pulsed using compressed air at up to approximately 100 pounds per square inch gauge (psig). During normal operation of the filtration systems, it is anticipated that the filter flux will decrease with time due to fouling of the filter pores by suspended and colloidal solids present in the waste. When filter performance has degraded to a point (based on observed filter flux and trans-membrane pressure) where back-pulsing cannot restore filter performance, the fouled filter will be taken off-line and cleaned with oxalic acid ($H_2C_2O_4$). If filter flux is not restored following cleaning, replacement of the filter cartridge may be required.

ASP Wash filter
The ASP Wash filter is of the same design and uses the same two-pump system as the ASP Alpha Sorption filters.

AFP Alpha Sorption filters
The size and operation of the CFFs, back-pulse tanks, and pumping system for the AFP filter systems are identical to the ASP. The AFP filter systems are designed with flanged connections to allow for removal of the entire filter assembly, as opposed to removal and replacement of the cartridge, as is planned for the ASP.

3.3.1.3. Relationship to Other Systems

As can be seen from Figure 1-2, the ASP Alpha Sorption filters receive MST/sludge slurry from Filter Feed Tank A, concentrate it to ~5 wt%, and send the concentrated slurry to the Sludge Solids Receipt Tank (SSRT).

The concentrated slurry in the SSRT is washed with process water to reduce the Na concentration from 5.6M to 0.5M. Approximately 2.4 gallons of process water will be used to wash 1 gallon of MST/sludge. The process water is added continuously while the SSRT contents are recirculated through the Wash Filter. The filtrate is collected in the Waste Water Hold Tank (WWHT), and the washed sludge is recycled to the SSRT for final transfer to DWPF.

The AFP Alpha Sorption filters receive MST/sludge slurry from Filter Feed Tank B, concentrate it to ~5 wt%, and send the concentrated slurry to the MST/Sludge Transfer Tank (MSTT) for eventual transfer to the SSRT.

3.3.1.4. Development History and Status

Cross flow filters are used in many industrial applications. They have been used in several applications at Savannah River Site and other DOE sites and will be used for liquid-solid separations in Hanford's Waste Treatment Plant (WTP) Pretreatment Facility.

Extensive testing on SWPF simulants has been carried out at engineering[37-42] and full scale.[14] Actual waste testing at bench scale has also been completed.[43-44] All tests show that the filter fluxes required by the SWPF are attainable. The tests have also demonstrated back pulse and cleaning operations. The current SWPF CFF design has ample margin to ensure that the SWPF throughput required by the present design/build contract will be achieved.

3.3.1.5. Relevant Environment

The relevant environment is described in the Process Basis of Design document.[2] Incoming waste must meet the SWPF Waste Acceptance Criteria (WAC) [17] given in Table 3-2.

Table 3-2. Proposed WAC Requirement for SWPF Feed

$Cs^{137} \leq 5.25$ Ci/gal
5.6M < Na < 7.0M
K < 0.05M @ 5.6M Na
Solids < 1200 mg/L @ 6.44M Na
^{90}Sr (Solids) < 3.56 E-02 Ci/g
^{90}Sr (Soluble) < 5.21 E-03 Ci/gal
$1.0M < [NO_{eff}] = ½*[NO_2^-] + [NO_3^-]$
TPB/TPB Degradation Products < 10 ppm
TBP < 25 mg/L

MST will be added to the waste to reach a concentration of 0.4 g/L. The mixture will then be concentrated to ~5 wt % using the ASP Alpha Sorption filters.

The concentrated slurry from the SSRT is washed with process water using the ASP Wash filter to reduce the Na concentration from 5.6M to 0.5M. Radiation levels in this filter are much lower than in the ASP Alpha Sorption filters as soluble radioactive species such as Cs^{137} and ^{90}Sr have been reduced.

If the AFP is used for a second strike, 0.4 g/l MST is added to waste that has been through the CSSX process. Consequently, AFP Alpha Sorption filters receive and concentrate solids slurries that are greatly reduced in radioactive species.

3.3.1.6. Comparison of the Relevant Environmental and the Demonstrated Environment

The CFF system has been successfully demonstrated on actual tank waste at bench scale, [43-44] on multiple simulants at engineering scale, [37-42] on real waste in the ISDP/ARP, [18] and on simulants at full scale[14]. Additional full scale simulant testing is planned for CSSX which will use the CFF for conditioning the CSSX feed. The simulant tests have demonstrated that filter performance scales well from bench to full scale. Simulants have been concentrated to 12 wt%, more than twice the concentration expected in SWPF with no processing issues observed.[42] Filter back pulsing and cleaning has also been demonstrated with simulants.[14, 42]

3.3.1.7. Technology Readiness Level Determination

The CFF CTE was evaluated and determined to be at TRL 6. Laboratory scale tests with real wastes and full scale tests with a range of simulants using prototypical equipment have been completed and are consistant.[13-21] Final reports on CFF technology testing and development have been issued.[19, 95] All required project documents for TRL 5 and 6 have been completed including a performance baseline, final design drawings (CD-3 approved), RAMI levels[19, 93], an operating requirements document, interface control documents, and a configuration management plan. See Table B-3 in Appendix B for the CFF TRL 6 evaluation.

3.3.2 Air Pulse Agitators (APA)

Because APAs require no moving parts that can wear out within the Process Vessel Cells they eliminate the need for remote in-cell equipment removal/replacement. They have found use in high level waste tanks that are enclosed in inaccessible black cells at the Sellafield site in the UK and have been included in designs for DOE HLW pretreatment facilities at Hanford (WTP) and SRS (SWPF). They have also been used in the Bethel Valley and Melton Valley tanks at Oak Ridge.

APA mixing systems will be used in the following major processing tanks in the ASP System: Alpha Sorption Tank A (AST-A), Filter Feed Tank A (FFT-A), Sludge Solids Receipt Tank (SSRT), Salt Solution Feed Tank (SSFT), and Water Wash Hold Tank (WWHT) (See Figure 1-2).[2]

3.3.2.1. Function of the APA System

The function of APA systems is to mobilize and uniformly mix the MST/sludge/salt-solution slurry in the tanks.

3.3.2.2. Description of the APA System

The operational principle of the APA is shown in Figure 3-1. During the suction phase, fluid from the tank is drawn into the APA pulse pot by liquid head pressure, vacuum assist, or a combination of the two. During the drive phase, the pulse pot is pressurized with air and the liquid in the pot is blown out of the bottom pulse pot nozzle and into the tank. Control valves for the APA are located outside the Process Vessel Cells.

The following description and figures are taken from the *Air Pulse Agitator Scale-up Validation* Test Report[27]. As shown in Figure 3-2., the SWPF baseline full-scale APA design consists of an American Society of Mechanical Engineers (ASME) dished bottom tank, pulse pots oriented around the tank perimeter, and one center pulse pot. There are six perimeter pulse pots in AST-A, FFT-A, SSFT, four in WWHT and three in SSRT. The jet nozzles are pointed down such that the jet impinges on the tank bottom dish at a 90-degree angle. Wear plates are installed on the tank bottom under the discharge nozzles to avoid erosion of the tank bottom by the jet pulses.

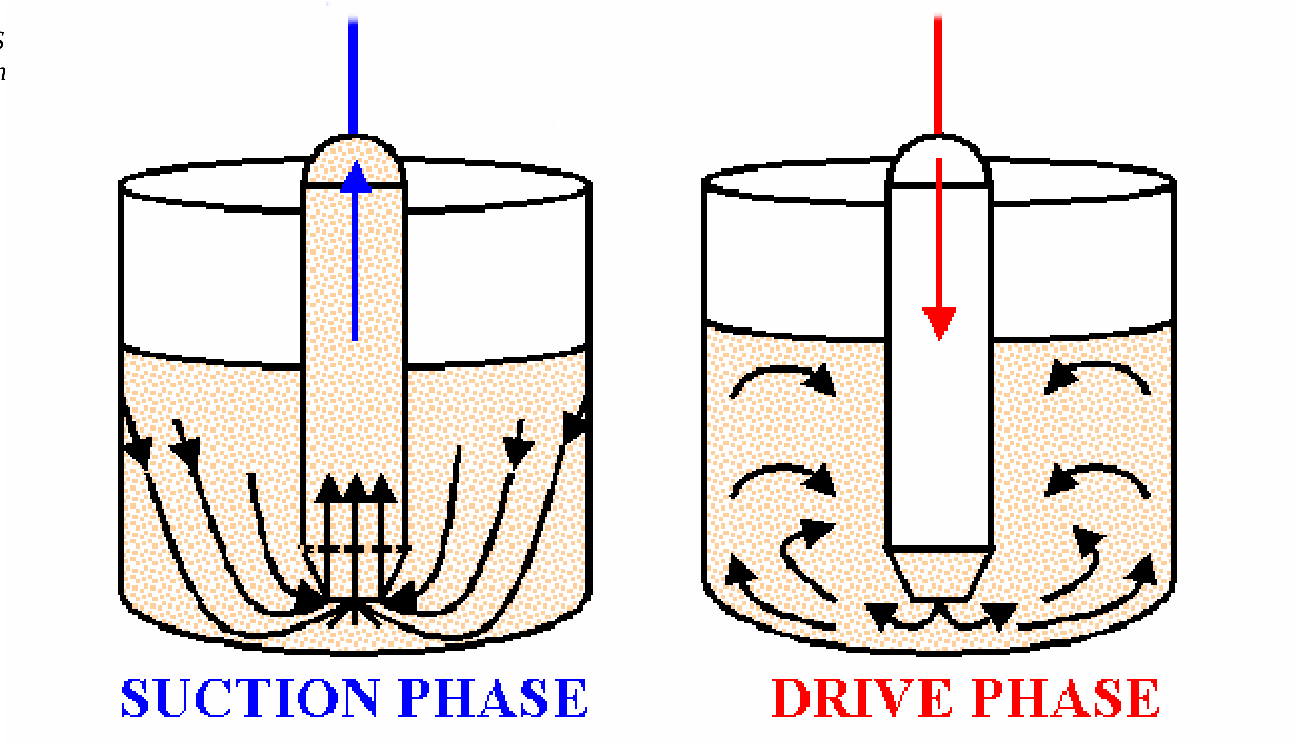

Figure 3-1. APA Operational Principle

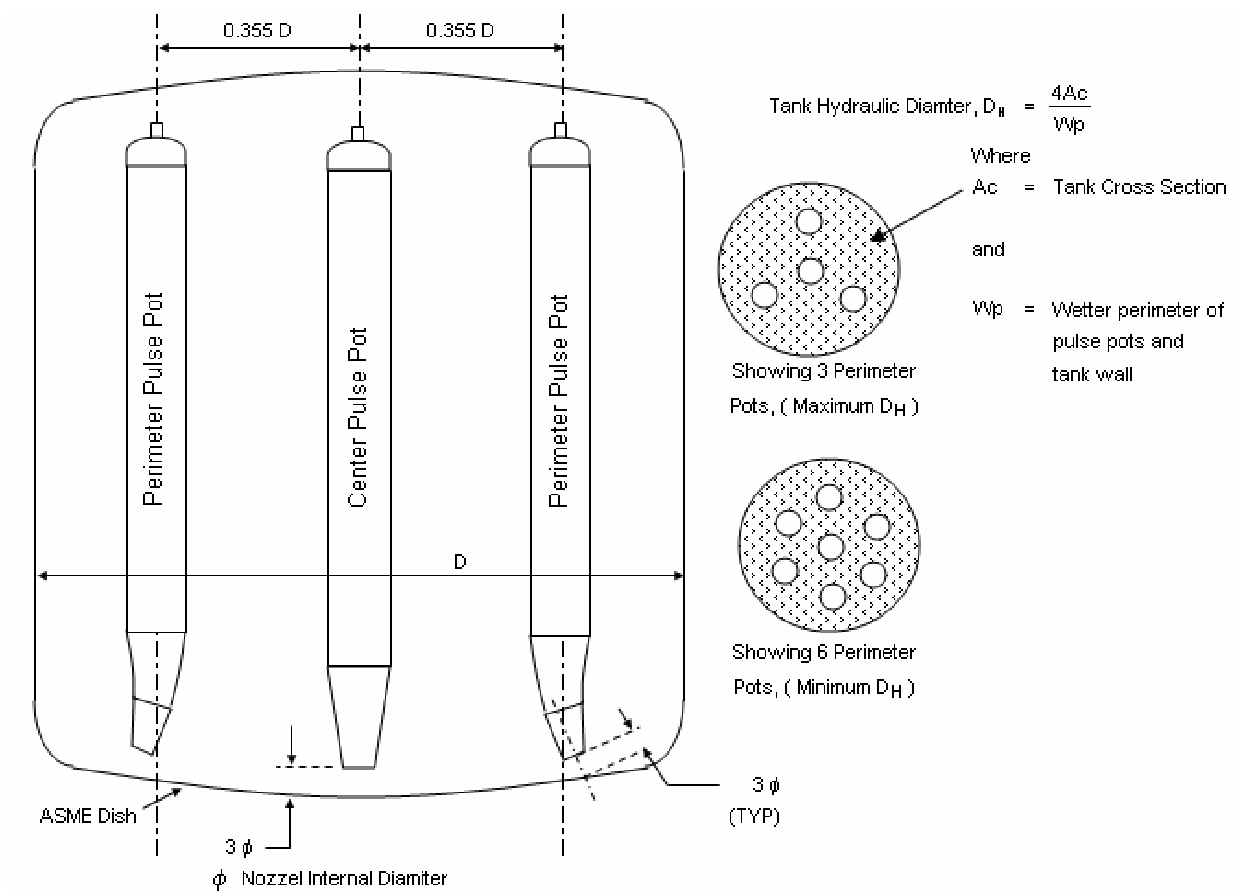

Figure 3-2. SWPF Baseline APA Configuration

The baseline components that operate the full-scale APAs are shown in Figure 3-3. During the drive phase, the three-way valve is open to the air receiver and air flows from node 1 to node 2. The drive pressure and jet velocity increases and the liquid level inside the pulse pot decreases. During the vent drive phase, the three-way valve is open to the vacuum header and air flows from node 2 to node 3. Liquid continues to exit the pulse pot until the hydrostatic pressure inside the pulse pot is in equilibrium with that of the tank. During the fill phase, liquid enters the pulse pot and continues to fill to an equilibrium level supported by the vacuum system. Figure 3-4 provides a graphical representation of the jet velocity, drive pressure, and liquid levels inside the pulse pot during the pulse cycle.

The APAs will be operated by firing single pulse pots sequentially in a cross-fire sequence (i.e., one opposite the other), as shown in Figure 3-5. The figure on the left represents the firing sequence using seven pulse pots, and the figure on the right represents the firing sequence with four pulse pots. Immediately following the drive phase of one pulse pot, the next pulse pot in the firing sequence will fire and so on. The firing sequence and pulse duration are controlled by digital controllers.

3.3.2.3. Relationship to Other Systems

The APAs are vented to the Pulse Mixer Ventilation System (PMVS). To increase the pulse pot rate of refill and available refill volume at low tank levels, the pulse pot vent header is maintained at a negative pressure. The PMVS exhaust fans draw air from the pulse pot vent header through one of two High-Efficiency Particulate Air (HEPA) filter trains. The PMVS exhaust air is discharged out the Exhaust Stack.

3.3.2.4. Development History and Status

APAs were developed at the Sellafield, UK reprocessing site. They have performed well in Oak Ridge's Melton Valley and Bethel Valley waste tanks, and are included in the design of the Hanford WTP. Pilot tests (~1/3 scale)[A] [26] Scale up validation tests (1/5, 5/8 scale) [27] carried out by the EPC have demonstrated the ability of the SWPF APA designs to suspend and mix SWPF MST/sludge simulant. Erosion from the pulses exiting the jet nozzles has been measured[28] and projected to be acceptable over the lifetime of the SWPF. Bench and pilot scale tests have demonstrated the ability of the APAs to resuspend simulant mixtures that have been allowed to settle for up to 61 days provided the mixtures are kept below 50^{o}C.[25, 31] (SWPF is intending to keep temperatures below 30^{o}C.) APA scale-up models have been developed and validated for SWPF simulants.[27]

[A] Note: although Reference 26 considered this a 1/3 scale (by volume), it is actually the same size as the 5/8 scale (by linear dimension).

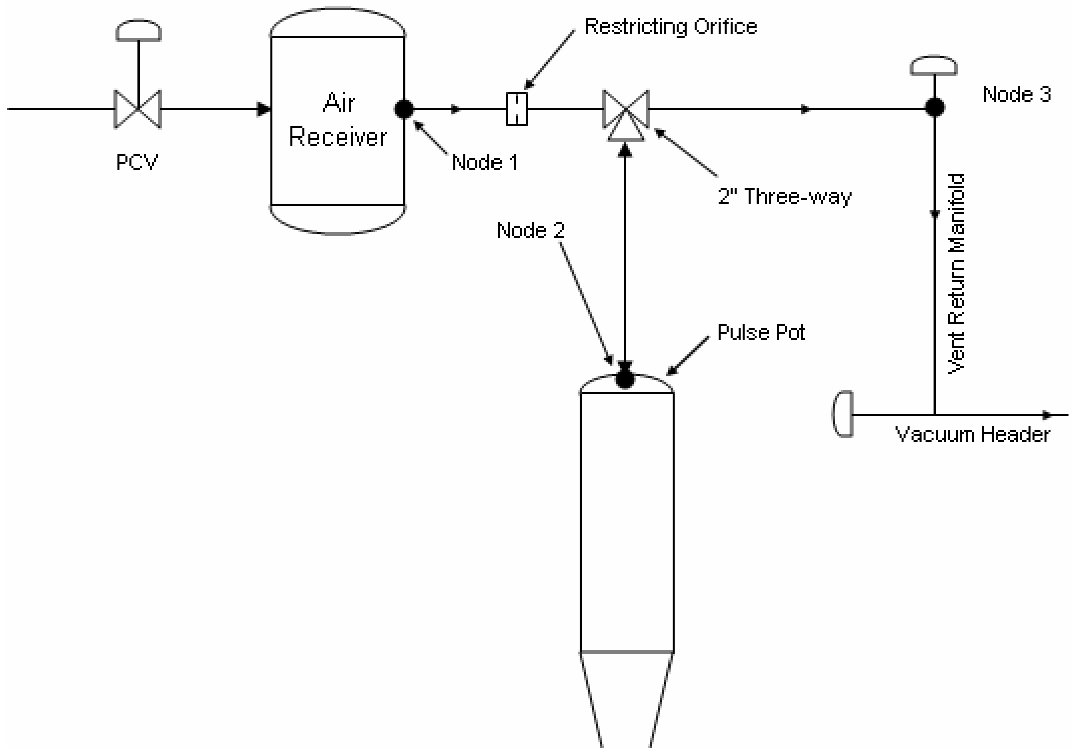

Figure 3-3. SWPF Baseline APA System Components

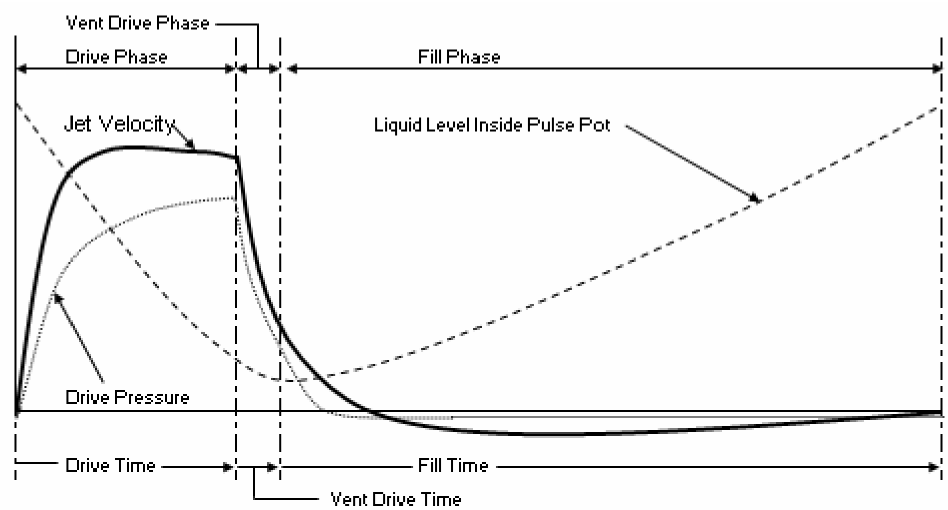

Figure 3-4. Pulse Pot Dynamics

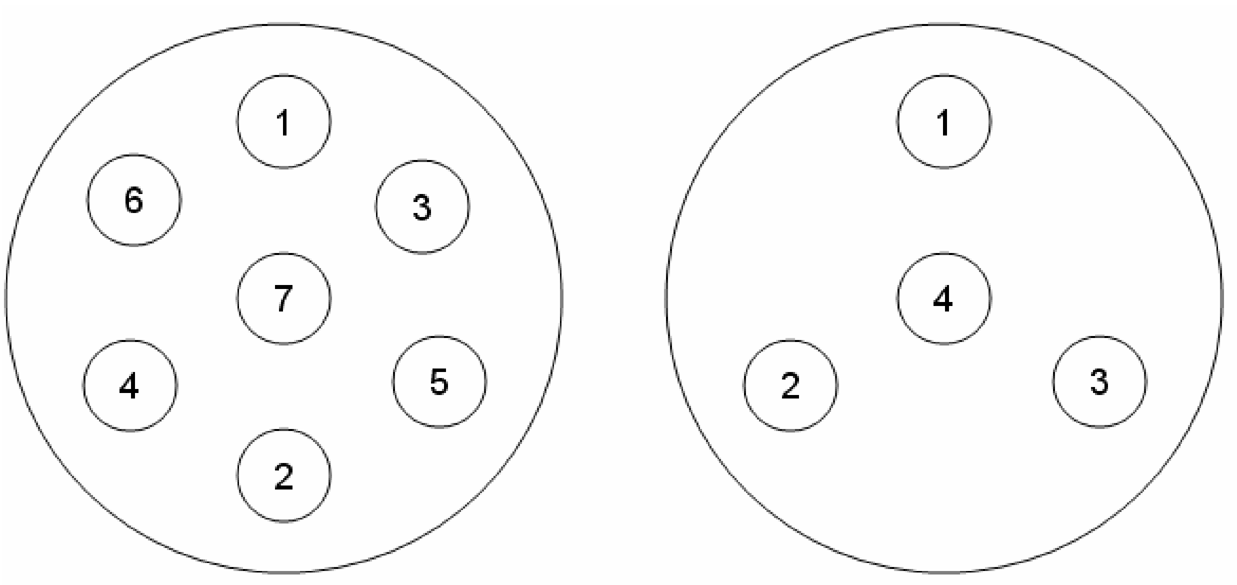

Figure 3.5- Pot and 4 Pot Firing Sequences

3.3.2.5. Relevant Environment

The relevant environment is the same as for the ASP filters. See Section 3.3.1.5

3.3.2.6. Comparison of the Relevant Environment and the Demonstrated Environment

Of necessity, the demonstrated environment has been confined to simulants. Testing of actual waste/MST mixtures at a scale that would be relevant to APA design would be difficult and very expensive due to the high radiation levels of the waste. Simulant testing has covered as much of the relevant environment as possible.

3.3.2.7. Technology Readiness Level Determination

The APA CTE was evaluated and determined to be at TRL 6. Laboratory scale tests with real wastes and full scale tests with a range of simulants using prototypical equipment have been completed and are consistant[2-4, 7]. Final reports on APA technology testing and development have been issued[2-4, 7, 95]. All required project documents for TRL 5 and 6 have been completed including a performance baseline, final design drawings (CD-3 approved), RAMI levels[2-4, 7, 93], an operating requirements document, interface control documents, and a configuration management plan. See Table B-4 in Appendix B for the APA TRL 6 evaluation.

3.4 Caustic-Side Solvent Extraction (CSSX)

Cesium (Cs) is removed from the salt waste in the Caustic-Side Solvent Extraction (CSSX) process. A flow diagram of the CSSX process is shown in Figure 1-2. CSSX Chemistry, CSSX Contactor and Solvent Recovery were identified as the CTEs (see Section 3.1 and Appendix A).

3.4.1 CSSX Chemistry

The second processing step in the SWPF is CSSX which is a solvent extraction process to remove the Cs from the clarified solution that was produced in the ASP.

3.4.1.1. Function of the CSSX Chemistry

The function of the CSSX chemistry is to preferentially extract Cs from highly caustic salt solutions to produce a decontaminated salt solution (DSS) that meets the waste acceptance criteria for transfer to the Saltstone Production Facility for disposal. The chemistry is to produce a Cs strip effluent solution (CSSE) that meets the WAC for vitrification in the DWPF.

3.4.1.2. Description of the CSSX Chemistry

The chemistry of the CSSX process involves both the organic and aqueous phases being mixed together in a continuous processing system to accomplish the desired separation of Cs from the waste solution. The chemistry of the CSSX process was developed to preferentially extract Cs from caustic solutions containing much higher concentrations of Na and K ions and to concentrate the Cs in an aqueous strip solution.

The solvent used in the CSSX process is primarily Isopar®L with a specialty extractant (BOBCalixC6) at 0.007M concentration, a modifier (Cs-7SB) at 0.75M concentration, and a suppressant (tri-n-octylamine) at 0.003M concentration.[45] The extractant is an organic molecule with a cavity sized to hold Cs preferentially and has high selectivity relative to Na and K. The high selectivity (two orders of magnitude for K and four orders of magnitude for Na) is required to achieve the desired Cs removal efficiency and purity. However, the lower separation factor for K requires limits on the K concentration in the feed in order to obtain sufficiently high Cs distribution into the organic phase and to attain the desired concentration factor for Cs in the strip solution. The modifier is a polar organic solvent added to ensure solubility of the BOBCalixC6 in the Isopar®L diluent. The tri-n-octylamine is added to aid stripping Cs from the solvent into a minimum volume of aqueous solution. Isopar®L is a mixture of branched chain hydrocarbons with 10-12 carbons with C-12 as dominant. Isopar®L has a non-trivial vapor pressure at operating temperatures. Vaporization changes the solvent properties and performance of Cs extraction and stripping.[46, 47] Controls are required to assure the organic phase performance is not adversely affected by evaporation. In addition, Isopar®L vapors are flammable and a potential explosion hazard. This hazard has been fully considered in the SWPF Preliminary Documented Safety Analysis[48] and appropriate controls have been established and approved by DOE[49]. Tri-n-octylamine is removed from the process by radiolytic degradation and solubility in the aqueous phase.[50, 51] Therefore, tri-n-octylamine concentration must be monitored and adjusted as necessary during operation.

The aqueous chemistry is equally important in assuring proper operation of the entire process. The main components of the waste solution are sodium hydroxide, sodium nitrate, sodium nitrite, and aluminum, as the aluminate ion. The solution also contains iron, silicon, sulfate, and fission products. The sodium hydroxide in the solutions in the high level waste tanks is maintained above 1.2 M to ensure aluminum remains in solution. However, some solutions are supersaturated in aluminum and/or silicon[12, 13] so that any reduction in hydroxide concentration by dilution or neutralization results in precipitation of solids containing aluminum, silicon or both. Although laboratory research and development activities for CSSX did not have problems with precipitation during CSSX operations, larger scale operation both by Parsons and WSRC (in the Integrated Salt Disposition Project) have observed precipitation resulting in deposits inside the contactors.[15, 18] Instability of the simulant was observed during one test at ANL when the solution was stored several weeks before use. The sodium aluminosilicate solids were pumped into the contactors along with simulant solution resulting in plugging of the feed stage with solids.[52, 53] A test with an ion exchange process is being studied along with CSSX in the R&D program had the column plug due to precipitation of solids in the column. Studies at SRNL at the time found that a number of the actual waste solutions were supersaturated with aluminum.[12, 13]

The process includes a scrub stream of 0.05 M HNO_3 which is mixed with the waste stream in the extraction feed stage. Although the flow of the scrub stream is low compared to the waste feed stream, the dilution could cause precipitation in some waste solutions. Precipitation could also occur in the aqueous phase of the scrub section if too much of the high caustic waste solution is entrained in solvent into the scrub stage resulting in neutralization of the mixture. Any solids that do not deposit on the walls are carried with the aqueous phase into the extraction section and mixed with the waste solution where the solids can act as seed crystals for further precipitation.[12] Thus, the chemistry of the incoming feed solutions must be maintained >2 M hydroxide to prevent precipitation in the feed to the contactors and aqueous entrainment from the extraction feed stage to the scrub must be minimized.[17, 54, 55]

3.4.1.3. Relationship to Other Systems

The chemistry must perform its functions in the Centrifugal Contactors for all feed solutions transferred from the Alpha Strike Process (ASP).

3.4.1.4. Development History and Status

Research and development of CSSX Chemistry started during the 1990's at ORNL with the synthesis of the extractant Calix[4]arene-bis(tert-octylbenzo-crown-6 (BOBCalixC6) and tests that demonstrated the compound's high selectivity for Cs over Na and K in caustic solutions representative of high level waste solutions at Hanford and Savannah River.[45-47, 53] The BOBCalixC6 is a high molecular weight compound with low solubility in non-polar solvents such as the n-paraffins normally used in nuclear reprocessing. Thus, a modifier was needed in the diluent to provide sufficient solubility to have a workable process. Funding for initial work was provided through DOE's Basic Energy Sciences Office. Further work was funded through the Efficient Separations Program of Environmental Management. In 1996, the In-Tank Precipitation Process planned for use at Savannah River to remove Cs was stopped due to safety related issues.[56] SRS personnel initiated literature studies to identify other Cs removal technologies for potential application to SRS tank wastes. The studies identified 4 different technologies to test for application in a new facility to treat the waste for final disposal.[57] DOE-SR requested that the Tank Focus Area (TFA) manage the development of all 4 processes to the point that sufficient data was available to select the best technology for application. The TFA put together a team from SRS and several national laboratories to do the research and development. The laboratories were ORNL, ANL, INEEL, SRNL (SRTC at that time) and PNNL. Extensive studies were done with simulants at all participating laboratories with all real waste work being done at SRNL.[18-24, 45-50, 52, 53, 58-70] Studies of solvent properties and improvement in performance were done at ORNL.[45-47,50] Several laboratories tested engineering scale contactors.[65-69] The CSSX process was selected for implementation in 2001. Studies were continued in order to answer questions that arose during earlier work. The EPC has continued testing at larger scales.[15, 71-73]

Distribution coefficient measurements using actual tank waste solution from different tanks confirmed extraction values of at least the minimum of 8 required to achieve decontamination and concentration.[19, 70] Laboratory scale tests with simulants and actual tank waste solutions in 2 cm contactors demonstrated decontamination factors of 100,000 to more than a million with real waste.[20-24, 50, 70]

3.4.1.5. Relevant Environment

The CSSX chemistry treats solutions with ^{137}Cs as high as 5.25 Ci/gal, <7 M sodium concentration, and >2 M hydroxide concentration. The chemistry is in a remote environment and is operated remotely. The reactions involving extraction, scrubbing and stripping must be rapid because the residence time in an SWPF contactor stage is 16-20 seconds when operating at a flow rate of 20 to 15 gallons per minute. Temperatures in extraction and scrub are $<25^0$C and in strip $<35^0$C.

3.4.1.6. Comparison of the Relevant Environmental and the Demonstrated Environment

The CSSX chemistry in the SWPF has been successfully tested at full scale in a prototypical system using non-radioactive simulant solution.[15] Further testing is planned with the full scale system. The relevant environment was identical except for the radiation. Laboratory simulant tests are underway with a 2 inch diameter test system to clarify and resolve minor problems with solids and emulsion formation observed during full scale tests.[71]

The CSSX chemistry is also being used successfully in the Integrated Salt Disposition Project (ISDP) at SRS although the radiation environment is much lower due to the wastes being treated having less Cs.[18, 74] However, the chemical environment and the temperatures are the same for both designs. The CSSX chemistry has fulfilled all design criteria related to the Cs concentrations in the decontaminated salt solution and the strip effluent.[18, 74] Although the system design and implementation are not identical, the environment is similar with the equipment located in a shielded area and operated remotely as will be the case with SWPF. The chemistry has also been demonstrated at the laboratory scale with actual SRS tank waste solutions.[19-24]

3.4.1.7. Technology Readiness Level Determination

The CSSX Chemistry was judged to be at TRL 6 because extensive laboratory data has been collected on the chemistry and the chemistry has been demonstrated with simulants and real waste at the laboratory scale and approximately one fourth scale at ISDP.[22-26, 28-42, 45-47,50-54] The ISDP facility is not prototypical from an equipment standpoint, but the chemistry is identical.[62, 64] The EPC has demonstrated the chemistry in full scale tests with a prototypical system using simulants.[15] All required project documents for TRL 6 have been completed including performance baseline and final design drawings (CD-3 approved), RAMI levels, operating requirements document, interface control documents, configuration management plan, and final test reports. Table B-5 in Appendix B captures the results of TRL 6 evaluation.

3.4.2 Centrifugal Contactors

3.4.2.1. Function of the Centrifugal Contactors

The Centrifugal Contactors are to provide continuous extraction of Cs from SRS high level waste salt solutions to produce a decontaminated salt solution that can be disposed as low level waste in the SPF and a Cs Strip Effluent solution (CSSE) for vitrification in DWPF.

3.4.2.2. Description of the Centrifugal Contactors[2]

The CSSX contactors provide a continuous flow process utilizing 36 contactor stages for extraction, scrubbing, stripping, and washing of the organic stream (See Figure 1-2 for the Flow Diagram). The Cs is removed by contacting the CSS (aqueous phase) with the engineered solvent (organic phase) in the extraction contactors (16 stages). The Cs-depleted aqueous outlet stream (DSS) is sent to the AFP for sampling and analysis prior to transfer to the SPF or for another Sr/actinide removal operation. Following extraction, the Cs-enriched solvent is scrubbed with 0.05 M nitric acid (HNO_3) in 2 scrub stages to remove impurities (primarily Na and potassium K). The solvent is then contacted with 0.001 M nitric acid (HNO_3) strip solution in the 16 stripping stages, where the Cs is transferred to the aqueous strip effluent (CSSE). Both the DSS and CSSE are sent to stilling tanks in Solvent Recovery.

The CSSX process will use Costner Industries Nevada Corporation (CINC) V-10 contactor units. These are centrifugal contactors with a nominal hydraulic capacity of 30 gpm (total aqueous and organic flow through the unit). A cutaway of a contactor stage is shown in Figure 3-6. For the SWPF, 16 extraction contactors were chosen to provide a measure of conservatism to ensure that, if the extraction distribution coefficients move in an unfavorable manner, the target DF of 40,000 will be achieved. Solvent flows through the extraction stages counter-current to the

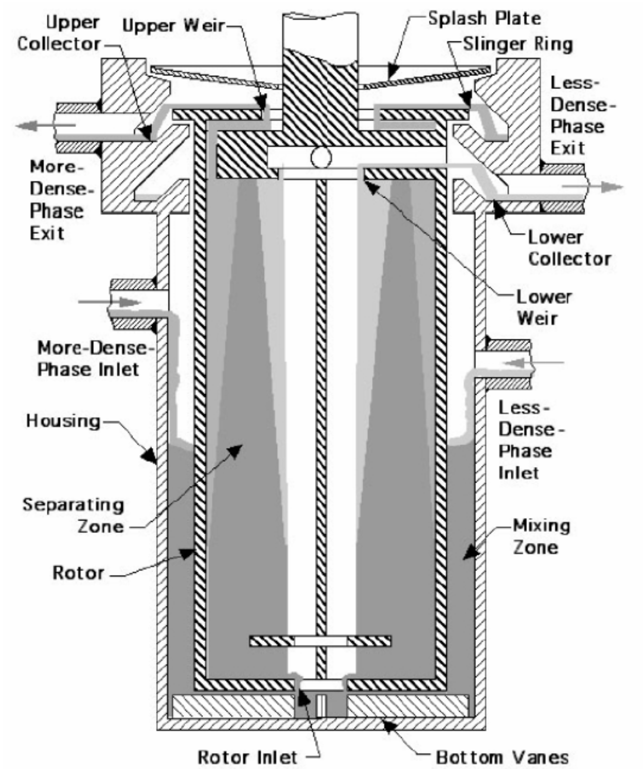

Figure 3-6. Cutaway of a Centrifugal Contactor Stage[2]

aqueous feed. Each individual stage provides mixing and separation of the aqueous and organic phases. Cs is transferred from the aqueous phase to the organic solvent phase in the extraction stages. The solvent used in the CSSX process is described in section 3.4.1.2 on CSSX Chemistry.

The flow rate of CSS feed to the CSSX extraction stages will be set by the operator, based on plant conditions and feed composition. Salt Solution Feed Pumps (SSFP) provide CSS feed to the extraction section from the SSFT. The SSFP are variable-speed positive displacement pumps with a maximum capacity of 30 gpm and a turndown ratio of 20:1. The CSS feed is transferred through the Salt Solution Feed Cooler to control the feed temperature at 73°F (23°C). Test data have shown that the Cs extraction process is most effective when maintained at approximately 73±5°F (23±2°C). The design feed flow rate to the CSS extraction section is approximately 21.6 gpm. The scrub section flow of approximately 1.4 gpm is added to the aqueous feed inlet to the extraction section. The corresponding solvent feed rate for the combined aqueous flow rate is approximately 7.2 gpm. The organic to aqueous (O/A) ratio (for solvent to CSS aqueous flow) is maintained nominally at 1:3.

Solvent is fed from the Solvent Hold Tank (SHT) to the extraction stage organic inlet by one of the two Solvent Feed Pumps (SFP). These variable-speed positive displacement pumps have a maximum design flow rate of 20 gpm with a 20:1 turndown ratio. The solvent flow set point is controlled to maintain a nominal extraction stage O/A ratio of 1:3. The pump discharge can also route solvent to the laboratory for sampling and solvent adjustment. A mixing eductor is installed in the SHT to provide homogeneity and improve the heat transfer efficiency of the tank cooling jacket. The SHT is cooled by chilled water flowing through a cooling jacket. The Solvent Feed

Coolers on the pump discharge control the solvent feed temperature to the extraction contactors at 73°F. Cooling jackets are provided on the exteriors of the extraction contactors to control the aqueous and solvent temperature at 73°F. DSS/CDCSS exits the extraction stages and gravity-flows to the DSS Stilling Tank which is part of the Solvent Recovery. Small amounts of solvent are entrained with the aqueous phase from the extraction stages.

Following Cs extraction, the solvent is scrubbed with 0.05M HNO_3 to remove soluble salts (Na, K, aluminum, iron, and mercury) from the solvent stream. Scrubbing the metal ions from the organic prevents transfer of these ions to the strip solution. Contacting the organic stream with the dilute acid also has the effect of neutralizing any caustic carryover from the extraction stages. Neutralization of the caustic carryover is necessary to ensure stable operation of the Cs strip stages. Two stages of scrub are provided. The scrub solution enters the second scrub stage and proceeds counter-current to the solvent. Scrub solution is provided from the Nitric Acid Scrub Makeup Tank by one of the two Scrub Feed Pumps located in the Cold Chemical Area. The scrub solution flow is controlled to maintain a nominal O/A ratio of 5:1 in the scrub stages. The scrub flow rate will be approximately 1.43 gpm at the design flow.

The scrubbed solvent flows to the Solvent Strip Feed Tank via gravity. The solvent temperature is controlled to a temperature of 91°F (33^{o}C). The strip solution is supplied to the aqueous inlet of Stripping Contactor from the Strip Feed Tank by the Strip Feed Pumps. The strip solution passes through the associated Strip Feed Heater, which heats the strip solution to 91°F (33^{o}C). In the strip section, Cs-laden solvent from the scrub contactors is contacted counter-current with the 0.001M HNO_3 strip solution in a series of 16 centrifugal contactors, resulting in the transfer of Cs to the strip solution. The low nitrate ion concentration in the aqueous phase shifts the equilibrium to favor the transport of the Cs ion from the solvent to the aqueous phase. The strip feed rate is controlled to a nominal O/A ratio of 5:1 to achieve a nominal Concentration Factor value of >12.

Strip effluent exits the strip stages and flows by gravity to the Strip Effluent Stilling which is part of the Solvent Recovery. The strip contactors have jackets supplied to control temperature, as required by the process. The system will be designed to maintain the contactor contents at a set point of 91°F (33^{o}C).

On leaving the strip stages, the stripped solvent flows to a caustic wash process that consists of two centrifugal contactors. Caustic wash solution is contacted counter-currently with the solvent through the two stages. The wash process is intended to remove impurities in the solvent that may interfere with solvent performance. The suppressant and modifier contained in the solvent degrade over time. The suppressant (tri-n-octylamine) forms dioctylamine and the modifier (Cs-7SB) forms a phenolic compound. The caustic wash stage is intended to remove these impurities and restore performance of the solvent. The solvent outlet from the wash stages will flow by gravity to the SHT. The Caustic Wash Tank and one of the two Caustic Wash Tank Pumps supply caustic wash solution to the wash contactor aqueous inlet. The pumps are variable-speed positive displacement pumps with a maximum capacity of 10 gpm and a turndown ratio of 20:1. The operating pump will operate at a flow control set point to maintain a nominal O:A ratio of 5:1. Caustic wash solution from the caustic wash contactors gravity-flows back to the Caustic Wash Tank. The pH of the Caustic Wash Tank will gradually decrease during operation. When the wash stage aqueous outlet pH decreases to a predetermined level (to be determined during testing and commissioning), contents of the Caustic Wash Tank will be transferred to the DSS Stilling Tank and pass out of the system with the DSS/CDCSS through the Ba-137 Decay Tank. The wash solution in the Caustic Wash Tank will then be replaced with 0.01M NaOH makeup provided by the Caustic Makeup Tank.

The Caustic Wash Tank level will remain approximately constant because the caustic wash solution is recirculated back from the wash stages. The tank has a working volume of 400 gallons, so caustic wash inventory should require purging and replacement on an infrequent basis. The Caustic Wash Tank has an installed overflow weir to allow recovery of any accumulated solvent. The required frequency of solvent recovery operations for the Caustic Wash Tank will be established during Commissioning. Solvent recovery is performed by adding caustic wash from the Caustic Makeup Tank to a level higher than the overflow weir. After allowing time for the tank contents to separate and settle, the overflow weir valve would be opened to recover the layer of solvent. The recovered solvent/aqueous mixture flows to the SDT.

Each contactor has two process inlets and two process outlets, one each for the aqueous phase and one each for the solvent phase (see Figure 3-6). Both the organic and aqueous outlet ports are vented to the Process Vessel Ventilation System (PVVS). In addition, the solvent and salt solution inlet to the first extraction contactors and the solvent inlet to the first strip contactors are vented to PVVS. Drain and flush connections are provided at the bottom of each contactor to allow for flushing of the contactor internals. Each contactor is equipped with internal Clean-in-place (CIP) sprays to facilitate contactor cleaning and flushing. The CIP system can be supplied with process water, caustic, or HNO_3, as necessary, to promote effective flushing and removal of solids buildup. A motor with a Variable Frequency Drive (VFD) drives each contactor. The VFD will be automatically controlled by the Distributed Control System (DCS) or manually controlled by the Operator. Instrumentation requirements for the contactors include speed, motor amperage, vibration, and bearing temperature. If an individual contactor fails in any of the CSSX stages, the whole contactor bank will shut down immediately, including the various pumps feeding the contactors. The exception to this is that if all of the strip contactors are operating and strip solution is flowing, the strip contactor bank is not shutdown. If failure of a contactor appears imminent based on vibration, temperature, or other indicators, a controlled system shutdown will be performed. A controlled shutdown allows flushing of residual Cs from the contactors by operating the CSSX on DSS feed. The contactors are then drained to the SDT. In the event of an unanticipated failure, the Operator will evaluate system performance If sufficient time is available, a controlled shutdown is performed. If not, all contactors are shut down and the SSFT feed pumps and the solvent, scrub, strip, and wash solution feed pumps are secured. The affected contactor is then drained to the SDT. The failed contactor would then be flushed by use of CIP flush connections. Other contactors may need to be drained and flushed to reduce radiation levels to allow access to the contactor operating area.

The top portion of the contactors penetrates through a steel grating that serves as an operating platform. All maintainable parts (e.g., motors, seals, etc.) on the contactors are accessible above the platform to facilitate maintenance. The contactor housing is located under the platform. Components and piping below the platform are designed so that access is not required over the life of the plant; however, portions of the grating can be removed if required to inspect or access specific contactor components.

3.4.2.3. Relationship to Other Systems

The Centrifugal Contactor feed is the clarified solution from the ASP. The DSS flows to the DSS stilling tank in Solvent Recovery. The CSSE flows to the CSSE stilling tank in Solvent Recovery. Gases and vapors are sent to the PVVS.

3.4.2.4. Development History and Status

Centrifugal contactors were initially developed and tested at the Savannah River Laboratory in the early 1960's. The contactor design included a mixing section at the bottom with an impeller whose shaft extended up through the center of the centrifuge bowl so both the bowl and mixer were attached to the same shaft and motor at the top. A laboratory scale system was built using 2 cm bowl diameter and tested with simulants and actual plant solutions of dissolved irradiated fuel in a PUREX flow sheet. The design was scaled up to 10 inches in diameter, tested with simulants and then 18 stages were installed in a Savannah River Plant separations facility. The centrifugal contactor system replaced a large mixer-settler used for extraction and scrubbing. The contactors performed well for more than 30 years. Contactor motor replacement was the principal maintenance required during most of their operation.
In the late 1960's, Argonne National Laboratory (ANL) personnel developed an improved contactor design in which the mixing is done in the annular space between the bowl and the housing. Vanes were provided at the bottom to increase mixing and direct flow of the mixed phases up into the bowl. This design is the basis for the contactors being manufactured for use in the SWPF. The advantage of the design is that the bowl and motor can be removed and replaced if the bowl became unbalanced during operation. The bottom of the contactor is easily replaced allowing different shaped vanes to be tested for the application. Extensive development was done at ANL with different diameter contactors; however, 2 cm diameter contactors became the accepted size for laboratory flow sheet development. Initial development of the CSSX process was done at ANL in 2 cm diameter contactors.[52] Testing of 5 cm and 5.5 cm diameter contactors was also carried out during the development program for the CSSX process during 2000-2003 at ANL, INEEL and ORNL.[65-69]

CINC Industries took the initial ANL contactor design and developed commercial centrifuges for separating immiscible phases in a wide variety of industries. They have improved the design with products ranging in size from 2 to 20 inches in diameter with clean-in-place and ability to replace the bottom vanes. CINC is the only commercial source of centrifugal contactors in the United States. CINC contactors with 5 inch (V-05) and 10 inch (V-10) diameter bowls were tested for application of the CSSX process. The ISDP selected V-05/V-10 contactors which best matched the design requirements for flow rates.[75] The contactors have been operating satisfactorily with low Cs salt solutions since May, 2008.[18,74] The EPC has chosen the V-10 contactors and tested them with simulants to characterize carryover of one phase into the other and efficiency of mass transfer.[72] A full scale prototypical system has been successfully tested with simulant solutions.[15]

3.4.2.5. Relevant Environment

The Centrifugal Contactor treats solutions with ^{137}Cs as high as 5.25 Ci/gal, <7 M sodium concentration, and >2 M hydroxide concentration. The system is operated in a remote environment by a distributed control system. The extraction, scrubbing and stripping must be rapid because the residence time in a SWPF contactor stage is 16-20 seconds when operating at a flow rate of 20 to 15 gallons per minute. Temperatures in extraction and scrub are $<25^0$C and in strip $<35^0$C.

3.4.2.6. Comparison of the Relevant Environmental and the Demonstrated Environment

The centrifugal contactors designed for use in the SWPF have been successfully tested at full scale in a prototypical system using non-radioactive simulant solution.[15] Further testing is planned with the full scale system. The relevant environment was identical except for the radiation including operators in a separate area. Laboratory simulant tests are underway with a 2 inch diameter test system to clarify and resolve minor problems with solids and emulsions formation observed during full scale tests.[71]

The Integrated Salt Disposition Project (ISDP) has smaller (except extraction) and fewer contactors than the SWPF design and the radiation environment is much lower due to the wastes being treated having less Cs. However, the contactor basic design, chemical environment and the temperatures are the same for both designs.[62] The ISDP contactors have fulfilled all design criteria related to the Cs concentrations in the decontaminated salt solution and the strip effluent since operations began in May, 2008.[18,74] Although the system design and implementation are not identical, the environment is similar with the equipment located in a shielded area and operated remotely as will be the case with SWPF.[74]

3.4.2.7. Technology Readiness Level Determination

The Centrifugal Contactors were determined to be TRL 6 because extensive laboratory data has been collected on the chemistry and contactors been demonstrated with simulants and real waste at the laboratory scale and approximately one-fourth scale at ISDP.[18, 21-24, 52, 61-76] The contactors as designed has been tested at full scale with simulants in a prototypic configuration.[15] Successful operation of similar contactors at SRS with actual tank waste gives assurance that the technology is mature.[18] All required project documents for TRL 6 have been completed including performance baseline and final design drawings (CD-3 approved), RAMI levels, operating requirements document, interface control documents, configuration management plan, and final test reports. Table B-6 in Appendix B captures the results of TRL 6 evaluation

3.4.3 Solvent Recovery

3.4.3.1. Function of the Solvent Recovery

The function of Solvent Recovery is to recover solvent entrained in the aqueous product streams from the Centrifugal Contactor in order to recycle the solvent minimizing the cost of facility operation and to ensure that entrained solvent concentrations do not exceed the Waste Acceptance Criteria for aqueous solutions sent to the DWPF and Saltstone.[77-79]

3.4.3.2. Description of the Solvent Recovery[2]

Solvent Recovery consists of stilling tanks and coalescers for the decontaminated salt solution (CDCSS) and the strip effluent solution. The solutions flow by gravity from the centrifugal contactors into the respective stilling tank. In the CDCSS Stilling Tank, the heavier aqueous phase overflows a weir and gravity-drains to the Barium (^{137}Ba) Decay Tank. The lighter organic phase overflows to the solvent hold tank. The stilling tank provides separation of the aqueous and organic phases and prevents large quantities of solvent from entering the ^{137}Ba Decay Tank in the event of a process upset. The ^{137}Ba Decay Tank is designed to allow sufficient decay of ^{137m}Ba to effectively measure the Cs concentration during transfer of CDCSS to the AFP. One of the two ^{137}Ba Decay Tank Transfer Pumps will be used to transfer the CDCSS to the DSS Coalescer. Figure 3-7 shows a cutaway of a coalescer. The ^{137}Ba Decay Tank Transfer Pumps are positive-displacement, variable-speed pumps with a maximum capacity of 30 gpm and a turndown ratio of 20:1. Two in-line gamma monitors are installed downstream of the ^{137}Ba Decay Tank Transfer Pumps to monitor the ^{137}Cs daughter product ^{137m}Ba concentration. A high-gamma alarm at this location is interlocked to reroute the ^{137}Ba Decay Tank Transfer Pump discharge to the SSFT to ensure that high ^{137}Cs material is not sent to the AFP. The ^{137}Ba Decay Tank is provided with a level detector that provides a control signal to adjust the ^{137}Ba Decay Tank Transfer Pump flow rate to maintain the tank level set point. The DSS Coalescer recovers solvent with installed stainless steel coalescing media. Recovered solvent gravity flows to the solvent hold tank. The aqueous phase (DSS) gravity-flows to a tank in the AFP.

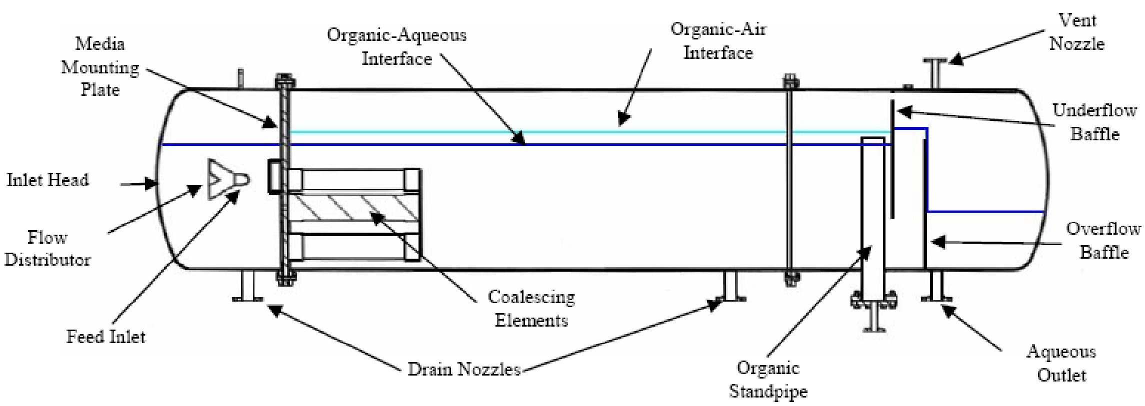

Figure 3-7. Cutaway of the Coalescer[2]

Strip effluent flows by gravity from the Centrifugal Contactors to the Strip Effluent Stilling Tank and then to the Strip Effluent Coalescer to remove trace amounts of entrained solvent in the aqueous phase. The recovered solvent from the Strip Effluent Stilling Tank and Strip Effluent Coalescer gravity flows to the Solvent Drain Tank (SDT). The SDT can be pumped by one of the pumps to the aqueous inlet line of the extraction stages in the Centrifugal Contactors. Aqueous effluent from the Strip Effluent Coalescer gravity-flows to the Strip Effluent Pump Tank and is pumped to the Strip Effluent Hold Tank (SEHT) by one of two Strip Effluent Pump Tank Pumps. The Strip Effluent Pump Tank is of minimum volume to maintain a suction head for the transfer pumps and allow tank level control. The outlet from the pumps is monitored by gamma monitors to determine the ^{137}Cs concentration in the strip effluent.

3.4.3.3. Relationship to Other Systems

Solvent Recovery receives Decontaminated Salt Solution (DSS) and Strip Effluent Solution from the Centrifugal Contactors. The recovered solvent is returned to the Solvent Hold Tank in the Centrifugal Contactor area. The DSS is sent to the third process system, AFP. The strip effluent stream is sent to DWPF. Gases and vapors are sent to the vessel vent system.

3.4.3.4. Development History and Status

Entrainment of one phase into another phase during solvent extraction operations is a well known and documented phenomenon and was studied during the research and development phase of the CSSX process.[62-69] Argonne National Laboratory performed studies on droplet size and several different methods for de-entraining the organic phase from the aqueous phase.[60] The methods studied were decanters, coalescers and centrifuges. A coalescer can be used to recover the entrained solvent. The coalescer consists of a large cylindrical vessel that houses mesh-like media (see Figure 3-7). Suspended solvent droplets adhere to the media and agglomerate over time. At a critical size, the inertial forces of the flowing liquids overcome the adhesive forces between the droplet and the mesh causing it to break free. The increased buoyancy of the enlarged droplets causes them to float to the surface of the aqueous phase, where they coalesce further to form a layer that can be effectively separated from the aqueous phase via a weir. A laboratory-scale coalescer was operated in tandem with a four stage 4-cm contactor unit. Results indicate that a 90% recovery of the entrained solvent can be achieved using a commercial coalescer equipped with Franken MN stainless steel media and at appropriate operating conditions.[64] Larger mesh sizes and polymeric media were not as effective. Polymeric media soaked in aqueous effluent for a period of weeks were found to be coated with a layer of organic which was not true of the stainless steel media.[64]

Due to the small size of the equipment and differences in operation of the contactors, further studies were done by the EPC for scale up of the process and WSRC implemented an intermediate scale process for interim processing of tanks with low ^{137}Cs concentrations.[15,72,75-76] The ISDP uses a coalescer from Pall Corporation with a polymeric media (Ryton).[80-85] The facility initially had problems with solids plugging the media that were found to be aluminum oxides when hot operations started last May.[80-83] The problems led to reduction in capacity and frequent down time to replace the media. Adjusting the feed chemistry and changes in equipment configuration were made to overcome the problem.[18, 54-55]

The EPC tests with simulant identical to that used at ANL have used Franken stainless steel media with small mesh size to confirm their design basis and the work done at ANL (see Figure 3-7).[15] Based on the problems encountered in ISDP, the EPC has doubled the media area and plans to test a decreased pore size to improve coalescing performance for the decontaminated salt solution from that tested earlier. The EPC has not experienced any problems to date similar to ISDP of coalescer plugging during operation. Further simulant tests are planned to confirm there are no problems prior to plant operation. The EPC has also revised acceptance criteria for feed received from Liquid Waste Operations into SWPF that ensure stability of the feed solutions during operation.[16, 17]

3.4.3.5. Relevant Environment

The DSS coalescer is located in an unshielded area due to the low Cs-137 concentration of its feed, and is exposed to solutions with high caustic and high salt concentrations as well as residual fission products and impurities. The strip effluent solution coalescer is located in a shielded area due to high radiation from the ^{137}Cs present at 66 Ci/Gal, is operated remotely, and is exposed to strip effluent solution with >0.001 M nitric acid.

3.4.3.6. Comparison of the Relevant Environmental and the Demonstrated Environment

The technology designed for use in the SWPF has been tested at the laboratory scale and a full scale system with simulant solutions.[15, 64, 72] The ISDP has similar equipment to that designed for SWPF except the media used in the coalescers is different and the radiation environment is much lower due to the wastes being treated having less Cs.[80-83] The strip effluent coalescer has performed well in the environment. The DSS coalescer has performed as designed since problems with feed solution instability were resolved. Although the required flows through the system are lower due to limited volume of solution to be treated in the facility, the environment is similar in that the equipment is located in a shielded area and operated remotely as will be the case with SWPF.

3.4.3.7. Technology Readiness Level Determination

Solvent Recovery was determined to be TRL 6 because the system as designed has been tested at full scale with simulants in a prototypic configuration. Successful operation of a similar system in ISDP with actual tank waste although not exactly the same gives assurance that the technology is mature. Use of coalescers for phase separations is a common industrial practice and the equipment to be used in the SWPF is made by an established company with materials known to withstand the relevant environment. All required project documents for TRL 6 have been completed including performance baseline and final design drawings (CD-3 approved), RAMI levels, operating requirements document, interface control documents, configuration management plan, and final test reports. Table B-7 in Appendix B captures the results of TRL 6 evaluation.

3.5 Product Handling - MST/Sludge

The SWPF treatment processes separate the radioactive elements (primarily actinides, Sr, and cesium [Cs]) from the bulk salt waste and concentrate them into two relatively small volume product streams. The MST/sludge product and CSSX strip effluent (Cs) will be transferred to DWPF for vitrification. The remaining bulk salt waste (DSS) contains only low levels of radioactive materials and is sent to the SPF for incorporation into grout.[2, 3]

The pumping of dilute liquid (strip effluent) and pumping of concentrated salt solutions (DSS) were considered routine operations and were not considered to be Critical Technology Elements. Also, pumping sludge slurries to DWPF is done routinely. However, suspending and pumping mixtures of MST and sludge product have much less operational experience, and it was concluded that the technology has been repackaged such that a new relevant environment has been realized. Thus, MST/sludge product handling was considered to be a CTE.

3.5.1 Function of the MST/Sludge Systems

The MST/sludge product handling system stores the washed MST/sludge in the Sludge Solids Receipt Tank (SSRT) as 5 wt% slurry. Sampling and analysis must verify that the DWPF Waste Acceptance Criteria are met. Transfers of MST/sludge are made to DWPF as needed for melter feed preparation and to maintain SWPF throughput requirements.

3.5.2 Description of the MST/Sludge Systems

The concentrated MST/sludge produced in the ASP and AFP filtration operations will be transferred to the SSRT for washing prior to transfer to DWPF. The combined MST/sludge volume (from both the ASP and the AFP) produced by processing 7 batches of waste feed through two MST strikes is approximately 4,130 gallons at 5 wt%.[2]

The SSRT has a working volume of 5,200 gallons to accommodate the combined volume of 7 concentrated batches from both FFT-A and FFT-B and approximately 500 gallons of line flush. After transfers to the SSRT, lines are flushed to remove residual solids using wash water from the WWHT or DSS from the DSS Hold Tank (DSSHT), respectively. The SSRT is equipped with a cooling jacket installed primarily to remove pumping and mixing energy.

The washed MST/sludge in the SSRT is pumped to the Precipitate Pump Tank (PPT) located in the Low Point Pump Pit (LPPP) by the Washing Filter Feed/Sludge Solids Transfer Pump. This pump is a variable-speed centrifugal pump. The transfer rate to the PPT will be limited to approximately 150 gpm. The waste transfer path to the LPPP will be flushed after each MST/sludge transfer.

3.5.3 Relationship to Other Systems

The MST/sludge product is produced in the ASP and AFP where the MST is added to remove actinides and Sr, and then the MST is removed by cross-flow filtration along with entrained sludge particles in the Tank Farm salt feed.

The MST/sludge must be washed with process water to reduce the sodium content and comply with the DWPF Waste Acceptance Criteria.

The MST/sludge and strip effluent transfer lines are routed out of the SWPF Process Building through the Waste Transfer Enclosure.

The washed MST/sludge in the SSRT is pumped to the Precipitate Pump Tank (PPT) located in the Low Point Pump Pit (LPPP) by a variable-speed centrifugal pump. The SSRT contents will be transferred to the DWPF approximately every seven days, which is approximately the time required for the SWPF to process and wash the MST/sludge resulting from seven waste feed batches.

In the DWPF, sludge slurry from the Tank Farm, MST/sludge, and Cs strip effluent are mixed and prepared as feed to vitrification.

3.5.4 Development History and Status

Extensive cross-flow filter (CFF) testing on SWPF simulants has been carried out at engineering[37-42] and full scale.[14] Actual waste testing at bench scale has also been completed.[43-44] All tests showed that the MST/sludge concentration (5 wt%) required by the SWPF is attainable.

The large-scale tests were conducted with high fidelity simulants (salt solution, MST, and sludge) using a full-scale filter housed in a custom-designed pressure vessel.[14] Operation involved pumping and recirculating a waste simulant and MST mixture through the CFF and removing filtrate until the feed solution reached a predetermined concentration of solids. A Filter Feed Tank (FFT) and two in-series pumps were used to re-circulate the feed solution through the CFF. The FFT used Air Pulse Agitators (APAs) to maintain the MST/solids in suspension. MST/sludge solids washing were successfully demonstrated. Also, MST/sludge solids were concentrated to much higher than the required 5 wt% and no difficulties were encountered in handling up to 20 wt% solids[14].

An evaluation of MST/sludge slurry piping and nozzle erosion determined that the erosive properties of the MST/sludge slurry will be acceptable in the SWPF during operations.[28]

In addition, one prototypical transfer of actual waste 5 wt% MST/sludge had been made from ISDP/ARP to DWPF .[18, 84]

3.5.5 Relevant Environment

The MST/sludge product (5 wt% solids) will be a highly radioactive slurry, but the bulk of the cesium will have passed through the cross-flow filters in the clarified feed to CSSX. The radionuclide content of the MST/sludge will be up to 0.09 Ci/gal alpha emitters, 4.25 Ci/gal Sr-90, and 0.77 Ci/gal Cs-137. The slurry will have a viscosity of approximately 1.44 and a pH of 12-14. The temperature could range from 10 to 40 degrees C.[3]

3.5.6 Comparison of Relevant Environmental and Demonstrated Environment

Chemical composition, physical properties, and temperatures of the demonstrated environment compared very well with the relevant environment. The CFF system has been successfully demonstrated to produce >5 wt% MST/sludge slurries on actual tank waste at bench scale[43, 44], on multiple simulants at engineering scale[37-42] and on simulants at full scale.[14] The simulant tests have demonstrated that filter performance scales well from bench to full scale. Simulants have been concentrated to 20 wt%[14], more than twice the concentration expected in SWPF[42] **with no processing issues observed.** Washing of MST/sludge solids to DWPF specifications also has been demonstrated with simulants.[14, 42]

3.5.7 Technology Readiness Level Determination

The MST/Sludge product handling was determined to be TRL 6 because of the range of laboratory- and bench-scale tests with simulant and actual waste and particularly by the large-scale CFF and APA equipment tests with SWPF feed simulant.[14, 26, 27] Testing on mixing and suspension of MST/sludge slurries was conducted in support of the Integrated Salt Disposition Project's Actinide Removal Process (ARP) operation.[30, 31] In addition, one prototypical transfer of actual waste 5 wt% MST/sludge had been made from ARP to DWPF .[18, 84]

All required project documents for TRL 6 have been completed including performance baseline and final design drawings (CD-3 approved), RAMI levels, operating requirements document, interface control documents, configuration management plan, and final test reports. Table B-8 in Appendix B captures the results of TRL 6 evaluation.

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4 Process Integration

This section of the TRA approaches the evaluation of SWPF "Technology Readiness" from the perspective of how the individual SWPF parts work together, and how the SWPF works within the broader context of overall waste processing at SRS.

This systems analysis approach is a new section within the general TRA review framework. The questions asked, and methods of review, are still under development and subject to change. However, there is widespread recognition that a more holistic, overall system evaluation can provide insight into how new technologies or facilities may (or may not) operate as expected.

An overall "systems" approach to the SWPF includes an evaluation of how sub-systems perform and how the entire SWPF "works" with other facilities on site to accomplish the overall mission of disposing of waste. The following is an analysis of SWPF internal sub-systems, and a discussion of how the SWPF interfaces with other facilities for waste processing (referred to as Global System Analysis)

4.1 SWPF Subsystems analysis

There are a great many subsystems that make up the SWPF. The bulk of this TRA has been the evaluation of the technical sufficiency or readiness of those individual systems, with appropriate consideration regarding how well they work together. The key points that will be discussed in this section are the Reliability, Availability, and Maintainability (RAM) analysis of those subsystems.

4.1.1 Subsystem Reliability, Availability, and Maintainability (RAM) [85]

To assess the adequacy of the SWPF throughput and plant availability goals, an Operations Assessment (OA) Model has been developed to do a detailed throughput and RAM analysis and estimate the plant's availability. A Tank Utilization (TU) Model for the plant has been developed to determine the adequacy of tanks sizes for meeting the desired plant capacity, and to study the interdependencies of plant operations. An important enabling assumption is the following:

> *Because the OA and TU Models only model the SWPF, they assume that feed is always available and that product can be transferred to receiving facilities at any time. Modeling of the overall High-Level Waste (HLW) System is performed by the Site Management and Operating (M&O) Contractor.* [86]

The assumption that adequate overall system modeling is being done to ensure that material can be transferred both to, and from, SWPF in sufficient quantities may require further investigation.

4.1.1.1. OA Model

Conservative estimates for failure rates and repair times were used to calculate system and plant availabilities. The statistical values used to calculate the mean time between failures (MTBF) and mean time to repair (MTTR) were based on running equipment to failure (i.e., no scheduled maintenance) and so the calculated availability is an inherent availability. The SWPF process is designed with equipment redundancy, so that maintenance can be performed on selected critical process-related equipment when one train has failed. Commercially available RAM databases with historical data for industrial facilities (such as nuclear plants and power generation facilities) were used for MTBF and MTTR.[86] The OA Model was developed for the Alpha Strike Process (ASP), Caustic-Side Solvent Extraction (CSSX) process (both single and double Monosodium Titanate [MST] strikes), and Alpha Finishing Process (AFP) and included the Analytical Laboratory and support systems essential to their operations. The availability factors estimated for the process areas, support systems, and Analytical Laboratory are listed in Table 4-1.

Table 4-1. Availability of Process Areas

Process Area	Availability (Percent[%])	
	Single MST Strike	Double MST Strike
Overall SWPF Plant	78.2	76.5
ASP	97	97
CSSX	89.4	89.6
AFP	Note 1	97.6
Support Systems	93.3	93.3
Analytical Laboratory	96.6	96.6
Note: 1. AFP equipment used in single-strike mode is modeled with the CSSX Process Area		

4.1.1.2.TU Model

The SWPF TU Model was developed by using a proprietary software package, iGrafx Process 2005 for Six Sigma. The Model included all major process unit operations for ASP, CSSX, and AFP plant areas. This model does not address tank utilization from the overall SRS liquid waste system, perspective.

4.2 Global System Analysis

One key area to analyze from a system’s perspective is the interfaces that exist at the “boundaries” of the individual systems. The following discusses the utilities interface, WAC interface, and product receiving/waste transfer interface. Figure 4-1 graphically illustrates the processing of salt waste. Figure 4-1 shows that the SWPF receives material from tanks, processes the material, then sends the processed material to the DWPF and SPF (Saltstone Production Facility). The lines on the figure indicate portions of the material flow process that can affect SWPF utilization or operation. If a problem occurs with the Saltstone facility, the SWPF must, at least temporarily, store material long enough for Saltstone to correct the problem and come back on line. If there is not sufficient SPF feed storage capacity, then an extended downtime at SPF will lead to shutdown of SWPF. The same holds true for DWPF.

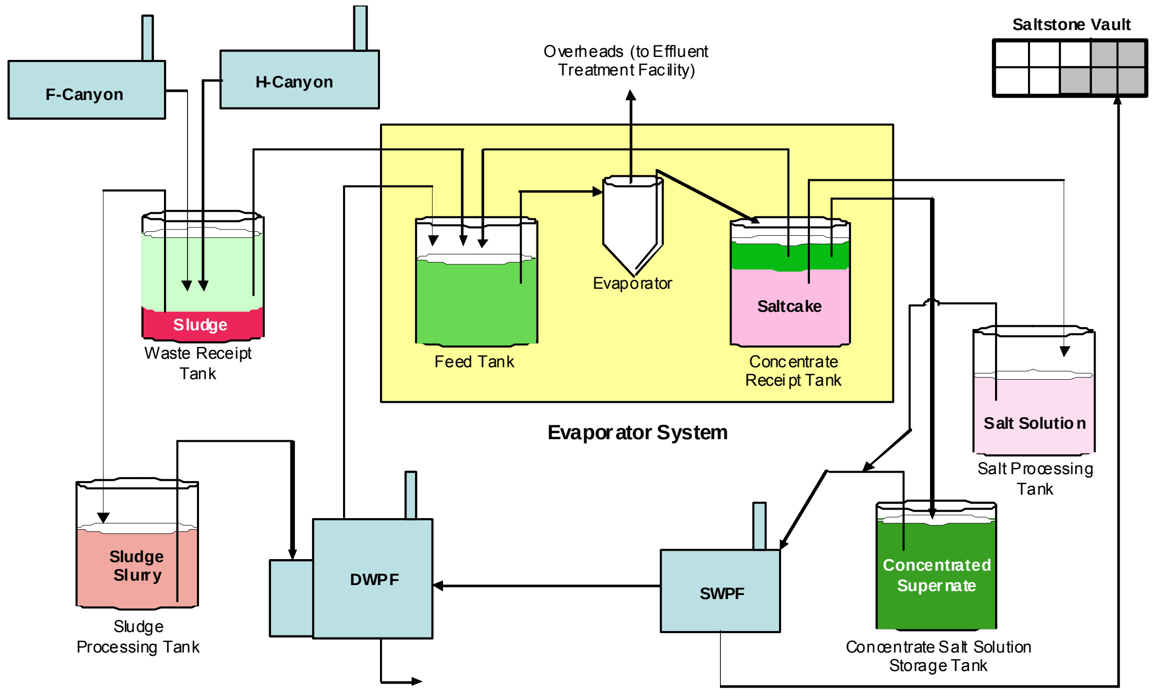

Figure 4-1. Salt Waste Processing

4.2.1 Interface Management

Interface management establishes and maintains SWPF Project interfaces with DOE, the Site M&O, other SRS contractors, and external agencies to ensure that Structure, Systems and Components (SSCs) and organizations fit and function together properly to achieve the Project goals. The SWPF relies on SRS and adjacent SRS facilities to provide electrical power, domestic water, fire suppression water, and disposal of solid waste, mixed waste, low-level radioactive waste, and sanitary sewage. The SWPF also obtains emergency response services (i.e., fire, medical, and hazardous material [HAZMAT]) from the Site, and participates in the SRS Emergency Response program. Access to these utilities and services is established through Interface Control Documents (ICDs) executed among the SWPF Engineering, Procurement, and Construction (EPC) Contractor, SRS Management and Operating (M&O) Contractor, and DOE-Savannah River.

The following are major facilities at which SWPF operations require physical and process interfaces: DWPF, H-Tanks Farm (HTF), and SPF. The process interface boundaries with these SRS facilities are discussed below.[10]

- DWPF Interface – The inter-area transfer lines and waste transfer facilities between DWPF and the SWPF Waste Transfer Enclosure (WTE), including the Low Point Pump Pit (LPPP) Building (511-S). SWPF operational responsibility ends at the seal plate outside the SWPF WTE.
- HTF Interface – The inter-area transfer lines and waste transfer facilities between HTF and the SWPF WTE, including the LPPP. SWPF operational responsibility ends at the seal plate outside the SWPF WTE.

- SPF Interface – The DSS inter-area transfer line from SWPF to the intersection with the DSS transfer line between HTF and SPF. SWPF operational responsibility ends at the seal plate outside the DSS Hold Tank (DSSHT)/Filter Feed Tank-B (FFT-B) area of the AFF.

It appears that the general engineering/technical interfaces between SWPF and other facilities have been adequately addressed. However, there are concerns regarding bottlenecks that could develop that are no fault of SWPF but could nonetheless impact SWPF production rates.

4.2.2 Waste Acceptance Criteria (WAC)

There has been considerable effort and analysis by SWPF to ensure that SWPF meet the WAC of both DWPF and SPF. It appears that SWPF will be able to generate a product stream that meets the WAC requirements for both DWPF and SPF.[87]

4.2.3 SWPF production volumes

The SWPF contractor must maintain a quality feed to the DWPF and Saltstone, and this feed must be in the quantities specified in the contract. It appears, based on the analysis conducted earlier in this report, that SWPF can technically meet volume and quality-of-feed production requirements. However, the overall waste volume flow through all processes at SRS needs further analysis. The SWPF Risk Management Plan[88] notes that this is considered an operational risk to the performance of the SWPF.

> *"Neither Saltstone nor DWPF has been able to achieve a level of attainment throughout their life cycles commensurate with that envisioned for SWPF. The close coupling of these three facilities could reduce SWPF operational throughput. This reduction in operational throughput could result in an extended program life cycle, with the EPC unable to meet Contract requirements.*[89]

4.2.4 Overall System RAM

The SWPF has done a very responsible, credible job of accounting for RAM within its own plant (subsystems). However, there is not an "overall systems model" for waste processing. Therefore, a RAM analysis of the entire SRS waste processing operation (from tanks to conversion into final waste disposition form) is not possible at this time. An evaluation of the SRS modeling program (called an External Technical Review-ETR) is currently in progress. The final report will be published by the end of summer, 2009. The results of that ETR will serve as the basis on which to evaluate the path forward to develop an overall, SRS waste processing model.

5 Conclusions

5.1 Conclusions on Technology Readiness

Based on interactions with DOE and Parsons SWPF project personnel and on review of extensive documentation during the course of this assessment, the TRA Team has reached the following conclusions:

- All SWPF Critical Technology Elements satisfy the requirements of Technology Readiness Level (TRL) 6. Availability of the full-scale plant for cold commissioning is required for advancement to TRL 7.
- DOE and Parsons have conducted a very thorough technology development and large-scale testing program.

5.2 Observations and Recommendations

5.2.1 Continued Study of Operating Limits to Prevent and/or Minimize Solids Formation in Feed Adjustment and Solvent Extraction

Observation: The recent Parsons' work[16] mentioned above made significant progress in assimilating existing data, conducting additional tests, and modeling applications to develop a much improved understanding of precipitation of aluminum-containing solids in the SWPF processes. This report also included recommendations for future laboratory and full-scale CSSX studies. The recommendations address enhanced feed stability, preventing solids formation in CSSX contactors, and alternative contactor flushing approaches. The TRA Team endorses these recommendations and believes that the results will bring significant benefits in refining optimum process conditions well before startup testing.

Recommendation: SWPF project management should ensure that adequate priority is provided to complete the studies recommended in Parsons' report 02-700-00654.[16]

5.2.2 Impact of Dissolving Aluminum in Tank Farm Sludge on SWPF Feed Chemistry

Observation: SRS is planning to utilize aluminum dissolution in the Tank Farm to reduce the aluminum concentration in feed to DWPF and, thereby, reduce the number of canisters that must be produced at DWPF. While reducing canisters has significant cost savings, it is not clear to the Team that the impact of the additional aluminum coming to SWPF has been assessed. Recent SWPF studies[16] have recommended a reduction of aluminum concentration (<0.5 Molar) as well as increased hydroxide concentration in SWPF feed. These changes are required for SWPF feed stability and prevention of solids formation downstream in the centrifugal contactors. The recommended lower aluminum concentrations and higher hydroxide concentrations would appear to increase the volume of feed to be processed in SWPF. Also, if precipitation is difficult to prevent in SWPF due to the increased aluminum input, some aluminum-containing solids could be filtered out in the ASP and sent to DWPF with the MST/sludge stream.

Recommendation: SRS should evaluate the impacts on SWPF and the entire Liquid Waste System of the aluminum in sludge being diverted from the DWPF feed to the SWPF feed.

5.2.3 Interaction between SWPF project and Integrated Salt Disposition project

Observation: SRS currently has another project, the Integrated Salt Disposition Project (ISDP), which is successfully utilizing most of the processes that will be employed at the SWPF. The ISDP's Actinide Removal Process (ARP) and Modular Caustic Solvent Side Extraction Unit (MCU) have successfully demonstrated removal of radioactive constituents from salt waste. The TRA team endorses the existing interaction between the ISDP Project and SWPF Project, but feels that both projects would benefit from enhanced interaction.

Recommendation: The interaction and communication between the two projects should continue and be enhanced as much as possible in the future in order to maximize the benefit of current ISDP operating experience. Exchange of personnel between the two projects should be considered.

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Appendix A
Determination of the Critical Technology Elements

Technology: Feed Adjustment - Al Chemistry

Set 1 - Criteria	**Yes**	**No**
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?	X	
• Is the technology modified?		
• 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?		

Technology: Actinide/Sr Removal - MST Performance

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?		X
• Has the technology been repackaged so a new relevant environment is realized?		X
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

Technology: Actinide/Sr Removal - CFF

Set 1 - Criteria	**Yes**	**No**
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?		X
• Has the technology been repackaged so a new relevant environment is realized?	X	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

Technology: Actinide/Sr Removal - APA

Set 1 - Criteria	**Yes**	**No**
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?	X	
• Has the technology been repackaged so a new relevant environment is realized?	X	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

Technology: CSSX - Chemistry

Set 1 - Criteria	**Yes**	**No**
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?	X	
• Is the technology modified?		
• 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?		

Technology: CSSX - Centrifugal Contactor

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?	X	
• Has the technology been repackaged so a new relevant environment is realized?	X	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		

Technology: CSSX - Solvent Recovery)

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?	X	
• Has the technology been repackaged so a new relevant environment is realized?	X	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	X	

Technology: Product Handling - Strip Effluent

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?		X
• Has the technology been repackaged so a new relevant environment is realized?		X
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

Technology: Product Handling - MST/ Sludge

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?		X
• Has the technology been repackaged so a new relevant environment is realized?	X	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

Technology: Product Handling - DSS

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?		X
• Has the technology been repackaged so a new relevant environment is realized?		X
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

Technology: Analytical Laboratory

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?		X
• Is the technology modified?		X
• Has the technology been repackaged so a new relevant environment is realized?		X
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

Technology: Process Integration

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	X	
• 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?		
Set 2 - Criteria	**Yes**	**No**
• Is the technology new or novel?	X	
• Is the technology modified?		
• 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?		

Appendix B[1]
Technology Readiness Level Results for SWPF Critical Technology Elements

Appendix B summarizes the responses to the TRL questions for each of the critical technology elements (CTEs). The following were evaluated:

Feed Adjustment
- Table B-1. Technology Readiness Level 5 Summary for Feed Adjustment - Al Chemistry
- Table B-2. Technology Readiness Level 6 Summary for Feed Adjustment - Al Chemistry

Actinide/Sr Removal
- Table B-3. Technology Readiness Level 6 Summary for Actinide/ Sr Removal - CFF
- Table B-4. Technology Readiness Level 6 Summary for Actinide/ Sr Removal -APA

Caustic Solvent Side Extraction
- Table B-5. Technology Readiness Level 6 Summary for CSSX - Chemistry
- Table B-6. Technology Readiness Level 6 Summary for CSSX - Centrifugal Contactor System
- Table B-7. Technology Readiness Level 6 Summary for CSSX - Solvent Recovery Systems

Product Handling
- Table B-8. Technology Readiness Level 6 Summary for Product Handling - MST/Sludge

[1] The references listed in Tables B-1 through B-8 are not the same as list of references for the main body of the report. The references that correspond to this section are listed in Appendix D.

Table B-1. Technology Readiness Level 5 Summary for Feed Adjustment - Al Chemistry

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. 46, 86
T	N/A	2. Plant size components available for testing	n/a
T	Y	3. System interface requirements known (How would system be integrated into the plant?)	Ref. 91, 97, 112
P	Y	4. Preliminary design engineering begins	CD-3 Approved
T	Y	5. Requirements for technology verification established	Ref. 95
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)	Ref. 44
M	n/a	8. Tooling and machines demonstrated in lab for new manufacturing processes to make component	n/a
T	Y	9. High fidelity lab integration of system completed, ready for test in relevant environments	Ref. 48-52
M	n/a	10. Manufacturing techniques have been defined to the point where largest problems defined	n/a
T	Y	11. Lab-scale, similar system tested with range of simulants	Ref. 48-52 (actual waste)
T	Y	12. Fidelity of system mock-up improves from laboratory to bench-scale testing	Ref. 48-52 (actual waste)
M	Y	13. Availability and reliability (RAMI) target levels identified	Ref. 93
M	Y	14. Some special purpose components combined with available laboratory components for testing	Ref. 48-52 (actual waste)
P	Y	15. Three dimensional drawings and P&IDs for the prototypical engineering-scale test facility have been prepared	Ref. 44
T	Y	16. Laboratory environment for testing modified to approximate operational environment	Ref. 48-52 (actual waste)
T	Y	17. Component integration issues and requirements identified	Ref. 91, 97, 112
P	Y	18. Detailed design drawings have been completed to support specification of engineering-scale testing system	Ref. 44

Table B-1. Technology Readiness Level 5 Summary for Feed Adjustment - Al Chemistry

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T	Y	19. Requirements definition with performance thresholds and objectives established for final plant design	Ref. 94, 98
P	Y	20. Preliminary technology feasibility engineering report completed	Ref. 44, 86
T	Y	21. Integration of modules/functions demonstrated in a laboratory/bench-scale environment	Ref. 44, 86
T	Y	22. Formal control of all components to be used in final prototypical test system	Ref. 44, 86
P	Y	23. Configuration management plan in place	Ref. 90
T	Y	24. The range of all relevant physical and chemical properties has been determined (to the extent possible)	Ref. 86
T	Y	25. Simulants have been developed that cover the full range of waste properties	Ref. 30, 44, 112
T	Y	26. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes	Ref. 44
T	Y	27. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 30, 44, 48-52 (actual waste), 112
T	Y	28. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed	Ref. 30, 44, 48-52 (actual waste), 112
T	Y	29. Test results for simulants and real waste are consistent	Ref. 30, 44, 48-52 (actual waste),
T	Y	30. Laboratory to engineering scale scale-up issues are understood and resolved	Ref. 30, 44, 48-52 (actual waste),
T	Y	31. Limits for all process variables/parameters and safety controls are being refined	Ref. 91, 111, 112
P	Y	32. Test plan for prototypical lab-scale tests executed – results validate design	Ref. 44
P	Y	33. Test plan documents for prototypical engineering-scale tests completed	Ref. 44
P	Y	34. Risk management plan documented	Ref. 103

Table B-2. Technology Readiness Level 6 Summary for Feed Adjustment - Al Chemistry

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. 44, 46, 86
M	Y	2. Availability and reliability (RAMI) levels established	Ref. 93
P	Y	3. Preliminary design drawings for final plant system are complete	CD-3 approved
T	Y	4. Operating environment for final system known	Ref. 91, 112
P	Y	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 44, 93
P	Y	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	CD-3 approved
T	n/a	7. Operating limits for components determined (from design, safety and environmental compliance)	n/a
P	Y	8. Operational requirements document available	Ref. 94
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 44
T	Y	10. System technical interfaces defined	Ref. 87, 88, 91, 112
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 44, 86
P	n/a	12. Scaling issues that remain are identified and understood. Supporting analysis is complete	n/a
P	Y	13. Analysis of project timing ensures technology will be available when required	Ref. 37, 86
P	Y	14. Have established an interface control process	Ref. 87, 88, 91, 112
P	Y	15. Acquisition program milestones established for start of final design (CD-2)	CD-3 approved
M	Y	16. Critical manufacturing processes prototyped	Ref. 44
M	Y	17. Most pre-production hardware is available to support fabrication of the system	Ref. 44
T	Y	18. Engineering feasibility fully demonstrated (e.g. would it work)	Ref. 44
M	Y	19. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Ref. 44

Table B-2. Technology Readiness Level 6 Summary for Feed Adjustment - Al Chemistry			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documents**
P	Y	20. Technology ”system” design specification complete and ready for detailed design	CD-3 approved
M	Y	21. Components are functionally compatible with operational system	Ref. 44
T	Y	22. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 44
P	Y	23. Formal configuration management program defined to control change process	Ref. 90
M	Y	24. Integration demonstrations have been completed (e.g. construction of testing system)	Ref. 44
P	Y	25. Final Technical Report on Technology completed	Ref. 44, 86
M	n/a	26. Process and tooling are mature to support fabrication of components/system	n/a
T	Y	27. Engineering-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 44, 112
T	n/a	28. Engineering to full-scale scale-up issues are understood and resolved	n/a
T	Y	29. Laboratory and engineering-scale experiments are consistent	Ref. 37, 44, 86
T	Y	30. Limits for all process variables/parameters and safety controls are defined	Ref. 91, 111, 112
T	Y	31. Plan for engineering-scale testing executed - results validate design	Ref. 44
M	n/a	32. Production demonstrations are complete (at least one time)	n/a

Table B-3. Technology Readiness Level 6 Summary for Actinide/ Sr Removal - CFF

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. 13-20
M	Y	2. Availability and reliability (RAMI) levels established	Ref. 93
P	Y	3. Preliminary design drawings for final plant system are complete	CD-3 approved
T	Y	4. Operating environment for final system known	Ref. 91, 92, 97,112
P	Y	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 19, 93
P	Y	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	CD-3 approved
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 19, 91, 92, 93, 99, 111
P	Y	8. Operational requirements document available	Ref. 91 94
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 19
T	Y	10. System technical interfaces defined	Ref. 91, 92, 110, 112, 121
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 13-19
P	Y	12. Scaling issues that remain are identified and understood. Supporting analysis is complete	Ref. 13-21
P	Y	13. Analysis of project timing ensures technology will be available when required	Ref. 19 Contract awarded for full scale elements (NUMET/Mott)
P	Y	14. Have established an interface control process	Ref. 91, 92, 100,110, 112,
P	Y	15. Acquisition program milestones established for start of final design (CD-2)	CD-3 approved
M	Y	16. Critical manufacturing processes prototyped	Ref. 19, Contract awarded for full scale elements (NUMET/Mott)
M	Y	17. Most pre-production hardware is available to support fabrication of the system	Ref. 19 Contract awarded for full scale elements (NUMET/Mott)
T	Y	18. Engineering feasibility fully demonstrated (e.g. would it work)	Ref. 13-21
M	Y	19. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Ref. 19 Contract awarded for full scale elements (NUMET/Mott)

Table B-3. Technology Readiness Level 6 Summary for Actinide/ Sr Removal - CFF

T/P/M	Y/N	Criteria	Basis and Supporting Documents
P	Y	20. Technology "system" design specification complete and ready for detailed design	CD-3 approved
M	Y	21. Components are functionally compatible with operational system	Ref. 19
T	Y	22. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 19
P	Y	23. Formal configuration management program defined to control change process	Ref. 90
M	Y	24. Integration demonstrations have been completed (e.g. construction of testing system)	Ref. 13-19
P	Y	25. Final Technical Report on Technology completed	Ref. 19, 95
M	Y	26. Process and tooling are mature to support fabrication of components/system	Ref. 19 Contract awarded for full scale elements (NUMET/Mott)
T	Y	27. Engineering-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 13-19
T	Y	28. Engineering to full-scale scale-up issues are understood and resolved	Ref. 13-19 Contract awarded for full scale elements (NUMET/Mott)
T	Y	29. Laboratory and engineering-scale experiments are consistent	Ref. 13-21
T	Y	30. Limits for all process variables/parameters and safety controls are defined	Ref. 91, 92, 110-112
T	Y	31. Plan for engineering-scale testing executed - results validate design	Ref. 19
M	Y	32. Production demonstrations are complete (at least one time)	Ref. 19 Contract awarded for full scale elements (NUMET/Mott)

Table B-4. Technology Readiness Level 6 Summary for Actinide/ Sr Removal - APA

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. 2-4, 7
M	Y	2. Availability and reliability (RAMI) levels established	Ref. 93
P	Y	3. Preliminary design drawings for final plant system are complete	CD-3 approved
T	Y	4. Operating environment for final system known	Ref. 91, 92, 97, 112
P	Y	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 2-4, 7, 93
P	Y	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	CD-3 approved
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 2-4, 7, 91, 92, 93, 99 ,111
P	Y	8. Operational requirements document available	Ref. 91, 94
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 2-4, 7
T	Y	10. System technical interfaces defined	ref. 91, 92, 100,110, 112
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 2-4, 7
P	Y	12. Scaling issues that remain are identified and understood. Supporting analysis is complete	Ref. 2-4, 7
P	Y	13. Analysis of project timing ensures technology will be available when required	Ref. 2-4, 7, Contract awarded for full scale elements (AIT)
P	Y	14. Have established an interface control process	ref. 91, 92, 100,110, 112
P	Y	15. Acquisition program milestones established for start of final design (CD-2)	CD-3 approved
M	Y	16. Critical manufacturing processes prototyped	Ref. 2-4, 7 Contract awarded for full scale elements (AIT)
M	Y	17. Most pre-production hardware is available to support fabrication of the system	Ref. 2-4, 7 Contract awarded for full scale elements (AIT)
T	Y	18. Engineering feasibility fully demonstrated (e.g. would it work)	Ref. 2-4, 7
M	Y	19. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Ref. 2-4, 7 Contract awarded for full scale elements (AIT)

Table B-4. Technology Readiness Level 6 Summary for Actinide/ Sr Removal - APA

T/P/M	Y/N	Criteria	Basis and Supporting Documents
P	Y	20. Technology "system" design specification complete and ready for detailed design	CD-3 approved
M	Y	21. Components are functionally compatible with operational system	Ref. 2-4, 7
T	Y	22. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 2-4, 7
P	Y	23. Formal configuration management program defined to control change process	Ref. 90
M	Y	24. Integration demonstrations have been completed (e.g. construction of testing system)	Ref. 2-4, 7
P	Y	25. Final Technical Report on Technology completed	Ref. 2-4, 7, 95
M	Y	26. Process and tooling are mature to support fabrication of components/system	Ref. 2-4, 7 Contract awarded for full scale elements (AIT)
T	Y	27. Engineering-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 2-4, 7
T	Y	28. Engineering to full-scale scale-up issues are understood and resolved	Ref. 2-4, 7 Contract awarded for full scale elements (AIT)
T	Y	29. Laboratory and engineering-scale experiments are consistent	Ref. 2-4, 7
T	Y	30. Limits for all process variables/parameters and safety controls are defined	Ref. 91, 92, 110-112
T	Y	31. Plan for engineering-scale testing executed - results validate design	Ref. 2-4, 7
M	Y	32. Production demonstrations are complete (at least one time)	Ref. 2-4, 7, Contract awarded for full scale elements (AIT)

Table B-5. Technology Readiness Level 6 Summary for CSSX - Chemistry

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. 23-26, 28, 44, 48-52, 54, 57
M	Y	2. Availability and reliability (RAMI) levels established	Ref. 93
P	Y	3. Preliminary design drawings for final plant system are complete	CD-3 approved
T	Y	4. Operating environment for final system known	Ref. 91, 92, 97, 112
P	Y	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 93
P	Y	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	CD-3 approved
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 23-26, 28, 44, 48-52, 54, 57, 91, 93, 99, 111
P	Y	8. Operational requirements document available	Ref. 91, 92, 94
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 44, 37
T	Y	10. System technical interfaces defined	Ref. 87, 91, 92, 100, 112
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 44
P	Y	12. Scaling issues that remain are identified and understood. Supporting analysis is complete	Ref. 23-26, 28, 44, 48-52, 54, 57
P	Y	13. Analysis of project timing ensures technology will be available when required	Ref. 44 CD-3 approved
P	Y	14. Have established an interface control process	Ref. 87, 91, 92, 100, 112
P	Y	15. Acquisition program milestones established for start of final design (CD-2)	CD-3 approved
M	Y	16. Critical manufacturing processes prototyped	Ref. 23-26, 28, 44, 48-52, 54, 57, Contract awarded and solvent procured for full scale quantity (Marshallton Lab)
M	Y	17. Most pre-production hardware is available to support fabrication of the system	Ref. 44 Contract awarded and solvent procured for full scale quantity (Marshallton Lab)
T	Y	18. Engineering feasibility fully demonstrated (e.g. would it work)	Ref. 44, 48-52

Table B-5. Technology Readiness Level 6 Summary for CSSX - Chemistry

T/P/M	Y/N	Criteria	Basis and Supporting Documents
M	Y	19. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Ref. 44 Contract awarded and solvent procured for full scale quantity (Marshallton Lab)
P	Y	20. Technology "system" design specification complete and ready for detailed design	CD-3 approved
M	Y	21. Components are functionally compatible with operational system	Ref. 23-26, 28, 44, 48-52, 54, 57
T	Y	22. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 23-26, 28, 44, 48-52, 54, 57
P	Y	23. Formal configuration management program defined to control change process	Ref. 90
M	Y	24. Integration demonstrations have been completed (e.g. construction of testing system)	Ref. 23-26, 28, 44, 48-52, 54, 57
P	Y	25. Final Technical Report on Technology completed	Ref. 44, 95
M	Y	26. Process and tooling are mature to support fabrication of components/system	Ref. 23-26, 28, 44, 48-52, 54, 57, Contract awarded and solvent procured for full scale quantity (Marshallton Lab)
T	Y	27. Engineering-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 44
T	Y	28. Engineering to full-scale scale-up issues are understood and resolved	Ref. 23-26, 28, 44, 48-52, 54, 57, Contract awarded and solvent procured for full scale quantity (Marshallton Lab)
T	Y	29. Laboratory and engineering-scale experiments are consistent	Ref. 23-26, 28, 44, 48-52, 54, 57
T	Y	30. Limits for all process variables/parameters and safety controls are defined	Ref. 23, 87, 91, 92, 111, 112
T	Y	31. Plan for engineering-scale testing executed - results validate design	Ref. 44
M	Y	32. Production demonstrations are complete (at least one time)	Ref. 44 Contract awarded and solvent procured for full scale quantity (Marshallton Lab)

Table B-6. Technology Readiness Level 6 Summary for CSSX - Centrifugal Contactor System

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. 38-42, 44, 77, 78
M	Y	2. Availability and reliability (RAMI) levels established	Ref. 93
P	Y	3. Preliminary design drawings for final plant system are complete	CD-3 approved
T	Y	4. Operating environment for final system known	Ref. 91, 92, 97, 112
P	Y	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 44, 93
P	Y	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	CD-3 approved
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 44, 91, 92, 93, 99,
P	Y	8. Operational requirements document available	Ref. 91, 92, 94
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 44, 37
T	Y	10. System technical interfaces defined	Ref. 87, 91, 92, 100, 112
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 44
P	Y	12. Scaling issues that remain are identified and understood. Supporting analysis is complete	Ref. 38-42, 44, 77, 78
P	Y	13. Analysis of project timing ensures technology will be available when required	Ref. 44 CD-3 approved
P	Y	14. Have established an interface control process	Ref. 87, 91, 92, 100, 112
P	Y	15. Acquisition program milestones established for start of final design (CD-2)	CD-3 approved
M	Y	16. Critical manufacturing processes prototyped	Ref. 44, Contract awarded for CSSX contactor skids (Wright Industries Inc)
M	Y	17. Most pre-production hardware is available to support fabrication of the system	Ref. 44 Contract awarded for CSSX contactor skids (Wright Industries Inc)

Table B-6. Technology Readiness Level 6 Summary for CSSX - Centrifugal Contactor System

T/P/M	Y/N	Criteria	Basis and Supporting Documents
T	Y	18. Engineering feasibility fully demonstrated (e.g. would it work)	Ref. 44, 48-52
M	Y	19. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Ref. 44 Contract awarded for CSSX contactor skids (Wright Industries Inc)
P	Y	20. Technology ”system” design specification complete and ready for detailed design	CD-3 approved
M	Y	21. Components are functionally compatible with operational system	Ref. 38-42, 44, 77, 78
T	Y	22. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 38-42, 44, 77, 78
P	Y	23. Formal configuration management program defined to control change process	Ref. 90
M	Y	24. Integration demonstrations have been completed (e.g. construction of testing system)	Ref. 44, 48-52
P	Y	25. Final Technical Report on Technology completed	Ref. 44, 95
M	Y	26. Process and tooling are mature to support fabrication of components/system	Ref. 44 Contract awarded for CSSX contactor skids (Wright Industries Inc)
T	Y	27. Engineering-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 44
T	Y	28. Engineering to full-scale scale-up issues are understood and resolved	Ref. 38-42, 44, 77, 78, Contract awarded for CSSX contactor skids (Wright Industries Inc)
T	Y	29. Laboratory and engineering-scale experiments are consistent	Ref. 38-42, 44, 77, 78
T	Y	30. Limits for all process variables/parameters and safety controls are defined	Ref. 44, 87, 91, 92, 100, 112
T	Y	31. Plan for engineering-scale testing executed - results validate design	Ref. 44
M	Y	32. Production demonstrations are complete (at least one time)	Ref. 44 Contract awarded for CSSX contactor skids (Wright Industries Inc)

Table B-7. Technology Readiness Level 6 Summary for CSSX - Solvent Recovery Systems

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. 33, 42- 44, 66-68, 77, 78
M	Y	2. Availability and reliability (RAMI) levels established	Ref. 93
P	Y	3. Preliminary design drawings for final plant system are complete	CD-3 approved
T	Y	4. Operating environment for final system known	Ref. 91, 92, 97, 112
P	Y	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 44, 93
P	Y	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	CD-3 approved
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 44, 91, 92, 99, 111
P	Y	8. Operational requirements document available	Ref. 44, 91, 92, 94
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 37, 44
T	Y	10. System technical interfaces defined	Ref. 87, 91, 92, 100, 112
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 44
P	Y	12. Scaling issues that remain are identified and understood. Supporting analysis is complete	Ref. 33, 42- 44, 66-68, 77, 78
P	Y	13. Analysis of project timing ensures technology will be available when required	Ref. 44 CD-3 approved
P	Y	14. Have established an interface control process	Ref. 87, 91, 92, 100, 112
P	Y	15. Acquisition program milestones established for start of final design (CD-2)	CD-3 approved
M	Y	16. Critical manufacturing processes prototyped	Ref. 44, Contract awarded for coalescer media (Franken) and housing (Joseph Oat)
M	Y	17. Most pre-production hardware is available to support fabrication of the system	Ref. 44 Contract awarded for coalescer media (Franken) and housing (Joseph Oat)
T	Y	18. Engineering feasibility fully demonstrated (e.g. would it work)	Ref. 33, 42- 44, 66-68, 77, 78
M	Y	19. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Ref. 44 Contract awarded for coalescer media (Franken) and housing (Joseph Oat)

Table B-7. Technology Readiness Level 6 Summary for CSSX - Solvent Recovery Systems

T/P/M	Y/N	Criteria	Basis and Supporting Documents
P	Y	20. Technology "system" design specification complete and ready for detailed design	CD-3 approved
M	Y	21. Components are functionally compatible with operational system	Ref. 33, 42- 44, 66-68, 77, 78
T	Y	22. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 33, 42- 44, 66-68, 77, 78
P	Y	23. Formal configuration management program defined to control change process	Ref. 90
M	Y	24. Integration demonstrations have been completed (e.g. construction of testing system)	Ref. 43, 44
P	Y	25. Final Technical Report on Technology completed	Ref. 43, 44, 95
M	Y	26. Process and tooling are mature to support fabrication of components/system	Ref. 44, Contract awarded for coalescer media (Franken) and housing (Joseph Oat)
T	Y	27. Engineering-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 44
T	Y	28. Engineering to full-scale scale-up issues are understood and resolved	Ref. 33, 42- 44, 66-68, 77, 78, Contract awarded for coalescer media (Franken) and housing (Joseph Oat)
T	Y	29. Laboratory and engineering-scale experiments are consistent	Ref. 33, 42- 44, 66-68, 77, 78
T	Y	30. Limits for all process variables/parameters and safety controls are defined	Ref. 44, 87, 91, 92, 111, 112
T	Y	31. Plan for engineering-scale testing executed - results validate design	Ref. 43, 44
M	Y	32. Production demonstrations are complete (at least one time)	Ref. 44 Contract awarded for coalescer media (Franken) and housing (Joseph Oat)

Table B-8. Technology Readiness Level 6 Summary for Product Handling - MST/Sludge			
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. 1-4, 6, 7, 19, 83
M	Y	2. Availability and reliability (RAMI) levels established	Ref. 93
P	Y	3. Preliminary design drawings for final plant system are complete	CD-3 approved
T	Y	4. Operating environment for final system known	Ref. 91, 112
P	Y	5. Collection of actual maintainability, reliability, and supportability data has been started	Ref. 1-4, 6, 7, 19, 83, 93
P	Y	6. Performance Baseline (including total project cost, schedule, and scope) has been completed	CD-3 approved
T	Y	7. Operating limits for components determined (from design, safety and environmental compliance)	Ref. 1-4, 6, 7, 19, 83, 91, 93, 99, 111
P	Y	8. Operational requirements document available	Ref. 91, 94
P	Y	9. Off-normal operating responses determined for engineering scale system	Ref. 1-4, 6, 7, 19, 83
T	Y	10. System technical interfaces defined	Ref. 87, 91, 100, 112
T	Y	11. Component integration demonstrated at an engineering scale	Ref. 1-4, 6, 7, 19, 83, 87
P	Y	12. Scaling issues that remain are identified and understood. Supporting analysis is complete	Ref. 1-4, 6, 7, 19, 83, 87
P	Y	13. Analysis of project timing ensures technology will be available when required	Ref. 1-4, 6, 7, 19, 83
P	Y	14. Have established an interface control process	Ref. 87, 88, 91, 100, 112
P	Y	15. Acquisition program milestones established for start of final design (CD-2)	CD-3 approved
M	Y	16. Critical manufacturing processes prototyped	Ref. 1-4, 6, 7, 19, 83
M	Y	17. Most pre-production hardware is available to support fabrication of the system	Ref. 1-4, 6, 7, 19, 83
T	Y	18. Engineering feasibility fully demonstrated (e.g. would it work)	Ref. 1-4, 6, 7, 19, 83
M	Y	19. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	Ref. 1-4, 6, 7, 19, 83
P	Y	20. Technology ”system” design specification complete and ready for detailed design	CD-3 approved

Table B-8. Technology Readiness Level 6 Summary for Product Handling - MST/Sludge			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documents**
M	Y	21. Components are functionally compatible with operational system	Ref. 1-4, 19, 83
T	Y	22. Engineering-scale system is high-fidelity functional prototype of operational system	Ref. 1-4, 19, 83
P	Y	23. Formal configuration management program defined to control change process	Ref. 90
M	Y	24. Integration demonstrations have been completed (e.g. construction of testing system)	Ref. 1-4, 19, 83
P	Y	25. Final Technical Report on Technology completed	Ref. 2-4, 19, 95
M	Y	26. Process and tooling are mature to support fabrication of components/system	Ref. 2-4, 19
T	Y	27. Engineering-scale tests on the full range of simulants using a prototypical system have been completed	Ref. 1-4, 6, 7, 19, 83
T	Y	28. Engineering to full-scale scale-up issues are understood and resolved	Ref. 1-4, 19, 83
T	Y	29. Laboratory and engineering-scale experiments are consistent	Ref. 1-4, 6, 7, 19
T	Y	30. Limits for all process variables/parameters and safety controls are defined	Ref. 91, 111, 112
T	Y	31. Plan for engineering-scale testing executed - results validate design	Ref. 2-4, 19
M	Y	32. Production demonstrations are complete (at least one time)	Ref. 2-4, 19

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Appendix C[1]
Process Integration Summary

Appendix C summarizes the responses to the TRL questions for the SWPF Wastes Processing System.

[1] The references listed in Table C-1 are not the same as list of references for the main body of the report. The references that correspond to this section are listed in Appendix D.

Table C-1. Technology Readiness Level 6 Summary for SWPF Waste Processing System (WPS)

	Y/N	Criteria	Basis and Supporting Documents
Processing	N	1. Does the WPS require an increase or change in capability for any TEs? (If so, the TEs may be CTEs.)	Ref. 91, 93, 98
	Y	2. Can the WPS accept the full range of wastes to be processed?	Ref. 112
	Y	3. Is the WPS capable of meeting targets for startup and completion of waste processing?	CD-3 baseline
	Y	4. Have the target operational and performance requirements for the WPS been determined?	Ref. 85, Key Performance Parameters
	Y	5. Have major sections of the WPS and their interfaces been modeled and/or piloted?	Ref. 19, 44, 56, 93
	N	6. Has WPS data collection and data flow been modeled/tested?	Distributed control system is expected to manage data collection and data flow satisfactorily. A simulator will be procured. Ref. 105-110
	Y	7. Has WPS process flow and process control been modeled/tested?	Ref. 56, 93
	Y	8. Have WPS single point and common mode failures been identified?	Ref. 89, 93
	Y	9. Can TEs be sized to meet WPS throughput requirements?	Ref. 91, 93, 98
	Y	10. Have all new or novel operating modes of the WPS been modeled and/or piloted?	Ref. 19, 44
	Y	11. Are all recycle streams fully characterized?	Ref. 56
	Y	12. Are all WPS recycle streams included in process models?	Ref. 56, 93
Disposal	Y	13. Will the WPS produce a product or products that can be dispositioned?	Ref. 85
	Y	14. Are all WPS waste streams identified?	Ref. 97
	Y	15. Have the waste streams that will be produced by the WPS been fully characterized?	Ref. 100, 121
	Y	16. Has a disposition path been determined for each waste stream, including, process liquids, off gases, and solids?	Ref. 97

Table C-1. Technology Readiness Level 6 Summary for SWPF Waste Processing System (WPS)

	Y/N	Criteria	Basis and Supporting Documents
	Y	17. Will the waste forms meet the waste acceptance criteria of the proposed disposition facilities?	Ref. 85
	Y	18. Have the disposition facilities/sites been contacted to ensure that the waste streams are compatible with disposal facility/site **operations, procedures, and regulations**?	Ref. 121
Interfaces	Y	19. Is the WPS dependent on any new relationships among systems? (If so, the interfaces among the systems are possible CTEs.)	Ref. 113-126
	Y	20. Are all WPS technology interfaces and dependencies determined and understood?	Ref. 113-126
	N	21. Will any of the TEs have to be modified to be integrated into the WPS? (If the answer is yes, the modified TEs are probably CTEs.)	
	Y	22. Have all WPS TE interfaces been modeled or piloted?	Ref. 56
	Y	23. Are the processing modes of the TEs (e.g., batch, continuous) compatible?	Ref. 91, 93

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Appendix D
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107. X-PCD-J-00003, *Automation Document*, Rev. B, March 28, 2007

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109. X-PCD-J-00005, *Automation Document*, Rev. B, March 27, 2007

110. X-WCP-J-00001, *Automation Document*, Rev. B, November 8, 2007

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115. V-ESR-J-00004, Stormwater *Interface Control Document (ICD-4)*, Revision 1,August 17, 2006
116. V-ESR-J-00005, Radioactive Liquid Effluent *Interface Control Document (ICD-5)*, Revision 1, November 1, 2005
117. V-ESR-J-00006, Liquid Sanitary Waste *Interface Control Document (ICD-6)*, Revision 1, August 15, 2006
118. V-ESR-J-00007, Facility Siting *Interface Control Document (ICD-7)*, Revision 1, April 3, 2008
119. V-ESR-J-00008, Electrical Power *Interface Control Document (ICD-8)*, Revision 4, September 2, 2008
120. V-ESR-J-00009, Road & Rail Access *Interface Control Document (ICD-9)*, Revision 2, April 3, 2008
121. V-ESR-J-00011, Sample & Analysis *Interface Control Document (ICD-11)*, Revision 1, September 8, 2006
122. V-ESR-J-00012, Emergency Response *Interface Control Document (ICD-12)*, Revision 2, April 7, 2008
123. V-ESR-J-00013, Telecommunications *Interface Control Document (ICD-13)*, Revision 1, August 24, 2006
124. V-ESR-J-00017, Fire Protection Water System *Interface Control Document (ICD-17)*, Revision 3, April 3, 2008
125. V-ESR-J-00018, Work Control *Interface Control Document (ICD-18)*, Revision 2, December 13, 2007
126. V-ESR-J-00019, Permitting & Monitoring *Interface Control Document (ICD-19)*, Revision 1, January 13, 2006

Appendix E
Technology Readiness Assessment Meeting Attendees and Team Resumes

KURT D. GERDES
May 2009

Education

B.S. Chemistry, Merrimack College
M.S. Environmental Management, University of Maryland

Employer

U. S. Department of Energy, Office of Environmental Management, Office of Waste Processing

Representative Skills and Experience

Mr. Gerdes has over 29 years experience working in private industry, Navy research facilities, and the Department of Energy on various chemical processes, tank waste treatment and immobilization projects. Current responsibilities include overseeing all technical assistance and reviews the Office of Waste Processing conducts, managing the International Program for DOE-EM, supporting research and development activities to reduce technical risk in the design/operation of the Waste Treatment and Immobilization Plant being constructed at the Hanford site in Washington state, and addressing High-Level Waste issues across the DOE Complex.

Publications

Mr. Gerdes has authored or co-authored over 20 journal articles and technical reports.

Affiliations

American Ceramics Society

HARRY D. HARMON

Education

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

Employer

Retired, Consultant

Representative Skills and Experience

Dr. Harmon has over 36 years experience in nuclear materials processing and radioactive waste management. The last 15 years of his career focused primarily on high-level waste processing and related technology development activities. He worked for E. I. DuPont and Westinghouse Savannah River Company at the Savannah River Site for 19 years and for over 3 years with Westinghouse Hanford Company as Vice President of the Tank Waste Remediation System. After four years in the private sector pursuing DOE contracts and consulting in radioactive waste management, Dr. Harmon joined Pacific Northwest National Laboratory as Technology Development Manager of the Salt Processing Program at the Savannah River Site. In this role, he is responsible for planning and managing the execution of the Salt Processing R&D program, involving work at five major DOE sites, several universities, and vendor sites. He also provided technical support to DOE-SR in their management of the Salt waste Processing Facility design and other related project activities.

Publications

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

Affiliations

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

HERBERT G. SUTTER

Education

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

Employer

Consultant

Representative Skills and Experience

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

From 2007 through the present Dr, Sutter has supported EM's 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. In 2002-2004, he was a senior scientist for Kenneth T. Lang Associates, Inc. and provided support to EM in several areas including the evaluation of HLW vitrification technologies at Hanford and pretreatment and separation technologies at Savannah River. He has also been a consultant to private industry on separation technologies. In 1990-2002 as a scientist for Science Applications International Corporation supported EM in the areas of nuclear waste treatment and characterization and analytical chemistry. In 1982-1990, Dr. Sutter was Vice President and Chief Scientist at Duratek Corporation and responsible for technical direction of all Duratek research and development and commercialization programs in ion exchange, filtration and separation techniques. Relevant experience includes: waste water treatment, bench and pilot testing, and waste treatment studies.

Publications

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

Affiliations

Member of the American Chemical Society and the American Nuclear Society

MAJOR C. THOMPSON

Education

B.S. Chemistry, Birmingham Southern College
M.S. Inorganic Chemistry, Ohio State University
Ph.D. Inorganic Chemistry, Ohio State University

Employer

Limited Service Employee of Savannah River Nuclear Solutions/SRNL
Consultant

Representative Skills and Experience

Dr. Thompson has more than forty five years experience in the fields of actinide chemistry and chemical separations including support of nuclear material production, high and low level radioactive waste treatment. During the past eighteen years he has provided technical and programmatic support to DOE's Office of Environmental Management (EM). Dr. Thompson has provided technical assistance to the DOE programs at Hanford, Savannah River, Argonne, and INL in (1) separation technologies; (2) technology development; (3) high level waste disposal; and (4); nuclear waste. As an independent consultant, he helped review the Aqueous Polishing Process of the MOX facility for DOE-HQ Project Management.

Dr. Thompson's support for DOE's Office of Environmental Management has included being a member of the core management team for the Efficient Separations and Processing Crosscutting Program, steering group for the Underground Tank Integrated Demonstration Program, and the Technical Advisory Group of the Tanks Focus Area. He was also the Tanks Focus Area System Lead for Solvent Extraction research and development during the selection process for SWPF technologies.

Dr. Thompson was the Technical Program Lead for SRTC and a member of the separations and waste management steering group for DOE-NE's Advanced Fuel Cycle Initiative and responsible for initial conception of the UREX Process for spent fuel reprocessing without plutonium recovery.

Publications

Dr. Thompson has authored or co-authored over 70 journal articles, chapters in books, articles in symposia proceedings, and technical reports.

Affiliations and Honors

Emeritus member of the American Chemical Society and Sigma Xi Society.
Winner of the Glenn T. Seaborg Award in Actinide Separations in 1997

JOHN R. SHULTZ

Education

B.S. Mechanical Engineering, University of Alabama in Huntsville
B.S. Business Administration, University of the State of New York, Regents College
M.S. Mechanical Engineering, Carnegie Mellon University
M.S. Engineering and Public Policy, Carnegie Mellon University
Ph.D. Engineering and Public Policy, Carnegie Mellon University

Employer

U.S. Department of Energy

Representative Skills and Experience

Dr. Shultz has extensive experience in systems engineering in a variety of areas. Dr. Shultz worked for 10 years at a national laboratory during which time he was the lead engineer for the High Temperature Gas Stream Cleanup Test Facility (testing novel flue gas filters for use in coal-fired power plants). In addition to experience in power generation, Dr. Shultz has consulted for the Mineral's Management Service regarding risks to offshore oil and gas production platforms and worked within DOE on strategies to prevent nuclear proliferation. Dr. Shultz is a former member of the U.S. Army: enlisted - Military Policeman; officer - Corps of Engineers. Dr. Shultz has authored or co-authored numerous journal articles, DOE policies, technical reports, and participated on the writing committees for national technical standards.

<u>Selected Publications and policy/standards writing</u>

- "The Effect of Standardizing Material Property Definitions on Nuclear Material Inventories in the U.S. Department of Energy", Shultz, John R., Journal of Nuclear Materials Management, Winter 2005
- "The Perception of Risk at Offshore Production Platform", Shultz, JR, Fischbeck, PF, International Gas Research Conference - 2001
- "Combustor Mapping Using Neural Networks", Shultz, JR, 11^{th} International Conference on Coal Science, International Energy Agency (IEA), September, 2001
- Primary author: DOE M 474.1-2A; "*Nuclear Materials Management Safeguards System (NMMSS*)", 2003
- Contributing author: DOE G 414.1-4: "*Safety Software Guide for use with 10 CFR 830 Subpart A, Quality Assurance Requirements*", April 2005
- Contributing author: Standards writing committee for ANSI/ANS 10.4-2008; "*Verification And Validation Of Non-Safety-Related Scientific and Engineering Computer Programs for the Nuclear Industry*", 2008

<u>Professional Registrations</u>

American Society for Quality, Certified Software Quality Engineer (CSQE), License # 3032

SAHID C. SMITH

Education

B.S. Chemical Engineering, Florida Agricultural and Mechanical University
Ph.D. Chemical Engineering, Florida Agricultural and Mechanical University

Employer

U.S. Department of Energy

Representative Skills and Experience

Dr. Smith is a general engineer in the K Basin Closure project group at the Richland Operations Office of the U. S. Department of Energy. He has worked on projects related to processing and disposition of spent nuclear fuel and transuranic waste. His technical expertise includes radioactive waste management, heat and mass transfer simulation, and CFD modeling of non-Newtonian flows

Publications

Dr. Smith has authored or co-authored 16 journal articles and technical reports.

Affiliations

Member of the American Institute of Chemical Engineers

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