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SRR Waste Removal and Operational Closure Strategy

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ACRONYMS/ABREVIATIONS

ADMP	Advanced Design Mixing Pump
AHP	Analytical Hierarchy Process
ARP	Actinide Removal Process
BOA	Bulk Oxalic Acid
BOAC	Bulk Oxalic Acid Cleaning
BWRE	Bulk Waste Removal Efforts
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLSM	Consolidated Low Strength Material
CSMP	Commercial Submersible Mixing Pump
CTS	Contingency Transfer System
CRC	Cesium Removal Column
D&R	Dismantling and Removal
DSA	Documented Safety Analysis
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility
DWS	Dissolution Water Skid
ECR	Effective Cleaning Radius
EDTA	Ethylenediaminetetraacetic Acid
ELSP	Encapsulated Lead Shipping Package
EPA	U.S. Environmental Protection Agency
ETP	Effluent Treatment Plant
FFA	Federal Facility Agreement
FTF	F-Tank Farm
GDL	Gravity Drain Line
HDB	H-Diversion Box
HM	H-Modified
HRR	Highly Radioactive Radionuclide
HTF	H-Tank Farm
INEEL	Idaho National Engineering and Environmental Laboratory
IW	Inhibited Water
LTAD	Low Temperature Aluminum Dissolution
LFL	Lower Flammability Limit
LL	Lessons Learned
LW	Liquid Waste
LWTRS-QAPP	Liquid Waste Tank Residuals Sampling–Quality Assurance Program Plan
LWTRSAPP	Liquid Waste Tank Sampling and Analysis Program Plan
MCU	Modular Caustic Side Solvent Extraction Unit
MEP	Maximum Extent Practical
MFB	Mechanical Feed-and-Bleed
NDAA	Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005
NEPA	National Environmental Policy Act
OA	Oxalic Acid

PA	Performance Assessment
PPE	Personal Protective Equipment
PUREX	Plutonium Uranium Extraction
RBOF	Receiving Basin for Offsite Fuels
RCRA	Resource Conservation and Recovery Act
SCD	Semi-Continuous Dissolution
SCDHEC	South Carolina Department of Health and Environmental Control
SDF	Saltstone Disposal Facility
SEE	Systems Engineering Evaluation
SLP	Standard Slurry Pump
SMP	Submersible Mixer Pump
SRR	Savannah River Remediation LLC
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SWPF	Salt Waste Processing Facility
THOREX	Thorium Extraction
UT	Ultrasonic Testing
WCS	Waste Characterization System
WD	Waste Determination
WOW	Waste on Wheels

1.0 INTRODUCTION

The liquid waste mission at Savannah River Site (SRS) involves the storage, treatment, and disposal of high level radioactive waste enabling the operational closure of underground waste storage tanks. The purpose of this document is to describe the plan for implementing the process for waste removal and closure of radioactive Liquid Waste (LW) tanks at the U.S. Department of Energy (DOE) SRS by Savannah River Remediation LLC (SRR). DOE and SRR are committed to safe, effective, and timely waste disposition and tank operational closure which protects workers, the public, and the environment.

This document describes the major activities, assumptions, and bases for each phase of waste removal, tank cleaning, and operational closure.

This document reviews lessons learned (LL) from past SRS experience with each phase. The evolution and technical maturation of the plan is described (see Section 4).

This document also provides planning guidance for waste removal and operational closure of future waste tanks with tank-specific cleaning strategies, tailored to the service history of the waste tank system, the physical and chemical characteristics of the tank waste, and the physical configuration of the waste tank system. This document does not contain sufficient detail for detailed execution; this guidance will reside in project-specific documents (e.g., Operating Plans, Technical Requirements and Criteria documents).

This document supersedes the *Tank Closure Sequencing Plan*, SRR-WRC-2010-0004, and the *Waste Removal Technology Baseline: Technology Development Description,* V-ESR-G-00003.

2.0 DESCRIPTION OF THE SAVANNAH RIVER SITE PROCESS

Since the early 1950s, the primary mission of the SRS had been to produce nuclear materials for national defense and deep space missions. A legacy of the SRS mission was the generation of high level radioactive waste from chemical separations processes in both F and H Areas. These high level radioactive wastes are stored in carbon steel-walled, concrete-encased, underground tanks.

The various nuclear processes used at SRS had a direct bearing on the radiochemical and mechanical properties of the waste in each tank in the LW system. As a result, the physical behavior of the waste differs slightly from waste tank to waste tank or even at different elevations in a single tank. This section describes the liquid waste process, the waste tanks, the type of waste encountered in the waste tanks, the physical characteristics of the waste tank forms, an overview of regulatory drivers, and a summary of the major steps leading to operational closure.

2.1 Location and Mission

SRS occupies an area of approximately 300 square miles on the upper Atlantic Coastal Plain of South Carolina. The LW mission at SRS involves the storage, treatment, and disposal of high level radioactive waste enabling the operational closure of underground waste storage tanks. The waste is stored in F-Tank Farm (FTF) and H-Tank Farm (HTF), which are located near the geographic center of SRS. The waste is also processed for solidification at the Defense Waste Processing Facility (DWPF) and Saltstone Disposal Facility (SDF). A full site description is provided in the FTF and HTF Performance Assessment (PA) documents. [SRR-CWDA-2010-00128, SRS-REG-2007-00002]

2.2 Liquid Waste Process Summary

High level waste at SRS is generated from the chemical separations facilities as acidic raffinates. The raffinates are pH-adjusted prior to discharge to the tank farms to a pH of 14 for corrosion control of the carbon steel tanks. This waste exists either as a solid sludge phase, liquid supernate, and/or as crystallized salts. The waste is stored in underground waste tanks in FTF and HTF. While stored in the waste tanks, the insoluble solids settle and accumulate on the bottom in the form of sludge. The liquid volume is reduced by evaporating excess water. As a result of evaporation of salt solutions, concentrated salts crystallize forming hard, but porous, salt cake. Since the first waste receipt in Tank 1 in 1954, SRS has generated over 150 million gallons of high level waste. Evaporator operations and waste disposition has reduced this volume to the present inventory of about 37 million gallons containing almost 290 million curies. [SRR-LWP-2009-00001] Tank Farm facilities also pre-treat the accumulated sludge and salt solutions to facilitate further processing in current treatment facilities (i.e., DWPF, Actinide Removal Process [ARP]/Modular Caustic Side Solvent Extraction Unit [MCU] and Salt Processing Facility) and a future treatment facility (i.e., Salt Waste Processing Facility [SWPF]. These treatment facilities convert the wastes to more stable forms suitable for permanent disposal.

2.3 Waste Tank Description

Between 1952 and 1981, 51 underground waste storage tanks were constructed of carbon steel and set in reinforced concrete vaults. Twenty-nine of the tanks are located in H Area and twenty-two are in F Area. The waste tanks are comprised of four types. The Type I tanks are the oldest with a nominal operating capacity of 750,000 gallons and a 5-foot high secondary containment steel liner within a concrete vault. The Type I tanks are approximately 75 feet in diameter and 24.5 feet in height. Next are the Type II tanks with a nominal operating capacity of 1,070,000 gallons with an 85-foot diameter. The Type II tanks also have a 5-foot high secondary containment steel liner within a concrete vault. The most modern waste tanks are the 1,300,000-gallon nominal operating capacity Type III/IIIA tanks. They boast a full secondary containment, an integral cooling and ventilation system, heat-treated carbon steel liners and numerous access openings. Each Type I, II, and IIIA tank has an intertwining internal array of 2-inch diameter cooling pipes. These pipes interfere with waste removal and waste tank closure activities. Type III tanks do not have installed cooling coils of the design used in Type I, Type II, and Type IIIA tanks; instead, they are cooled with insertable or deployable coils installed through the tank top risers. The 1,300,000-gallon nominal operating capacity un-cooled waste tanks make up the fourth design (often referred to as the Type IV tanks). The un-cooled waste tank variety has a self-supporting dome roof and no internal cooling coils. Type IV waste tanks were used primarily to store low activity waste, and have a lower associated inhalation dose potential limit when compared to other waste tanks. All the waste tanks are either subterranean or surrounded and covered with soil for radiation shielding. [WSRC-SA-2002-00007]

There are twelve Type I, four Type II and eight Type IV tanks. These twenty four tanks do not meet all requirements for secondary containment as defined in the Federal Facility Agreement (FFA), which is discussed in more detail in Section 2.5. These twenty four tanks are referred to as old-style tanks. There are twenty nine Type III/IIIA tanks, referred to as new-style tanks, which do meet all requirements for secondary containment.

Six of the twenty four old-style tanks (Tanks 5, 6, 17, 18, 19, and 20) have completed the operational tank closure process.

2.4 Regulatory Documentation Pathway to Operational Closure

Figure 2.4.1 depicts the integration of the numerous regulatory documents required by different Federal laws, DOE Orders and State requirements to achieve waste tank operational closure. Waste tank operational closures at SRS have multiple regulatory requirements and many area-specific documents that tie into each other and feed into the waste tank-specific documents that authorize waste tank-specific actions (e.g., State and U.S. Environmental Protection Agency (EPA) approval authority to cease waste removal and grout the tanks).

Figure 2.4-1: Regulatory Documentation Path to Tank Closure

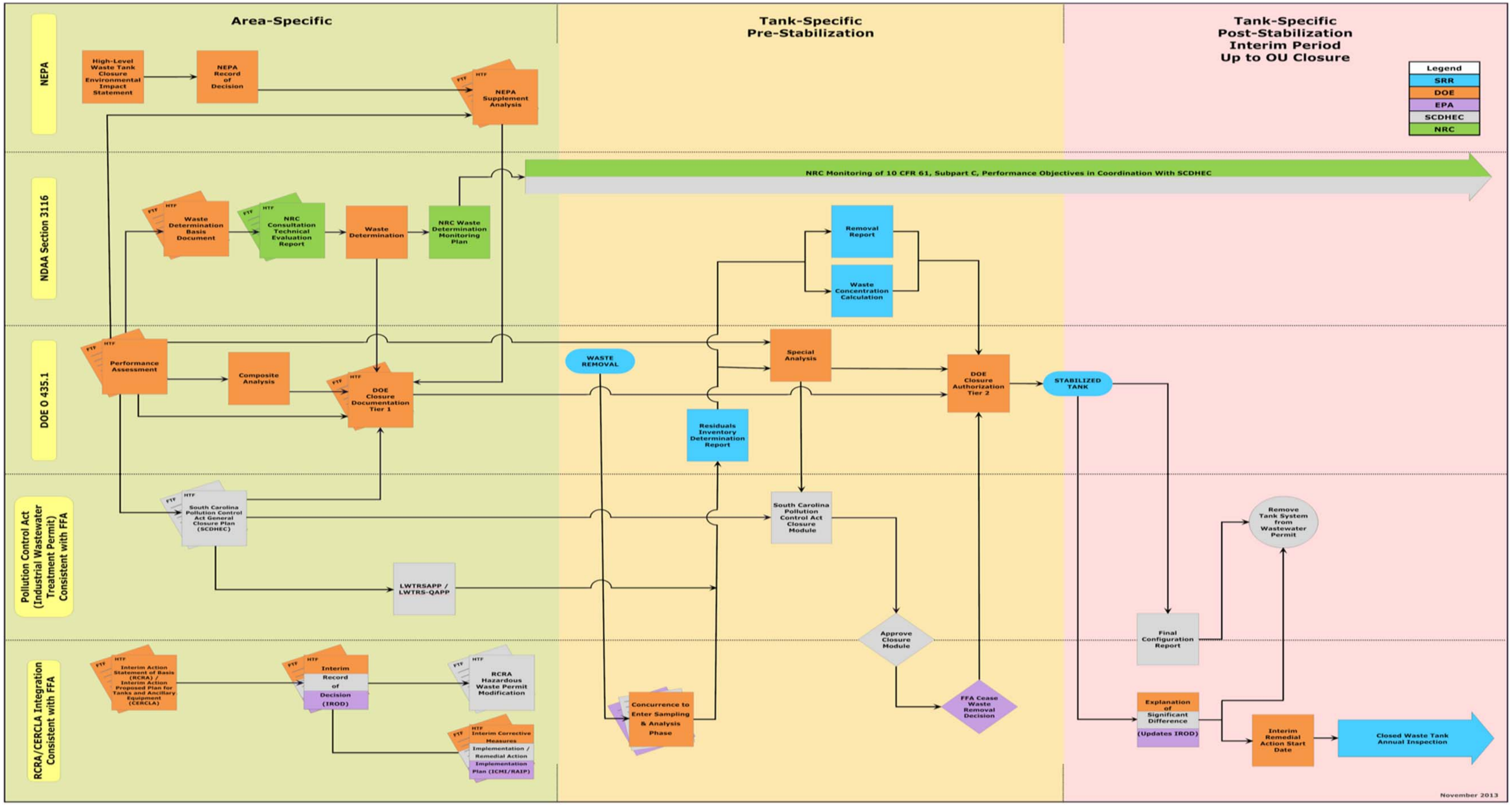

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Figure 2.4-1 is organized into "swim lanes" to help understand relationships between the various documents and how the requirements of the following five regulatory drivers associated with waste tank operational closures are satisfied:

- National Environmental Policy Act (NEPA)
- "*Ronald W. Reagan National Defense Authorization Act (NDAA) for Fiscal Year 2005,"* Section 3116 [NDAA Section 3116]
- *Radioactive Waste Management,* [DOE O 435.1, Chg. 1]
- South Carolina Pollution Control Act (Industrial Wastewater Treatment Permit) Consistent with FFA)
- Resource Conservation and Recovery Act (RCRA)/ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program pursuant to the 1993 *Federal Facility Agreement for the Savannah River Site* [WSRC-OS-94-42]

The three columns on the figure convey whether a document is applicable for a tank farm area (i.e., HTF or FTF) or for a specific waste tank (e.g., Tank 18) pre-stabilization or for a specific waste tank post-stabilization.

A more detailed discussion on these regulatory documents and associated requirements can be found in the *Tier 1 Closure Plan for the F-Area Waste Tank Systems at the Savannah River Site* (SRR-CWDA-2010-00147) and the *Tier 1 Closure Plan for the H-Area Waste Tank Systems at the Savannah River Site* (SRR-CWDA-2014-00040) currently under development.

2.5 Waste Removal Overview

Waste removal involves the removal of liquid, sludge solids and salt from the tank to a level that allows for entering final residual characterization. It includes both removing the bulk of the waste (primarily salt and sludge) and final heel removal (including both cooling coil flushing and annulus cleaning, as appropriate) activities.

Sludge waste is sent to a sludge batch preparation tank to prepare feed for the DWPF. Salt waste is dissolved, removed, and staged for feed to ARP/MCU or, in the future, the SWPF. Removing the bulk of the sludge or salt from a waste tank typically employs agitation/mixer pumps to suspend solids and potentially dissolve soluble material. After the bulk waste is removed, to include salt cake, sludge solids, and contaminated liquids, only a residual heel remains in the waste tank. At this point, bulk waste removal efforts (BWRE) may be declared complete. The definition of BWRE, as provided in an addendum to Appendix L of the Federal Facility Agreement (FFA) is as follows:

> *Completing efforts to remove the bulk of waste (waste includes salt cake, sludge solids, and contaminated liquids) from a tank leaving only a residual heel. Sufficient liquid may be added subsequent to this point to facilitate heel cleaning and removal. Any further addition of contaminated liquids may be reintroduced after completion of bulk waste removal efforts upon approval by SCDHEC and EPA.* [WSRC-OS-94-42]

The completion of BWRE from waste tanks is a milestone in the FFA and requires concurrence from SCDHEC and EPA. To date, BWRE has been declared on Tanks 4, 7 and 8 in FTF and

Tanks 11 and 12 in HTF. Post BWRE being declared, heel removal activities will be performed to removal additional material from the waste tank. The following sections provide some additional background information associated with sludge, salt and heel removal activities.

2.5.1 Sludge Removal

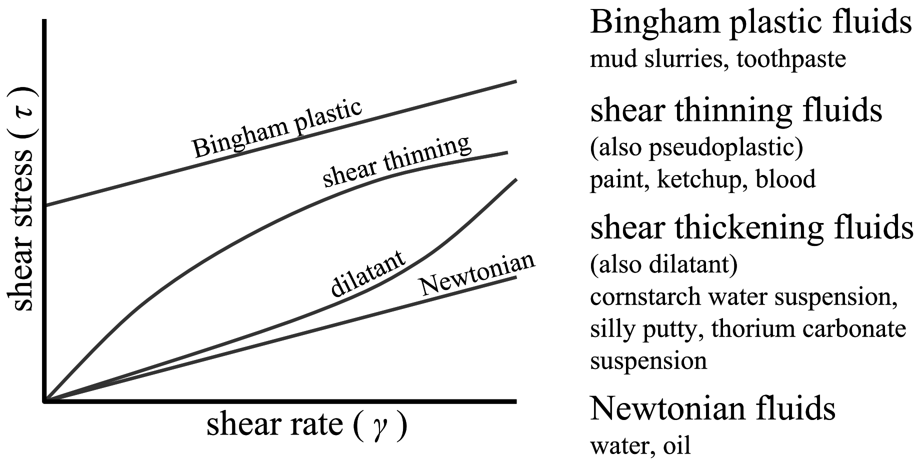
2.5.1.1 Separations Processes and the Effects on Sludge Properties

The types of nuclear reprocessing carried out at SRS included plutonium uranium extraction (PUREX), H-Modified (HM) PUREX, and thorium extraction (THOREX). The waste products from these processes differ in composition, but each is a result of a liquid-liquid organic extraction process with ion exchange. PUREX removes plutonium, uranium, and technetium isotopes from irradiated fuel rods (dissolved in concentrated nitric acid). Similar to PUREX, HM PUREX is modified to recover enriched uranium, and to process limited amounts of other isotopes such as neptunium and californium. Specialized campaigns to recover americium and curium were also performed. THOREX is a method to remove U-233 from thorium targets. Each process carried out in the SRS separations facilities or canyons, is acidic. Because the waste tanks are made of carbon steel, the waste stream is neutralized with sodium hydroxide and corrosion inhibited with sodium nitrite in the separation facilities before being sent to the tank farms. The neutralization reaction creates the salts and the solids precipitate when the solution cools.

For wastes originating from either F- or H-Canyons, the waste was designated in accordance with the generating stream. Waste from dissolving, head end, and first cycle product recovery, was designated as high activity (or “high heat”) waste, and contained the majority of fission product waste. Low activity (or “low heat”) waste was generated primarily from second recovery cycle, solvent recovery, and decontamination activities, and had a lower radioactivity level.

Insoluble solids are also sent to the waste tanks. The settled solids form sludge and follow a Bingham plastic rheology model; this sludge possesses a yield stress. In other words, a certain amount of force has to be applied before the fluid starts to move (like toothpaste in a tube, the sludge is difficult to pour). Figure 2.5-1 shows the differences between Bingham plastic behavior and other fluids.

Figure 2.5-1: Stress versus Rate Relationship for Various Fluids



The composition of the sludge solids depends primarily on the original separations process. For example, the solids that settle out from the waste generated from the PUREX process are predominately iron-based compounds with small amounts of depleted uranium and trace amounts of plutonium. The PUREX sludge is characteristically dark brown with quick-settling solid particles. The HM process produces less dense sludge that is aluminum-based, with a longer settling time. Settled HM sludge is difficult to re-suspend because of the cohesiveness of the small particles. Refer to Figure 2.5-2 for a photo of representative HM-Sludge.

Figure 2.5-2: Tank 11 (HM-Sludge) Sample Being Extracted from a Collection Vessel at the Savannah River National Laboratory (SRNL)

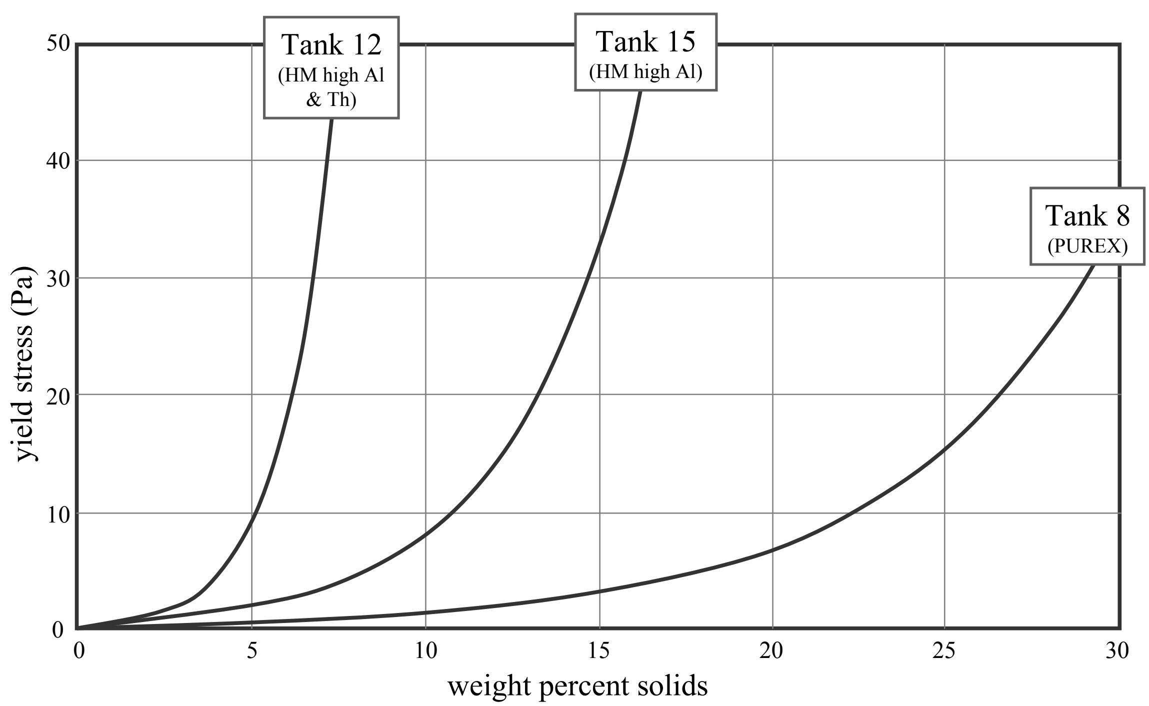
Waste solids from the THOREX process exhibit unusually high yield stresses at relatively low concentrations. At high concentrations, THOREX sludge behaves like a gel and must be diluted several fold, more than PUREX or HM sludge, to be pumpable. [DPST-64-238] HM sludge is located in HTF waste tanks. PUREX sludge is located in FTF waste tanks, and in a few old-style HTF waste tanks. THOREX sludge is present in several of the old-style HTF waste tanks. [LWO-LWE-2007-00250]

2.5.1.2 Sludge Behavior in Various Waste Tanks

As discussed in Section 2.5.1.1, SRS engaged in several radioactive separations processes, each producing waste streams with different physical properties. Therefore, the waste tanks contain wastes that have drastically different fluid behavior. Figure 2.5-3 illustrates how the yield stress can differ in solids concentration from one waste tank to another.

In addition to variation from one waste tank to another, individual waste tanks have received waste of varying composition over time, resulting in layers of sludge with varying rheological properties. The Waste Characterization System (WCS) is a database that has been used to capture the best available process knowledge about the composition of wastes in each waste tank.

Figure 2.5-3: Yield Stress (Power Input) Versus Solids Concentration for Various Waste Tanks



2.5.1.3 Sludge Removal Equipment/Techniques

If permanent infrastructure is available, sludge removal planning maximizes the use of this infrastructure to most effectively remove waste. This planning includes the use of structural steel, cable trays, existing slurry pumps, transfer pumps, and ventilation. If permanent infrastructure is not available, the waste on wheels (WOW) concept has been utilized on some waste tanks to perform BWRE. The WOW concept (Figures 2.5-4 and 2.5-5) relies upon portable and temporary equipment to meet tank infrastructure needs.

Figure 2.5-4: WOW Deployment for BWRE

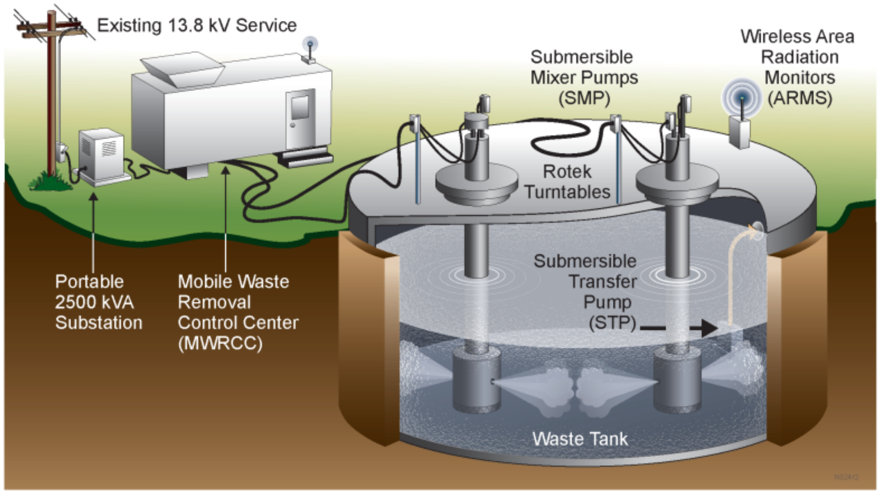


Figure 2.5-5: Relocation of WOW Mobile Control Room

The primary components of the WOW system are:

- longer-lasting submersible mixer pumps (SMPs)
- portable field operating station containing pump drives and controls
- portable substation to provide 480-, 240-, and 120-volt power to the WOW equipment
- disposable carbon steel transfer pumps.

WOW equipment is deployed at the tank as a field operating station, providing temporary power and control for BWRE equipment. When BWRE is completed on one tank, the WOW equipment is reconfigured to support waste removal on the next tank. Pumps are sized to fit through the nominal 23-inch diameter openings (risers) in old-style tanks. To the extent that risers are available, pumps are set in optimal configurations within the waste tanks. Product lubricated bearings and motor cooling eliminate the need for continuous bearing and seal water supply. These pumps can be decontaminated, reducing exposure to personnel during relocation to an adjacent tank. The waste is transferred to the receipt tank using existing underground transfer lines and diversion boxes. If the transfer system is degraded or non-existent, above-grade hose-in-hose technology may be deployed rather than investing in costly repairs. Temporary shielding is provided as necessary to reduce exposure to personnel.

Sludge removal operations have been conducted with two, three, or four SMPs. Sufficient liquid is added to the tank to suspend sludge solids, usually with existing supernate to minimize introduction of new liquids into the system. Operation of the SMPs suspends the solids, which are then transferred as a slurry from the tank. This operation is repeated, periodically lowering the SMPs, until the contents of the tank can no longer be effectively removed by this method.

Sludge batches were originally configured to remove sludge from old-style tanks. Bulk sludge has been successfully removed from all old-style tanks except for Tank 15. Currently, sludge batch configurations balance the sludge batch composition of PUREX and HM sludges to optimize sludge batch preparation and processing in DWPF.

2.5.2 Salt Removal

To date, removing salt waste from a waste tank has not posed as great a technological hurdle or difficulty compared to removing sludge. However, nuclear safety concerns (e.g., criticality and hydrogen generation) still have to be addressed, and salt tanks have not been operationally closed under the current Safety Basis. Typically, salt cake is removed by dissolving with fresh water and then transferring the solution to another waste tank for eventual inclusion in a salt batch, for eventual processing at ARP/MCU. When available, salt solution will be processed in SWPF. In some cases, agitating the waste tank with mixing pumps expedites the dissolution process. Salt dissolution leaves insoluble solids and sludge in the waste tank, which is then managed as a sludge heel removal process.

Currently, salt waste removal is being accomplished using either a modified density gradient process (Figure 2.5-6) followed by mechanical agitation or by semi-continuous dissolution (SCD) (Figure 2.5-7).

Figure 2.5-6: Modified Density Gradient Salt Removal

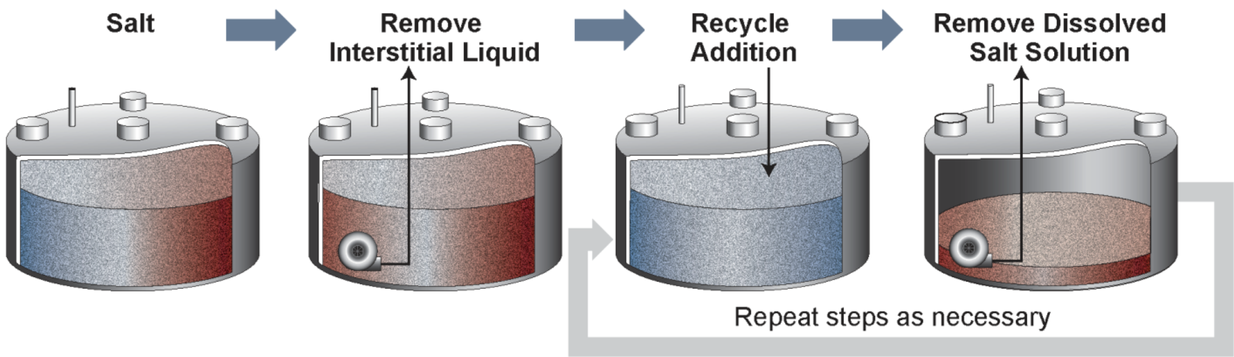
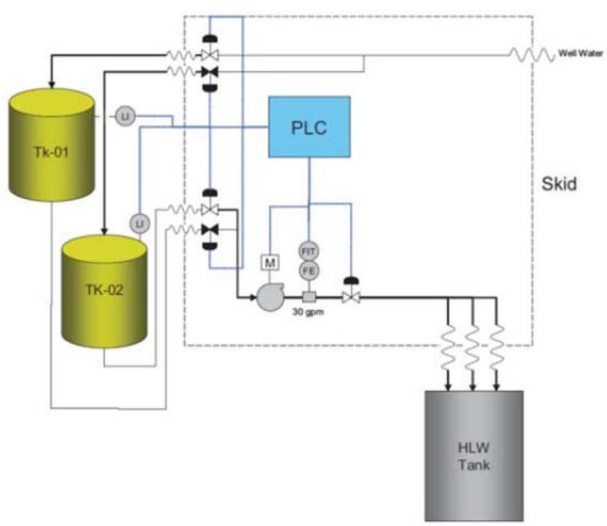


Figure 2.5-7: Dissolution Water Skid (DWS) Diagram



During modified density gradient salt dissolution, a well may be mined through the saltcake down to the tank bottom. A transfer pump is installed at the bottom of the well, along with instruments to monitor waste density, to pump the interstitial liquid out of the tank until the well is dry. Water is added to dissolve the salt and, as the density increases, the saturated solution migrates to the bottom of the well to be pumped out. The initial process involves no moving parts in the tank except the transfer pump. DWPF recycle may be used where possible to dissolve salt in order to conserve tank space. The dissolved salt solution is prepared as close to saturation as possible prior to pumping out the tank. As salt dissolution progresses and the soluble fraction is pumped from the tank, the insoluble materials dispersed throughout the salt matrix may blanket the underlying salt and the dissolution rate can decrease significantly. Removal of salt and insoluble solids from the bottom of the tank may require installation of mixing pumps to complete waste removal. Mixer pumps suspend and remove insoluble solids at the end of the dissolution step, similar to sludge removal.

An alternative to the modified density gradient salt removal process is SCD utilizing a Dissolution Water Skid (DWS) (Figure 2.5-7). This process adds well water to the tank via the DWS, and transfers dissolved salt solution from the tank at approximately the same rate. The well water is distributed evenly to several risers (nominally three) in the tank. Each of the risers is equipped with a low volume distribution eductor installed above the salt cake, but below the supernate level. During dissolution, the saltcake level is periodically checked, and the eductors and transfer pump are gradually lowered as the saltcake level decreases.

2.5.3 Heel Removal

Heel removal will be performed after completion of BWRE. Heel removal consists of mechanical and/or chemical cleaning. In general, mechanical removal is done prior to chemical cleaning. However, the actual process utilized for heel removal can vary depending on past service history of the waste tank, the physical characteristics of the waste remaining, the physical configuration of the waste tank and the timing of the heel removal actions.

2.5.3.1 Mechanical Heel Removal

For mechanical heel removal, vigorous mixing and transfer continues, using either existing or new mixing pumps, to remove waste to the maximum extent practical. More aggressive methods, such as pump indexing campaigns, targeted lancing of sludge mounds, remotely operated robotic crawlers, etc., may be employed for difficult heels.

2.5.3.2 Chemical Heel Removal

Chemical heel removal may also be performed when necessary to remove additional waste tank heel residuals. Two chemical cleaning methods, low temperature aluminum dissolution (LTAD) and bulk oxalic acid cleaning (BOAC) have been deployed to remove residual heels.

LTAD is a chemical cleaning technique applicable to waste tanks containing sludge with high aluminum content. In LTAD, concentrated supernate high in hydroxide content (and low in dissolved aluminum), or concentrated sodium hydroxide are introduced to the remaining solids in the tank to the minimum liquid level required to enable mixer pump operation. The contents of the tank are agitated until the tank achieves a sufficiently high temperature for the aluminum dissolution reaction to occur. The contents are then transferred to a receipt tank. LTAD has been successfully used in modifying the waste rheology to allow more effective residuals suspension and mixing, once aluminum compounds are dissolved and removed.

In BOAC, oxalic acid (OA) is added to the remaining solids in the tank to a liquid level that allows mixer pump operation. The contents of the tank are agitated and then the dissolved and slurried sludge is transferred to a receipt tank for neutralization. OA may also favorably change the sludge rheology improving the removal of insoluble solids from the tank.

2.5.4 Cooling Coil Flushing

For waste tanks with cooling coils, the inner surface of the cooling coils may be flushed with water to remove the remaining chromated cooling water, residual waste, and other contaminants that have migrated into the coils, to the degree necessary to reduce environmental risks. This flush also reduces the sodium chromate (corrosion inhibitor) coating on the interior of the coils. The cooling coil flushing step would normally be performed sometime during heel removal.

2.5.5 Annulus Cleaning

Some tanks have waste in the annulus space. The waste is typically a soluble form of salt appearing as dried nodules on tank walls at leak sites and on the bottom of the annulus pan. If necessary, this waste can be removed from the annulus by dissolving the salt deposits with water and transferring the solution out of the annulus. Spray wands or crawlers may be used to rinse salt nodules from the tank walls to the floor where the solution can be collected and transferred to the tank primary or to another tank. The annulus cleaning step would normally be performed sometime during heel removal.

2.6 Sampling and Characterization

The next to last step in the operational closure sequence is inspection and sampling of the residual material after waste removal is complete. SRR seeks concurrence from DOE, South Carolina Department of Health and Environmental Control (SCDHEC), and EPA prior to entering the sampling and analysis phase.

This residuals characterization step is performed in accordance with the Liquid Waste Tank Residuals Sampling and Analysis Program Process, as documented in the *Liquid Waste Tank Sampling and Analysis Program Plan (LWTRSAPP)*, SRR-CWDA-2011-00050, and the *Liquid Waste Tank Residuals Sampling–Quality Assurance Program Plan (LWTRS-QAPP)*, SRR-CWDA-2011-00117.

The residual material that remains in the waste tanks after BWRE, heel removal, and cleaning will be representatively sampled and characterized to evaluate the long-term hazards of operational closure and to verify that the assessment of performance remains valid.

2.7 Isolation and Stabilization

Isolation and stabilization consists of the following activities:

- Isolating the tank from all operating systems in the surrounding tank farm (e.g., electrical, instruments, steam, air, water, waste transfer lines, and tank ventilation systems),
- Grouting of the tank primary, annulus, and cooling coils, as applicable, and
- Capping tank risers, as necessary.

2.7.1 Tank Isolation

Isolation is the physical process of disconnecting transfer lines and services from the tank. The process begins by preparing the ancillary equipment in advance of waste removal and incorporating tank isolation requirements. Tank isolation includes cutting and capping or blanking mechanical system components (transfer lines, water piping, air piping/tubing, steam piping, etc.) and disconnecting electrical power to all components on the tank.

2.7.2 Grout Selection and Manufacture

A reducing grout provides long-term chemical durability and minimizes leaching of residual waste over time. The reducing grout selected is self-leveling, and encapsulates the equipment remaining inside the tank and annulus. The grout also provides for intruder prevention in tanks that do not have a thick concrete roof. Grouting activities include applicable field modifications, temporary ventilation, grout plant mobilization, and grout installation.

Liquid waste tanks undergoing closure are required to be filled with grout for the purpose of chemically stabilizing residual material, filling the tank void space, and discouraging future intrusion. A formulation that was used as the bulk fill grout in Tanks 18 and 19 and reflected in *Furnishing and Delivery of Tank Closure Grout*, C-SPP-F-00055, was evaluated in 2011 in *Tanks 18 and 19-F Structural Flowable Grout Fill Material Evaluation and Recommendations*, SRNL-STI-2011-00551, and has been chosen as the grout mix to be used in future tank closure. [SRNL-STI-2011-00551]

Experience with grouting Tanks 18/19 and then with Tanks 5/6 showed that high slump flow values were advantageous in minimizing mounding of the grout under the pour point, therefore, the grout formula was adjusted to enhance flow in future waste tanks. The supplier selected to provide grout will be required to demonstrate the ability to batch and deliver the flowable, structural fill grout. Samples of material batched at full-scale will be tested to qualify the ability of the grout subcontractor to produce and deliver the mix.

2.7.3 Tank Stabilization

Grout fill operations, including site preparation, grout procurement, pumper truck placement, grout plant set up (if required), grout delivery lines, and grout equipment placement are established around the tank. A sequence for filling waste tanks with an annulus is established to fill voids and to protect the structural integrity of the tank.

2.7.4 Equipment Stabilization

For waste tanks with installed equipment or cooling coils, internal voids are filled with a flowable grout mixture.

Various types of equipment from previous operations may remain in the waste tanks. The goal of equipment grouting is to eliminate vertical fast flow paths down through the grout to the residual material on the tank floor. Vertical fast flow paths may reduce the effectiveness of two of the primary purposes of the entire grouted tank:

1. Slow water infiltration and
2. Chemically treat the infiltrating water to retard contaminant migration.

Open vertical pathways (pump discharge lines, thermowells, etc.) in the tank are filled with grout to the extent practical. Remaining equipment at the start of grouting is documented in a tank specific grouting strategy. To ensure the grouting is in alignment with the PA assumptions, sequencing of the grouting activities are required to accomplish grouting of the internals of opened ended equipment. Vertical pipes closed at the bottom, such as thermowells, may be grouted at any time. Vertical pipes open at the bottom, such as dip tubes, must have the bottom open end of the pipe covered by bulk fill grout before they are grouted.

A minimum level of grout (as determined by engineering) is placed into the tank prior to the grouting of any cooling coils in order to provide structural support for coil attachments to the tank top. Engineering judgment is used in determining when the minimum grout depth has been reached. Limiting the grout level allows the greatest opportunity for guillotined (i.e., coils that are broken) cooling coils to vent during grouting, and provide adequate structural support. Coils having a guillotine failure are grouted from each end until indicated to be full. Sections of coils with guillotined breaks not connected to the coil inlets and/or outlets may exist. These intermediate sections of coils with guillotined breaks may not be fully filled with grout internally due to their configuration. Portions of guillotined coils connected to the coil inlet or outlet may not be completely filled with grout due to their configuration.

Grouting of the intact cooling coils is completed by adding grout through the inlet side of the coil until grout is visually detected at the cooling coil outlet. Additional grout is introduced into the cooling coils in order to ensure uniform filling of the coil.

The cooling coil grouting methodology described above grouts cooling coils to the extent practical.

2.7.5 Riser Closure and Capping

The final step in grouting of a tank is the riser filling. Type I tanks have nine primary and four annulus risers. Type II tanks have twelve primary and four main annulus risers (with several small inspection ports). Type IV tanks have seven primary risers. Each riser is stepped to provide radiation shielding, with a larger upper portion. The riser is filled with grout from the tank top to grade, and is capped by a riser cover plate or poured concrete plug. Risers (or other tank penetrations extending to above the grade level) will not require capping, if the grout level in the riser or penetration also extends above the grade level. The grout level in these risers or penetrations is brought to the level of the riser opening. This level of grout combined with the riser cover will minimize potential water intrusion. In those risers or tank penetrations where bringing the grout level to above the grade level is not achievable, a grout cap may be placed surrounding the riser or penetration at the grade level.

3.0 TECHNOLOGY SELECTION PROCESS

Technology selection is performed in a structured approach to identify and compare viable alternatives to meet the defined functions and requirements for waste removal and closure.

Removal of highly radioactive radionuclides (HRRs) to the maximum extent practical (MEP) is a key criterion for both NDAA 3116 compliance and SCDHEC requirements. The HRRs for each tank farm were determined as part of the NDAA 3116 Waste Determination (WD) Basis Document for the respective tank farm. Based on lessons learned from the FTF WD, and the *Basis for Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, DOE-WD-2005-001, performance objectives, the Idaho National Engineering and Environmental Laboratory (INEEL) WD process, as well as the draft *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations, Draft Final Report for Interim Use*, NUREG-1854, key points in successful removal of radionuclides to the MEP are:

- a rigorous decision-making process for technology selection that includes
  - an evaluation of the tank being operationally closed,
  - characterization of residuals remaining in the tank, a system impacts evaluation,
  - a systematic evaluation of an appropriate range of technologies,
  - a comparison of the characteristics of the techniques considered, and
  - a technical basis for the waste removal goal
- demonstration of effective operation of the selected technology that includes an evaluation of the removal achieved
- a sound technical basis for ceasing waste removal activities such as the demonstration that the point of diminishing returns has clearly been reached
- an analysis of the risks and benefits of additional radionuclide removal that clearly demonstrates that implementation of additional waste removal technologies is not practical.

Procedure S4 ADM.53 MEP Documentation Process was developed to provide the implementing approach used to document, during the waste removal and operational closure process, the decision process for technology selection to remove waste to the MEP in accordance with NDAA 3116.

This section describes how a technology is evaluated, introduced, and used for waste removal. The selection includes establishing a set of physical and operational constraints, deciding on selection criteria based on those constraints and performance goals, identifying new technologies from a number of sources and evaluating those technologies against the criteria using proven decision-making methods. Once completed the results may be used for one or more waste tanks.

3.1 Program Requirements

The technology selection process must consider program requirements, to include regulatory, facility, and fiscal parameters.

3.1.1 Regulatory Requirements

Section 2.4 summarizes the tank operational closure regulatory process and some of the key requirements that must be met. For example and as discussed in Section 3.0, technology selection must consider the ability of a chosen technology to satisfy MEP requirements.

3.1.2 Fiscal and Schedule Considerations

Funding for waste removal activities is contingent on the federal budget with the priority ranked among other DOE environmental and defense programs. Therefore, technology selection may include a cost benefits analysis. In addition, the schedule for deploying a technology must be compared to waste processing needs and regulatory commitment dates. The LW System Plan, which uses the latest budget projections as inputs to its development, provides the SRS tank closure sequence. [SRR-LWP-2009-00001]

3.1.3 Downstream Effects

The process streams resulting from waste removal operations must be compatible with the existing facility, and congruent with the feed streams of DWPF, SWPF, and the SDF. In other words, the streams must have a viable disposal path.

3.1.4 Job Waste Disposal

Similar to downstream effects, the equipment used for waste removal must also have a disposal path. The equipment is often large due to the size of the waste tanks (e.g., the mixer pumps are 45 feet long), challenging packaging and disposal. Accordingly, waste removal technologies must consider long-term equipment disposition in the design.

3.1.5 Waste Tank Integrity

The earliest waste tanks are approximately 60 years old. The age of the waste tank requires consideration as removal methods are selected. Since the waste tanks are constructed of carbon steel, the use of strong acids or oxidizers to dissolve waste residue is precluded. Many of the old-style waste tanks (Type I and II tanks) have leaked from the primary vessel into the secondary pan through cracks caused by stress corrosion cracking. Although the conditions that caused the cracks have been abated, the cracks in these waste tanks are still present. Waste removal efforts often involve disturbing former leaks sites and may reveal leak sites not previously identified; therefore, compensatory actions are put in place during waste removal activities, ensuring waste is contained and to avoid the spread of contamination. The new-style waste tanks (Type III/IIIA tanks) have no known leaks.

The FFA Section IX provides requirements for assessing and demonstrating that high-level waste tanks have sufficient structural integrity for storage and treatment of hazardous and/or radioactive waste and prevention of release of waste to the environment. The FFA also includes requirements for the containment and detection of releases, the disposition of leaking waste tanks, and DOE plans and schedules for waste removal to support removal of waste tanks from service. [WSRC-OS-94-42]

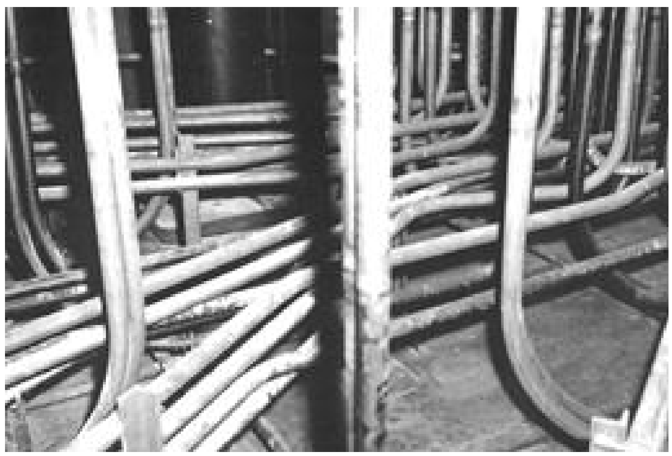
3.2 Physical Constraints

This section describes some physical constraints to which the waste removal and tank closure program must adhere.

3.2.1 Waste Tank Interior Inferences

Waste removal methods must be able to work around (or with) interferences, such as interior support columns, horizontal and vertical runs of cooling coils, discarded equipment and installed waste tank monitoring equipment. Refer to Figure 3.2-1 for a depiction of congestion formed by the array of cooling coils in a typical Type I tank.

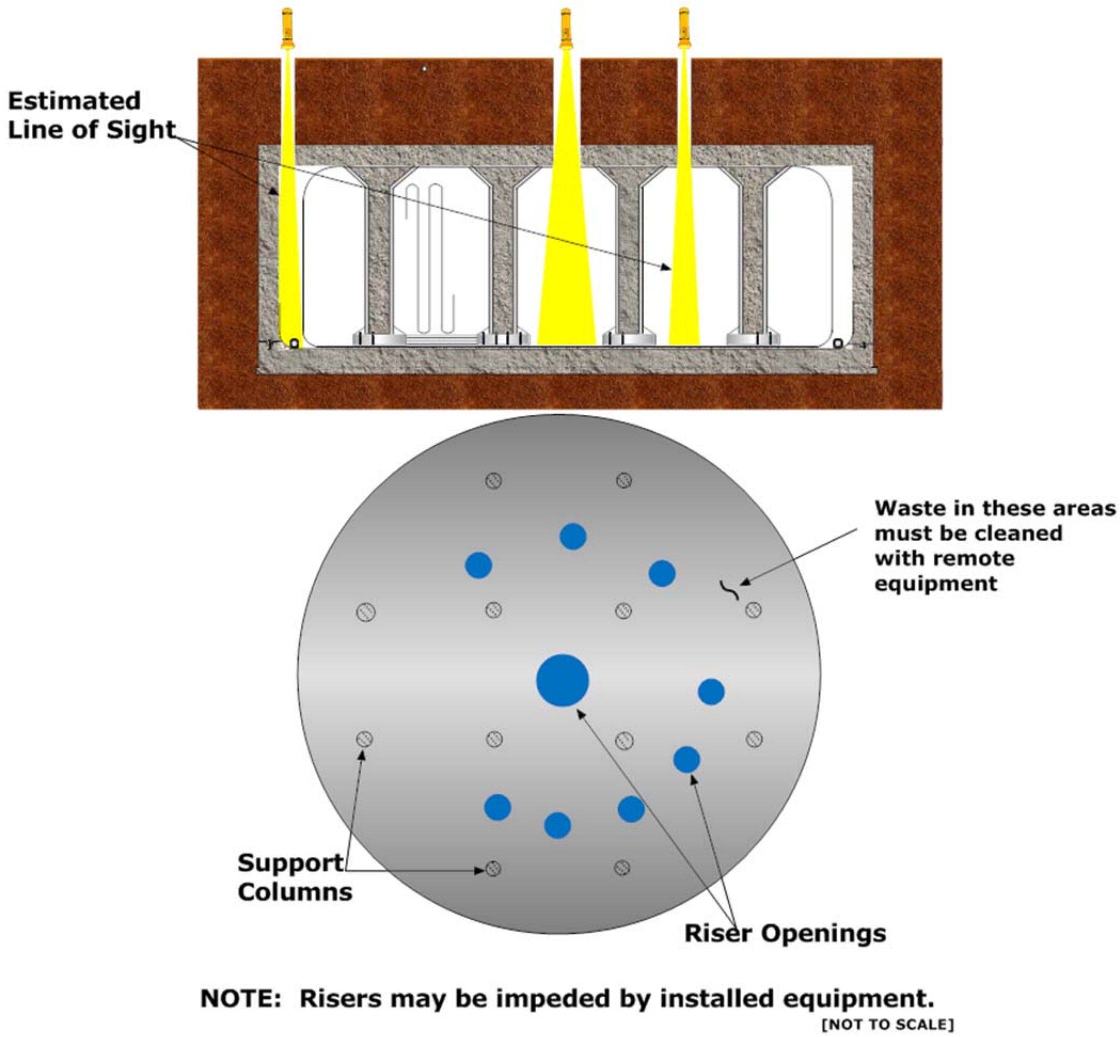
Figure 3.2-1: Tank 4 Cooling Coils (1953 Pre-Operation)



3.2.2 Remote and Limited Tank Interior Access

The waste tank bottom is 45 to 50 feet below ground level. There is limited access to the tank interior as illustrated in Figure 3.2-2. The majority of the risers are less than 2 feet in diameter. For the Type I tanks, the risers can be as long as 10 feet. Construction tolerances resulted in waste tank risers not being uniform in diameter (eccentric). Waste removal methods must be sufficiently tolerant to address limited waste tank accessibility and to account for field discrepancies in waste tank dimensions. Furthermore, installing additional risers, although feasible, is a difficult endeavor because of the high radiation fields and remote access to the tank tops.

Figure 3.2-2: Typical Type I Waste Tank Access Area



For Type IV Tanks 18 and 19, some additional risers were installed to support waste removal activities. [SRR-CWDA-2011-00091] The Type IV tanks, compared to Type I and II tanks, have easier access to the tank top and a reduced roof thickness.

3.2.3 Limited Tank Storage Space

The tank farms have a limited amount of storage space. Executing the waste removal program requires more available tank space than simply accommodating the waste being removed. Additional dilution and mixing liquid is used to render the waste pumpable, and to aid in the mixing evolutions. Detailed system integration planning is completed to coordinate the use of waste tank space meeting processing and regulatory commitments. The use of excessive volumes of liquid should be limited. Many industrial tank-cleaning processes use large volumes of liquid or solvents. Space limitations reduce the possibility of adapting commercial tank cleaning methods. The majority of SRS new-style waste tanks are at or near full capacity, and have little remaining working space, beyond required emergency contingency space management.

The SRS FFA establishes that, among other things, the SRS waste tanks that do not meet secondary containment standards (i.e., Type I, II, and IV tanks) must be removed from service according to the FFA schedule. Without SCDHEC approval, the FFA does not permit reuse of waste tanks that have completed BWRE unless it is for purposes to support waste removal from another tank.

3.2.4 Transfer System Integrity

The transfer lines and valve boxes connecting the waste tanks have aged and in some cases are not useable. Most of the pipes were designed and constructed without consideration for the high pressures that are possible when transporting high yield stress slurries. As a result, viable waste removal technologies and processes must consider the limitations of the piping used for transporting the waste.

3.2.5 Operational Conflicts

Waste tanks that are targeted for waste removal and closure reside in an operational facility. Other tanks in the tank farms are safely storing waste or are being used to prepare and feed waste to downstream facilities. Equipment (e.g., cranes), facilities (e.g., evaporation systems), and resources (e.g., radiation technicians) are often shared. Consequently, waste removal technologies must consider the impacts to other ongoing operations.

3.3 Hazards

This section describes some unique hazards associated with waste removal and tank closure operations. These are hazards that must be considered in addition to the nuclear safety hazards described in the Documented Safety Analysis (DSA), and associated controls, to include criticality prevention, flammability management, waste aerosolization prevention, transfer controls, and structural integrity.

3.3.1 Radiological Contamination

Radiation contamination potential requires strict radiological control protocols surrounding work areas in close proximity to any waste tank opening. Engineering controls, such as ventilation or containment, are utilized to prevent spread of contamination. Workers also use personal protective equipment (PPE), and have active monitoring for contamination at the job site. Technology selected for waste removal must consider risks of contamination control during technology deployment, use, and during removal of equipment from the tank.

3.3.2 Radiation

Waste tank risers must be opened for equipment installation. The radiation fields near an open riser are hazardous. Personnel must be protected using "as low as reasonably achievable" exposure principles. In addition, the ionizing radiation fields inside a waste tank are strong enough to damage certain types of equipment. Some commercial-grade elastomers and most electronic equipment have limited operating life when used inside a waste tank. Electrical motors, gaskets, seals, hoses, and electronics must be specially designed to be radiation hardened (i.e., resilient in high radiation fields).

3.3.3 Chemical Exposure

During waste removal, worker chemical exposure potential exists from waste tank off-gas, particularly from organic mercury compounds and nitrogen oxides.

The waste form is strongly caustic, and naturally reacts with some structural materials (such as aluminum). During OA cleaning, if necessary, the tank is made acidic to dissolve sludge. Technology selection must ensure materials of construction are chemically compatible with the intended use.

3.3.4 Natural Phenomena

The tank farms are located outside without the protection of a containment structure. Equipment must be able to withstand high summer temperatures prevalent in the southern United States as well as subfreezing conditions and hurricane force winds and rain. Containment structures in the tank farm must be designed to withstand all types of natural phenomena hazards.

3.4 Systems Engineering Evaluations for Technology Selection

Technology selection efforts through the years have employed different techniques and methods. The most commonly used are systems engineering tools. Option selection is one of the methods used in the systems engineering discipline. A tool used extensively for option selection is the analytical hierarchy process (AHP), which is described below in greater detail.

When a clear alternative is not available or when several alternatives must be considered, a more complex method of selection is required. Since 1998, SRS teams have been following the guidelines outlined in the *Systems Engineering Methodology Guidance Manual*, WSRC-IM-98-00033, for managing complex engineering decisions. Appendix A of the manual provides guidance for alternative studies, often referred to as a Systems Engineering Evaluation (SEE). A SEE selects an alternative from two or more options constrained by specific functions, selection criteria, and requirements. After identifying the functions, requirements, and selection criteria, options are screened and then evaluated. One method of evaluation is the structured method of handling complex decisions called AHP. The AHP helps decision makers find the option that best suits the needs and understanding of the problem. The team first decomposes the problem into a hierarchy of attributes, each analyzed independently. The hierarchy elements can relate to any problem attribute that applies to the decision at hand. For waste removal, the team may select the attributes of safety, development schedule, deployment/operations schedule, development cost, technical/operational effectiveness, and technical/operational complexity.

With the hierarchy of attributes identified, the team systematically evaluates the options by comparing one to another, two at a time (called a pair wise comparison). The team uses concrete data, experience, and judgment to make the comparisons. During the comparisons, the preference of each option is compared to each of the other options for the selected evaluation criteria using values of importance on a scale from 1 to 10, with 10 having the highest importance.

In the final step of the process, the options numerical scores are calculated by considering each attribute's weight of importance. The score represents the option’s relative ability to achieve the decision goal, and allows a straightforward and documented decision over the various available courses of action.

Generally, the preferred option is clear if that option's score exceeds the others by 10% or greater. If not, then a sensitivity analysis is performed. The purpose of a sensitivity analysis is to validate the option evaluation and ranking of options that result from the decision process by demonstrating that small changes do not change the ranking. These small changes could occur for the option scores against the criterion weights. The sensitivity analysis evaluates the impacts of adjusting criterion weights up and down by approximately 10%. If these small changes do not affect the overall results, then the analysis is insensitive to the alternative scores.

The examples below used the AHP for evaluating technologies to perform waste removal:

- Tank 19 Waste Removal (1998) [PIT-MISC-0040]
- Tank 18 Waste Removal (2001) [WSRC-RP-2001-00024]
- Waste Removal Balance of Program (2003) [G-ESR-G-00051]
- FTF Chromate Cooling Water Supply (2006) [G-ADS-F-00014]
- Tanks 5 and 6 Heel Removal (2009) [SRR-CES-2009-00022]
- Inhibited Water (IW) Supply for Tank 13 to 15 Closure (2010) [SRR-LWE-2010-00173]
- Tank 15 Transfer System Restoration (2013) [G-AES-H-00003]

SRR continues to evaluate new technologies for potential use in waste removal applications. In addition, SRR evaluates, case-by-case, any special conditions that occur during waste removal activities that may require application of additional or alternative technologies.

3.5 New Technology Identification

The source for new technologies is many-fold. SRR and assisting research staff have several information avenues at their disposal. Conferences, technical exchanges, and corporate sharing are ways to gather and share information.

When a new method or approach is discovered, subject matter experts are assembled to review the new technology. During this evaluation, a preliminary recommendation for a path forward may be made. The path forward may be one of the following recommendations:

- Do not pursue because of non-applicability or poor technical fit with the tank farm system.
- Pursue for further development and maturation. This indicates the new technology has promise for improving the HRR removal performance of the baseline methods, but requires further study and refinement before being considered an option as part of the selection process.
- Adapt immediately into the program without significant maturation. This decision implies the technology is mature enough to integrate into the baseline without significant programmatic risk.

The decision to change a planned technology for a waste removal process step (e.g., BWRE, heel removal, etc.) is documented (typically in the Operating Plan or Technical Requirements and Criteria documents). The documentation typically assesses, at a minimum, the technologies' expected HRR removal capability, likelihood to meet the desired results effectively, costs, technical maturity, technical complexity, and reusability. Furthermore, costs considered may include dose to workers, dose to the public, financial, system-wide impacts (e.g., effects on downstream systems, generation of secondary waste streams), impacts to DOE's mission and schedule, transportation risks, and radiological control requirements.

4.0 WASTE REMOVAL LESSONS LEARNED

This section provides a summary description of the equipment used, methods, lessons learned, and expected performance for the waste removal phases. Also included, is a discussion on the historical progression of technologies. Today's technologies are the product of decades of research and operational experience.

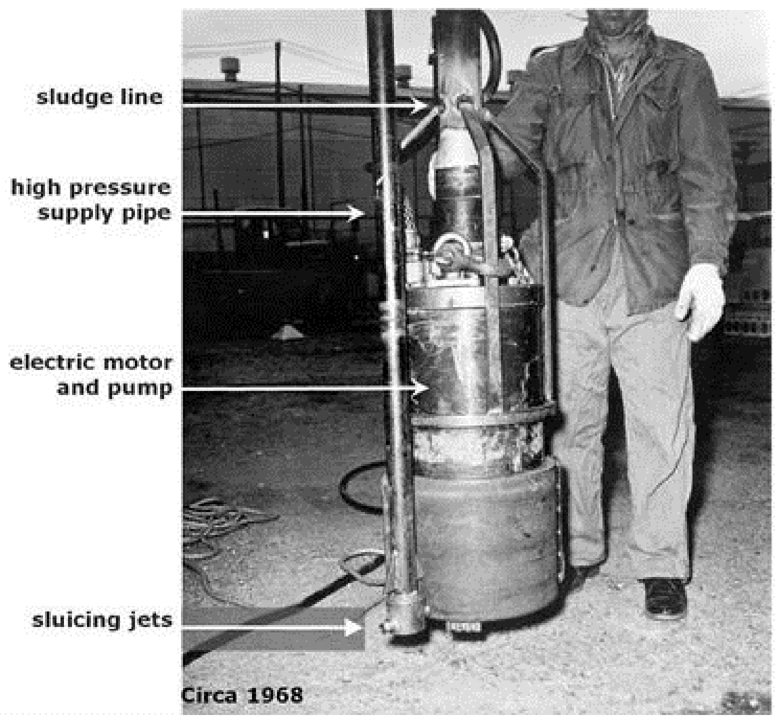
4.1 Bulk Waste Removal Lessons Learned

4.1.1 Cleaning Type I and Type II Tanks with High-Pressure Jets

Between 1967 and 1969 SRS removed the sludge from several Type I tanks using high-pressure water jets (3,000 psig) as seen in Figure 4.1-1. In the early 1970s, SRS began investigating the use of slurry pumps:

> *The removal of sludge is made difficult by a network of horizontal cooling coils located close to the bottom of the tanks… One promising method…is the use of high velocity jets of water to suspend the sludge for a sufficient time to allow the slurry to be pumped from the tank.* [DP-1093]

Figure 4.1-1: Type I Tank Sludge Removal Rig before Being Installed in the Waste Tank



The high velocity water jets dispersed the sludge into slurry that was removed using centrifugal transfer pumps. The opposing sluicing jets, mounted on a pipe mast, were rotated allowing the high velocity nozzles to sweep horizontally across the waste tank bottom. The transfer pumps, located next to the nozzle set, pumped out the slurry.

Rotation was provided by a rudimentary slewing gear that was located topside and driven by an electric motor connected with a drive chain. Each waste tank used up to six nozzle-pump assemblies. This early effort served as a basis for future BWRE.

Although effective, the method required large volumes of fresh water (approximately 5 gallons of water for every gallon of sludge removed). The first sludge removal program conducted over a 2.5-year period filled the tank farms to capacity with jet water and took years for the extra volume to be reduced through evaporation. Figure 4.1-2 shows the high pressure supply line rotated and driven by an electric-driven chain with the safety guard removed for the photograph.

Figure 4.1-2: High-Pressure Line Rotated with Chain Drive (Circa 1968)

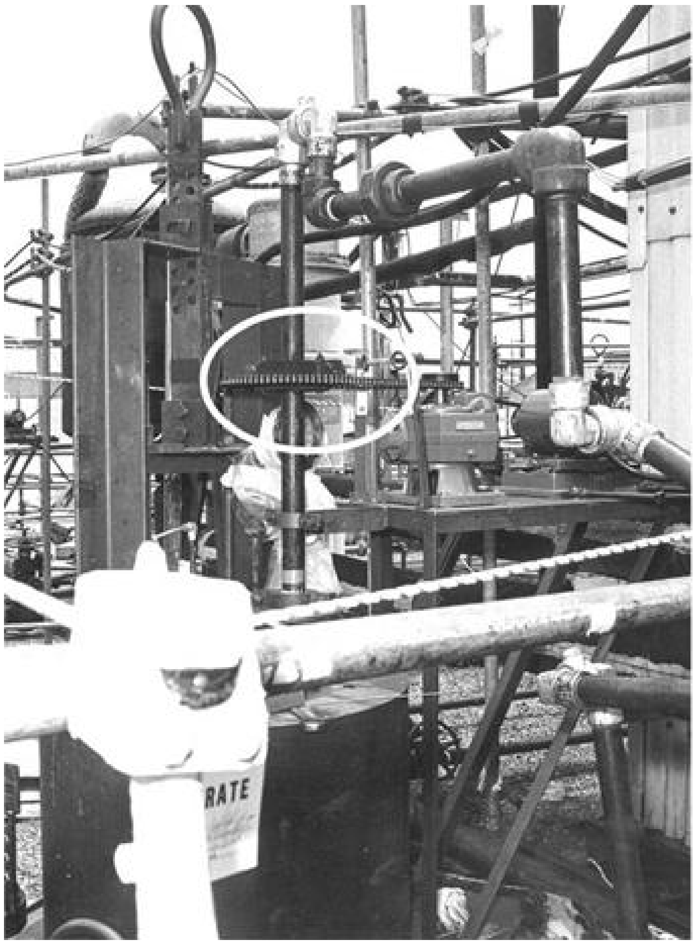


Table 4.1-1, below, summarizes the results of waste removal using high-pressure jets.

Table 4.1-1: High Pressure Jet Sludge Removal Summary

Tank Number	2F	9H	10H	3F	14H	1F	11H
Sludge Removal Date	2/66	7/66	2/67	6/68	12/68	5/69-8/69	10/69
Initial Sludge Level, Inches	18	15.5	32	26	28	15 – 8	83
Type of Sludge	PUREX High Level	PUREX High Level	PUREX High Level	PUREX High Level	PUREX-High Level HM-Low Level	PUREX-High Level	PUREX-Low Level HM-High Level
Residual Sludge Level, inches	1-2	1-2	1-2	1-2	5	8-2.5	18
Sludge Removed, %	90-95	90-95	90	90-95	82	83	79
Sludge removed, kgal	44	38	58	67	80	34	176
Ratio of water addition to sludge removed	5.4	6.3	4.0	4.8	4.7	15	4.9
Appearance of residual sludge	Slumped ooze	Slumped ooze	Slumped ooze	Slumped ooze	Slumped ooze	Broken chunks	Broken chunks
Number of sluicers	4	5	5	5	4	5 - 6	5
Max. Water pressure, psig	3000	3500	3500	3500	3500	3000	3500
Transfer pumps operating	4	4	3	3	2	4	4
Transfer pumps failed	0	0	1	1	2	0	4
Max. sludge temp., ℃	110	67	125	115	115	344	128

[DPST-70-512]

Waste removal from Tank 14 was less effective due to two transfer pumps failing during use. Five sluicing jets were recommended rather than four for a Type II tank, due to the large center column. Waste removal from Tank 1F and 11H was considered to be less effective because these tanks had been filled multiple times, and had been subjected to higher temperatures for a longer portion of their operating history.

The primary lessons learned documented from the early sluicing campaigns was that an average of 5 gallons of fresh water was added to the system for every gallon of sludge removed. This level of liquid addition was considered to be too great an impact to tank space management. This sluicing method employed multiple unshielded above grade transfer lines, with no secondary containment for lines, fittings, or valves. This method was disruptive to tank farm operations (and would not be permitted under current Nuclear Safety constraints). One significant release occurred during sluicing (during Tank 10 sludge removal) resulting in 40-50 gallons of slurry (estimated at 250 Curies) released to grade. [DPSPU 78-11-11]

4.1.2 Standard Slurry Pump Development and Tank 16 Cleaning

SRS began investigating ways to remove sludge with less water addition. In 1977, SRNL completed development of a technique using recirculation of supernatant liquid. The liquid re-suspended and mixed the sludge eliminating the need to accommodate the extra volume. This method consisted of a single-stage centrifugal pump (called a slurry pump) operating in the sludge with an operating pressure of approximately 100 psig. Recirculation liquid is drawn into the bottom of the pump and forced out through two oppositely directed nozzles. The resultant jetting action produced a sludge-slurry capability similar to that obtained with the high-pressure system. In addition to eliminating the large quantities of water, the low-pressure liquid recirculation technique required less than 1/5th the power needed by the high-pressure system. [DP-1468]

The first successful test runs of a slurry pump were conducted in December 1978 and January 1979 in Tank 16. The test involved running a single Bingham-Willamette pump (now Sulzer Pumps) installed in Riser 2 for a total of 294 hours of mixing. Over 19,000 gallons of the original 77,000 gallons of settled sludge was mobilized and transferred. Almost 22,000 gallons of seal water (approximately 1 gpm) and 29,500 gallons of supernatant liquid (from Tank 23) were added to the waste tank. The pumps obtained a 30-foot effective cleaning radius (ECR). [DPSP 79-17-12]

In January 1979 and February 1979, two more slurry pumps were started totaling three pumps in Tank 16. The purpose of the multi-pump test was to extrapolate the number of pumps required to mix a waste tank. From the test results, it was determined that three or four pumps were needed. [DPSP 79-17-17] The field performance showed an improved performance over the original technical data summary, which predicted that ideally 5 pumps should be installed, with co-located waste transfer pumps. [DPSTD-241-TK-16H] Based on the test results, the slurry pump was a satisfactory candidate for use in the waste removal program. The researchers recommended improvements in the pump design to reduce seal leakage and to facilitate decontamination.

4.1.3 Standard Slurry Pump Development

Since 1979, 16 waste tanks have used standard slurry pumps (SLPs) or some variation thereof for sludge removal, salt dissolution, and sludge mixing for DWPF feed preparation. The SLPs were first provided by Bingham-Williamette, followed by Lawrence Pumps. The second manufacturer provided SRS with a competitive alternative supplier. However, despite gradual improvements in manufacturing, SLPs experienced operating life spans of 1,000 hours or less (approximately 42 days of continuous operation). The reliability problems were driven by seal and bearing failures, which were caused by vibrations of the long shafts in the pump. SRS continues to use the jet mixing methods provided by the SLP. By 2001, SRS engineers made several design improvements to extend operating life. Using such improvements as fluidic bearings and seals, operating life extended to greater than 8,000 hours of operation. Table 4.1-2, below, summarizes sludge removal activities completed using SLPs.

Table 4.1-2: Standard Slurry Pump Bulk Sludge Waste Removal Summary

Tank	Sludge Removal Date	Amount of Settled Sludge Removed (kgal)	Number of Slurry Pumps	Number of Waste Transfers	Receipt Tank
16	1978-1979	67	1-3	5	15, 21
15	1982	125	2	2	42
17	1983-1985	373	3	7	18
18	1986-1987	518	3	17	40, 42, 51
21	1986	205	3	2	42, 51
22	1986	78	3	3	21, 40, 51
8	2000, 2004	126, 11	4	3	40
7	2003	192	4	4	51
11	2005	106	4	5	51
12	2009	199	2 – 4	7	51

[CBU-PIT-2005-00233, CBU-PIT-2006-00045, HLW-STE-98-0218, DPSTD-84-100-TL, M-ESR-H-00240, M-ESR-H-00256, MO-RPT-86-JUL1, MO-RPT-86-SEP1, U-ESR-F-00013, U-ESR-F-00027, U-ESR-H-00062, U-ESR-H-00093]

The SLP still in use employs a design founded on the work by SRNL in the 1970s (the waste tank end is shown in Figure 4.1-3). The SLP is capable of pumping approximately 2,000 gallons per minute when driven at full speed by the 150 horsepower electric motor. The pump connects to the motor with a long shaft through a water-filled column. The column is pressurized to prevent the migration of contamination to travel up the spinning shaft and outside of containment.

Figure 4.1-3: SLP Staged for Trial Runs at the SRS Test Facility

The SLP can operate at relatively lower tank levels (approximately 30 inches minimum submergence for full speed operation). The SLP motor is above the tank, and is air cooled, so the SLP can operate at higher tank temperatures.

A mixer pump generates jet flow by acquiring suction from the pump bottom and discharging horizontally out of two diametrically opposed nozzles. The distance from the nozzle discharge to where sludge can be mobilized is called the ECR. The ECR depends largely on the sludge consistency and the time spent addressing the sludge layer. The pump bodies are rotated on a slewing gear at slow speeds (approximately 0.2 rpm) in a manner that causes the jet streams to sweep transversely over the vessel floor, thereby mobilizing waste across the effective radius of the jet streams. The SLP has an ECR of 24-26 feet. Within this radius, approximately 95% or more of the sludge may be mobilized and removed.

In accordance with the FFA, BWRE was declared complete for Tanks 7, 8, 11, and 12 following waste removal with SLPs. Based on past success in performing waste removal from Tanks 7, 8, 11, and 12, four SLPs would typically be recommended for performing waste removal from a Type I tank. For Type III tanks, a larger modified SLP is available, driven by a 300 hp motor. This pump is referred to as the Quad-Volute design. Four Quad-Volute SLPs have been demonstrated to be successful in mixing Tank 40 and 51.

The primary operational lesson learned for BWRE is to minimize transfer pump operation when the waste tank is not actually being mixed. This lesson is applicable to any type of mixing device.

4.1.4 Submersible Mixer Pump

In conjunction with DOE sponsored alternative waste removal technologies, SRS engineers began investigating alternative mixer pump designs. In 1998, a submersible pump and motor design was proposed that would eliminate many of the vibration issues and the bearing water system. In 1999, funding through the DOE Office of Science and Technology enabled SMP development. The SMP is a "from the ground up" redesign of the mixer pump concept that can be inserted through most 2-foot riser openings and provide a larger mixing capacity.

The SMP is a 7,600-gpm pump driven by a closed coupled 300 hp electric motor. Curtiss-Wright Electro-Mechanical Corporation specifically designed and manufactured the pump for utilization in SRS waste tanks. The SMP acquires suction from the bottom and pumps some of the slurry through cooling chambers in the motor before discharging out through two diametrically opposed side nozzles machined in the pump-motor casing. The fluid, with high velocity, exits the nozzles that mix and agitate the waste tank contents. The pump-motor assembly mounts at the end of a long mast and inserts through a waste tank riser. The entire assembly oscillates on a slewing gear allowing the jets to sweep horizontally across the waste tank. In Figure 4.1-4, a jet nozzle can be seen as a hole in the casing side. The SMPs operate with higher waste tank liquid levels than the SLPs.

Figure 4.1-4: SMP Base During Pre-Installation Testing

The SMP is product cooled, and is routinely operated with a submergence of approximately 110 inches to cover the motor cooling discharge ports. Because the SMP is product cooled, the SMPs cannot be operated in tank temperatures greater than 70℃. The SMP adds significant pump/motor heat to the waste, requiring tank cooling. SMPs are vulnerable to pump inlet screen pluggage, which can result in motor overheating (at least two previous pump failures were potentially caused by motor overheating and bearing damage due to inadequate cooling flow).

Other disadvantages of the SMP include the long lead time, expense, and increased power requirements. SLP and SMP diameters are limited by the waste tank riser inside diameter. The placement of these pumps through the riser is a carefully controlled crane evolution. In 2012, the Tank 6 project encountered difficulties when moving SMPs to Tank 8. The Tank 8 risers contained anomalies (uneven edges and a lack of roundness) that led to an SMP becoming ‘stuck’ during installation.

The advantages of SMP use are the greater power, and resulting increase in ECR (the SMP has an ECR of 52 feet) when compared to SLPs. The SMP does not need bearing water service, and since the motor is close coupled to the pump, there is not the same risk of shaft vibration.

Waste removal performed to date using the SMP is summarized in Table 4.1-3. Some of the transfers summarized in this table were performed after declaration of BWRE complete (during Heel Removal). BWRE was declared complete for Tanks 4, 5, and 6 using SMPs. Based on waste removal performed to date, three SMPs would typically be recommended for performing waste removal from a Type I or II tank.

Table 4.1-3: SMP Bulk Sludge Waste Removal Summary

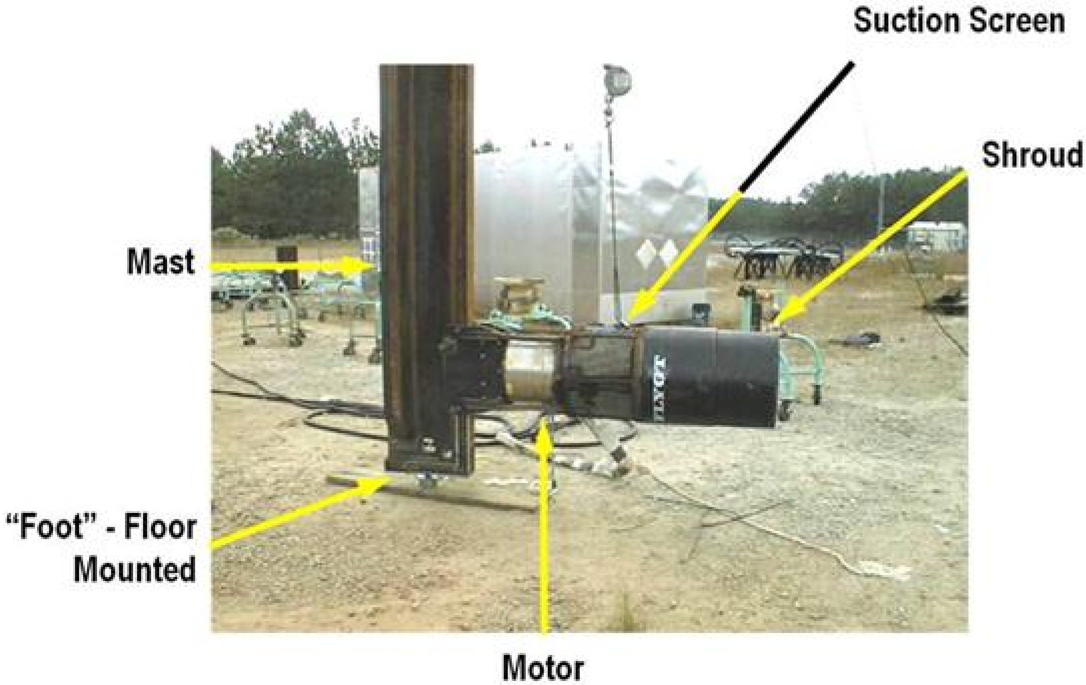
Tank	Sludge Removal Date	Amount of Settled Sludge Removed (kgal)	Number of SMPs	Number of Waste Transfers	Receipt Tank
4	2011	82	2-3	7	7, 51
5	2005	18	2-3	2	7
6	2008	19	2	11	7
13	2012	209	2-3	3	51

[M-ESR-F-00107, M-ESR-F-00109, M-ESR-F-00147, SRR-CWDA-2012-00071, G-ESR-H-00161, U-ESR-F-00026, SRR-LWE-2011-00100, SRR-LWE-2012-00161]

4.1.5 Other Bulk Waste Removal Technologies

Free Jet Flow Agitators: During Tank 17 operational closure in 1997, a small, submerged agitator was installed in the waste tank before the liquid contents were removed. The purpose was to agitate sludge fines promoting transfer to an adjacent waste tank. The agitators (Flygt mixers), manufactured by ITT Corporation, are commonly used to suspend municipal sludge in wastewater treatment plants (Figure 4.1-5). The effect of the mixer was not apparent, but the tank liquid clouded when the mixer was started providing sufficient justification to pursue this mixer type for further study. In 1998, mixing studies began on Tank 19 (a tank holding roughly 33,000 gallons of fast-settling zeolite particles).

Figure 4.1-5: Tank 19 Flygt Mixer at the SRS Test Facility



The Pacific Northwest National Laboratory, SRNL, and SRS sponsored waste tank mixing studies using three Flygt mixers mounted on a vertical mast with the flow direction aimed horizontally. The studies recommended rotation of a mounting mast for increased mixing success. After considerable development, three of these mixers were installed in Tank 19 for sludge and zeolite mixing. Consistent with first-of-a-kind developmental efforts, several technical issues arose that reduced the efficacy of the method. First, the diameter of the mixer blades had to be cut down to fit through the 24-inch tank opening reducing the hydraulic power of each mixer. Second, the mixers did not exhibit the long-term durability realized in commercial applications (one of the mixers failed shortly after start up). Third, the zeolite layer proved more tenacious than the surrogate material used during mock up testing. However, several lessons were learned from the experience that carried through to future technology development efforts:

- Mock up testing (including surrogates) must emulate field conditions.
- Commercial technologies require significant development to be "tank ready" for waste removal. The cost savings of using an off-the-shelf component is often overtaken by the expense to adapt the component for a waste tank. The mast assembly cost for each Flygt mixer was comparable to the SLP.
- Development or adaptation of one technology sometimes provides use in later applications. The oscillating slewing gear to turn the mixers were later adapted for the SMP. In addition, the mixer's floor-mounted foot support was found of use with the SMPs.

Advanced Design Mixing Pump: The advanced design mixer pump (ADMP) was originally conceived by the Hanford Site and supported by SRS to provide a more reliable and maintainable mixer pump for use throughout the DOE complex. The ADMP underwent an extensive test program at SRS between 1998 and 2002 to assess reliability and hydraulic performance. The ADMP was a departure from the SLP design. Like the SLP, the ADMP was a long-shaft, vertical, centrifugal mixer pump with two tangential nozzles. However, the column was filled with gas, instead of liquid, the bearings were oil lubricated, and the ADMP is bigger than the SLP. The pump is 55 feet long, with a 16-inch column, 39-inch casing, 18-inch mixed-flow impeller, two 6-inch diameter nozzles, and a 300 hp motor. The ADMP did not fit through a 2-foot opening, but did fit through an FTF Type IV tank center riser. The pump flow rate was 10,400 gpm at 1,185 rpm with 52 feet of head. The theoretical cleaning radius was over 50 feet. However, despite the horsepower, the mixer pump underperformed when used in Tank 18, primarily due to inlet screen pluggage. The large size precluded use in non-Type IV tank remediation.

Commercial Submersible Mixing Pump (CSMP): In 2012, a team was formed to review sludge removal technologies with a goal to find a more cost effective alternative to the mixing technology currently in use. The team performed an informal SEE to include industry and DOE complex methods. The team determined that mixing technology was the best alternative (compared to sluicing, etc.), but that there was a potential for savings through the use of modified commercial pumps, instead of procuring radiation-hardened long life pumps. Commercial pumps have already been successfully used as a cost effective alternative for transfer pumps. Several vendors were identified that had commercial pumps that could be adapted to tank mixing requirements. Due to the significant cost saving potential, a procurement package was approved and is in progress to obtain CSMPs for testing and use.

4.2 Mechanical Heel Removal Lessons Learned

Mechanical heel removal step uses several methods to remove the stubborn accumulations of residuals remaining after BWRE. The purpose of mechanical heel removal is to remove residuals to the maximum extent practical, thereby reducing, or eliminating the chemicals necessary during chemical cleaning, if performed. The methods used for mechanical heel removal are highly dependent on the type of waste tank and associated internal references (e.g., cooling coils).

4.2.1 Mechanical Heel Removal for Waste Tanks with Cooling Coils:

If installed, the same mixer pumps used for BWRE can continue to be used for additional heel removal. This process may be augmented using a *mechanical feed-and-bleed* (MFB) process, which extends the mixing time by maintaining the waste tank liquid level. Maintaining a higher tank level is crucial since mixing pumps must be shut off at lower levels in the waste tank (the exact level is dependent on the type of mixer pump and depth of insertion), to prevent damage to the mixer pump and to comply with nuclear safety constraints associated with aerosolization.

The equipment for the MFB method is listed below:

- Downcomer (for fresh water addition)
- Temporary recirculation line (for continuous recirculated decant)
- Existing transfer lines and pumps (for batch recirculated decant, i.e., a saw tooth campaign versus a continuous feed and bleed)

The temporary recirculation line is typically a hose-in-hose configuration, and shielded with lead blankets to reduce personnel exposure.

MFB uses waste tank agitation and liquid makeup. Removal is accomplished by agitating the contents using three or four mixer pumps while simultaneously pumping the sludge suspension to a destination waste tank. Makeup liquid is supplied at the same rate as the transfer rate to maintain the source waste tank level thus extending the mixing time. The makeup liquid can either be fresh water supplied through an installed downcomer or recirculated supernate supplied through a dedicated return line from the destination waste tank. For the latter case, the destination waste tank serves as a settling basin allowing the particles to sink. A temporary waste transfer and pumping system decants the clarified portion of the supernatant. Refer to Figure 4.2-1 for a schematic of this method. Both of these arrangements maximize mixing time, which allows more time for material to be removed. The dedicated transfer line method offers the benefit of not adding water volume to the tank farms. Similar results may be achieved using the existing transfer system, in a batch recirculation process. Batching involves pumping the contents of the source waste tank down to a minimum level while maintaining mixer pump operation. After sufficient settling, the same liquid volume is returned from the destination waste tank back to the source waste tank. Figure 4.2-2 shows the temporary recirculation line installed above-grade that was used to clean a Type I tank.

The MFB method is a relatively new development, but uses a proven concept. The method was first proposed in 2005 with a tabletop demonstration and was adopted as a viable heel removal method in September 2009. [SRR-CES-2009-00022] The fresh water feed and bleed method was employed on Tank 5 in January 2010 and the continuous recirculation method was used for Tank 6 in July and August of 2010. [U-ESR-F-00024, SRR-CES-2010-00031] Batch recirculation was performed on Tank 4 between October 2010 and February 2011. [SRR-LWE-2010-00350] These feed and bleed methods differ from the original slurry pump recirculation technique proposed from the late 70's in that these only require the use of two waste tanks, versus having a third tank as a supernate supply.

Figure 4.2-1: MFB Heel Removal Method

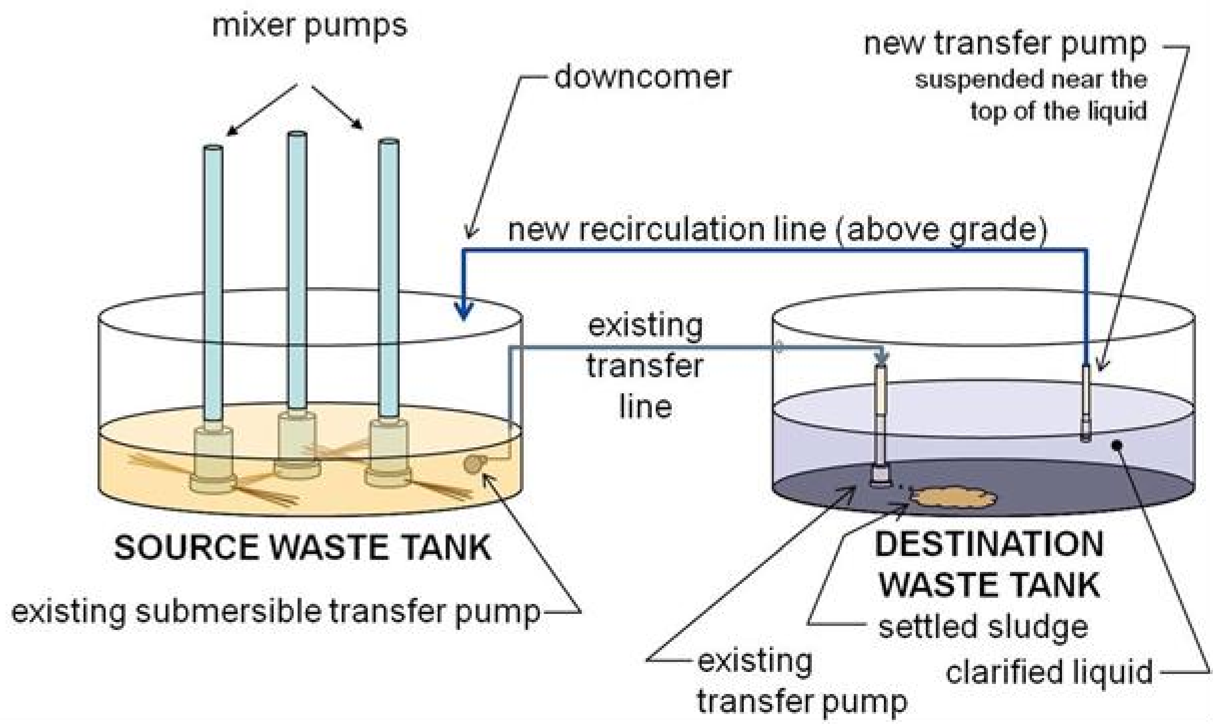
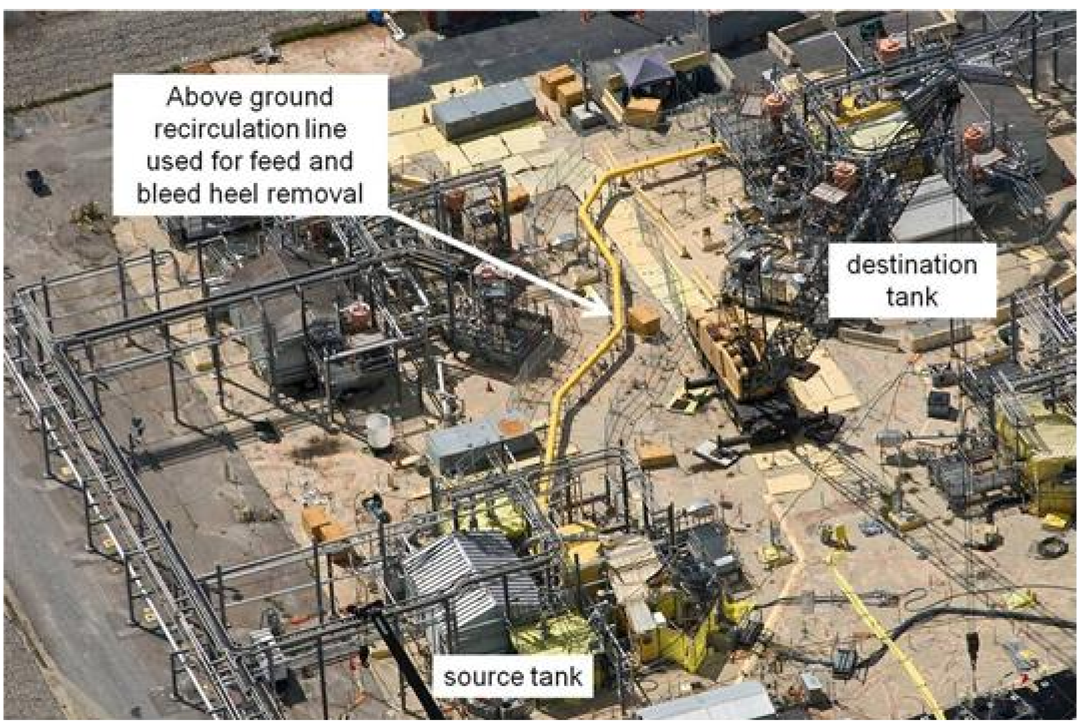
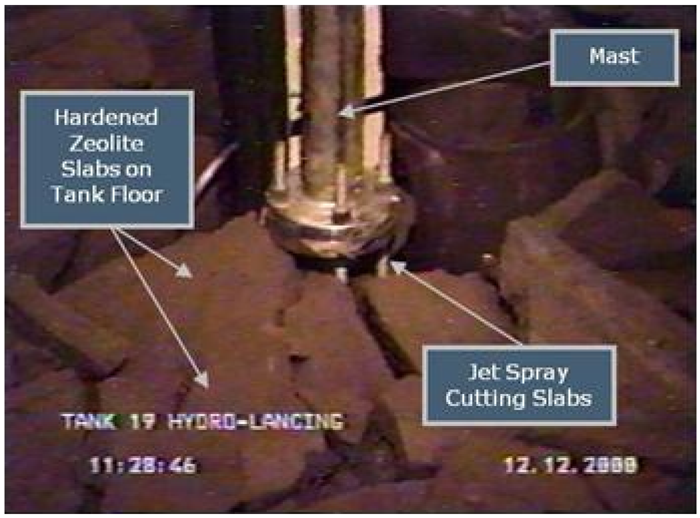


Figure 4.2-2: Above-Grade Shielded Line Transfers Clarified Liquid between Tank 7 and Tank 6 (2010)



These techniques are adaptations of heel removal methods found in the chemical process industry and in storage tanker cleaning. Commercial methods encourage the reuse of liquid and the minimization of secondary waste streams. Other tools, such as lances and sluicers, are sometimes employed to dislodge hard mounds or hard-to-reach deposits. For example, a hydro-lance broke up hardened zeolite mounds in Tank 19 (Figure 4.2-3). These lances are used while the waste tank level is low when the waste can be remotely accessed.

Figure 4.2-3: Tank 19 Zeolite Blocks Being Broken Up By a High Pressure Hydro-Lance



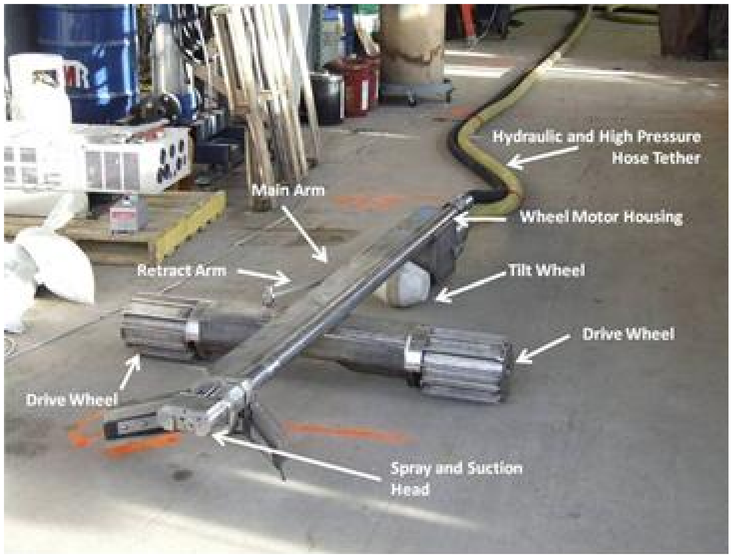
Another technique to enhance heel removal is to direct the nozzles of the mixer pumps towards a mound and leave the mixer in a stationary position for an extended time (indexing method). Experience has shown that mounds formerly outside mixer pump reach can be reduced using this technique. The time needed to make this method effective is substantially longer than that normally used for routine BWRE. [DP-MS-89-61]

4.2.2 Mechanical Heel Removal for Waste Tanks without Cooling Coils:

The absence of internal interferences expands the type of cleaning tools that can be installed. In addition to the mixer pumps, robotic crawlers are available for vacuuming the waste tank bottom. The crawler can be equipped with an eductor that is used to aspirate material off the floor and transfer the suspension to a nearby waste tank. The crawler can also be equipped with forward sprays to dislodge and suspend hardened sediment. The rig can be controlled by an operator using hydraulic controls located near the waste tank. For Type IV Tanks 18 and 19, a crawler, called the Mantis, was deployed to vacuum residuals from the tank bottom.

The illustration in Figure 4.2-4 shows the Mantis platform.

Figure 4.2-4: Mantis Platform in the Vendor's Test Facility



The volume of the heel in Tanks 18 and 19 was reduced using the Mantis that crawled across the bottom of the tank aspirating and transporting the waste material. To break up solidified accumulations, forward water sprays were attached to the crawler. The crawler motion was controlled by a nearby operator using a multi-function joystick while observing the movement on a video screen.

The Mantis performance in Type IV tanks is dependent on the physical properties of the waste. Previous results demonstrated that sticky, mud-like sludge like that of Tank 18 is more difficult to remove than the grainy sand-like sludge found in Tank 19. [LWO-CES-2006-00006]

4.3 Chemical Heel Removal Lessons Learned

Following BWRE and mechanical heel removal, additional residual removal may be required. For those situations, two different methods of chemical cleaning have been deployed. Tanks high in aluminum content can undergo LTAD with caustic chemical additions or high caustic supernate to dissolve aluminum species; however, there is negligible impact to other metals. Chemical cleaning with bulk oxalic acid (BOA) can also be utilized to treat the residual solids remaining after mechanical waste removal campaigns and potentially LTAD campaigns.

4.3.1 Low Temperature Aluminum Dissolution

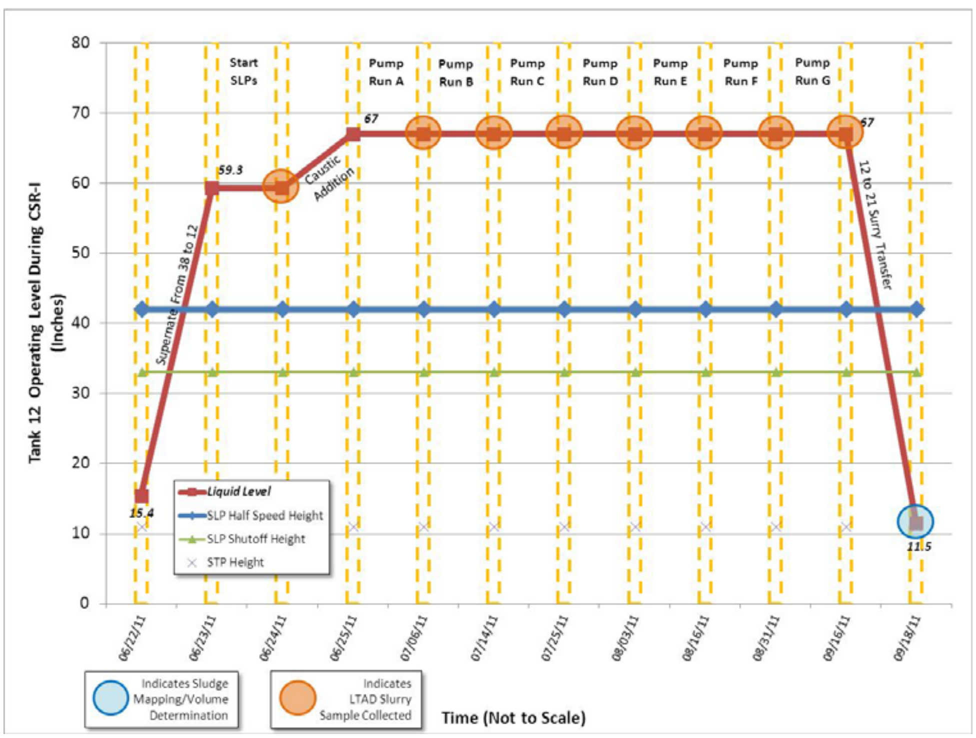
Aluminum dissolution was originally developed for bulk sludge processing, to remove excess aluminum content from HM process sludges to enable better DWPF operation. Aluminum dissolution has been performed on bulk sludge removed from Tank 15 (actual process performed in in Tank 42) and Tanks 11 and 12 (actual process performed in in Tank 51).

Upon beginning Tank 12 BWRE process, samples of Tank 12 sludge slurry indicated that about 80% of the waste heel in Tank 12 was aluminum compounds in the form of boehmite ($AlOOH$). SRNL testing indicated that much of this aluminum could be dissolved using heated caustic. Lab studies also indicated the yield stress of the sludge would be improved, facilitating greater waste removal using the installed mixing pumps. For bulk sludge moved from Tank 12 to Tank 51, Sludge Batch 6 material balance indicated that 145,000 kg out of a total of 270,000 kg of aluminum solids present in Sludge Batch 6 were dissolved. Given the success with Sludge Batch 6, caustic dissolution of the sludge heel still remaining in Tank 12 was performed.

Concentrated supernate from Tank 38 supplemented with 50 wt% sodium hydroxide was added to Tank 12 to dissolve aluminum compounds. Tank 12 held 180,000 gallons with a pre-dissolution concentration of 8.5M sodium, 5.4M hydroxide, and 0.07M aluminum. The tank was mixed using three slurry pumps in a mixing and indexing campaign, attaining near 80°C for about two months. Following mixing, the sludge slurry was transferred to Tank 51; the aluminum-laden leachate was incorporated into a batch to feed ARP/MCU. The Tank 12 solids volume was reduced from 13,700 gallons of solids to 7,800 gallons of solids. [SRR-LWE-2012-00009] In addition, later mixing campaigns validated the earlier SRNL testing results that the Tank 12 remaining sludge heel yield stress was improved.

Conducting LTAD in Tank 12 demonstrated that LTAD is a viable treatment step for tanks with similar type sludges. [SRR-CWDA-2013-00125] Figure 4.3-1 provides an overall summary of the Tank 12 LTAD campaign.

Figure 4.3-1: Tank 12 LTAD Summary



4.3.2 Bulk Oxalic Acid Cleaning

Tanker trucks can be used to add chemicals to the waste tanks through downcomers or spray wash nozzles. Mixer pumps (SMP or SLP) provide the mixing. The standard chemical used is OA in strengths from 1 to 8 wt%, depending on flowsheet requirements.

Chemical cleaning employs OA to reduce particle size and to dissolve or otherwise loosen solids not easily removed by mechanical methods and water addition alone. The OA may be pumped or sprayed into the waste tank to clean contaminants from the internal waste tank surfaces (e.g., walls, cooling coils, support columns, equipment). The OA is dilute with well water to submerge mixer pumps and facilitate agitation. The mixer pumps provide agitation and heat to accelerate the chemical reaction and to suspend loosened solids. After several days of continuous agitation, the spent solution is pumped to a waste receipt tank. The receipt waste tank holds excess sodium hydroxide (from a previous addition) to neutralize the low-pH spent solution, thus maintaining corrosion control. Several (typically three) of these evolutions ("strikes") are performed. At the conclusion of the chemical cleaning campaign, the waste tank interior is washed with water to rinse the acid from internal surfaces and further dislodge loose contamination.

Some specific lessons learned from OA cleaning in five SRS waste tanks (Tanks 5, 6, 12, 16, and 24) are included in the following sections. In general, OA has proven effective in dissolving iron-based compounds in sludge, and in removing some HRRs, such as cesium, technetium, and uranium isotopes. OA cleaning is less effective in dissolving aluminum-based sludge compounds. Plutonium is only sparingly soluble in OA, and is not removed effectively from waste tank heels by OA cleaning. Nuclear safety requirements for OA cleaning require significant facility modifications. Each waste tank cleaned with OA generates approximately 32,000 kg of spent oxalate, which does not currently have a viable disposition path for removal. As a result, the consideration of using OA cleaning for one of the heel removal steps for future waste tanks should include a cost-benefit evaluation in the decision process.

4.3.2.1 Bulk Oxalic Acid Cleaning Technology Development

The development of heel removal techniques using chemicals began over 40 years ago. In the 1970's SRS chose OA over other chemicals, including ethylenediaminetetraacetic acid (EDTA) and sulfamic acid, for several reasons: [DP-1471]

- **Strength -** OA is over 3,000 times stronger than acetic acid. [ISBN: 9780071432207] Mineral acids such as hydrochloric or sulfuric have the tendency to attack the waste tank metal and produce excessive amounts of flammable gasses when reacting. Stronger organic acids are inclined to be toxic (trichloroacetic acid), explosive (picric acid), or possess violent reactivity (benzenesulfonic acid).
- **Safe -** OA is an attractive cleaning agent because the corrosion damage to the carbon steel waste tanks is limited through the passivation of the metal with the formation of iron (II) oxalate. [WSRC-TR-2004-00043] OA is safely handled using appropriate personal protection equipment.
- **Available -** The reagent is commercially available from several sources.
- **Compatible with long-term lay-up -** The oxalates formed from the acid-base reaction are also reducing agents, which favor closure chemistry.
- **Effective -** OA dissolves most iron compounds, some aluminum compounds, and some uranium compounds. The acid works as a dispersant by reducing the size of other solids.

Sludge that has reacted with OA is easier to mobilize and transport out of a waste tank. [DPSP-80-17-23]

On the down side, laboratory studies show that nickel-based sludge is unaffected by OA. [WSRC-TR-2004-00043] Moreover, plutonium-based solids are resistant to OA attack. [WSRC-RP-98-00091] This would imply that using OA would preferentially dissolve the clean compounds, leaving behind some contaminants (e.g., plutonium). This concern was identified by SRS engineers when OA was first proposed for Tank 16 heel removal in 1978. [DPSPU-78-272-33] However, sampling performed after completion of chemical cleaning on Tank 16 did not indicate a separation of components and researchers confirmed the mixer pumps effectively suspended the sludge treated with OA. [DPST-81-441]

Additionally, corrosion of the carbon steel tanks was a concern as OA contacted the carbon steel tank walls during the chemical cleaning campaigns. Studies conducted on PUREX waste observed general corrosion and pitting of the carbon steel in contact with OA. [WSRC-STI-2007-00209] Rates observed approached 0.4 mils/day utilizing 8 wt% OA at 75°. [C-ESR-F-00041] During the studies, the corrosion induced hydrogen generation rate was also examined, and the corrosion induced hydrogen generation rate instantaneous maximum was determined to be 3.1E-06 ft^3/ft^2-min. These rates formed the basis of the inputs for the DSA change supporting chemical cleaning of F Area (i.e., PUREX) waste tanks. In 2012, laboratory testing with H-Area waste indicated a higher corrosion rate. Prior to chemical cleaning an HTF tank under the current DSA, testing was conducted on HM waste (i.e., Tank 12 waste) to determine the impacts on corrosion and the hydrogen generation rate potential. General and pitting corrosion were observed during the experiments totaling 2.4 mils/day utilizing 8 wt% OA at 75°C. Additionally, the corrosion induced hydrogen generation rate was calculated based on a correlation of the corrosion rates, and the instantaneous rate was determined to be 4.3E-05 ft^3/ft^2-min. [SRNL-STI-2012-00305] Due to these rates observed, the flowsheet and DSA for BOAC was revised to maximize the effectiveness of the chemical cleaning process, as described in Section 4.3.2.5.

Two challenges in working with OA are described below:

- **Byproducts -** The products are toxic to humans. The conjugate base is an oxalate ($C_2O_4^{-2}$) with sodium oxalate ($Na_2C_2O_4$) being the most common salt formed during waste tank cleaning. Proper personal protection equipment will safeguard workers when handling this material.

  The oxalates also have limited solubility in solutions with high sodium and hydroxide concentrations. To counteract this effect, the solutions should be removed from the waste tank before the compounds have a chance to precipitate.

- **Dissolution Effects -** OA causes the preferential dissolution of some compounds over the others. Presently, no single acid has been identified that will dissolve all of the sludge compounds equally while not also damaging the waste tank wall. However, OA is the most "complete" chemical for dissolving most of the compounds (while protecting the waste tank), and aiding in the dispersion and suspension of the remaining compounds.

In 2003, a Heel Removal Task Team was formed to investigate the best method to dissolve waste tank heels, and to implement the method into the modern LW program. The team concluded OA to be the safest and most effective cleaning agent. [WSRC-TR-2003-00401]

Three more alternative evaluations concluded OA as the preferred component in chemical heel removal. The Waste Removal Balance of Program (2003) SEE selected OA as the preferred candidate for chemical cleaning. [G-ESR-G-00051] In 2007, a method of inventive problem solving identified an enhanced process using OA, which formed the basis for investigating Enhanced Chemical Cleaning, a process with proven chemistry, but was ultimately abandoned due to implementation costs. [WSRC-STI-2007-00587] In 2009, a SEE investigated multiple chemical cleaning regimens, which included OA. The OA plus nitric acid scored highest with OA (baseline reagent) coming in second. Additional testing, analyses, and safety evaluations are needed before OA supplemented with another reagent can be used in the waste tanks. [SRNL-L3100-2009-00118]

Technology development continues to improve chemical cleaning methods. The SRNL has researched possible augmentation or replacement of OA to improve overall removal rates. The SRNL investigated improving dissolution performance using supplemental acids mixed with traditional OA solutions. However, further testing, analyses, and safety evaluations are needed before being considered as part of the chemical heel removal baseline. The SRNL found that an OA-nitric acid mixture or an OA-sulfuric acid mixture dissolves iron-based sludge more completely than OA alone. [SRNL-STI-2010-00541]

4.3.2.2 Tank 16 Lessons Learned from BOAC

Tank 16 was the first tank to have BOAC deployed. BOAC was performed on Tank 16 as part of a demonstration project to evaluate various waste removal options that would become the planning basis for future waste removal efforts. Based on SRNL testing, a BOAC flowsheet was developed to maximize parameters such as temperature, mixing, and amount of sludge surface exposed.

In November 1979, two water washes were performed on Tank 16 to dissolve remaining water soluble salt deposits that had adhered to the cooling coils and to remove residual caustic in the sludge to prevent neutralization of the OA. [DPSTD-241-TK-16H] The water was added at 90°C through 5 rotary spray jets, followed by operation of three SLPs.

Following the water wash sludge preparation, three chemical strikes were performed. The acid was added directly to the tank bottom, and was added via the existing rotary sprays. The acid was heated to 90°C prior to addition. The acid was added at 4 wt%, and subsequently diluted to 1 wt% to allow slurry pump operation. At the conclusion of pump operation, the spent acid sludge slurry was transferred to Tank 21 or Tank 22. [DPSP-80-17-23]

BOAC and water washes in Tank 16 were successful in reducing the final residuals in the tank.

4.3.2.3 Tank 24 Lessons Learned from BOAC

In 1985, Tank 24H was cleaned with two OA washes in an attempt to remove approximately 10,000 gallons of zeolite solids. The first strike added 22,500 gallons of 8 wt% OA to the 11,000 gallon heel. Twelve thousand gallons of dilution water were added, and the tank was mixed with three slurry pumps for three days. The mixture was then neutralized in place using 2400 gallons of 50 wt% sodium hydroxide, and was transferred to Tank 38.

Between strikes, the tank was rinsed two times with water, with the first rinse being 9600 gallons and the second rinse being 19,100 gallons. These rinses were also transferred to Tank 38.

The second strike added 23,500 gallons of 8 wt% OA to the 13,000 gallon heel. Following the addition, the tank was gradually diluted to 75,000 gallons total liquid volume while mixing the tank, and the mixture was neutralized in place using 2400 gallons of 50 wt% sodium hydroxide. Solution temperatures during the 1st and 2nd acid washes varied from 40 – 44 °C and 45 – 55 °C, compared to a goal established by laboratory testing and studies of greater than 70 °C. The neutralized sludge slurry was transferred to Tank 38.

Sample results following acid cleaning indicated that the chemical structure of the zeolite had been modified over time in the caustic waste environment to a form of hydroxy sodalite. It was theorized that the excess hydroxide ion in the silica matrix of the solid would require 2.8 times more acid than originally anticipated to complete the program. [DPST-85-782] As a result, chemical cleaning is not considered viable for waste tanks with appreciable quantities of zeolite.

Other Tanks Containing Zeolite

From 1963 to 1990, cesium removal columns (CRCs), which utilized ion exchange resins that contained zeolite, were used in the LW system to reduce the cesium activity in the evaporator overheads prior to their release to the seepage basins, thereby minimizing releases to the environment. The CRCs were taken out of service after the Effluent Treatment Plant (ETP) was constructed and placed in service in 1990. When a CRC was removed from service, the zeolite resin was deposited to various locations in the LW waste tank system. As a result of subsequent transfers, considerable inventories of zeolite exist in 9 operating waste tanks (FTF Tanks 7, 25, and 27 and HTF Tanks 24, 32, 38, 40, 42, and 51). [SRR-LWE-2010-00055, CBU-PIT-2005-00099]

4.3.2.4 Tanks 5 and 6 Lessons Learned from BOAC

BOAC was performed in Tanks 5 and 6 in 2008. The planned flow sheet was to dilute the supernate heel in the treatment tank, to remove sodium, and then perform three strikes using 8 wt% OA at 50 °C, with SMP mixing on the first batch. The last strike was planned to be added via a spray wash tool. Following acid cleaning, the flowsheet planned to spray wash the tank using water, and perform a final well water wash with SMP mixing.

The residual solids volume decreased after the first strike but increased after the second strike in both waste tanks, indicating precipitation of oxalate solids. The volume for the third acid strike was reduced to the minimum required for acid spray wash. It was believed that using 8 wt% OA (near the saturation limit) contributed to the formation of oxalate solids.

The first acid strike in Tank 5 was not as effective as expected. The pH of Tank 5 did not reach the target (<2) during the first acid strike; the probable cause was believed to be a higher level of basic ions in the sludge than expected.

The transfer of the second strike was delayed due to equipment issues in the receipt tank (Tank 7). This delay likely contributed to the formation of solids as the saturated OA solution continued to dissolve solids and increase in pH until sodium oxalate precipitation occurred.

As a result of acid cleaning in Tanks 5 and 6, recommendations for future tank acid cleaning included establishing favorable initial conditions (minimize sludge volume, pre-wash extensively to remove sodium), use more dilute OA, maintain pH conditions <2, transfer when reaction is complete to prevent precipitation, and perform more vigorous mixing throughout the process. [SRR-CWDA-2009-00057]

4.3.2.5 Tank 12 Lessons Learned from BOAC

BOAC was conducted in Tank 12 in 2013. Prior to executing chemical cleaning in Tank 12, the flowsheet was revised to incorporate the lessons learned from previous chemical cleaning campaigns to maximize the effectiveness of the evolution. Additionally, the safety analysis was updated to reflect corrosion testing completed on the HM sludge that typically exists in the HTF waste tanks.

Due to the observed corrosion rates of carbon steel in the presence of OA dissolving HM sludge, restrictions were placed on mixing in the waste tank during BOAC. Mixing in the treatment tank and transfers from the treatment tank could not be initiated until the OA mixture was diluted to ≤4 wt%. Furthermore, to protect the annulus pan from overflowing in the event a leak was observed from the primary tank wall, waste level restrictions were placed on the tank during execution of BOAC.

The modified chemical cleaning flowsheet implemented a number of improvements based on previous lessons learned. First, the material in Tank 12 was washed prior to BOAC in order to reduce the sodium concentration to less than 0.5M. This action was intended to reduce the liquid ionic strength, which increases the oxalate solubility and minimizes the potential for solids precipitation. Second, the pH of the acidic solution was monitored during the dissolution process to ensure the solution pH remained below 2. Because the oxalate solubility is related to the pH of the solution, maintaining a low pH would also minimize the potential for solids precipitation during the process. Next, mixing was employed as soon as a sufficient liquid level was reached in the tank to support full speed mixing of the SLPs, and a sufficient number of SLPs (i.e., 4 pumps) were utilized to maximize tank cleaning coverage of the pumps. Focused indexing campaigns were also executed to deliberately attack and disperse the mounds that remained in Tank 12. Finally, the highest temperature allowed by the safety basis was maintained throughout the cleaning process. Based on testing completed, a temperature limit of 60°C was placed on the tank. Cooling coils were valved in/out as necessary to maintain the tank temperature as close to this limit as practical. The higher temperature limit was intended to increase the kinetics of the dissolution process, and more effectively dissolve sludge components remaining in the residual heel.

Through these enhancements to the flowsheet, the Tank 12 chemical cleaning campaign resulted in greater than 75% of the residual solids heel being removed from the tank. Based on preliminary sample data, comparable radiological removal rates were observed in Tank 12 as observed during Tank 5 and Tank 6 chemical cleaning. [X-ESR-H-00599]

4.3.2.6 Fate and Impact of Sodium Oxalate in the Liquid Waste System

Historically, oxalates have been added to the Tank Farm from Canyon separation processes and from reactor heat exchanger and other cleaning operations. The majority of oxalates generated today are primarily formed in the Tank Farm, with a small amount generated during the filter cleaning process in 512-S (part of the ARP) and from H-Canyon separation processes. The oxalates generated in the Tank Farm are predominantly created during BOAC. For a limited number of waste tanks, BOAC has been utilized to dissolve the sludge heel remaining after mechanical removal is completed in a waste tank. During its limited use, BOAC has been generally effective at removing some additional residuals from the waste tank. However, this treatment comes with negative impacts (i.e., formation of oxalates) to the overall execution of the waste processing program. The OA added during BOAC quickly disassociates in the liquid waste system to its conjugate base, the oxalate anion ($C_2O_4^{2-}$). The oxalate anion reacts with various materials found in the waste to form oxalate salts, primarily sodium oxalate. Sodium oxalate is sparingly soluble in high sodium aqueous solutions and therefore a challenge to remove from the Tank Farms for final disposition in either DWPF or SDF.

Rough estimates of oxalates in the tank farm based on transfer information from the WCS indicate an inventory of approximately 346,000 kg of oxalate in the combined sludge, supernate, and salt layers. Review of historical Canyon records and improved salt characterization information may allow for the estimate of total oxalates in the waste tanks to be refined. A tank cleaned by BOAC adds approximately 32,000 kg of oxalate (based on a Tank 12 type cleaning strategy).

SRS dispositions waste through the DWPF in sludge batches and through Saltstone in treated salt batches. During routine salt dissolution, the sodium concentration of the salt solution inhibits the sodium oxalate from going into solution. Therefore, only minor amounts of oxalate are dispositioned to SDF via salt waste processing. A fraction of the oxalates present in a sludge batch are transferred to DWPF; the fraction carried forward varies based on the specific washing needs of the sludge batch. Disposition of significant amounts of oxalates in the DWPF is constrained since the DWPF sodium limit is low enough that most of the sodium oxalate is washed out during preparation of a sludge batch.

Soluble sodium oxalate removed during washing is sent to an evaporator system where it precipitates in the feed and drop tanks. The biggest evaporator impact is the reduced usable work space as sodium oxalate precipitates in either the drop or feed tanks. Future feed for ARP and the MCU depends heavily on salt dissolution from evaporator systems; the solid sodium oxalate may cause issues when salt dissolution is performed on the waste tanks. Ineffective salt dissolution campaigns could impact production goals negatively by reducing volume processed or increasing salt dissolution duration.

There are no requirements for oxalates to be removed from the tank farm, but removal may be desirable for processing improvement. Currently, the full impact of the presence of oxalates on tank farm processing is unknown and warrants further investigation. An effective pathway for removal of significant amounts of oxalates from the tank farm has not been identified. The impacts and disposition path of oxalates in the tank farm need to be evaluated as part of the decision to perform additional OA chemical cleaning of waste tanks. In addition, the need for development of a disposition pathway (which may include permanent disposition in the tank farm, destruction of current tank farm oxalates, and/or methods to avoid further production of oxalates) should be evaluated. [X-ESR-G-00037]

4.4 Cooling Coil Flushing

Flushing cooling coils has been performed using technologies that were commercially available. This process is considered a routine decontamination method employed by nuclear industry. [EPRI NP-6169]

Cooling coil flushing involves flushing the residue from the interior surfaces of the cooling coils with clean water using standard pipe flushing methods.

Flushing the cooling coil assembly involves connecting a clean water supply to each coil circuit by first isolating the circuit and removing pipe spool pieces located in the valve house (above grade) so that connections can be made. Fresh water is provided through hoses that are connected to the circuits using quick disconnects. Water is allowed to flow through the pipes (cooling coil) for nominally a three-volume flush. The slightly contaminated rinse water is collected in a tanker vessel or routed to another waste tank. When there are broken coils, the flush water drains into the waste tank where it is later collected and pumped to another waste tank, or allowed to evaporate.

Coil flushing is conducted during tank closure as needed to prevent creation of mixed waste during grouting operations (waste generated by collecting waste grout and cooling water with chromate residue at the cooling coil discharge).

4.5 Annulus Cleaning

The small wall cracks observed in some Type I and II tanks only allow soluble liquid components to leak from the primary liner to the secondary liner. The cracks are too small for solid particles to pass through (BOAC operations allow for the failure of the tank wall and could impact crack size and allow solids into the annulus space). Therefore, the soluble waste in the annulus can be washed off with clean water, if needed.

Clean water sprayed on the exterior of the primary liner (waste tank wall) can remove small salt deposits from the wall and annulus floor. A pump, installed through one of the access openings (on top of the annulus), can remove the liquid from the annulus to the primary waste tank leaving the annulus in a near-dry condition. [LWO-LWE-2008-00018] A commercially available crawler (Force Institute Commercial Wall Crawler) assisted in removing deposits in Tanks 5 and 6. [WSRC-STI-2008-00308] The small number and size of the salt deposits permitted effective use of the crawler. [LWO-LWE-2008-00018]

Waste was removed from Tank 16 annulus using recirculation jets in 1977. Steam was introduced to the annulus vapor space to dissolve salt nodules off the tank exterior. A process liquid level of 18 inches was established in the annulus, and the jets operated for 190 hours. The cleaning program removed an estimated 2700 gallons of additional solids from the Tank 16 annulus. [SRR-CWDA-2013-00041]

In 1958-1959, Tank 9 annulus was successfully cleaned by adding nine 2,000 gallon batches of water, and then jetting the annulus to the tank primary. Each batch was allowed to soak for 1-2 weeks. [DPSP-61-1609]

Currently, Tanks 9 and 14 are anticipated to require additional annulus cleaning. A team evaluation conducted in 2012 recommended eliminating the annulus cleaning step for several tanks with minor amounts of salt waste in the annulus (Tanks 1, 10, 11, 13, and 15). This evaluation concluded that annulus cleaning for these waste tanks should not be required, so long as additional leak sites are not activated, since, the amount of residual material in the annulus pan was insignificant compared to the anticipated residual volume in the tank primary. Not performing annulus cleaning in these five waste tanks results in opportunities for cost savings and reduced radiological and occupational safety risks by eliminating scope to dismantling and removal (D&R) equipment from risers and installation of a transfer pump and transfer lines. [SRR-WRC-2012-0021]

4.6 Residual Sampling

Residual sampling has been performed in seven waste tanks to date, to include Tanks 5, 6, 16, 17, 18, 19, and 20. Sampling in Type IV tanks (Tanks 17, 18, 19, and 20) did not present significant challenges, since these waste tanks did not have internal cooling coils.

In Tank 20, three distinct samples were obtained to include: a swipe of the waste tank floor, a solids sample using an SRNL-designed "mud snapper", and a scrape sample of the floor solids. In Tank 17, two solids samples were obtained (under 80 inches of liquid) with an electric sampling pump. The pump discharge was fitted to a filter and a sample vial. Samples from both waste tanks contained sludge solids. Tank 20 also contained white solids, which were analyzed and determined to contain cryolite (Na_3AlF_6) enriched in Tc-99. [CBU-PIT-2005-00282]

Tanks 18 and 19 were sampled using a crawler to directly access floor residuals. Most of the lessons learned from Tanks 18 and 19 related to crawler failures and sample tool management.

Residuals sampling in Tanks 5 and 6 required additional sampling capability to access undisturbed mounds obstructed by waste tank cooling coils. Again commercial line crawlers were used to obtain the samples. A mock-up of the waste tank bottom and cooling coil interferences was constructed to ensure the crawler approach would be successful (Figure 4.6-1).

Tank 16 was the first waste tank residuals to be sampled under the approved LWTRSAPP and LWTRS-QAPP (see Section 2.6). In addition to the greater statistical rigor of sampling, the primary difference for Tank 16 residuals sampling was obtaining samples of material in the annulus pan and ventilation duct.

Residuals sampling has involved tank-specific approaches that continue to be refined for future application. With the approval of the LWTRSAPP and LWTRS-QAPP, the residuals sampling program has been established in a context of statistical and quality control.

Figure 4.6-1: Mock-up of Waste Tank Bottom and Interferences with Crawler

4.7 Waste Tank Isolation and Stabilization

Isolation and stabilization has been performed on six tanks; in order, these were Tanks 20, 17, 18/19, and 5/6.

For stabilization of Tank 17 and 20, a batch plant was established outside the FTF boundary and grout slick lines were routed on grade and scaffolding to the waste tank risers (Figure 4.7-1).

Three grout formulations were used in stabilizing Tanks 17 and 20. A layer of reducing grout was poured onto the waste tank floor to cover and stabilize the residuals. Consolidated Low Strength Materials (CLSM) was then used to fill the waste tank to near the top. A high compressive strength grout was then used to fill the waste tank and risers to prevent intrusion.

Figure 4.7-1: Tanks 17 and 20 Concrete Batch Plant

Tanks 18 and 19, and Tanks 5 and 6, were stabilized with grout delivered by vendor trucks, unloaded to a gasoline-driven grout pump, and piped via slick line to the waste tank riser (Figure 4.7-2) A single grout formulation was developed to meet both reducing chemistry and compressive strength requirements.

Figure 4.7-2: Vendor Truck Unloading Grout at Tanks 5 and 6

Following the grouting of Tanks 18 and 19 (Type IV tanks with no cooling coils), the grout formula was slightly modified to increase grout flowability for Tanks 5 and 6, which are Type I tanks containing many internal obstructions (i.e., cooling coils and support columns). The grout with increased flowability successfully spread around and over the internal obstructions in Tanks 5 and 6 and remained relatively level, leaving no noticeable voids.

Equipment fill grout for all four tanks and cooling coil grout for Tanks 5 and 6 was formulated with previously developed and tested cable grout. This grout was mixed on-site, was highly flowable, and contained no aggregate. [WSRC-STI-2008-00298] Special techniques were successfully employed to fill the entombed equipment as much as reasonably possible. These techniques, which were practiced in mockups prior to actual equipment fill, included equipment modifications for venting, slow and adjustable grout flow rates and pressures, and angled grout addition lines to provide a vertical path to improve grout flow into equipment voids.

Cooling coil grouting was preceded by a water flush that acted as a lubricant for grout flow inside the coils, as recommended from previous testing. Failed coils were grouted from both directions (inlet and outlet) to fill as much of the coils as reasonably possible. Grouting of intact coils continued until all flush water exited the outlet end of the coils and approximately 35 additional gallons of grout exited the coils. This technique was used to ensure all water and the water-to-grout interface exited the coils, leaving only grout.

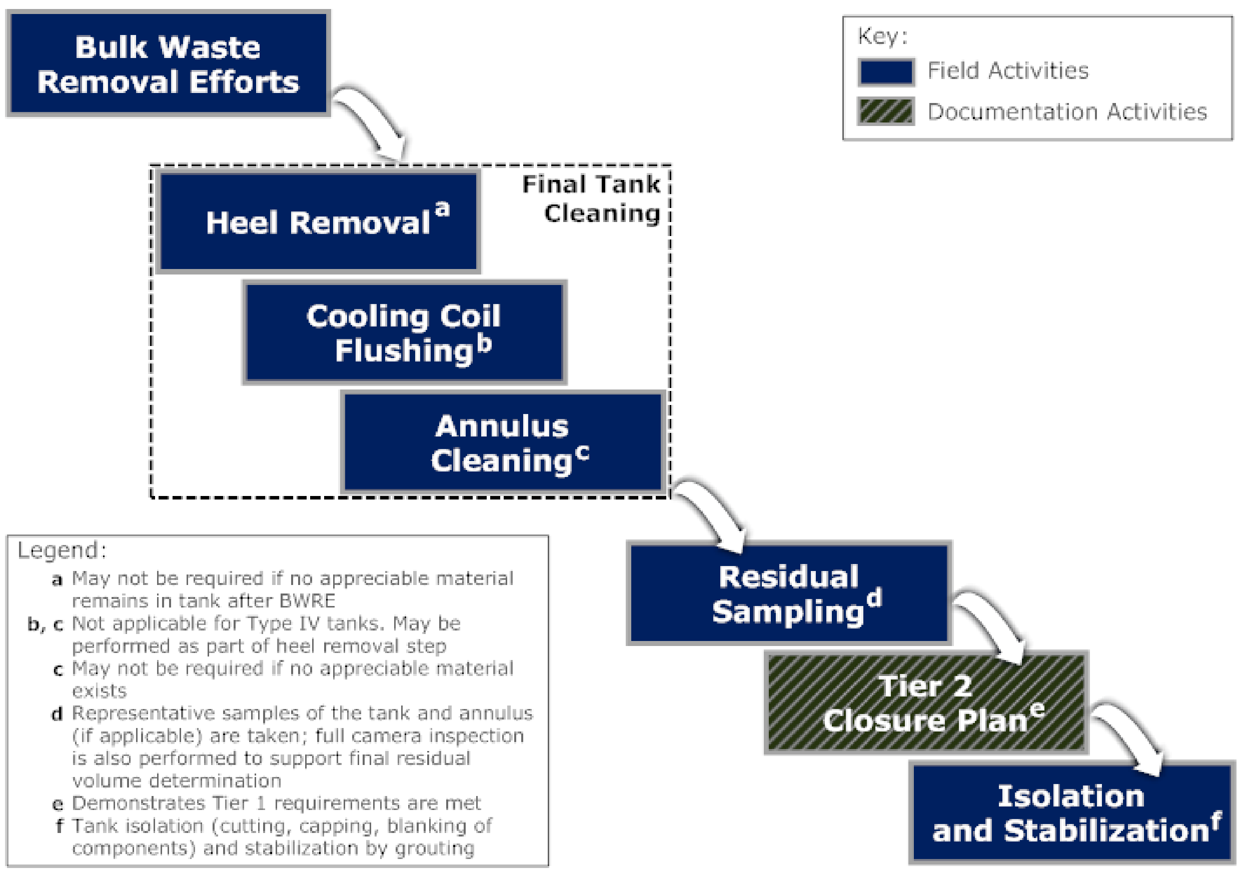
Tanks 5 and 6 were the first two tanks with annuli that required grouting. Based on structural calculations, grout placement was alternated between the tank primary and annulus to avoid excessive stresses on the tank liner. [T-CLC-F-00496] A base layer of grout placed on the annulus floor successfully supported the annulus duct during subsequent placement of duct fill grout. Flowability of the grout was sufficient to allow the annulus to be filled from grout placement through two annulus risers.

5.0 WASTE REMOVAL AND TANK CLOSURE PROCESS OVERVIEW, INPUTS, AND ASSUMPTIONS

The LW System Plan integrates and documents the activities required to disposition the existing and future waste and to operationally close the LW tanks and facilities. The planning of projects to perform waste removal and operational closure activities is based on the LW System Plan. [SRR-LWP-2009-00001]

With the completion of Tanks 18, 19, 5 and 6 over the last few years, the inputs and assumptions for future tank waste removal and closure activities can be enhanced. Lessons learned from these successful activities guide future planning. The waste removal and tank closure process is outlined in Figure 5.1-1. Note that some process steps may not be performed in the order listed; some steps may not be required on some waste tanks.

Figure 5.1-1: Approach to Waste Removal



5.1 Bulk Waste Removal Efforts

The BWRE phase extracts the bulk of the tank waste, to include salt cake, sludge solids, and contaminated liquids, leaving only a residual heel. This is a mechanical process using pumps to agitate the solids and transfer waste feeds to Sludge and/or Salt Batch processing preparation tanks. See Section 2.5 for more discussion on BWRE. The inputs and assumptions are described in Table 5.2-1.

Table 5.2-1: BWRE Inputs and Assumptions

Attribute	Basis
Remove Salt by Modified Density Gradient or SCD.	• Based on LL. Modified Density Gradient salt removal has been previously performed on Tanks 3, 25, and 41. Semi-continuous salt dissolution has been performed on Tanks 10 and 37. • Assumes Gas Release Modifications are not required for SCD.
For sludge tanks, operate 4 SLPs or 3 SMPs at maximum allowable speed.	Number of pumps that supports coverage of the entire tank bottom so that: • Insoluble salt species are suspended • Sludge particles are suspended for transfer • Pumps are usually operated in oscillating mode to facilitate general tank mixing. Assumes nominal rheology – high aluminum tanks may require more pumps. Operating pumps at maximum speed requires 110 inches submergence for SMPs and 35 inches submergence for SLPs. Refer to Table 4.1-2 and 4.1-3 for SLP and SMP LL.
Tank top mounting of mixing pumps is required.	• Waste levels are assumed to be high enough to prevent lowering mixing pumps to the floor. Therefore, mixing pumps will be suspended either from structural steel or a steel plate at the riser.
Planning basis of 3 mixing campaigns to slurry the tank and 3 removal campaigns to complete BWRE.	• Based on LL, mixing pumps may be lowered into the sludge slurry 10 inches per mixing campaign. • Based on LL, a minimum of three sludge slurry transfers will be required to complete BWRE.
After completion of BWRE for a sludge tank, an approximately 3 to 6 inch heel (10 to 20 kgal) of waste may remain.	• Based on LL from historical performance (see Table 4.1-2 and 4.1-3).
After completion of BWRE for a salt tank, a heel of approximately 2 to 3 feet (90 to 130 kgal) of insoluble waste heel may remain.	• This assumption is based upon the salt removal LL from Tanks 19 and 20.

5.2 Mechanical Heel Removal

The heel removal phase is designed to leave the primary waste tank (i.e., the main storage vessel) ready for sampling and closure. Typically, the mechanical heel removal step continues until no longer effective. The inputs and assumptions are described in Table 5.3-1.

Table 5.3-1: Mechanical Heel Removal Inputs and Assumptions

Attribute	Basis
4 SLPs or 3 SMPs at maximum allowable speed.	Number of pumps that supports coverage of the entire tank bottom so that: • Insoluble salt species are suspended • Sludge particles are suspended for transfer • Focused indexing can be performed on mounds Assumes nominal rheology – high aluminum tanks may require more pumps. Operating pumps at maximum speed requires 110 inches submergence for SMPs and 35 inches submergence for SLPs. Refer to Table 4.1-2 and 4.1-3 for SLP and SMP lessons learned.
Mechanical cleaning is estimated to require approximately 30:1 ratio of liquid to solids removed.	• Based on LL; Tank 18 heel removal required 800 kgal to remove 43 kgal sludge (20:1 ratio). 30:1 is a reasonable planning assumption (for system planning purposes only). • Although supernate may be used for some of the liquid, a minimum of 150 kgal new water should be planned for heel removal.
Mechanical feed-and-bleed is available to extend mixing time while transferring waste from the tank.	• LL from previous heel removal from Tanks 4, 5, 6, 16, and 18

5.3 Chemical Heel Removal

Chemical cleaning is an option during waste tank cleaning and assists in removing waste constituents that could not be removed using mechanical methods.

Two primary methods of chemical cleaning have been used in heel removal, BOAC, and LTAD. The inputs and assumptions for each are described in Tables 5.4-1 and 5.4-2, respectively.

Table 5.4-1: BOAC Inputs and Assumptions

Attribute	Basis
Pre-wash Sludge Heel.	• Based on LL from Tank 5 and Tank 6, pre-wash to a Na concentration <0.5M prior to BOAC. This LL was successfully incorporated in the Tank 12 BOAC campaign. • Target is based on solubility of sodium oxalate.
4 SLPs or 3 SMPs at maximum allowable speed.	Number of pumps that supports coverage of the entire tank bottom so that: • Contact between OA and sludge is maximized • Insoluble particles are suspended for transfer • Focused indexing can be performed on mounds LL from OA cleaning in Tanks 5, 6, 12, 16, and 24 indicated that aggressive mixing is preferred to remove insoluble species, and to disturb mounds of waste.

[X-CLC-H-00896, U-SOW-H-00010]

Table 5.4-1: BOAC Inputs and Assumptions (Continued)

Attribute	Basis
Disperse Sludge Mounds during Pre-wash (to the extent practical).	• Distribution of mound material will increase surface area of sludge that is contacted during the addition of OA, increasing effectiveness of the addition.
Planning basis of 3 OA Strikes.	• Based on LL, 3 strikes in Tanks 12 & 16 were more effective than 2 strikes in Tanks 5 & 6. • 70% of the sludge heel is assumed to be dissolved in the 1st strike, 50% of the remaining sludge in the 2nd strike, and 30% of the remaining sludge in the 3rd strike. • OA Spray wash has the potential to dissolve sludge material on the vertical surfaces of the tank (walls, columns, cooling coils, etc.) not submerged during the previous strikes.
Maximum Volume ratio of 20:1 OA to Sludge.	• Fill height determined by starting solids concentration. • Previous corrosion and waste testing completed at ratio of 20:1. • Tank level limitations during OA cleaning may restrict volume of acid added to the tank. This may affect the efficiency of the dissolution process.
Maximum OA Concentration of 8 wt% OA (diluted to 2-4 wt% during mixing and transfer).	• Previous corrosion and waste testing completed with 8 wt% OA. • DSA controls based on 4 wt% in the transfer line. • 2 to 4 wt% OA is recommended because 8 wt% OA is close to the solubility limit of oxalate.
Process Temp 75 ºC maximum, normal operations ≤ 60 ºC	• Previous corrosion and waste testing completed at ≤ 75 ºC with no agitation and ≤ 60 ºC with agitation. • LL from Tank 16 indicates higher temperatures resulted in more effective dissolution. • approximately 50 ºC OA was used for Tanks 5 and 6.
Maintain pH < 2.	LL showed the following: • Increased pH (>2) reduces the solubility of metals, thereby precipitating oxalates. • Delays in transfers from treatment tank (during cleaning of Tanks 5 and 6) allowed acid to more fully react, changing pH, and resulting in precipitation of solids.
Pump down between strikes to a minimum level.	Reducing the liquid heel volume: • Increases the OA/sludge contact on subsequent strikes • Maintains a lower pH reducing precipitation of oxalates, and • Removes spent acid from the treatment tank
Tank modifications are required to establish corrosion, tank overflow, flammability, and chemical compatibility controls for OA cleaning.	LL from Tank 12 and nuclear safety controls.

[X-CLC-H-00896]

Table 5.4-2: LTAD Inputs and Assumptions

Attribute	Basis
Sufficient hydroxide to dissolve a significant portion of aluminum compounds; and a low aluminum concentration.	• Sufficient hydroxide is required to dissolve gibbsite or boehmite in a timely manner, and, if desired, to maintain its' solubility after subsequent cooling or dilution. • The dissolution rate is impacted by the hydroxide content, as well as the temperature, degree of agitation, and sodium concentration. Sources of added hydroxide include 50 wt.% truckloads, and 242-16H Evaporator concentrate (DWPF recycle).
Process temperature as high as practical.	• Higher temperature improves dissolution rate, especially for boehmite. • Sources of heat include the exothermic dilution of caustic, Evaporator concentrate delivered at higher temperature, and mechanical heat from slurry pump operation. • The maximum temperature attained for LTAD of the Tank 12 heel was 86 ^{o}C. The temperature attained for Sludge Batch 5 bulk LTAD (in Tank 51) was 65 ^{o}C.
Use at least three SLPs.	• To mobilize solids to enhance contact with high hydroxide concentration. It may not be necessary to run all pumps all the time. For example, only periodic slurrying may be necessary for sufficient mass transport after dissolution rate inevitably slows, but operating one or two pumps relatively continuously might be useful to control the maximum temperature. • To mobilize solids remaining after dissolution for slurry transfer. • To provide a heat source to optimize the reaction rate. • SMPs have not been employed for LTAD. Suction head requirements for SMPs could necessitate more caustic and limit the heat-up rate. Temperature limits for SMPs will limit the maximum temperature.

[X-CLC-H-00871, X-TRT-H-00006]

5.4 Cooling Coil Flushing

Type I and II tanks contain both intact and failed cooling coils. Intact and failed cooling coils may require flushing prior to the introduction of grout. Previously identified cooling coils that have large or guillotine-type leaks are flushed from each coil end back into the primary tank, while minimizing the addition of water to the tank. The inputs and assumptions are described in Table 5.5-1.

Table 5.5-1: Cooling Coil Flushing Inputs and Assumptions

Attribute	Basis
Coils requiring flushing will be flushed as needed to prevent creation of mixed waste during coil grouting.	• A three-volume flush is expected to remove greater than 99% of the loose contamination and chromate cooling water in the coiling coils. This is the flush volume traditionally used for flushing the SRS waste transfer lines. However, based on process sampling, Tanks 5 and 6 cooling coils were successfully flushed with a 1 – 2 line volume flush.
Broken cooling coils requiring flushing will be flushed from the inlet and outlet.	• Flushing from the inlet and outlet ensures contaminants are flushed from each end of the broken (e.g., guillotine) coils. Leaking coils with small leaks will be flushed with intact coils.

[WSRC-TR-2002-00403]

5.5 Annulus Cleaning

Many of the old-style waste tanks (Type I and II) have had waste leak from the primary vessel into the annulus. Annulus cleaning for removal of contaminants may involve rinsing the outside walls of the waste tank and the annulus pan, followed by transfer to the tank primary, or to another tank. Annulus cleaning may be performed along with the primary tank heel removal activities because the rinse solution is sent to the primary waste tank, or another waste tank. The annulus is inspected before requesting concurrence to cease waste removal activities to confirm previously documented conditions, and to determine if additional leakage from the primary waste tank occurred during the waste removal process. The inputs and assumptions are described in Table 5.6-1.

Table 5.6-1: Annulus Cleaning Inputs and Assumptions

Attribute	Basis
Annulus waste accumulations are supernate only.	• Any material that leaks from a waste tank into the waste tank annulus would only be supernate. Insoluble solids cannot leak from the waste tank to the annulus due to the restricted size of the cracks in the waste tank walls (provided BOAC was not performed).
Salt nodules may be dissolved from the primary tank wall exterior by either direct water spray, or spray from a magnetic wheeled crawler.	• Previous LL from Tanks 5 and 6 annulus cleaning.
Annulus pan cleaning may be accomplished by batch water additions, and transfer to another tank or to the tank primary.	• Batch water additions are sized to prevent overflow of the annulus pan. Previous LL Tank 9 annulus cleaning.

[S-CLC-G-00235]

5.6 Residual Sampling/ Isolation

When a waste tank is cleaned and ready to remove from service, residual waste samples are taken from the primary tank (and annulus, if applicable) to assist characterization of the remaining radiological and hazardous components. In addition, waste tank services and transfer lines are physically isolated preventing unintentional or inadvertent waste tank operation. The inputs and assumptions are described in Table 5.7-1.

Table 5.7-1: Residual Sampling/Isolation Inputs and Assumptions

Attribute	Basis
Assume a minimum of fifteen samples will be obtained from the tank primary.	• *Liquid Waste Tank Sampling and Analysis Program Plan (LWTRSAPP)*, SRR-CWDA-2011-00050. Based on condition of primary tank, the number of samples can be revised.
Fifteen samples will be required from tanks with significant annulus accumulation.	• *Liquid Waste Tank Sampling and Analysis Program Plan (LWTRSAPP)*, SRR-CWDA-2011-00050. Based on condition of annulus, the number of samples can be revised.
Samples away from an accessible riser will be retrieved using a crawler.	• Previous sampling experience has shown that use of a crawler, such as an Inuctin 450 Crawler, away from a riser to be the most efficient manner for obtaining samples.
Samples under a riser may be retrieved with a pole mounted vacuum or scraper.	• Previous experience in Tanks 5, 6, and 16.
Samples are transported to SRNL in the 6 ton Cask or SRNL's Encapsulated Lead Shipping Package (ELSP).	• Experience with sampling has shown transporting samples with the 6 Ton Cask or ELSP is the most efficient. The size of both containers allows sufficient time to lower flammability limit (LFL) before the sample must be removed.
The number of tanks having closure samples undergoing analysis at one time is limited.	• Constraint is driven by the number of high-level cells at SRNL and the coordination/integration of all campaigns that the cells support (i.e., tank closure, DWPF, salt processing, etc.).
Coil sampling may be required.	• Experience with Tank 6 and Tank 12 indicates that if a large amount of residual solids adhere to the coils, especially the upper regions, sampling may be required.
The tank shall be isolated for closure.	• *Performance Assessment for the F-Tank Farm*, SRS-REG-2007-00002. *Industrial Wastewater General Closure Plan for F-Area Waste Tank Systems*, LWO-RIP-2009-00009.
All potential influents are isolated.	• Once the tank is determined to be ready for closure, no other fluids that might add to the inventory (Radiological and Chemical) of the tank can be added (without an evaluation). This includes the isolation of Bearing Water, Inhibited Water, Waste Transfers, and Chromated Cooling Water.
All potential energy sources are isolated.	• Once the tank is determined to be ready for closure, there is a desire to reduce maintenance, construction, configuration management, and design cost by utilizing work packages for follow-on activities. Energy sources include Plant Air, Instrument Air, Electrical, and Steam.
A tank specific configuration management plan will be developed.	• *Configuration Management Implementation Plan for F Tank Farm, H Tank Farm, 299H, and Effluent Treatment Project*, G-ESR-H-00127. • The tank specific plan provides guidance for the utilization of work packages to control configuration management.
Commodities will be air gapped as field conditions allow.	• The use of air gaps supports the use of work packages for follow-on work, configuration management, and the reduction of formal designs.
An isolation matrix (similar to that required by the Site Out of Commission Process) will be used to document isolation.	• Isolation matrix is used to positively document hazardous energy and potential influents have been removed from the tank.

5.7 Tier 2 Closure Plan

Tier 2 Closure Plans are prepared to demonstrate that the closure of the waste tank or waste tank group meets the requirements and objectives outlined in the Tier 1 Closure Plan (see Section 2.4).

5.8 Stabilization

Filling the waste tank with grout stabilizes the tank and prevents water intrusion. Cement-based grout: 1) fills void spaces, 2) reduces the risk of subsidence, 3) provides a physical barrier from weather exposure, 4) is a physical deterrent to casual intruders, and 5) creates chemical conditions that discourage transport of remaining residue. The inputs and assumptions are described in Table 5.9-1.

Table 5.9-1: Stabilization Inputs and Assumptions

Attribute	Basis
Procurement Specification Number C-SPP-F-00055 is used for the bulk fill grout (primary and annulus, if applicable).	• SRNL testing has shown that grout meeting the requirements of Specification C-SPP-F-00055 have the required physical properties needed to perform bulk fill of the tank. [SRNL-STI-2011-00551]
Equipment fill grout will meet the requirements of SRNL-STI-2011-00592.	• Grout meeting the requirements of *Tanks 18 and 19-F Equipment Grout Fill Material Evaluation and Recommendations,* SRNL-STI-2011-00592, meet all requirements of the PA and has been shown to have the required physical properties needed to successfully fill equipment void spaces.
Cooling Coil fill grout (when applicable) will meet the requirements of WSRC-STI-2008-00172.	• Grout meeting the requirements of *Closure of HLW Tanks – Formulation for A Cooling Coil Grout,* WSRC-STI-2008-00172, meet all requirements of the PA and has been shown to have the required physical properties needed to successfully fill cooling coil void spaces.
Grout will be directed to desired risers by either a pump truck or slick line.	• *Grout Strategy for Closure of Type I, II, and Type IV Tanks*, SRR-LWE-2012-00150.
In-Tank Equipment may be filled by hand (bucket) or with a hand pump and hose.	• *Grout Strategy for Closure of Type I, II, and Type IV Tanks*, SRR-LWE-2012-00150.
Grouting of the tank (primary, annulus, and cooling coils, as applicable) must not compromise the integrity of the tank.	• *Grout Strategy for Closure of Type I, II, and Type IV Tanks*, SRR-LWE-2012-00150.
Risers will be filled or capped as conditions dictate.	• *Grout Strategy for Closure of Type I, II, and Type IV Tanks*, SRR-LWE-2012-00150.

6.0 TANK SPECIFIC CLEANING STRATEGIES

This section provides long-term planning guidance for waste removal and operational closure of future tanks tailored to the service history of the waste tank system, the physical and chemical characteristics of the waste in the tank, and the physical configuration of the waste tank system. This guidance attempts to optimize tank cleaning by maximizing the effectiveness of each cleaning step and attempts to project equipment re-use, where applicable. This document does not contain sufficient detail for detailed execution; instead providing guidance for the project when the execution documents are produced.

Revision 0 of this document provides tank-specific cleaning strategies for five waste tanks (Tanks 9, 10, 11, 14, and 15). For these five waste tanks the following information is included:

- Background,
- Receipt summary,
- Waste physical and chemical characteristics,
- Waste removal to date,
- Current tank infrastructure and system interface considerations, and
- Cleaning recommendations for:
  - BWRE, and
  - Heel removal.

This document will be revised in the future, as needed, to provide cleaning strategies for additional waste tanks as they roll into the planning window, incorporating LL and new information to date. These are the next five waste tanks (Tanks 9, 10, 11, 14, and 15) in the System Plan designated for cleaning. See Section 6.6 for more information on future waste tanks to be cleaned.

6.1 Tank 9 Cleaning Strategy

6.1.1 Tank 9 Background

Tank 9 is a 750,000-gallon HTF Type I tank. The primary tank is 75 feet in diameter, and has an 80 foot diameter, five foot deep annulus pan.

Tank 9 was constructed between 1951 and 1953 and entered service in 1955 as the first H-Canyon waste receipt tank. This waste tank remained active and operational until 1973. The largest volume of waste stored in Tank 9 has been approximately 740,000 gallons. [DPSP 58-1-7-S] As of March 31, 2014, Tank 9 contained approximately 14,000 gallons of supernate, 2,700 gallons of sludge, and 534,000 gallons of saltcake. [SRR-LWP-2014-00014] In 1955, Tank 9 received high-heat waste from the H-Canyon PUREX process, prior to H-Canyon conversion to the HM process. In 1965 and 1966, the supernate and sludge were removed from Tank 9 to allow the waste tank to serve as a concentrate receipt tank for the 242-H evaporator. Tank 9 supported the 242-H evaporator until 1973. Since 1973, the waste tank has served as a salt waste storage tank. [DPSPU 79-11-1] Tank 9 is known to have leaked and approximately 8 to 10 inches of salt deposits has been observed on the annulus floor. However, the exact location of the leak sites has not been identified.

6.1.2 Tank 9 Receipt Summary

Tank 9 was initially filled by January 1956 with PUREX high heat waste from H-Canyon, and remained at this level until November 1965.

In July 1966, approximately 15 inches of sludge was removed by high pressure sluicing to Tank 13, so that Tank 9 could be converted to use as the 242-H Evaporator concentrate receipt (“drop”) tank. In March 1967 the gravity drain line was completed from the 242-H Evaporator to Tank 9, and the tank was placed into service as an evaporator drop tank. In May 1967 crystallized salts bridged and plugged the drop riser (Riser 6) below the gravity drain line (GDL) resulting in a spill to grade of approximately 100 to 200 gallons of evaporator concentrate. As a result of the spill response (and the unavailability of the GDL), Tank 9 was converted to be the second stage of a proposed two-stage transfer system (evaporator drop tank). First, evaporator concentrate was sent to Tank 10. The cooling water was turned off in Tank 10 during this operation to minimize crystallization and allow only low solubility salts to settle. Supernate from Tank 10 was then transferred to Tank 9 where it was cooled to cause maximum crystallization. As Tank 9 filled with supernate, recycle transfers were made to return evaporator feed to Tank 13. Tank 9 gradually filled with 198 inches of crystallized salt from 242-H Evaporator, transferred via Tank 10. [DPSPU 79-11-1]

6.1.3 Tank 9 Waste Physical and Chemical Characteristics

The remaining small volume of Tank 9 sludge is exclusively from initial H-Canyon PUREX operations prior to the HM-Process renovations in 1959. Gluconic acid was used during this initial period of Canyon operations as a complexing agent. No rheology data is available. The sludge rheology is expected to be similar to other PUREX sludges. It is not known what volume of insoluble solids will remain after salt dissolution is completed, or the impact of these solids on overall rheology for final tank cleaning.

6.1.4 Tank 9 Waste Removal to Date

Tank 9 leakage was discovered in October 1957. In 1958 and 1959, the Tank 9 annulus was cleaned with nine water flushes of approximately 2,000 gallons each. Each flush was allowed to soak for 1-2 weeks, and then the solution was pumped to the primary. It was estimated that 9000 pounds of solids were dissolved from the annulus (equivalent to about 3000 gallons of waste removed).

In July 1966, supernate from Tank 9 was transferred to Tank 13, and sludge removal operation was begun, using high pressure sluicers (see Section 4.1.1). Five sluicers and four transfer pumps were employed. In August 1966, a limited periscopic inspection following sludge removal showed an unevenly distributed quantity of sludge remained, estimated to be about 1.5 inch average depth.

In the early 1980’s, Project S1959, an early waste removal project, planned to install two slurry pumps to dissolve salt by agitation, and prepared Risers 4 and 6 with structural steel and spray chambers. However, tank farm space constraints at the time prevented further work activity. Project S2081, another early waste removal project from the 1980's, planned to install two additional slurry pumps into Tank 9 in Risers 1 and 8, but these risers were not prepared.

6.1.5 Tank 9 Current Tank Infrastructure and System Interface Considerations

Risers 4 and 6 currently have structural steel to support mixing pump insertion. An existing transfer jet in Riser 3 is connected to an unqualified line segment to H-Diversion Box (HDB) 1, and transfers through this system are not permitted. No qualified transfer infrastructure currently exists for Tank 9.

Tank 9 currently has three known leak sites and at least one unknown leak site based on 13% visual inspection of the primary tank wall. It is expected that additional leaksites exist in areas that have not been inspected. The summary of leak sites is recorded in Table 6.1-1. The annulus has an estimated 8 to 10 inches of salt accumulation on the annulus floor.

Table 6.1-1: Tank 9H Leak Site Summary

Leak Site	Discovery Date	Location	Elevation
1	Oct. 1957	West	276 inches
2	Oct. 1957	North	271 inches
3	Oct. 1957	South	130 inches
4	Oct. 1957	Unknown	Unknown

[C-ESR-G-00003]

Of the 34 cooling coils originally installed, Tank 9 currently has only five operable cooling coils and these are connected to the chromate cooling water distribution header. Tank 9 cooling coils had begun to fail shortly after the initial sludge removal campaign.

6.1.6 Tank 9 Cleaning Recommendations

The following general guidelines are recommended considering the tank specific receipt summary, waste physical and chemical characteristics, existing tank infrastructure, system impact considerations, and previous waste removal experience on other tanks. These guidelines are shown below as recommendations (abbreviated as R1, R2, etc.), with an associated basis for each.

Tank 9 Bulk Waste (Salt) Removal Efforts:

R1 D&R as necessary to install salt removal equipment to dissolve salt by SCD:

- Re-use the DWS from Tank 10.
- Install low volume mixing jets. Note that riser availability may limit the number of jets that may be installed for initial salt dissolution.
- Install hose-in-hose transfer capability to either Tank 11, to a new Above Grade Valve Box, or to HDB2, to allow transfers during salt dissolution.
- Refurbish the Annulus to Primary transfer jet gang valve, or design and install a shielded Annulus to Primary transfer system.

R1 basis Experience with salt dissolution on Tanks 10 (See Section 6.10) and Tank 37 indicates the majority of salt will be readily dissolved using SCD. Using SCD avoids gas release modifications typically required for density gradient salt dissolution. Previous leakage history on Tank 9 indicates the tank is likely to accumulate significant quantities of dissolved salt solution in the annulus during BWRE, necessitating transfers from the annulus to the primary.

Tank 9 Heel Removal:

R1 Perform additional D&R, and install heel removal equipment as follows, maximizing use of infrastructure previously installed under Project S1959:

- Mine the simulated vertical cooling coil and remove from Riser 1. This simulated coil was installed following conversion to an evaporator drop tank to monitor force transmitted to the tank roof by salt adhering to the tank coils (the test coil was supported by a force gauge). Reuse an SMP from Tank 10, and install on the floor of Tank 9.
- Remove abandoned purge inlet piping from Riser 8. Perform riser mining to the floor of the tank. Reuse an SMP from Tank 10, and install on the floor.
- Remove spray chamber from Riser 4 and install a third SMP from Tank 10. The decision to hang this pump from the tank structural steel or to mine the pump to the tank bottom will depend upon the depth of residual material following salt removal.
- Establish hose-in-hose transfer capability to Tank 11, to a new Above Grade Valve Box, or to HDB2, to allow transfers during heel removal. A recirculation transfer route is preferred to maximize removal effectiveness.

R1 basis Using 3 SMPs ensures the heel will be mixed thoroughly, considering the rheology predicted for Tank 9 sludge slurry. Mounting pumps in Riser 1 and 8 on the floor of the tank requires tank mining (and employee dose), but avoids structural steel design and installation. Performing ongoing recirculating transfers during heel removal is preferred, to maximize waste removal effectiveness, and to take advantage of the cooling capacity of the sludge receipt tank, but may not be possible due to tank heating from SMP operations.

R2 Establish a heel removal operating strategy. Raise tank liquid level to submerge pumps. Operate mixing pumps at full speed in oscillating mode for the necessary period to disturb sludge to the full ECR of the pumps. Initiate a Tank 9 transfer, and pump down to transfer pump suction, performing sludge mapping during pump down.

R2 basis Operating the SMPs for the full period to establish pump ECR maximizes the probability that the affected region of each pump is fully mixed. Pumping the entire contents of the tank to the target receipt tank enables sludge mapping, and places the heated supernate in a tank with cooling capability.

R3 Based on sludge mapping during initial heel removal transfer, develop a pump indexing (or lancing) strategy to disperse mounds and continue waste removal. At the end of each pump run campaign, initiate a transfer, shut down pumps, and pump the tank to heel, mapping the remaining sludge volume. This process should be repeated until the mapping indicates diminished return.

R3 basis Waste removal campaigns in Tanks 4, 5, 6, and 12 benefitted from performing indexed mixing pump operations to disperse and suspend sludge accumulated in mounds.

R4 No chemical cleaning is recommended for Tank 9.

R4 basis The amount of uranium predicted in the Tank 9 heel is low, and much will be removed by mechanical heel removal. OA cleaning is predicted to be marginally beneficial for the sludge heel. The high iron to aluminum ratio does not indicate LTAD would be beneficial. [SRR-WRC-2013-0006]

R5 Perform annulus cleaning, as described in Section 5.5. Add heated flush water or inhibited water, in batches, and pump to the primary to dissolve accumulated annulus salts.

R5 basis Annulus cleaning was previously performed successfully in Tank 9 by batch water addition.

R6 If indexed pump operations are not effective in achieving MEP, perform a fresh water feed and bleed mixing evolution (if a recirculating transfer route has not previously been used). If recirculating transfers have been used, use IW or fresh water to perform a targeted waste removal campaign.

R6 basis A fresh water feed and bleed mixing evolution was effective in achieving MEP on Tank 5. Using IW as a final mixing medium ensures maximal removal of water-soluble HRRs.

6.2 Tank 10 Cleaning Strategy

6.2.1 Tank 10 Background

Tank 10 is a 750,000-gallon HTF Type I tank. The primary tank is 75 feet in diameter, and has an 80 foot diameter, five foot deep annulus pan. Tank 10 was constructed between 1951 and 1953 and entered service in 1955 as an H-Canyon waste receipt tank. The largest volume of waste stored in Tank 10 has been approximately 727,000 gallons. [DPSP 59-1-4-S] As of March 31, 2014, Tank 10 contained approximately 270 gallons of supernate, 2,700 gallons of sludge and 203,000 gallons of saltcake. [SRR-LWP-2014-00014] From 1955 through 1959, Tank 10 received high-heat waste from the H-Canyon PUREX process, prior to H-Canyon conversion to the HM process. In 1967, the supernate and majority of sludge were removed from Tank 10 to allow the waste tank to serve as a concentrate receipt tank for the 242-H evaporator. During the sludge removal operation, a spill of approximately 40 to 50 gallons occurred near Riser 5 on Tank 10 [DPSP 67-1-2-S]. From 1967 until 1974, Tank 10 served as a concentrate receipt tank for the 242-H evaporator and, during this time, underwent several salt removal campaigns. The remaining saltcake resulting from receipts of the evaporator bottoms was left in storage in Tank 10. [DPSPU 78-11-11] Additional salt removal campaigns were performed in Tank 10 beginning in 1979 and 1982. [DPSP 79-21-5, DPSP 82-21-12, DPSP 83-21-2] In 1985, water additions to Tank 10 were made to support tank operations and, during the late 1980's, several transfers of supernate were made from Tank 10. From 1985 until 2013, the waste tank has served as a salt waste storage tank. [SRR-LWP-2012-00061] A recent salt removal campaign was conducted in 2013 using SCD. Tank 10 is known to have leaked and approximately 2 to 3 inches of salt deposits has been observed on the annulus floor. However, the exact location of the leak sites has not been identified.

6.2.2 Tank 10 Receipt Summary

Tank 10 was initially filled to 93% capacity with high heat PUREX waste from H-Canyon operations, by September 1956.

In February 1967, sludge removal was performed, and most of the sludge was removed to Tank 13. The tank was temporarily filled in 1967 with diluted evaporator concentrate from Tank 9. Then the tank was placed into service as the first stage of a proposed two-stage transfer system (evaporator drop tank). The cooling water was turned off during this operation to minimize crystallization and allow only low solubility salts to settle. The supernate was then transferred from Tank 10 to the second stage tank (Tank 9) where it was cooled to cause maximum crystallization. Tank 10 gradually filled with approximately 200 inches of crystallized salt from 242-H Evaporator operations, prior to termination of use as an evaporator concentrate waste receiver in 1974. [DPSPU 78-11-11]

6.2.3 Tank 10 Waste Physical and Chemical Characteristics

Tank 10 sludge is almost exclusively from H-Canyon PUREX operations prior to the HM-Process renovations in 1959. The sludge has not been sampled since 1967, and no rheology data is available. The sludge rheology is expected to be similar to other PUREX sludges. It is not known what volume of insoluble solids will remain after salt dissolution, or the impact of these solids on overall rheology for final tank cleaning.

The sludge heel in Tank 10 currently underlies approximately 60 inches of saltcake

6.2.4 Tank 10 Waste Removal to Date

In February 1967, supernate from Tank 10 was transferred to Tank 13, and sludge removal operation was begun, using high pressure sluicers. Five sluicers and four transfer pumps were employed. Estimates of 58,000 to 63,000 gallons of sludge were slurried with 232,000 gallons of water and pumped to Tank 13. Near the end of the operation, a transfer pump discharge hose ruptured and 40 to 50 gallons of radioactive waste leaked. The leakage contaminated approximately 1,000 square feet of graveled area south of Riser 5. The total spill was estimated to be approximately 250 Curies. In December 1967, a 40-foot periscope inspection of Tank 10 following waste removal showed no sludge mounds rising above a 7-inch liquid level. The liquid level was dark and opaque. A sounding beneath Riser 7 indicated a solids depth of about 0.50 inch to 0.75 inch. Soundings beneath three risers in February 1967 had indicated solids less than 0.25 inches deep. [DPSP 67-1-12]

In December 1970, and April 1971, two transfers of dilute waste from the Receiving Basins for Offsite Fuels (RBOFs) were received into Tank 10, to dissolve bulk salt and to remove overhanging salt on the upper portions of the vertical cooling coils.

In April 1979, a salt removal demonstration was begun on Tank 10 using a density gradient method. Water was pumped from Tank 23 into Tank 10 to establish a tank liquid level. Then a low flow rate transfer (15 – 18 gpm) was started from Tank 23 into Tank 10, and a low flow rate transfer was started from Tank 10 to Tank 29, using a jet mined into the salt in Tank 10. [DPSP 79-21-4] This demonstration was suspended in May 1979, due to an evaporator bottoms line failure, and a resulting reappraisal of transfer line stresses. Subsequent sampling of Tank 10 indicated the dissolved salt solutions were higher in NaNO3 than Technical Standards limits, requiring a subsidiary Test Authorization to continue dissolution. Salt dissolution in Tank 10 resumed in May 1980, and suspended in 1982 due to lack of available space in H-Tank Farm. About 211,000 gallons of salt were estimated to have been removed from the tank (47% of the total tank salt volume), leaving 79 inches of saltcake. [DPSP 83-21-3, DPSP 79-17-11]

Project S2081 originally planned to install four slurry pumps into Tank 10. Plans for waste removal were revised in October 1984 to only install three slurry pumps into Tank 10, due to the success of salt dissolution by mechanical agitation in Tanks 19 and 24, and due to the development of a single-discharge slurry pump (never deployed) by SRNL. [DPSP 84-21-10] Due to changes in site priorities for waste removal, additional salt removal efforts were suspended until salt processing facilities were available.

In May 2013, salt dissolution resumed on Tank 10, using a SCD method. Approximately 101,000 gallons of well water was added to Tank 10 and approximately 96,000 gallons of dissolved salt solution was transferred from Tank 10 to Tank 11. Approximately 48,000 gallons of saltcake was dissolved during Stage 1 with an estimated salt dissolution ratio of 2.08 (volume of liquid added/volume of dissolved saltcake). The salt solution in Tank 11 was then pumped to Tank 21, providing solution for Salt Batch 7. [SRR-LWE-2013-00099] Further salt removal for future salt batches was then suspended until the dissolved salt solution can be handled by salt processing facilities.

6.2.5 Tank 10 Current Tank Infrastructure and System Interface Considerations

Project S2081 prepared Risers 1, 4, and 8 with structural steel to support mixing pump insertion. The tank risers were not probed, due to the existing salt accumulation (however, video inspection of Riser 1, 4, and 8 indicated a possible interference from a bracket and a return cooling coil possible interference on Riser 1). [SRR-LWE-2011-00241] Currently Low Volume Mixing Jets are installed in these three risers. A submersible transfer pump assembly is installed in the center riser, and an above-grade, hose-in-hose transfer line is routed to Tank 11, Riser 2. An existing transfer jet in Riser 2 is connected to an unqualified line segment to HDB1, and transfers through this system are not permitted.

Tank 10 currently has an unknown number of leak sites based on 19% visual inspection of the primary tank wall. The annulus has an estimated 2 to 3 inches of salt accumulation. [C-ESR-G-00003] Leakage of waste into the annulus was first detected in 1959.

Tank 10 cooling coils began failing shortly after the tank was placed in service. The failure pattern of Tank 10 cooling coils has been abnormal compared to all other tanks. Many of these failures occurred in the first 1-1/2 years of operation, suggesting that abnormal conditions were responsible. After seven leaking coils had been detected, a caustic deficiency in the supernate was discovered by sampling. Caustic was added to the tank to correct the tank chemistry, but no mixing was provided to stir the supernate phase. After Tank 10 was placed into service as an evaporator bottoms tank, the tank was put into high temperature service (85 – 90 ºC) as a receiver of first stage bottoms (as part of a two tank evaporator bottoms process). The cooling was kept off the tank for approximately four years. It was theorized that the stoppage of flow of chromate-inhibited cooling water to the coils may have led to coil failure due to depletion of the inhibitor. By 1974, twenty cooling coils had failed on Tank 10. Following recent and historical salt removal campaigns, the Tank 10 supernate phase chemistry was outside corrosion controls, and remained in this condition for an extended period of time following initial salt removal. The underground cooling water supply and return headers are abandoned in place.

6.2.6 Tank 10 Cleaning Recommendations

The following general guidelines are recommended considering the tank specific receipt summary, waste physical and chemical characteristics, existing tank infrastructure, system impact considerations, and previous waste removal experience on Tank 10 and other tanks.

Tank 10 Bulk Waste (Salt) Removal Efforts:

R1 Restore the DWS and transfer system to service, and perform salt removal by SCD until the limit of technology is reached. Salt dissolved from Tank 10 may be used as part of a salt batch for MCU, or for SWPF.

R1 basis Experience with salt dissolution on Tank 10 indicates the majority of salt will be readily dissolved using SCD. Previous samples have been used to qualify Tank 10 dissolved salt to feed MCU.

Tank 10 Heel Removal:

R1 Perform intrusive D&R, and install heel removal equipment as follows, maximizing use of infrastructure previously installed under Project S2081:

- Remove spray chambers from Risers 1, 4, and 8, and install 3 SMPs or equivalent to establish adequate mixing. The decision to hang pumps from the tank structural steel or to mine the pumps to the tank bottom will depend upon the depth of residual material following salt removal.
- Do not restore tank chromate cooling water supply.

- Establish hose-in-hose transfer capability to Tank 11, to a new Above Grade Valve Box, or to HDB2, to allow transfers during heel removal. A recirculation transfer route is preferred to maximize removal effectiveness.

R1 basis Using 3 SMPs ensures the heel will be mixed thoroughly, considering the rheology predicted for Tank 10 sludge slurry. Given the extensive failures of the existing cooling coils, and the likelihood of total failure during SMP operations, the effort and cost to restore chromate cooling water to the remaining 10 potentially operable coils is not warranted. Performing ongoing recirculating transfers during heel removal is preferred, to maximize waste removal effectiveness, and to take advantage of the cooling capacity of the sludge receipt tank, but may not be possible due to tank heating from SMP operations.

R2 Establish a heel removal operating strategy. Raise tank liquid level to submerge pumps. Operate mixing pumps at full speed in oscillating mode for the necessary period to disturb sludge to the full ECR of the pumps. Initiate a Tank 10 transfer, and pump down to transfer pump suction, performing sludge mapping during pump down.

R2 basis Operating the SMPs for the full period to establish pump ECR maximizes the probability that the affected region of each pump is fully mixed. Pumping the entire contents of the tank to the target receipt tank enables sludge mapping, and places the heated supernate in a tank with cooling capability.

R3 Based on sludge mapping during initial heel removal transfer, develop a pump indexing (or lancing) strategy to disperse mounds and continue waste removal. At the end of each pump run campaign, initiate a transfer, shut down pumps, and pump the tank to heel, mapping the remaining sludge volume. This process should be repeated until the mapping indicates diminished return.

R3 basis Waste removal campaigns in Tanks 4, 5, 6, and 12 benefitted from performing indexed mixing pump operations to disperse and suspend sludge accumulated in mounds.

R4 No chemical cleaning is recommended for Tank 10.

R4 basis The amount of uranium predicted in the Tank 10 heel is low, and much will be removed by mechanical heel removal. OA cleaning is predicted to be marginally beneficial for sludge heel treatment. The high iron to aluminum ratio does not indicate LTAD would be beneficial. [SRR-WRC-2013-0006] If a stubborn heel remains following salt dissolution that is not affected by indexing campaigns, then consider sampling of the heel to determine if a chemical approach is warranted.

R5 If indexed pump operations are not effective in achieving MEP, perform a fresh water feed and bleed mixing evolution (if a recirculating transfer route has not previously been used). If recirculating transfers have been used, use IW or fresh water to perform a targeted waste removal campaign.

R5 basis A fresh water feed and bleed mixing evolution was effective in achieving MEP on Tank 5. Using IW as a final mixing medium ensures maximal removal of water-soluble HRRs.

6.3 Tank 11 Cleaning Strategy

6.3.1 Tank 11 Background

Tank 11 is a 750,000-gallon HTF Type I tank. The primary tank is 75 feet in diameter, and has an 80 foot diameter, five foot deep annulus pan. Tank 11 was constructed between 1951 and 1953 and entered service in 1955 as an H-Canyon waste receipt tank. The largest volume of waste stored in Tank 11 has been approximately 744,000 gallons. [DPSP 60-1-9-S] As of March 31, 2014, Tank 11 contained approximately 116,000 gallons of supernate and 19,000 gallons of sludge. [SRR-LWP-2014-00014] From 1955 through 1956, Tank 11 received low-heat waste from the H-Canyon PUREX process, prior to H-Canyon conversion to the HM process. In 1961, supernate was transferred from Tank 11 and, from 1961 through 1968, the waste tank received high-heat waste from the HM process and THOREX. In 1969, a sludge removal campaign was performed in Tank 11. Tank 11 again became a receipt tank for high-heat waste from the HM process and served in that role until 1982. [DPSPU 78-11-12, DPSP 82-21-1] In 2004, a sludge removal campaign was performed in Tank 11. [CBU-PIT-2004-00002] In 2008, aluminum rich supernate from a Low Temperature Aluminum Dissolution campaign conducted in Tank 51 was transferred into Tank 11 for short-term storage. [SRR-LWP-2010-00007] In 2012, a portion of the aluminum rich supernate was transferred from Tank 11 to Tank 8 to be staged for future processing. [SRR-LWP-2012-00061] Tank 11 is known to have leaked at two identified leak sites and trace amounts of waste are present on the walls near the leak sites and on the annulus floor. [C-ESR-G-00003]

6.3.2 Tank 11 Receipt Summary

In July 1955, Tank 11 became the active receiver for H-Canyon PUREX low heat waste. Tank 11 was filled six times with waste from H-Canyon waste receipts. To support these receipts, the tank was decanted as needed to Tank 13 (leaving the sludge). A summary of waste receipts through 1974 is recorded in Table 6.3-1.

Table 6.3-1: Tank 11H Waste Receipt Summary Through 1974

Date	Source of Material	Volume/Comments	Approximate Sludge Level
July 1955	H-Canyon low heat waste	Between July 1955 and February 1957, Tank 11 was filled with H-Canyon PUREX low heat waste.	10 inches
November 1961	H-Canyon frame	In November 1961, approximately 261 inches of Tank 11 supernate was decanted to Tank 13. Tank 11 then received 221-H Frame waste (from recovery of Neptunium and Plutonium-238), and received waste from rerun and building flushes.	10 inches
July 1962	H-Canyon high heat waste	A supernate transfer was made to Tank 13 (approximately 88,000 gallons) to make space in Tank 11 to receive HM high heat waste. Between July 1962 and February 1963, the tank was filled to 268.5 inches.	10 inches
June 1965	H-Canyon high heat waste	About 230 inches of supernate were decanted to Tank 13. The tank was then filled with HM high heat waste (including waste from THOREX) by May 1966.	40 inches
July 1967	H-Canyon high heat waste	Supernate was again decanted to Tank 13, and Tank 11 was again filled with HM high heat waste (including waste from THOREX) by April 1968.	83 inches
October 1969	NA	Sludge removal was performed.	18 inches
November 1969	Tank 13, Tank 9, Tank 10	The tank received two transfers of liquid for temporary storage. The first transfer was 80 inches of waste containing mostly sludge removal liquid from Tank 13 with Tank 9 concentrated supernate. The second transfer was 110 inches of hot concentrated supernate from Tank 10.	18 inches
August 1970	H-Canyon high heat waste	The supernate was decanted to Tank 13, and Tank 11 resumed service as an HM high heat waste receiver. The tank was filled by May 1971.	20 inches
March 1973	H-Canyon high heat waste	The supernate was decanted to Tank 13, and Tank 11 resumed service as an HM high heat waste receiver. The tank initially received a 20-inch transfer of supernate from Tank 31. The tank was filled to approximately 255 inches by January 1974.	approximately 38 inches

[DPSPU 78-11-12]

Following 1974, Tank 11 continued service as an HM high heat waste receiver through July 1976. The tank was decanted and was filled with HM low heat waste from September 1978 to August 1979, and was reclassified as high heat waste because of cesium-137 content. HM low heat waste was received from May 1981 through January 1982. At the beginning of the second BWRE campaign, in November 2003, the Tank 11 sludge level was 51 inches, with a supernate level of 101.5 inches. [M-ESR-H-00240]

6.3.3 Tank 11 Waste Physical and Chemical Characteristics

Tank 11 sludge is estimated to be 6% PUREX low heat waste, 26% HM low heat waste, 6% HM high heat waste, and 1% THOREX high heat waste. [U-ESR-H-00058] The sludge was sampled in 1979, and the results of analyses were generally in agreement with the WCS. The sludge rheology was confirmed during BWRE to be similar to other high aluminum, HM sludges.

At the completion of BWRE, the actual sludge volume was estimated to be about 18,000 gallons.

6.3.4 Tank 11 Waste Removal to Date

In October 1969, sludge removal operation was begun, using high pressure sluicers (see Section 4.1.1). A total of 854,000 gallons of water was used over six days to sluice and remove sludge slurry from Tank 11 to Tank 13. The sludge volume was reduced from 225,000 gallons to an estimated 49,000 gallons. Removal was discontinued because the removal rate had become negligible and additional tank space was not available to store the slurry. Mounds of sludge remained after sludge removal; mounds four to five feet high were present. Sludge removal was performed to convert the tank over to salt service. The presence of mounds prevented conversion, so the tank was returned to fresh waste receipt.

In the early 1980's, Project S2081 planned to install four slurry pumps into Tank 11, and installed structural steel and spray chambers at Risers 1, 3, 5, and 8. Due to a change in site priorities for waste removal, no sludge removal was performed until sludge processing facilities (i.e., DWPF) were available.

Starting in 2000, preparations began for the resumption of waste removal to support sludge batch preparation for DWPF processing. Four new Lawrence SLPs were installed along with a new submersible transfer pump, at a cost of 17 million dollars. The pumps were operated in five sludge removal campaigns. The sludge volume was reduced from 138,000 gallons to about 18,000 gallons. Tank 11 is complete with BWRE. These waste removal campaigns experienced numerous instances of SLP stop/restarts due to low current indication (apparent pump screen pluggage). The transfer pump failed after the second transfer from the tank. The slurry pumps were subsequently moved to Tank 12 to meet sludge processing needs and used to complete BWRE on Tank 12. [SRR-WRC-2011-0003]

6.3.5 Tank 11 Current Tank Infrastructure and System Interface Considerations

SLPs (and their associated bearing water stations) from Tank 12 are being returned to Tank11 to provide mixing for mechanical heel removal. A submersible transfer pump assembly is installed in Riser 6, and is connected above grade to an abandoned jet discharge in Riser 7.

Tank 11 currently has two known leak sites based on 25% visual inspection of the primary tank wall. The leak sites are at 189 inches and 235 inches from the tank bottom. The leak sites consist of nodules on the tank wall with trace amounts on the annulus pan due to solids being washed down the tank wall.

Tank 11 currently has eleven operable cooling coils and is connected to the chromate cooling water distribution header. Tank 11 cooling coils began failing shortly after the initial sludge removal campaign. Video inspection of the tank at the time did not reveal coil leakage above the waste level. Historical documentation implies that these coil failures may have been due to impingement forces of the 3500 psi sluicing jets during sludge removal performed in the 1960's.

6.3.6 Tank 11 Cleaning Recommendations

The following general guidelines are recommended considering the tank specific receipt summary, waste physical and chemical characteristics, existing tank infrastructure, system impact considerations, and previous waste removal experience on Tank 11 and other tanks.

Heel Removal:

R1 Reinstall SLPs from Tank 12 in Risers 1, 3, 5, and 8. Restore bearing water stations.

R1 basis Using 4 SLPs ensures the heel will receive adequate mixing. Using SLPs instead of SMPs allows reuse of the Tank 12 SLPs and allows the variable frequency drives for the SLPs to be reutilized. The SLPs can be operated at lower tank levels, and can be operated to higher temperatures, making them a better choice for heel removal activities.

R2 Develop a flowsheet, and perform chemical cleaning by LTAD (see Section 4.3).

R2 basis Previous BWRE mixing and indexing campaigns reached a point of diminished return for mechanical cleaning. Tank 11 sludge heel is high in aluminum compounds, and much of the remaining 18,000 gallons may be dissolved by LTAD.

R3 Based on sludge mapping during LTAD decant, develop a pump index (or lancing) strategy to disperse mounds and continue waste removal. At the end of each pump run campaign, initiate a transfer, shut down pumps, and pump the tank to heel, mapping the remaining sludge volume. This process should be repeated until the mapping indicates diminished return. Use IW as a final mixing medium.

R3 basis Waste removal campaigns in Tanks 4, 5, 6, and 12 benefitted from performing indexed mixing pump operations to disperse and suspend sludge accumulated in mounds. Using IW as a final mixing medium ensures maximal removal of water-soluble HRRs.

6.4 Tank 14 Cleaning Strategy

6.4.1 Tank 14 Background

Tank 14 is a 1,070,000-gallon HTF Type II tank. The primary tank is 85 feet in diameter, and has a 90 foot diameter, five foot deep annulus pan. Tank 14 was constructed between 1955 and 1956 and entered service in 1957 as an H-Canyon waste receipt tank. The largest volume of waste stored in Tank 14 has been approximately 1,061,000 gallons. [DPSPU 77-11-19] As of March 31, 2014, Tank 14 contained approximately 28,000 gallons of sludge and 130,000 gallons of saltcake. [SRR-LWP-2014-00014] From 1957 through 1959, Tank 14 received high-heat waste from the H-Canyon PUREX process until waste leakage into the Tank 14 annulus was detected and fresh high-heat waste receipts were diverted to another waste tank. From 1959 through 1965, Tank 14 was used sparingly to receive high-heat waste from the HM process and high-heat waste that had leaked into the Tank 16 annulus. In 1968, supernate was removed from Tank 14 in preparation for a sludge removal campaign and, in December 1968, a sludge removal campaign was initiated. From 1969 through 1970, Tank 14 received concentrated supernate from several waste tanks and, in 1972, 14,000 gallons were siphoned from the primary tank into the Tank 14 annulus via the annulus jet, the waste was immediately returned to the primary tank. [DPSPU 77-11-19] Tank 14 remained idle until 1977 when waste from the Tank 16 annulus was transferred into Tank 14. [SRR-CWDA-2011-00126] Since 1977, the waste tank has remained idle. Tank 14 is known to have leaked at 33 identified leak sites, and it is estimated that there are about 50 leak sites in this waste tank. Approximately 10 to 13 inches of salt deposits has been observed on the annulus floor. [SRR-STI-2012-00346, C-ESR-G-00003]

6.4.2 Tank 14 Receipt Summary

Tank 14 began service in 1957 as a receiver of neutralized high heat waste from the PUREX process in H-Canyon. Waste leakage into the annulus was first detected in April 1959 when the tank was approximately half full, and waste receipts into Tank 14 were suspended. In September 1960, supernate was transferred into Tank 14 from Tank 16 annulus to address Tank 16 leakage. In November 1960, Tank 14 began receiving HM high heat waste, but receipts were suspended in December 1960, as annulus leakage rates increased. In June 1965, Tank 14 again began receiving HM high heat waste and was filled by November 1965. [DPSPU 77-11-19]

In July and August 1968, supernate from Tank 14 was removed. In December 1968, sludge was removed by high pressure sluicing to Tank 13.

Following sludge removal, Tank 14 was again filled to capacity with supernate blended from Tanks 10 and 13. This material was gradually transferred to Tank 13 as space was available. In 1977, Tank 16 annulus cleaning was performed, and the Tank 16 annulus material was transferred to Tank 14. In 1978, the Tank 14 level was gradually reduced to approximately 70 inches by transfer to Tank 13. This material was allowed to naturally evaporate from within the tank. Tank 14 currently has approximately 45 inches of salt over the sludge heel.

6.4.3 Tank 14 Waste Physical and Chemical Characteristics

Tank 14 sludge is a mixture of high activity H-Canyon PUREX waste, and low activity waste from the HM-Process. No rheology data is available.

The salt in Tank 14 is the result of in situ evaporation of moisture from the waste. This salt should be similar to other HM process salts. It is not known what volume of insoluble solids will remain after salt dissolution, or the impact of these solids on overall rheology for final tank cleaning.

6.4.4 Tank 14 Waste Removal to Date

In December 1968, sludge removal operation was begun, using high pressure sluicers. Four sluicers and four transfer pumps were employed. Early in the effort, two of the four transfer pumps failed. Inspection of the tank after sludge removal indicated a large pile of sludge on the north side and some sludge above the 10 inches liquid surface along the wall below Riser 6. Subsequent inspection indicated large areas of sludge visible above an 8 inch liquid level. Approximately 80% of the initial sludge level was removed by high pressure sluicing.

Project S2081 planned to install four slurry pumps into Tank 14 in Risers 2A, 4A, 6 and 8, but these risers were not prepared.

6.4.5 Tank 14 Current Tank Infrastructure and System Interface Considerations

An existing transfer jet in Riser 2 is connected to an unqualified, untestable line segment to Tank 13, and transfers through this system are not permitted. No qualified transfer infrastructure currently exists for Tank 14.

Tank 14 currently has about 50 known leak sites based on 89% visual inspection of the primary tank wall. The annulus has an estimated 10 to 13 inches of salt accumulation. The lowest known leak site is 16 inches from the tank bottom, and the highest is 288 inches. [C-ESR-G-00003] During October and November 1960, annulus level increases were monitored and an approximate 75-gallon per day leak rate was confirmed (the tank had approximately 220 inches of waste at the time).

Tank 14 currently has 35 operable cooling coils (out of 44 total), but is not connected to the chromate cooling water distribution header. Tank 14 cooling coils began failing shortly after the initial sludge removal campaign. The supply piping to the tank cooling coils is routed on the tank floor versus overhead, and will result in a need for greater mixing.

6.4.6 Tank 14 Cleaning Recommendations

The following general guidelines are recommended considering the tank specific receipt summary, waste physical and chemical characteristics, existing tank infrastructure, system impact considerations, and previous waste removal experience on other tanks.

Tank 14 Bulk Waste (Salt) Removal Efforts:

R1 Perform riser D&R as necessary to install salt removal equipment to dissolve salt by SCD:

- Re-use the DWS from Tank 9.
- Install new low volume mixing jets.
- Install hose-in-hose transfer capability to 13, or to HDB5 or HDB2, to allow transfers during salt dissolution.
- Refurbish the Annulus to Primary transfer jet system, or design and install a shielded Annulus to Primary transfer system.

R1 basis Experience with salt dissolution on Tanks 10 and Tank 37 indicates the majority of salt will be readily dissolved using SCD. Using semi-continuous salt dissolution avoids gas release modifications typically required for density gradient salt dissolution. Previous leakage history on Tank 14 indicates the tank may accumulate quantities of dissolved salt solution in the annulus during BWRE, necessitating transfers from the annulus to the primary.

<u>Tank 14 Heel Removal:</u>

R1 Perform additional D&R, and install heel removal equipment:

- Relocate 4 SMPs from Tank 15 and install to establish adequate mixing. Mine the waste tank at each of the four risers to allow the pumps to be set on the tank floor.
- Establish hose-in-hose transfer capability to and from Tank 13, to allow recirculating transfers during heel removal.
- Restore tank chromate cooling water supply to intact coils.

R1 basis Using 4 SMPs ensures the heel will be mixed thoroughly, considering the rheology predicted for Tank 14 sludge slurry. Four SMPs are recommended, versus three, considering:

- Previous sluicing campaign on Tank 14 with four sluicers was considered unsuccessful;
- Coiling coil headers are routed to the floor of Tank 14 versus the ceiling and provide greater resistance to mixing; and
- Four pumps and associated electrical infrastructure are available for re-use from Tank 15.

Mounting pumps on the floor of the tank requires tank mining (and employee dose), but avoids structural steel design and installation. Performing ongoing recirculating transfers during heel removal is preferred, to maximize waste removal effectiveness. Restoring tank cooling minimizes tank overheating due to power input from the SMPs.

R2 Establish a heel removal operating strategy. Raise tank liquid level to submerge pumps. Operate SMPs at full speed in oscillating mode for the necessary period to disturb sludge to the full ECR of the pumps. Initiate a Tank 14 to Tank 13 transfer, and an associated recirculation transfer (from Tank 13 to Tank 14), and perform the transfer for a period equivalent to 6 to 10 tank liquid volume turnovers. Then pump down to transfer pump suction, performing sludge mapping during pump down.

R2 basis Operating the SMPs for the full period to establish pump ECR maximizes the probability that the affected region of each pump is fully mixed. Operating the transfer system in recirculation mode then removes suspended material and prevents settling beyond the reach of the transfer pump suction. Operating the transfer pump (and recirculating system) for 6 to 10 tank liquid volume turnovers (not tank volume) maximizes waste removal in the mixing pump affected zone. Pumping the entire contents of the tank to the target receipt tank enables sludge mapping.

R3 Based on sludge mapping during initial heel removal transfer, develop a pump indexing (or lancing) strategy to disperse mounds and continue waste removal. Establish an operating level in Tank 14, and operate SMPs and transfer recirculation system. At the end of each pump run campaign, pump the tank to heel, mapping the remaining sludge volume. This process should be repeated until the mapping indicates diminished return.

R3 basis Waste removal campaigns in Tanks 4, 5, 6, and 12 benefitted from performing indexed mixing pump operations to disperse and suspend sludge accumulated in mounds.

R4 Perform annulus cleaning, as described in Section 5.5. Add heated flush water or inhibited water, in batches, and pump to the primary to dissolve accumulated annulus salts.

R4 basis Annulus cleaning was previously performed successfully in Tank 9 by batch water addition.

R5 If significant accumulation of sludge remains following mechanical mixing campaigns, a sample of the remaining heel should be obtained to determine the predicted effectiveness of OA cleaning. Based on sample results and a cost-benefit evaluation, perform OA cleaning as described in Section 4.3.2.

R5 basis The predicted iron to aluminum ratio, and predicted quantity of uranium in the Tank 14 heel make this tank a potentially good candidate for OA cleaning. However, a cost-benefit evaluation would need to be performed. A sample of the heel would be used to confirm these predictions, and to tailor the chemical cleaning flow sheet. [SRR-WRC-2013-0006] Tank 14 sludge heel is not predicted to be a good candidate for LTAD since it is primarily PUREX high heat waste mixed with HM low heat waste.

R6 If OA cleaning is not performed, perform a final mixing campaign with IW or well water.

R6 basis Using IW as a final mixing medium ensures maximal removal of water-soluble HRRs.

6.5 Tank 15 Cleaning Strategy

6.5.1 Tank 15 Background

Tank 15 is a 1,070,000-gallon HTF Type II tank. The primary tank is 85 feet in diameter, and has a 90 foot diameter, five foot deep annulus pan. Tank 15 was constructed between 1955 and 1956 and entered service in 1960 as a receipt tank for supernate from Tank 16. The largest volume of waste stored in Tank 15 has been approximately 1,075,000 gallons (note that this level is slightly above the lowest tank penetrations). [SRR-CWDA-2012-00164] As of March 31, 2014, Tank 15 contained approximately 159,000 gallons of sludge and 76,000 gallons of saltcake. [SRR-LWP-2014-00014] In 1960, in response to leakage in Tank 16, Tank 15 was placed into service to initially receive supernate from Tank 16. From 1960 through 1978, Tank 15 received high-heat waste from the HM process and, during this time, supernate was periodically removed from Tank 15 to allow continued receipt of waste from H-Canyon. [DPSPU 77-11-26] From 1978 to 1980, Tank 15 received sludge slurry transfers from Tank 16. [SRR-CWDA-2011-00126] In 1982, a sludge removal campaign was performed in Tank 15. Since 1982, the waste tank has remained idle. [DPSP 82-21-3] Tank 15 is known to have leaked at 15 identified leak sites and trace amounts of waste are present on the walls near the leak sites and on the annulus floor. In 1973, 12 new annulus risers were installed to provide nearly 100 % waste tank wall area surveillance capability. [DPSPU 77-11-26, C-ESR-G-00003]

6.5.2 Tank 15 Receipt Summary

Tank 15 first received waste from Tank 16 and then became the active receiver for HM high heat waste. Tank 15 was filled six times with HM high heat waste. Between June 1964 and November 1972, the supernate was decanted 5 times (leaving the sludge) to allow the tank to be refilled. The tank also received the Tank 16 annulus cleaning waste. A summary of waste receipts through 1983 is recorded in Table 6.5-1.

6.5.3 Tank 15 Waste Physical and Chemical Characteristics

In the mid-1980's, three sludge samples were obtained from Tank 15 and analyzed during demonstration of aluminum dissolution performed in Tank 42 on sludge originating from Tank 15. Those sample results indicated that Tank 15 sludge was approximately 28 wt% aluminum and 5 wt% iron (wt% of washed dried sludge sample). Rheological tests indicated that Tank 15 samples ranged from 3 to 14 wt% insoluble solids, and possessed a yield stress from 12 to 187 dynes/cm^2. [DPSP-84-00439] Another important conclusion of this study was that the rheological properties of the Tank 15 sludge slurries were not changed significantly by aluminum dissolution. However, future SRNL aluminum dissolution studies on Tank 12 sludge, which is similar to Tank 15 sludge, did indicate a positive impact on sludge rheology.

Other studies have proposed that the presence of THOREX campaign waste (from U-233 production) contributed to the difficulty in performing waste removal in Tank 12. [SRR-CES-2010-00009] Tank 15 is estimated to contain over 15 metric tons of thorium. [DPSP 83-17-3] Since Tank 15 has greater concentrations of thorium than Tank 12, the Tank 15 flow sheet should incorporate lessons learned from Tank 12 waste removal.

Historically, Tank 15 has been a significant source of Rn-220 (thoron) emanation. Thoron is a gaseous decay product of Th-232. It is a noble gas, and decays with a 56 second half-life. Thoron progeny are particulates and can result in excessive exhaust filter loading, and can result in thoron contamination during tank access, if not mitigated by providing increased ventilation, or by covering the sludge with liquid to prevent the thoron from reaching the tank vapor space.

Table 6.5-1: Tank 15 Waste Receipt Summary

Date	Source of Material	Volume/Comments	Approximate Sludge Level
October 1960	Tank 16	369,000 gallons of supernate was moved from leaking tank 16 to reduce tank 16 below numerous leak sites.	Unknown
December 1960	H-Canyon high heat waste	Tank 15 began receiving HM high heat waste. In June 1964, 956,000 gallons of supernate was transferred to Tank 13.	Unknown
September 1964	H-Canyon high heat waste H-Canyon low heat waste H-Canyon THOREX	Tank 15 resumed high heat waste receipt service. In December 1964, fresh THOREX campaign waste was received. In March 1965, Low heat waste also was diverted to Tank 15. Tank 15 was filled by July 1965. In February 1966, 437,500 gallons of supernate was transferred to Tank 13 to permit suspended strontium-bearing sludge to settle in Tank 13 away from thermal currents created by fresh high heat sludge receipt in Tank 15. In April 1966, two additional transfers of supernate totaling 464,000 gallons were made to Tank 13.	30 inches
May 1966	H-Canyon high heat waste	Resumed receipts of fresh high heat waste, filling Tank 15 by the end of December 1966. In March 1968, 768,000 gallons of supernate were decanted to Tank 13.	80 inches
April 1968	H-Canyon high heat waste	Resumed receipt of high heat waste. In December 1969, 700,000 gallons of supernate were decanted to Tank 13 in four transfers.	85 inches
February 1970	Tank 12	Tank 15 was filled with supernate from Tank 12. This waste was subsequently decanted to Tank 13 in four transfers. Tank 15 was then filled with supernate from Tank 10.	90 inches
May 1971	H-Canyon high heat waste	Resumed high heat waste receipt. The final high heat waste receipt in Tank 15 was in February 1972.	90 inches
1979	Tank 16 (HM high heat waste, HM low heat waste)	Received four sludge slurry transfers from Tank 16 heel, adding approximately 67,000 gallons of sludge solids.	Unknown
1980	Tank 16	Received water wash/feed and bleed transfers.[1]	Unknown
March 1983	Tank 16	Received Tank 16 annulus cleaning fluid.[2]	Unknown

[DPSPU 77-11-26, DPSP 79-17-17]
1 DPSP-80-17-23
2 DPSP 83-21-3

6.5.4 Tank 15 Waste Removal to Date

Two long shaft slurry pumps from Tank 16 were installed in Tank 15, in Risers 6 and 4, in January 1982. [DPSP 82-21-1] In February and March 1982 two sludge slurry transfers were made to from Tank 15 to Tank 42. The second transfer was terminated when the transfer pump apparently overloaded. [DPSP 82-21-3] This waste removal campaign was performed to provide sludge for a demonstration of in-tank aluminum dissolution in Tank 42. These two transfers removed approximately 125,000 gallons of sludge solids to Tank 42. [DPSP 83-17-3] Because of the installed slurry pump locations in Tank 15, sludge was only disturbed from a portion of the tank. Three sludge soundings taken in 2010 and 2011 from Risers 1, 8, and the 3-foot 6-inch riser have given sludge depth measurements of 70.1 inches, 39.7 inches, and 26.4 inches respectively, indicating that the sludge heel is sloped consistent with previous slurry pump locations. [SRR-LWE-2013-00039]

In May 1982, the two slurry pumps were raised to 152 inches from the tank bottom. [DPSP 82-21-5]

In July 1983, riser probing results for Tank 15 were reported as shown in Table 6.5-2.

Table 6.5-2: Tank 15H Riser Probing Summary

Riser	Height of Observed Obstruction Above Tank Bottom, Inches	Nature of Obstruction
1	55	Unidentified
2	19	Hard Sludge
3	27	Hard Sludge encountered at 27 inches [1] (Iron Bar at 324 inches removed).
4	8	Hard Sludge
5	approximately 60	Dropped Riser Probe
6	48	Unidentified
7	15	Hard Sludge
8	51	Unidentified Metallic Object
3 foot 6 inches	6	Hard Sludge

[DPSP 83-21-7]
1 DPSP 83-21-8

Based on riser probing results, Project S2081 planned to install slurry pumps into Risers 2, 3, 4, and 8. The Riser 8 slurry pump was planned to be a fixed position pump 53 inches through 55 inches from the tank bottom, with an angled discharge nozzle design.

Following the in-tank processing demonstration, the slurry pump in Riser 6 was relocated (by Project S2081) to Riser 3. Subsequently, the motors were removed from both pumps.

6.5.5 Tank 15 Current Tank Infrastructure and System Interface Considerations

Project S2081 prepared Risers 2, 3, 4, and 8 with structural steel to support mixing pump insertion. The existing failed transfer pump remains in Riser 7, and the transfer line between Tank 15 and HDB2 is routed through an unqualified pipe encasement.

The Tank 15 underground chromate cooling water supply and return headers are abandoned in place.

Tank 15 currently has twenty known leak sites based on 96% visual inspection of the primary tank wall. The lowest leak site is at the lower circumferential weld at 30 inches and the highest leak site is at 200 inches. Fourteen of the twenty leak sites are covered by salt nodules. Some of the nodules have accompanying trails of salt to the annulus floor with a small amount of waste on the annulus floor. The summary of leak sites is recorded in Table 6.5-3.

Table 6.5-3: Tank 15H Leak Site Summary

Leak Site	Discovery Date	Location	Elevation
1	Apr 1972	North	34 inches
2	Apr 1972	North	34 inches
3	1973	South	130 inches
4	1973	NW	90 inches
5	1973	NW	30 inches
6	1973	NW	96 inches
7	1973	NW	30 inches
8	1973	NW	34 inches
9	1973	NE	30 inches
10	1973	NE	30 inches
11	1973	NE	150 inches
12	1973	NE	38 inches
13	1973	NE	150 inches
14	1998	East	150 inches
15	1998	East	150 inches
16	1998	West	200 inches
17	2000	NW	30 inches
18	2000	East	30 inches
19	2002	NE	129 inches
20	2005	East	31 inches

[C-ESR-G-00003]

Six additional partial through-wall cracks (not active leak sites) have been identified using Ultrasonic Testing (UT). These partial through-wall cracks range in length from 0.55 inches to 5.4 inches. [C-ESR-H-00026]

6.5.6 Tank 15 Cleaning Recommendations

The following general guidelines are recommended considering the tank specific receipt summary, waste physical and chemical characteristics, existing tank infrastructure, system impact considerations, and previous waste removal experience on Tank 15 and other tanks.

Re-wet:

R1 Restore purge ventilation to service. Perform minimum essential D&R to initiate re-wet. Install a re-wet downcomer and level detection (radar). Procure contingency transfer system (CTS). Stage, but do not install tank transfer system, and perform drills.

R1 basis Prevent radon/thoron releases during future intrusive D&R by performing these activities post re-wet. The purchase of additional CTS equipment and drills are an appropriate contingency.

R2 Establish annulus level management strategy. Raise and set annulus conductivity probes. Develop camera inspection plan. Revise annulus leak detection Abnormal Operating Procedure. Establish procedure/package to operate annulus under negative pressure.

R2 basis Reactivation of some leak sites should be anticipated. Past activities in this tank have not resulted in gross leakage to the annulus, indicating that a permanent, installed annulus-primary transfer system is not warranted.

R3 Revise safety basis to reflect Tank 15 as a wet tank.

R3 basis Tank is currently listed as a dry sludge tank, with administrative controls to prevent dry sludge tank accidents.

Tank 15 Bulk Waste Removal Efforts:

R1 Perform intrusive D&R, and install BWRE equipment as follows, maximizing use of infrastructure previously installed under Project S2081:

- Install 4 SMPs or equivalent to establish adequate mixing. Stage SMPs above sludge layer (approximately 90 inches).
- Install hose-in-hose transfer capability to and from Tank 13, to allow recirculating transfers during BWRE. Set initial transfer pump suction near the SMP discharge elevation.
- Restore tank chromate cooling water supply to intact cooling coils.

R1 basis Using 4 SMPs ensures the tank will be mixed effectively, considering the difficult rheology predicted for Tank 15 sludge slurry. Establishing the transfer system with recirculation capability allows waste removal transfers to begin prior to mining pumps into the waste (minimizing the risk of pump pluggage), and uses Tank 13 cooling capability in addition to the restored Tank 15 cooling coils.

Restoring tank cooling extends mixing pump operating time (SMPs have an operating temperature limit of 70 ºC). The installation of the transfer line before raising the liquid level above the re-wet height will provide a pump down capability if required to control leakage.

R2 Establish BWRE operating strategy. Raise tank liquid level to submerge pumps. Operate SMPs at full speed in oscillating mode for the necessary period to disturb sludge to the full ECR of the pumps. Initiate a Tank 15 – Tank 13 transfer, and a recirculation transfer, and perform the transfer for a period equivalent to 6 – 10 tank liquid volume turnovers. Pump down to pump suction, or to the minimum submergence for SMP operation. Following the transfer termination, perform sludge sounding in Tank 15, and lower SMPs and Transfer Pump suction accordingly, but do not mine pumps into waste. Repeat as needed until the pumps are fully inserted. Then perform a final mixing and transfer campaign, and pump to tank heel, performing sludge mapping during pump down.

R2 basis Operating the SMPs for the full period to establish pump ECR maximizes the probability that the affected region of each pump is fully mixed. Operating the transfer system in recirculation mode then removes suspended material and prevents settling beyond the reach of the transfer pump suction. Operating the transfer pump (and recirculating system) for 6 – 10 tank liquid volume turnovers (not tank volume) maximizes waste removal in the mixing pump affected zone. Terminating the transfer at pump suction ensures the majority of supernate is staged in Tank 13 to cool while sludge sounding and pump lowering is performed in Tank 15 (more cooling coils are anticipated to be operable in Tank 13 than Tank 15). Lowering pumps to the sludge layer (but not mining into the sludge) enables gradual removal of the sludge without undue risk of pump pluggage due to high wt% suspended solids.

<u>Tank 15 Heel Removal:</u>

R1 Based on sludge mapping during final BWRE transfer, develop a pump indexing strategy to disperse mounds and continue waste removal. Establish an operating level in Tank 15 from Tank 13, and operate SMPs and transfer recirculation system. Shut down pumps, and pump the tank to heel, mapping the remaining sludge volume. This process should be repeated until the mapping indicates diminished return.

R1 basis Waste removal campaigns in Tanks 4, 5, 6, and 12 benefitted from performing indexed mixing pump operations to disperse and suspend sludge accumulated in mounds.

R2 If indexed pump operations are not effective in achieving MEP, perform LTAD per baseline (see Section 5.3). Maximize re-use of existing tank supernate or DWPF recycle. Perform indexed pump operations as needed to maximize sludge contact and to regulate tank temperature and dissolution reaction.

R2 basis Sample analysis indicates that Tank 15 sludge is up to 28% aluminum, and previously, LTAD successfully dissolved 77% of aluminum in Tank 15 sludge in

Tank 42. High aluminum and low uranium content do not make this tank a good candidate for chemical cleaning with OA. [SRR-WRC-2013-0006]

R3 Following LTAD, perform targeted mixing and waste removal operations (repeat R1) with supernate or water (for the last campaign) to achieve MEP.

R3 basis Using IW or well water as a final mixing medium ensures maximal removal of water-soluble HRRs.

6.6 Future Waste Tank Cleaning Strategy

In the current System Plan, the remaining old-style waste tanks (Tanks 1-4, 7, 8, 13, and 21-24) have not been scheduled for cleaning in the near future. As these additional waste tanks are scheduled for cleaning, this strategy document will be updated, as necessary, with cleaning efforts likely to follow similar processes presented above. See the FTF and HTF Basis documents for additional background information on these future waste tanks. [DOE/SRS-WD-2012-001, DOE/SRS-WD-2013-001]

7.0 SUMMARY

The SRS has applied the knowledge learned over the past 50 years to optimize numerous waste removal technologies that can be implemented in the tank farms. Technology selection is performed in a structured approach to identify and compare variable alternatives to meet the defined functions and requirements for waste removal and operational closure. A MEP procedure (S4 ADM.53) is used to document, during the waste removal and operational closure process, the decision process for technology selection to remove waste to the MEP in accordance with NDAA 3116.

Even with the success of waste removal and operational closure to-date, new opportunities, technologies, and LL are routinely identified to optimize the cleaning method. Some examples of current technology development efforts include:

- Developing new cost-effective mixer pumps for optimized agitation and multipurpose use based on lessons learned from SLPs and SMPs
- Monitoring technology progress at other DOE sites (e.g., Mobile Arm Retrieval System, the advanced reach sluicing system at the Hanford Site)
- Continuing development of crawler and vacuum technology to sample tanks for closure
- Monitoring tank sonar mapping technology development

SRS has successfully completed BWRE from seven waste tanks and has performed operational closure on six waste tanks. Waste removal technologies, to include mixing, transfer, isolation, and stabilization, continue to be refined, based on experience.

SRS has performed OA cleaning on five waste tanks. In general, OA cleaning has proven effective in dissolving iron-based compounds in sludge, and in removing some HRRs. OA cleaning is less effective in dissolving aluminum-based sludge compounds. OA cleaning is relatively ineffective at removing plutonium. Each waste tank cleaned with OA generates approximately 32,000 kg of spent oxalate, which does not currently have a viable disposition path for removal. The consideration of using OA cleaning for one of the heel removal steps for future waste tanks should include a cost-benefit evaluation in the decision process.

The tank-specific processes used for waste removal and closure vary depending on the waste tank service history, the remaining waste physical characteristics, the tank system physical configuration, and the waste removal timing. In summary, SRS has a proven waste tank cleaning process that removes greater than 99% of tank inventory. [SRR-CWDA-2011-00005, SRR-CWDA-2011-00033, SRR-CWDA-2011-00091] Also in place is a robust, rigorous technology selection process to evaluate new technologies as they mature. Based on LL from each completed tank, the selected technologies continue to be optimized to address physical, chemical, and system challenges. However, future improvements may be incremental since current processes are already removing greater than 99% of original waste volume.

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