SRR-CWDA-2013-00091
Revision 0

# INDUSTRIAL WASTEWATER CLOSURE MODULE FOR LIQUID WASTE TANK 16H
## H-AREA TANK FARM, SAVANNAH RIVER SITE

**February 2015**

**Industrial Wastewater Construction Permit No. 17,424-IW**

Prepared by: Savannah River Remediation LLC
Regulatory Management & Administration
Aiken, SC 29808

Prepared for U.S. Department of Energy Under Contract No. DE-AC09-09SR22505

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ACRONYMS

| | |
|---|---|
| AEA | Atomic Energy Act of 1954 |
| BOA | Bulk Oxalic Acid |
| C&WDA | Closure & Waste Disposal Authority |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CFR | Code of Federal Regulations |
| CHA | Consolidated Hazard Analysis |
| CM | Closure Module |
| CMCOC | Contaminant Migration Constituent of Concern |
| CSR | Chemical Sludge Removal |
| CTS | Concentrate Transfer System |
| DCF | Dose Conversion Factor |
| DOE | United States Department of Energy |
| DWPF | Defense Waste Processing Facility |
| ECR | Effective Cleaning Radius |
| EDE | Effective Dose Equivalent |
| EIS | Environmental Impact Statement |
| EOI | Expression of Interest |
| EPA | United States Environmental Protection Agency |
| FFA | Federal Facility Agreement |
| FMB | Fourmile Branch |
| FTF | F-Area Tank Farm |
| GCP | General Closure Plan |
| GSA | General Separations Area |
| HDB | H-Tank Farm Diversion Box |
| HLLCP | High Liquid Level Conductivity Probe |
| HTF | H-Area Tank Farm |
| H&V | Heating and Ventilation |
| ICM | Integrated Conceptual Model |
| IP | Inspection Port |
| IROD | Interim Record of Decision |
| IW | Inhibited Water |
| LWTRS-QAPP | Liquid Waste Tank Residuals Sampling - Quality Assurance Program Plan |
| LWTRSAPP | Liquid Waste Tank Residuals Sampling and Analysis Program Plan |
| MOP | Member of the Public |
| MCL | Maximum Contaminant Level |
| MDC | Minimum Detectable Concentration |
| MSR | Mechanical Sludge Removal |
| OA | Oxalic Acid |
| OU | Operable Unit |
| PA | Performance Assessment |
| PP | Pump Pit |
| RCRA | Resource Conservation and Recovery Act |
| RFP | Request for Proposal |
| RFS | Removal from Service |

| | |
|---|---|
| RSL | Regional Screening Level |
| SA | Special Analysis |
| SCDHEC | South Carolina Department of Health and Environmental Control |
| SDF | Saltstone Disposal Facility |
| SEC | Safety and Ecology Corporation |
| SLDR | Sample Location Determination Report |
| SLP | Slurry Pump |
| SPF | Saltstone Production Facility |
| SRNL | Savannah River National Laboratory |
| SRR | Savannah River Remediation LLC |
| SRS | Savannah River Site |
| STP | Submersible Transfer Pump |
| TDL | Target Detection Limit |
| TEDE | Total Effective Dose Equivalent |
| TNX | Training and Experimental Test Facility |
| UCL95 | 95% Upper Confidence Limit |
| UTR | Upper Three Runs |
| WTS | Waste Transfer System |

# EXECUTIVE SUMMARY

The United States Department of Energy (DOE) and the State of South Carolina have developed the *Industrial Wastewater General Closure Plan for H-Area Waste Tank Systems* (SRR-CWDA-2011-00022) to support the removal from service (RFS) of the H-Area Tank Farm (HTF) underground radioactive waste tanks and ancillary structures at the Savannah River Site (SRS). The HTF General Closure Plan (GCP) establishes the protocol by which DOE intends to close HTF waste tank systems at SRS and receive approval from the South Carolina Department of Health and Environmental Control (SCDHEC) following a public comment period. This Closure Module (CM) has been prepared in accordance with the HTF GCP to support the RFS of underground radioactive waste Tank 16H in the HTF under the *Construction Permit #17,424-IW, SRS F/H-Area, Aiken and Barnwell County* (hereinafter referred to as Construction Permit #17,424-IW). [DHEC_01-25-1993]

Construction Permit #17,424-IW addresses both the HTF and F-Area Tank Farms (FTF). Due to a historical release which occurred in 1961, Tank 16H was not originally included in Construction Permit #17,424-IW but was added on November 23, 2010 to facilitate planned waste removal efforts in support of this waste tank being removed from service under the approved waste removal and operational closure schedule in the Federal Facility Agreement (FFA). [SRR-CES-2010-00067, DHEC_11-23-2010]

The SRS is a Federal facility owned by DOE. Since beginning operations in the early 1950s, uranium and plutonium recovery processes have generated liquid radioactive waste, which is currently stored in underground waste tanks in the F and H Areas at the site. The DOE intends to remove from service all of the waste tanks with priority being given to the old-style waste tanks that do not meet the standards established in Appendix B of the SRS FFA. [WSRC-OS-94-42] The FFA has been entered into pursuant to Section 120 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Sections 3008(h) and 6001 of the Resource Conservation and Recovery Act (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (hereinafter jointly referred to as RCRA) and the Atomic Energy Act of 1954 (AEA), as amended, 42 U.S.C. § 2011.[1] Once SCDHEC, the United States Environmental Protection Agency (EPA) and DOE mutually agree that waste removal from Tank 16H may cease, any residual contaminants will be stabilized through operational closure and then the tank will be removed from service under Construction Permit #17,424-IW. [DHEC_01-25-1993] Subsequently, the stabilized tank will be monitored and maintained in accordance with the requirements of an Interim Record of Decision (IROD) and the SRS RCRA Hazardous Waste Permit, Module VIII, as a solid waste management unit.

This CM describes the processes by which DOE has removed waste from Tank 16H, sampled residual contaminants, determined the remaining residual inventory and isolated the tank from the HTF facilities that remain operable. The DOE intends to remove from service Tank 16H in accordance with SCDHEC Regulation 61-82, *Proper Closeout of Wastewater Treatment Facilities*, and SCDHEC Regulation 61-67, *Standards for Wastewater Facility Construction*. In

[1] DOE's submittal of this plan does not waive any DOE claim of jurisdiction over matters reserved to it under the Atomic Energy Act of 1954.

addition, RFS of Tank 16H by this process is intended to be consistent with the applicable requirements of RCRA and CERCLA described in the FFA, which will govern the subsequent remediation of the HTF operable unit (OU). These regulations were reviewed at the time of development of this CM and have been verified to have no changes since the HTF GCP was issued. [SCDHEC R.61-82, SCDHEC R.61-67, WSRC-OS-94-42]

A performance assessment (PA) has been developed to assess the long-term fate and transport of residual contaminants in the environment resulting from the RFS of the HTF waste tanks. [SRR-CWDA-2010-00128] Considering the layout of the HTF and the presumed footprint of a potential closure cap (if deemed necessary and appropriate when a final remedy is selected for the HTF OU), it is expected that monitoring wells will be located approximately 100 meters from the HTF boundary (i.e., line of demarcation enclosing the HTF waste tanks). The HTF PA has used 100 meters as a point of assessment to predict long-term performance.

Before initiating this RFS process for Tank 16H under SCDHEC R.61-82 and SCDHEC R.61-67, DOE removed waste using mechanical and chemical techniques. The DOE then characterized radiological and non-radiological residual contamination in the waste tank and used the HTF PA to assess the long-term impact of the residual contaminants. This evaluation concluded that the stabilized Tank 16H would be protective of human health and the environment.

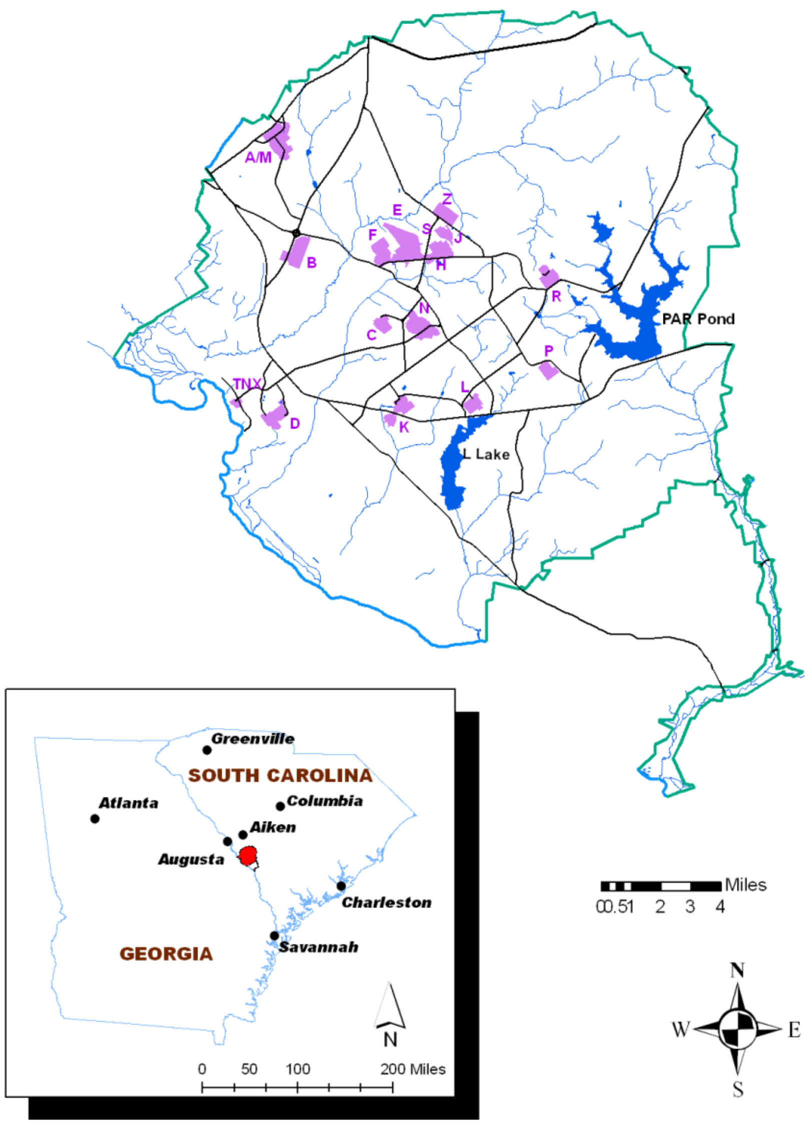
Based on the information provided in this CM and supporting documents, it may be concluded that (1) there is reasonable assurance that, at the time of final FFA corrective/remedial actions, groundwater concentrations derived from residual contamination in the tank and ancillary structures will meet the HTF GCP performance objectives and (2) further waste removal is not technically practicable from an engineering perspective.

The DOE has determined that all HTF GCP requirements have been met to proceed with removing Tank 16H from service and is ready to complete the process by stabilizing the waste tank with grout. Through approval of this CM, SCDHEC is agreeing that waste removal activities for Tank 16H can cease and authorizes stabilization of the tank and the residual contaminants under Construction Permit #17,424-IW. [DHEC_01-25-1993] Following operational closure, DOE will submit a Final Configuration Report for Tank 16H to SCDHEC (as described in the HTF GCP) with certification that the RFS activities have been performed in accordance with the HTF GCP (SRR-CWDA-2011-00022) and this CM.

# 1.0 INTRODUCTION

Since the early 1950s, the primary mission of SRS had been to produce nuclear materials primarily for national defense and deep space missions. A legacy of the SRS mission was the generation of liquid waste from chemical separations processes in both F and H Areas. Since the beginning of SRS operations, an integrated Liquid Waste System consisting of several facilities designed for the overall processing of liquid waste has evolved. Two of the major components of this system are the HTF and FTF located in H Area and F Area, respectively, which are near the center of the site (Figure 1.0-1). In H Area, neptunium, uranium, and other radionuclides were separated from irradiated fuel and target assemblies using chemical separations processes. The tank farms, which store and process the chemical separations waste, include waste tanks, evaporators, transfer line systems and other ancillary structures.

**Figure 1.0-1: SRS Operational Area Location Map**



In support of environmental remediation activities at SRS, DOE, EPA and SCDHEC signed the SRS FFA pursuant to Section 120 of CERCLA, Sections 3008(h) and 6001 of RCRA. The agreement became effective in August 1993. As part of this comprehensive agreement, DOE committed to submit and comply with a schedule to remove from service those liquid radioactive waste tank systems that do not meet the standards set forth in Appendix B of the FFA. Appendix B of the FFA also describes the specific radioactive waste tank systems that are subject to the agreement. [WSRC-OS-94-42]

The HTF GCP establishes the general protocols for removal of the HTF waste tanks and ancillary structures from service in accordance with SCDHEC R.61-82 and SCDHEC R.61-67. This CM provides specific information on the RFS of Tank 16H at the HTF and demonstrates that activities have been performed in accordance with requirements set forth in Section 6.0 of the HTF GCP. [SRR-CWDA-2011-00022]

This CM contains the following elements:

Introduction (Section 1.0) – Defines the purpose and scope of this CM.

Facility Description (Section 2.0) – Describes Tank 16H and provides a history of the waste tank and the waste types that have been managed in the system.

Waste Removal and Closure Configuration (sections as annotated below) – Describes the process used to remove waste from Tank 16H. These sections focus on the following sub-elements:

- Summary description of the technology selection process for waste removal (Section 3.0)
- Details of the waste removal process (Section 3.0)
- Characterization of residual waste (Section 4.0), including sampling and analysis details (Section 4.2)
- Waste tank system isolation process (Section 7.1)
- Description of structures and equipment that are part of this RFS activity including any equipment that will remain in the waste tank at the time of stabilization and RFS (Section 7.2)
- Stabilization strategy including type and characteristics of fill material, as appropriate (Section 7.3)

Performance Evaluation (Section 5.0) – Using the fate and transport model from the HTF PA, information is presented concerning the predicted peak groundwater concentrations.

Waste Removal Analysis (Section 6.0) – An analysis is provided to demonstrate that it is not technically practicable from an engineering perspective to continue with active waste removal activities. This analysis considers technology capabilities, schedule impacts and relative benefit.

Maintenance and Monitoring (Section 8.0) – This section provides a description of the HTF maintenance and monitoring plans that will be used for the interim period from the time Tank 16H is removed from service until the final closure of the HTF OU.

Conclusion (Section 9.0) – This section provides the conclusion that DOE has demonstrated that the proposed RFS configuration is protective of human health and the environment and that the closure actions will continue to be supportive of meeting the applicable performance standards for the closure of the HTF OU.

Waste Tank Systems Tracking (Appendix A) – This section tracks the tanks and ancillary structures to ensure that all components of the HTF will be addressed in a CM. This table will be updated in each CM with the RFS date and the document number of the CM that addresses each of the tanks and ancillary structures.

# 2.0 FACILITY DESCRIPTION

The HTF site was chosen because of its favorable terrain and its proximity to the H-Canyon Separations Facility (the major waste generation source), which was located near the center of the site, away from the SRS boundaries. Figure 2.0-1 shows the setting of H Area and HTF within the General Separations Area (GSA).

The HTF occupies 45-acres and consists principally of approximately 74,800 feet of transfer lines, 10 pump pits (PPs) (each has one pump tank except HPP-1 which has none), two concentrate transfer system (CTS) PPs, one catch tank, three evaporators, and 29 waste tanks (Figure 2.0-2). There are four major waste tank types in HTF: Type I tanks with a nominal capacity of 750,000 gallons, Type II tanks with a nominal capacity of 1,070,000 gallons, and Type III/IIIA and Type IV tanks with nominal capacities of 1,300,000 gallons.[2] The differing waste tank types have varying degrees of secondary containment and intra-tank obstructions, such as cooling coils and columns. The HTF design features (e.g., waste tanks, transfer lines, evaporator systems) are discussed in more detail in Sections 3.2.1 and 3.2.2 of the HTF PA. [SRR-CWDA-2010-00128]

The HTF was constructed to receive waste generated by various SRS production, processing and laboratory facilities. The use of HTF isolated these wastes from the environment, SRS workers and the public. Facilities are in place to treat the accumulated sludge and salt waste (supernate and saltcake) to enable the management of these wastes within other SRS facilities (i.e., Defense Waste Processing Facility [DWPF] and Saltstone Production Facility [SPF]). These treatment facilities convert the sludge and salt waste to more stable forms suitable for permanent disposal in a Federal repository or the Saltstone Disposal Facility (SDF), as appropriate. The Effluent Treatment Project, located southeast of the HTF, collects and treats wastewater and evaporator overheads from FTF and HTF operations.

[2] These are typical operating capacities. The Documented Safety Analysis operational limit for Type II tanks is 1,070,000 gallons. [WSRC-SA-2002-00007]

**Figure 2.0-1: Layout of the GSA**

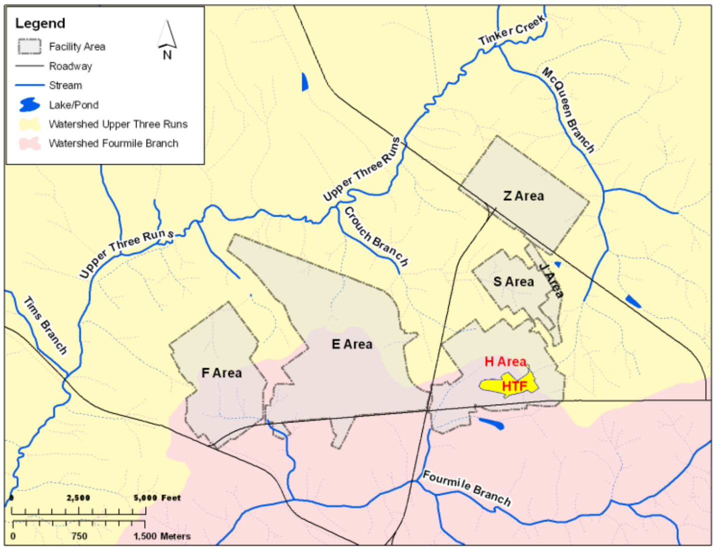



**Figure 2.0-2: Layout of HTF**


## 2.1 Tank 16H Design and Construction

### 2.1.1 Type II Waste Tank Design

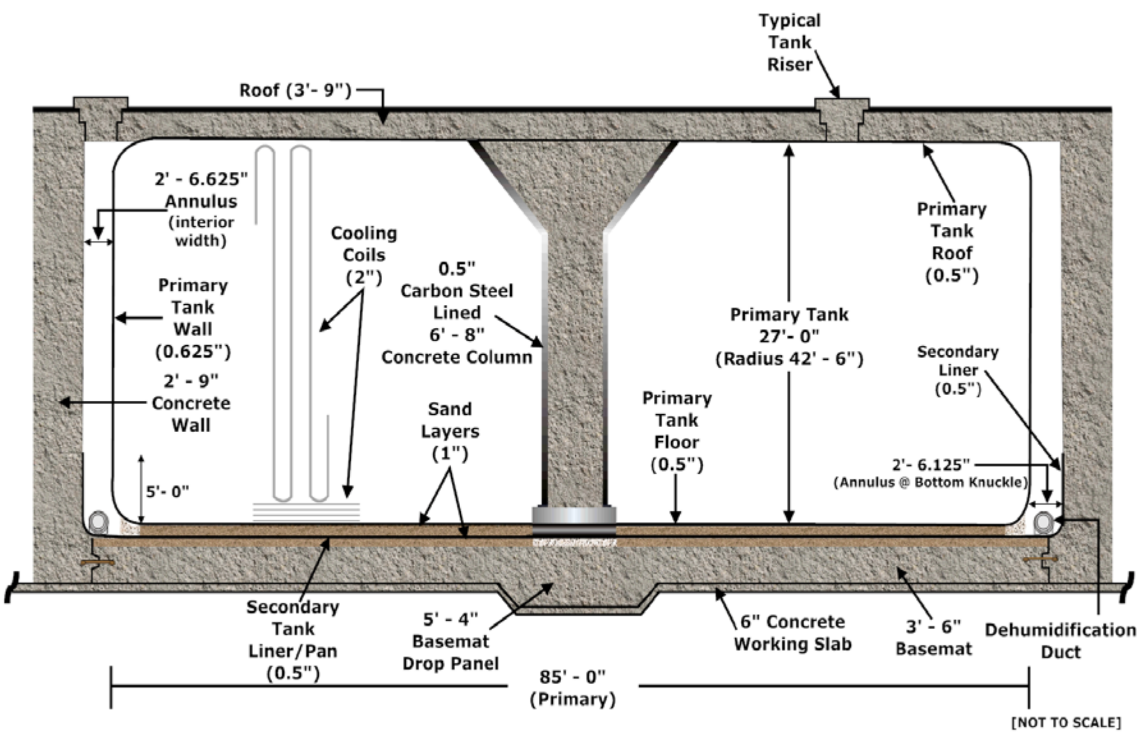
Tank 16H is one of the four Type II waste tanks (Tanks 13H through 16H) in HTF that were constructed between 1955 and 1956. The characteristics of typical Type II waste tanks are shown in Figure 2.1-1. A 95-foot-8.5-inch outer diameter concrete vault surrounds the Type

II tank primary liner creating a 2-foot-6.625-inch wide annulus. The vault has 2-foot-9-inch thick reinforced concrete walls and a 3-foot-9-inch thick reinforced concrete roof that surrounds the primary liner and connects to the basemat. The concrete vault height is approximately 34 feet 6 inches. The bottom of Tank 16H is approximately 6.5 feet below the mean elevation of the water table. [SRR-CWDA-2010-00128]

An HTF Type II tank has a primary tank inner radius of 42 feet 6 inches (excluding a 0.625-inch liner thickness) and a secondary liner (annulus pan) inner radius of 45 feet 1.5 inches (excluding a 0.5-inch liner thickness). The primary tank inner height is 27 feet and has a nominal operating capacity of 1,070,000 gallons. [WSRC-SA-2002-00007]

The annulus pan material is 0.5-inch thick carbon steel. [W162688] The annulus pan is 5 feet high with a 6 inch by 4 inch carbon steel stiffener angle welded to the top of the annulus pan to ensure rigidity of the top of the pan. It has an approximate volume of 25,700 gallons. [N-ESR-G-00001] Dehumidification equipment consisting of an above ground heater and fan connected to a metal ductwork system on the annulus pan floor were installed to keep the annular space dry by circulating warm air at a temperature above its dew point.

**Figure 2.1-1: Typical Type II Tank Cross Section**

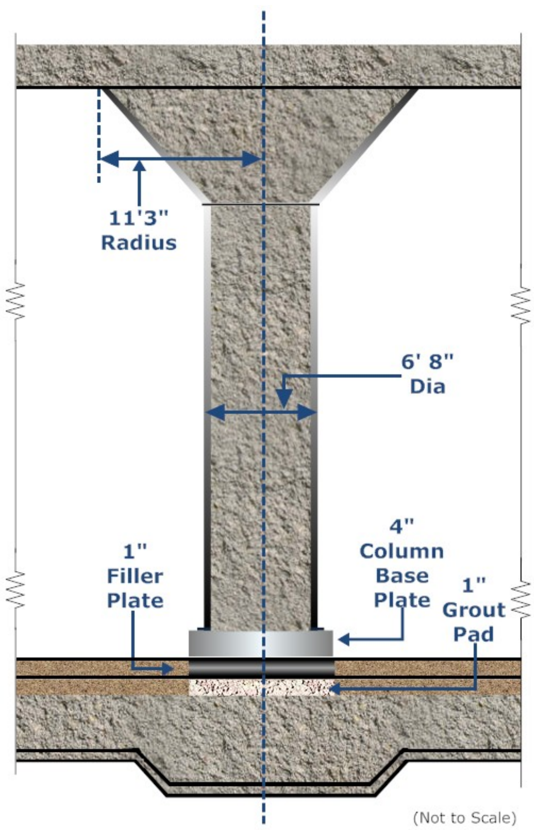



There are two separate ductwork sections that both begin in the southeast sector of the annulus. From their inflow point, one section runs clockwise and the other counterclockwise. They both terminate in the northwest annulus sector leaving an approximate 14-foot gap between the ends. The ends are closed off. The ductwork sections vary in diameter from a maximum of 20 inches at the inflow to a minimum of 12 inches at the distal end. Eight 14-inch long by 6-inch wide openings are equally spaced along the top of each ductwork section. [DP-1358]

The working slab for the four HTF Type II tanks is 6 inches thick with the waste tanks placed within a 255-foot by 274-foot rectangle. A 3-foot-6-inch thick reinforced concrete basemat is located on top of the working slab. The basemat and working slab were installed with 3,000-pounds per square inch strength at a 28-day cure time concrete. The basemat has reinforcing bars placed throughout. The depth, length and type of rebar vary depending upon the location within the basemat. There is a 1-inch thick layer of leveling sand between the top of the basemat and the secondary liner (annulus pan) and another 1-inch thick leveling sand layer between the annulus pan and primary tank floor. The 1-inch thick layers of sand, contained by an outer ribbon of "Sika-Igas™," were placed to create a level platform for the annulus and primary tank floor constructions. Sika-Igas™ is a black non-meltable mastic manufactured from blends of refined asphalts, resins and plasticizing compounds reinforced with long-fiber asbestos. [DP-1358]

One central reinforced, carbon steel jacketed concrete column supports the roof of a Type II tank (Figure 2.1-2). The column has an inside diameter of 6 feet 8 inches and a 0.5-inch thick carbon steel jacket. During construction, the column was first welded to a steel bottom plate, rebar was installed internally for reinforcement and then the column was filled with concrete.

**Figure 2.1-2: Support Column Dimension Details**




The Type II tanks have 44 cooling coils inside the primary tank. There are 40 vertical cooling coils arranged in 22 sections (rows) supported by hanger and guide rods that are welded to the roof and floor of the primary tank. The coils are approximately 24 feet high and extend from 8.5 inches above the floor to 2 feet 3 inches below the roof. The coils nearest the support column were field fitted and are shorter. Four horizontal cooling coil runs extend across the bottom of the primary tank and are supported by guide rods and steel angles welded to the primary tank floor. The floor coils are generally arranged in 20 row runs set at 90 degrees to each other. The centerline of the upper and lower coil run pipes are 5 inches and 2 inches above the floor, respectively. In some areas the runs are parallel and coils are stacked four high (Figure 2.1-3). [W163658] All cooling coils are 2-inch inside diameter, schedule 40 carbon steel seamless pipes. The total coil length is 29,400 feet. [W163593] Figure 2.1-3 shows the Tank 16H cooling coils and center support column.

**Figure 2.1-3: Tank 16H Center Column and Cooling Coils**

Access to the interior of a Type II tank for visual examination and equipment manipulation is restricted by the design configuration of the waste tank risers. As shown in Figure 2.1-4, riser configuration above the waste tank top restricts equipment insertions and views of the waste tank floor to small circular areas. The riser dimensions also limit the manipulation of long-handled mechanical tools and choices for the types of remote equipment that can be successfully deployed. As originally designed and constructed, the Type II tank roofs have eleven risers allowing access to the primary tank and four risers allowing access to the annulus. Ten of the primary tank risers are 24 inches in diameter. The eleventh access riser is 3 feet 6 inches in diameter. Type II tanks also have four additional risers for access to the North, East, South, and

West areas of the waste tank annulus. Due to leakage from the Tank 16H primary tank into the annulus pan, thirteen additional annulus riser openings, or inspection ports (IPs), were added later to permit 100% annulus inspections. Figure 2.1-5 shows the Tank 16H riser configuration as viewed from above.

Additional details for the Type II tanks are provided in Section 3.0 of the HTF PA. [SRR-CWDA-2010-00128]

**Figure 2.1-4: Type II Waste Tank Access Risers for Waste Removal Equipment Diagram**

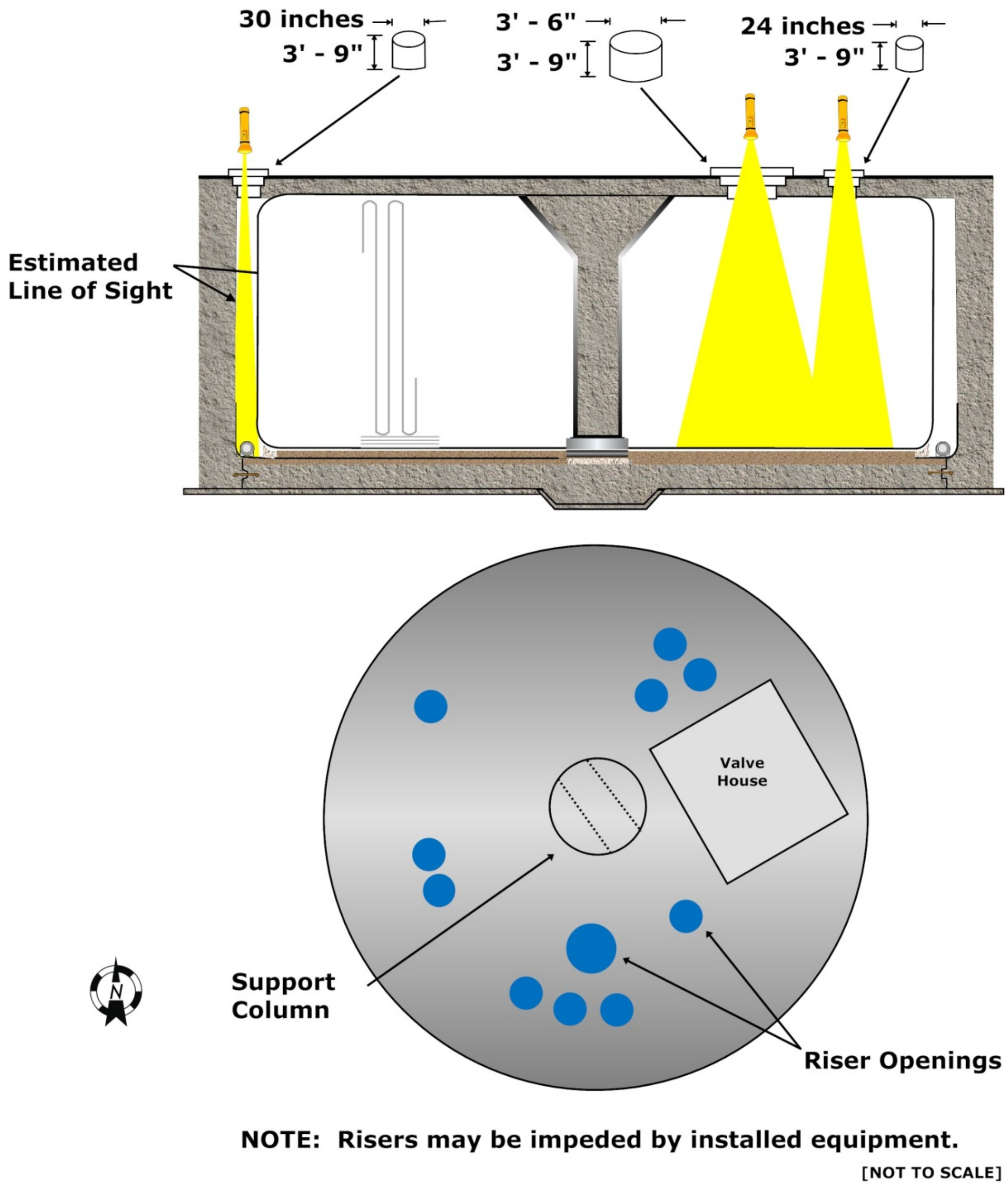
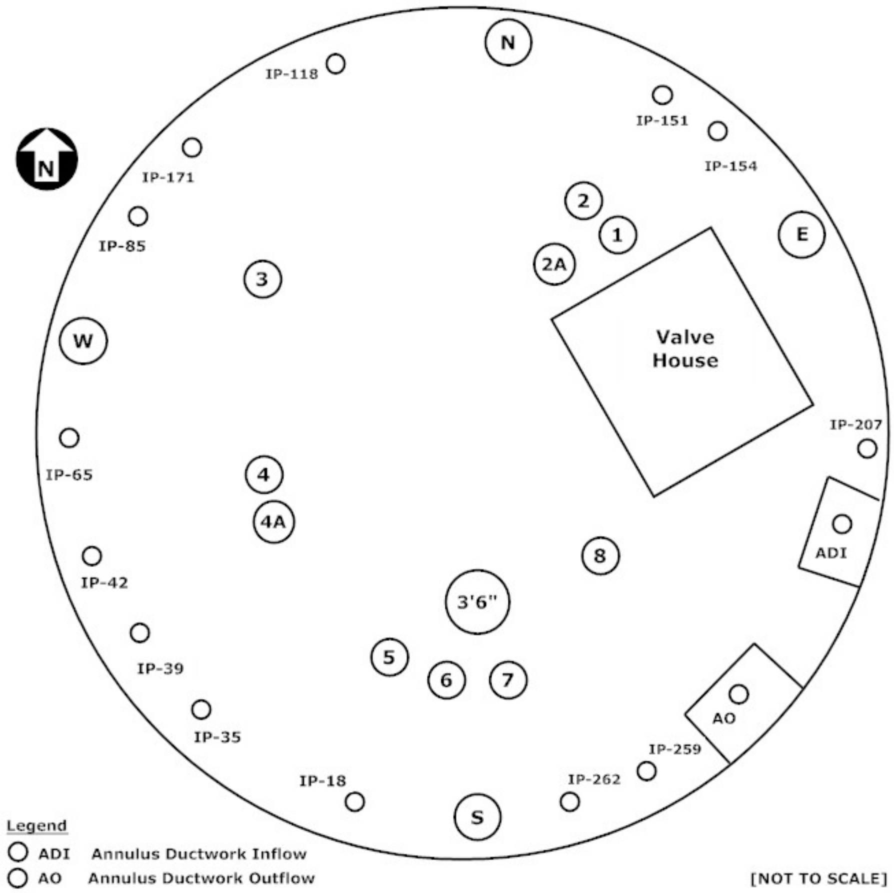


**Figure 2.1-5: Tank 16H Primary and Annulus Riser Configuration**




## 2.2 Waste Tank 16H Operational Service History

This section summarizes information on the waste types received and processed through Tank 16H. It is not intended to be a detailed accounting of all waste transfers to and from the tank throughout its operational history. Details on the waste removal operations conducted in Tank 16H are provided in Section 3.0.

### 2.2.1 Tank Operational Service Summary

Tank 16H was placed in service to receive fresh high-heat waste from H-Canyon operations in May 1959. In November 1959, leakage from the primary tank to the annulus was first identified when solid material was observed in the annulus on the outside of the primary tank wall. An evaluation was conducted, and using the facts available at the time, it was determined that it was safe and prudent to continue using Tank 16H for waste receipts. The bases for the decision to continue using Tank 16H were:

1. The level of waste leaked into the annulus could be maintained below the top of the annulus pan. If needed, an annulus transfer jet could be installed to transfer material to another tank.

2. The amount of storage capacity in H Area was limited to unfilled volumes in Tanks 14H, 15H, and 16H. At this time, additional waste storage capacity was needed to support H-Canyon operations.
3. Experience with other previously leaking waste tanks (i.e., 9H, 10H, and 14H) had shown that typical leakage rates were generally slow (less than 0.05 gallons per minute) and intermittent. Also, normal evaporation occurring in the annulus, aided by the operation of dehumidification equipment, was sufficient to evaporate the liquid in the escaping supernate, leaving behind sodium salts that essentially sealed leak sites, preventing further leakage. [DP-1358]

Based on the evaluation, waste transfers to Tank 16H were resumed after the November 1959 evaluation. [DP-1358]

In May 1960, Tank 16H reached its highest historical fill level (primary tank level of 303 inches equal to 1,060,000 gallons[3]). Annulus visual inspections conducted in August 1960 showed evidence of increased leakage into the annulus. Therefore, waste receipts were stopped and investigations into the nature of leak site formation were started.

In September 1960, the annulus was observed to have 4.5 feet of liquid present. The level continued to rise at an estimated peak leak rate of four gallons per minute and reached a maximum height two inches (700 gallons) above the five-foot high annulus pan. [DP-1358] A transfer jet was installed in the annulus within two days and waste transfer to Tank 14H was started. During this time, an estimated "few tens of gallons of waste" escaped the concrete encasement (presumably through the construction joint near the top of the annulus pan) and entered the surrounding soil. [DP-1358] The waste level in the annulus was lowered by transferring waste to Tank 14H. There were no other occurrences of waste escaping the concrete encasement into the surrounding soil because the annulus waste level was maintained below the top of the five foot high annulus pan. In October 1960, to reduce the primary tank waste level, a transfer jet was also installed in the primary tank and the liquid waste was transferred to Tank 15H. During the transfer, the leak rate decreased stepwise and indicated three major areas of leakage at about 223 inches, 192 inches and 160 inches. [DP-1358] Leakage to the annulus stopped when the primary tank's liquid level was lowered to 147 inches (approximately 514,500 gallons). This height is approximately the elevation of the middle horizontal primary tank weld. [SRR-CWDA-2014-00017] It should be noted that visual observation indicated that leak sites were associated with primary tank weld locations.

Starting in October 1961 and continuing into 1962, extensive studies were performed to determine the cause of the cracking of the primary tank wall. During this time period, thirteen additional IPs were installed into the annulus to support the studies (Figure 2.1-5). One of the new IPs, IP-262, was installed into the annulus in October 1961 for access to obtain a 5.75 inch diameter sample of the primary tank wall. The wall sampling area was first sandblasted and then the wall sample was cut out and retrieved. This same procedure was performed in April 1962 at IP-39. Additional sandblasting activities were performed in June 1962 at IP-151 to support dye-penetrant inspection of the primary tank's vertical welds. Sandblasting the carbon steel wall

[3] The Documented Safety Analysis operational limit for Type II tanks is 306 inches or 1,070,000 gallons. [WSRC-SA-2002-00007]

surface enabled a more thorough inspection of leak site areas. Overall, the sandblasting of the primary tank wall surface resulted in the accumulation of several tons of sand on the annulus floor. Relatively more material accumulated in the areas where sandblasting had occurred at IP-151, IP-154 and IP-262.

After exhaustive study, it was determined that the cracks in the primary tank and resultant leakage was caused by stress corrosion from the action of sodium hydroxide and sodium nitrate on areas of high local stress in the steel plate, such as welds. The phenomenon is now known as nitrate-induced stress corrosion cracking. [DP-1023] Information from these studies was incorporated into the design for subsequent waste tanks constructed at SRS.

No additional waste receipts into Tank 16H occurred from late 1960 through most of 1967. After installation of a permanent annulus dehumidification system and with a new operational constraint to maintain the liquid level at, or below 252 inches, a height 18 inches lower than the top horizontal weld. At the time, the use of Tank 16H was justified because, by controlling the dehumidification system, any leakage into the annulus would self-seal by forming a hardened salt nodule at the leak site. In October 1967 the decision was made to resume using Tank 16H for receipt of saturated (i.e., salt-laden) supernate from other HTF tanks. These receipts were a combination of fresh waste from H-Canyon and supernate from other HTF tanks that had been concentrated by an evaporator system. By June 1968, Tank 16H was refilled to the new operational limit of 252 inches (882,000 gallons). Between August 1969 and July 1970, the primary tank was emptied and refilled several times to support overall HTF processing needs. [DPSPU 77-11-17]

In January and February 1972, inspection of the Tank 16H annulus revealed new leak sites on the primary tank wall as evidenced by enlarged salt deposits on the primary tank wall and on the annulus floor. By March 1972, the use of the Tank 16H for additional waste receipts had ceased and supernate removal to remove liquid from the primary tank was initiated.

# 3.0 WASTE REMOVAL

Introduction

The details of the Tank 16H waste removal process are unique when compared to the six FTF waste tanks (Tanks 5F, 6F, 17F through 20F) that are operationally closed. Many of the technologies used for performing waste removal in those six waste tanks were based upon the demonstration of Tank 16H waste removal efforts during the 1970s and subsequent lessons learned. Tank 16H is unique because its operational service history included extensive leakage from the primary tank into the annulus pan. As summarized in Section 2.2, leakage of salt waste into the annulus pan was confirmed within six months of the waste tank being placed into operational service. Eventually, approximately 350 individual leak sites were identified on the primary wall. [DP-1358] During evaluations to understand the Tank 16H primary liner failure mechanism, extensive sandblasting of the carbon steel primary liner surface in the annulus added tons of sand to the annulus. Over time this sand combined with the salt waste present in the annulus to form water-insoluble sodium aluminosilicate compounds.

Due to its extensive leakage history, the use of Tank 16H for fresh waste receipts from H-Canyon was limited as compared to other HTF and FTF waste tanks (e.g., Tanks 12H and 15H) in similar service. In 1972, it was determined that Tank 16H would not receive any additional waste. Tank 16H was the first tank in either HTF or FTF to receive this stipulation. Soon thereafter, planning was initiated to remove waste from Tank 16H as a demonstration project. The intent was not to expedite waste removal from Tank 16H or to conserve tank storage space. Remember that treatment facilities for sludge and salt waste did not exist at that time and excess waste tank storage space was not at such a premium. Rather, the multiple primary tank and annulus pan waste removal campaigns summarized in this section were performed to evaluate various waste removal options that would become the planning basis for future waste removal efforts. [DPSP-80-17-23] For example, the Tank 16H demonstration project introduced the use of slurry mixer pumps and bulk oxalic acid (BOA) cleaning.

The Tank 16H demonstration project waste removal campaigns were initiated in the late 1970s, only a few years after fresh waste receipts were stopped. The Tank 16H waste removal may have been more successful than waste removals recently performed in other tanks because the sludge removal was started relatively quickly. For example, sludge removal from Tank 12H was performed 34 years after the last waste receipt; a dormant period five times longer than what elapsed in Tank 16H. Experience has shown that if more time is allowed for physical and chemical changes to occur in settled sludge, the more difficult it will be to suspend.

In addition, because Tank 16H waste removal efforts were performed more than 30 years ago, many of the current safeguards related to nuclear safety, such as preventing waste aerosolization, were either not in place or were not as restrictive at that time. These safeguards have been established or modified over time as new information on waste characteristics has evolved and lessons learned from throughout the nuclear industry have been implemented. Therefore, the extraordinary success described in Section 3.1 for the primary tank cleaning may not be indicative, or possible for future waste removal efforts on other tanks. Similarly, though several other waste tanks have experienced salt waste leakage into the annulus pan, none of these waste tanks have had sandblasting performed. Therefore, extensive quantities of water-insoluble sodium aluminosilicate compounds resulting from the combination of salt waste and sand are unique to Tank 16H. Removal of salt waste from the annulus pan of other waste tanks, if required, is not expected to be as challenging due to the high solubility of salt waste.

Waste removal for the Tank 16H primary tank and the annulus pan are described separately in this section. The waste removal history for the primary tank is summarized in Section 3.1. The waste removal history for the annulus is summarized in Section 3.2.

## 3.1 Tank 16H Primary Tank Waste Removal Overview

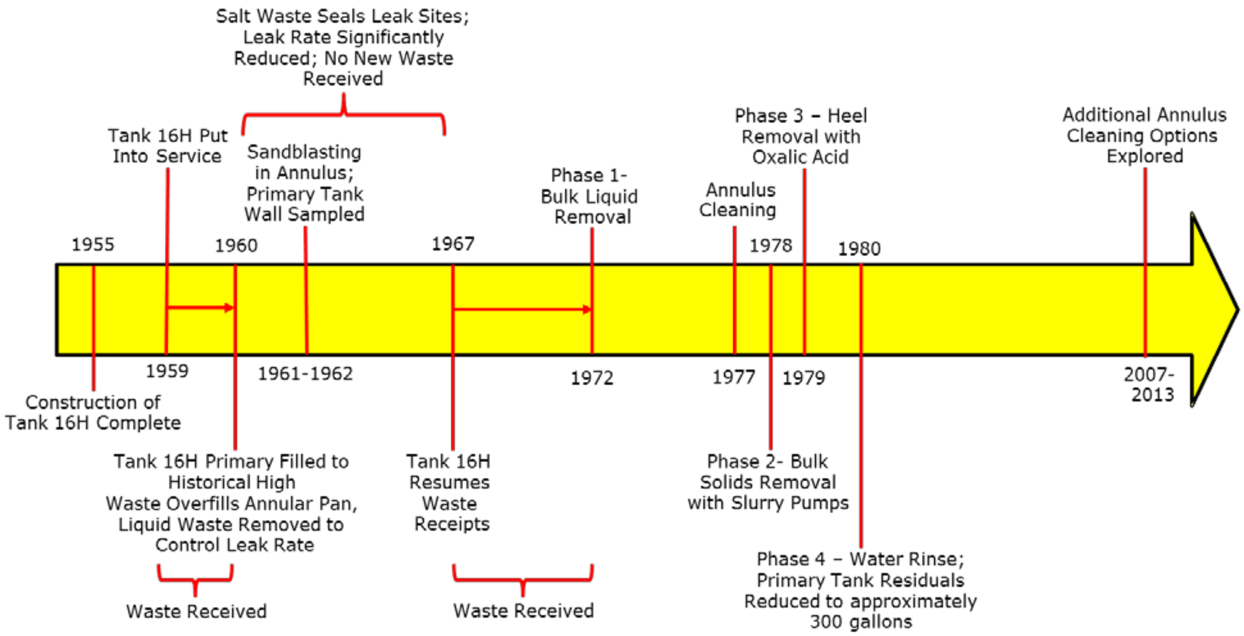
In March 1972, DOE began waste removal in the primary tank using a series of mechanical mixing and chemical cleaning campaigns. These waste removal efforts, which continued through 1980, resulted in a final primary tank waste volume of 330 gallons. [U-ESR-H-00113]

Waste removal in the primary tank was conducted in four phases:

- Phase 1: Bulk Liquid Waste Removal
- Phase 2: Bulk Solids Waste Removal with Slurry Pumps (SLPs)
- Phase 3: Heel Removal Using Oxalic Acid (OA)
- Phase 4: Heel Removal Using a Water Rinse

Figure 3.1-1 shows the Tank 16H historical timeline that includes waste removal activities. The key activities on this timeline are described in more detail throughout this section.

**Figure 3.1-1: Tank 16H Historical Timeline**




[NOT TO SCALE]

### 3.1.1 Tank 16H Primary Tank Waste Removal Phase 1: Bulk Liquid Waste Removal

Figure 3.1-2 shows the Tank 16H primary tank condition prior to the March 1972 start of waste removal efforts. Table 3.1-1 summarizes the Tank 16H primary tank volume change history up to the end of the Phase 1: Bulk Liquid Waste Removal. The 768,000 gallon supernate transfer to Tank 13H in March 1972 left approximately 114,000 gallons of sludge solids with associated interstitial liquid. [DPSP 79-17-12, DPSP-79-17-17] The liquid was allowed to evaporate, leaving a residual heel volume of 77,000 gallons for removal (Figure 3.1-3).

These volumes do not account for leakage to the annulus. Annulus volume changes are presented in Table 3.2-1

**Figure 3.1-2: Tank 16H Primary Tank Condition in March 1972 Prior to the Start of Waste Removal**

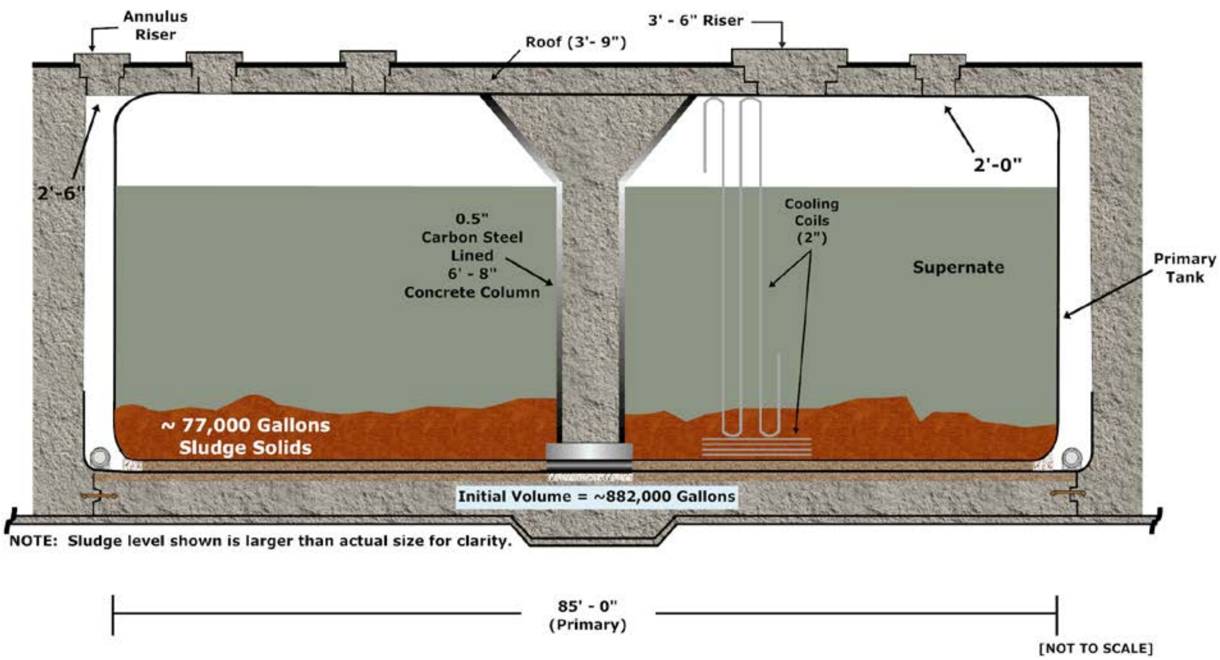
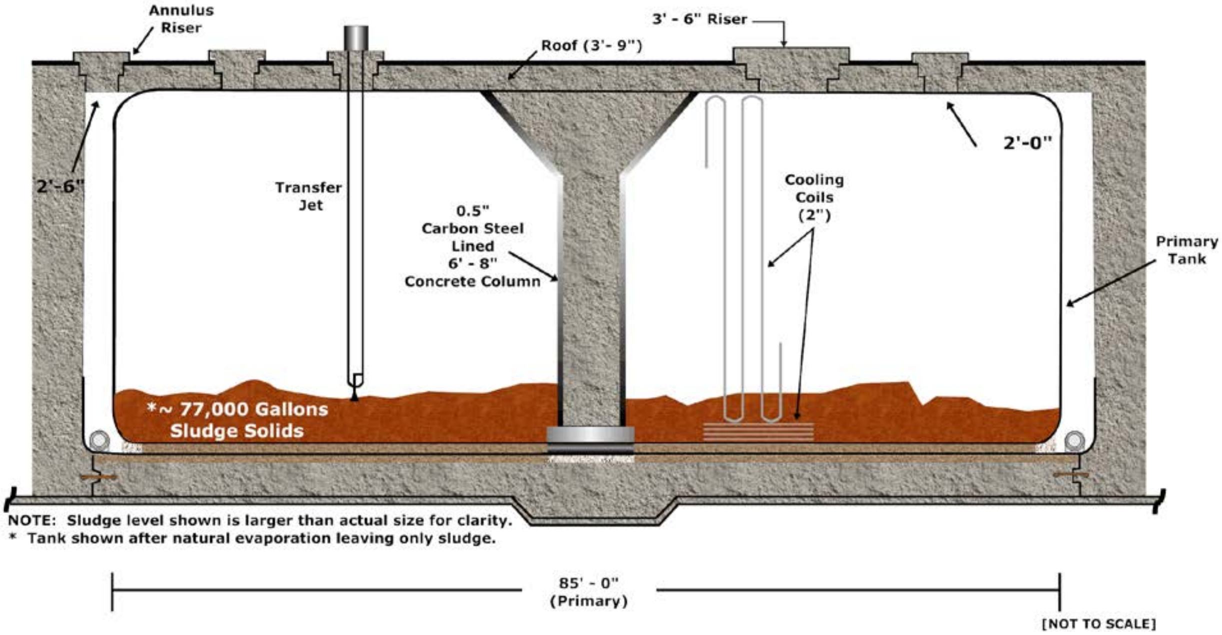



**Table 3.1-1: Tank 16H Primary Tank Volumes Summary Prior to Bulk Solids Waste Removal**

| Date | Tank Condition | Net Change (gallons)[a] | Estimated Waste Volume (gallons)[a] |
|---|---|---|---|
| **May 1960** | Historic maximum fill level | – | 1,060,000 |
| **1960-1972** | Waste transfers into and out of Tank 16H from routine operations | -178,000 | 882,000 |
| **March 1972** | 768,000 gallon supernate transfer to Tank 13H | -768,000 | 114,000 |
| **March 1972 to Dec 1978** | 37,000 gallons (liquid) lost to evaporation | -37,000 | 77,000 |
| **Dec 1978** | Phase 1 - Bulk liquid waste removal ends<br>Bulk solids (sludge) removal starts | – | 77,000 |
| **Total Volume Change** | | -983,000 | – |

– Not Applicable
Note: The annulus waste volumes summary is presented in Table 3.2-1.

**Figure 3.1-3: Tank 16H Primary Tank Condition After Phase 1: Bulk Liquid Waste Removal**

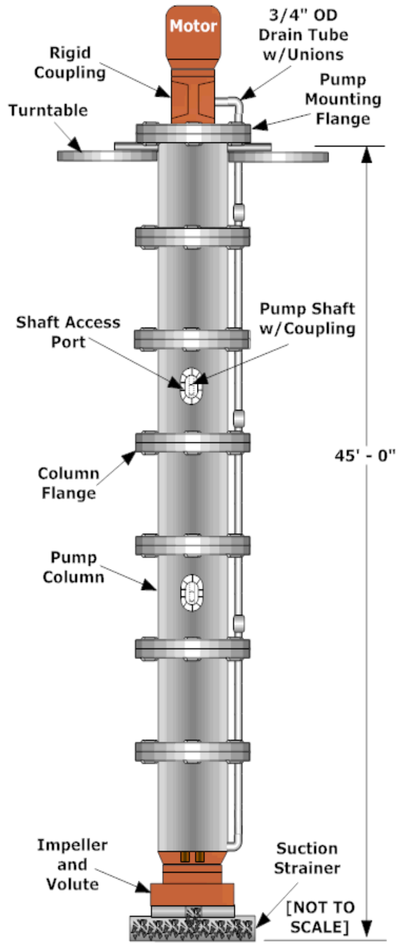



## 3.1.2 Tank 16H Primary Tank Waste Removal Phase 2: Bulk Solids Waste Removal with Slurry Pumps

### *3.1.2.1 Technology Selection for Phase 2: Bulk Solids Waste Removal with Slurry Pumps*

Between 1966 and 1969, high-velocity water jets were used to remove sludge for consolidation and management purposes from seven waste tanks (1F, 2F, 3F, 9H, 10H, 11H, and 14H) in FTF and HTF. The consolidation allowed five of these seven tanks to be subsequently used as evaporator concentrate receipt tanks. [HLW-STE-98-0218] The drawbacks for these types of jets were the large water volumes required to slurry the sludge (approximately five times the volume of sludge removed) and the high pressures needed to operate the jets (approximately 3,000 pounds-per-square-inch gauge). Additionally, the high-pressure, positive-displacement pumps used to operate these jets were not designed to be operated and maintained in the high radioactive environment present within a waste tank. Studies later showed that using a low-pressure, single-stage centrifugal pump as a recirculating pump was feasible for mobilizing sludge waste. In 1977, a new waste tank cleaning technology was developed by Savannah River National Laboratory (SRNL) that utilized this low-pressure, sludge-slurrying technique using supernate, thus eliminating the need for water addition. This sludge-slurrying pump drew supernate and suspended sludge into the bottom of the pump and forced it out through two oppositely directed nozzles to produce liquid jets with a sludge-slurrying capability equal to that of the previously used high-velocity jet system. [DP-1468] Figure 3.1-4 shows a typical SLP design.

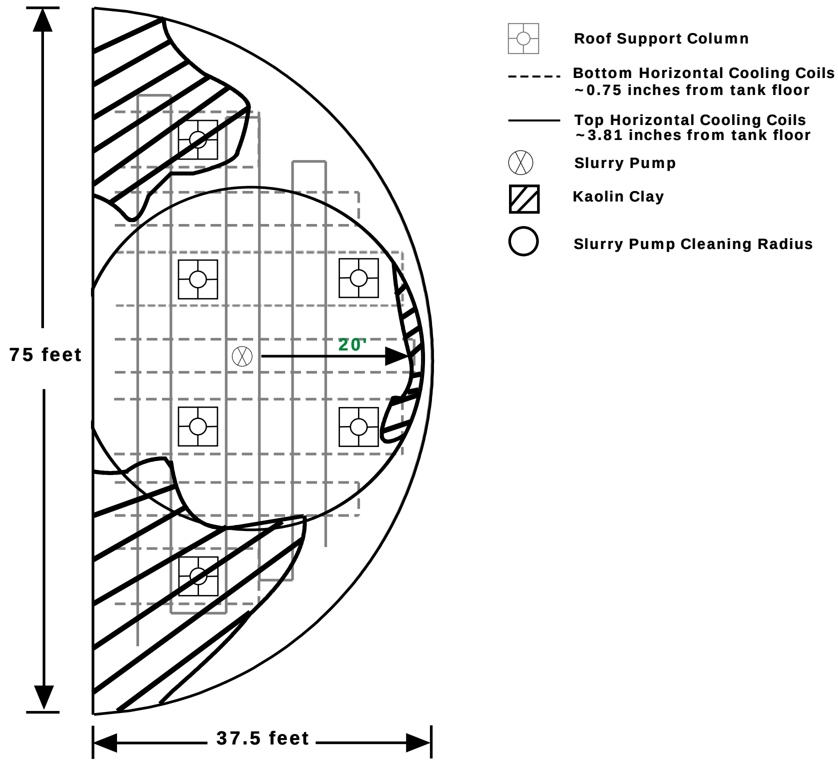
**Figure 3.1-4: Slurry Pump**




[DOE/SRS-WD-2014-001]

The first pumps were designed to fit in a 24-inch waste tank riser. Pump testing was done using a half-tank mockup of a Type I tank at the SRS Training and Experimental Test Facility (TNX) in 1977. This mockup consisted of horizontal cooling coils and six roof-support columns simulating an actual waste tank. The mockup used kaolin clay to simulate the radioactive sludge and water to simulate supernate. The cleaning pattern of the SLP was judged by the depth and location of the kaolin clay on the mockup floor after the slurry simulant (kaolin and water mixture) was removed. The slurrying ability of the pump was described by the effective cleaning radius (ECR), which was defined as the radial distance on the mockup floor from the impeller center having a residual layer of kaolin less than one-eighth of an inch thick after slurry simulant removal. The testing results showed that the ECR of the pump was approximately 20 feet at an impeller speed of 1800 revolutions per minute. [DP-1468] Figure 3.1-5 shows the half-tank mockup testing result.

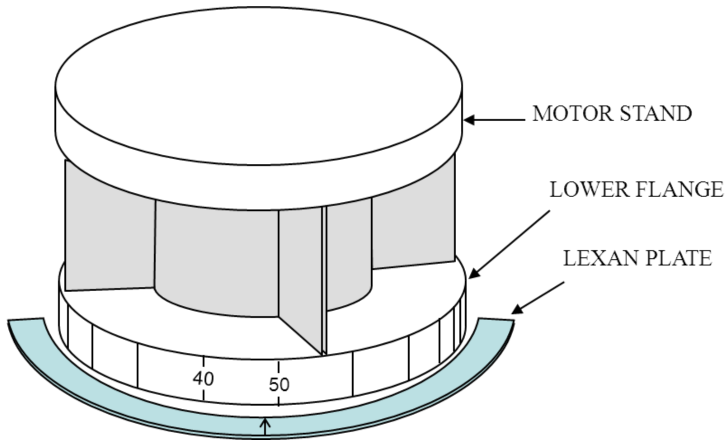
**Figure 3.1-5: Half-Tank Mockup Testing Result**




[DP-1468]

During the four phases of cleaning, the SLPs were run in two modes, oscillatory and indexing. During oscillatory runs, the spray nozzles were rotated 360 degrees using a turntable assembly to create a circular cleaning pattern. The turntable was driven by a 0.5 horsepower reversible motor equipped with a variable speed pulley for adjusting the turntable speed from 0.2 to 0.5 revolutions per minute. Testing of the prototype SLP at the TNX facility using the kaolin clay sludge simulant material showed that periodic reversal in the direction of rotation had a significant effect on removing clay behind the obstacles on the mockup tank floor. [DPSTD-241-TK-16H] In indexing mode, a specific location in the waste tank was targeted. The pump turntable assembly was set to a fixed position which also fixed the direction of the pump discharge spray. Figure 3.1-6 shows an example of a SLP turntable, which has a similar set up to the SLPs used on Tank 16H.

**Figure 3.1-6: SLP Turntable**

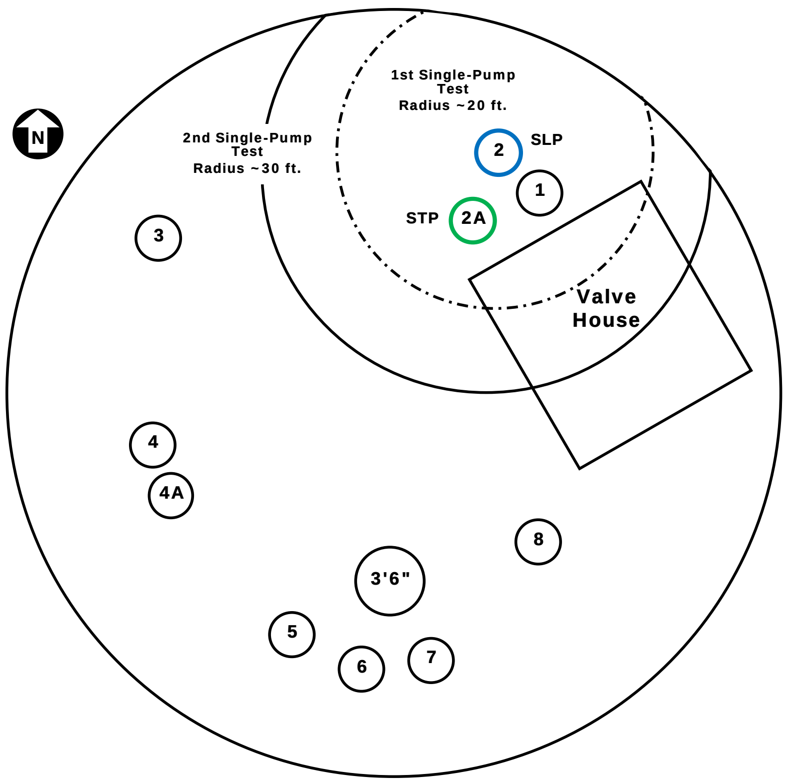



Note: Pump is indexed to the 48° position
[SRR-LWE-2011-00156]

### *3.1.2.2 Single Slurry Pump Operation for Bulk Solids Waste Removal in the Primary Tank*

As discussed in Section 3.1.2.1, SLPs were the chosen technology for the bulk solids waste removal process in the Tank 16H primary tank. This technology is called mechanical sludge removal (MSR). MSR refers to any cleaning campaign to remove sludge solids during bulk or heel waste removal involving SLPs. The MSR campaigns focused on the removal of hazardous constituents through gross removal of the solids, and were not expected to preferentially separate any radiological constituents. To determine the ECR of a pump in an actual waste tank for comparison with the half-tank mockup testing, two demonstrations, or campaigns, were first performed in Tank 16H utilizing a single SLP. Figure 3.1-7 shows the initial layout of the equipment in Tank 16H and the ECR for the two, single-SLP campaigns. An SLP was placed in Riser 2 to suspend the sludge solids and supernate into a slurry using supernate and water additions. A submersible transfer pump (STP) was placed in Riser 2A to transfer the slurry out of the waste tank. [DPSP 79-17-12] For each single-SLP campaign, the pump was operated in oscillatory mode.

**Figure 3.1-7: ECR for the Tank 16H Solids Removal Testing Using a Single SLP**




[DPSP 79-17-12] [NOT TO SCALE]

*Mechanical Sludge Removal Campaign 1*

In December 1978, SRS successfully demonstrated in Tank 16H the cleaning effectiveness of the low-velocity hydraulic cleaning concept with the use of a SLP. To prepare for the test, 8,000 gallons of water were added to the 77,000 gallons of sludge present in Tank 16H. The SLP was run for 86 hours, during which time an additional 9,000 gallons of bearing water were added at an average rate of 1.0 gallons per minute. Bearing water was used to lubricate the seals in the pumps and pressurize the SLP column, preventing the tank waste from migrating up the pump shaft. This test yielded a transfer of 22,100 gallons of sludge-slurry to Tank 15H via the STP in Riser 2A. An estimated 11,500 gallons of solids were removed leaving an estimated 65,500 gallons of sludge on the waste tank floor. [DPSP 79-17-12] *Note: Volume percent solids measurements were made on dip samples collected from the tank during slurrying. Since this measurement was highly variable depending on the campaign parameters, there is not a one-to-one volume correspondence for liquid gallons added and gallons of solids removed during transfers.*

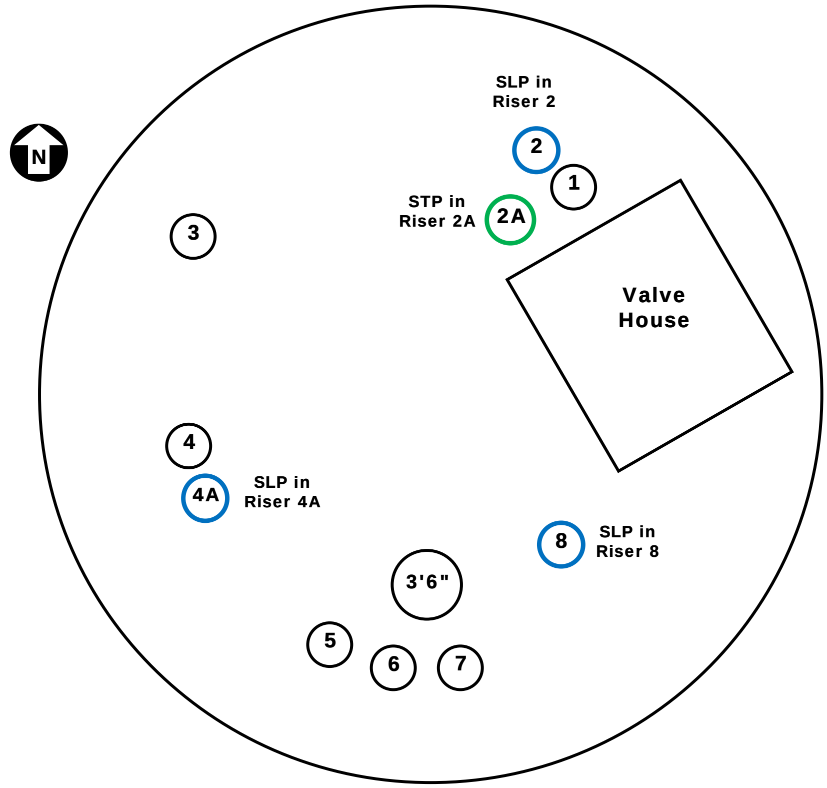
*Mechanical Sludge Removal Campaign 2*

The test was repeated a second time following the addition of 29,500 gallons of supernate from Tank 21H. [DPSP 79-17-12] Supernate was used in this test because it had a higher specific gravity and it was a beneficial reuse in terms of overall tank farm tank space. Slurry samples were collected at various times to determine pump effectiveness in suspending sludge solids. After 208 hours of slurrying, the sample analyses indicated that no additional sludge was being suspended. During this campaign 56,500 gallons of sludge-slurry was transferred to Tank 15H. After this campaign, an estimated 15,600 gallons of sludge had been removed leaving approximately 49,900 gallons of sludge. [DPSP-79-17-17]

#### *3.1.2.3 Multiple Slurry Pump Operation for Bulk Solids Waste Removal in the Primary Tank*

The next step in Tank 16H Phase 2 cleaning was to determine the minimum number of pumps required to slurry all the sludge in the waste tank. The MSR Campaigns 3 through 5 all involved the use of multiple SLPs. Three pumps were installed using Risers 2, 4A and 8 with an STP in Riser 2A. The equipment layout in Tank 16H for the multi-SLP campaigns is shown in Figure 3.1-8.

**Figure 3.1-8: Equipment Locations for the Tank 16H Solids Removal Testing Using Multiple SLPs**




[NOT TO SCALE]

*Mechanical Sludge Removal Campaign 3*

In January 1979, to prepare for MSR Campaign 3, 16,200 gallons of supernate from Tank 22H were added to the Tank 16H primary tank. [DPSP-79-17-17] For this campaign, each of the three pumps was run in oscillatory mode at a rate of 0.2 revolutions per minute with the direction reversed every two to four hours. The pumps in Risers 2 and 8 were allowed to run first for a total of 70 hours. Periscopic inspection showed evidence of sludge that had not been slurried on the western side of the waste tank beyond the cleaning radius of the pumps in Risers 2 and 8. The pump in Riser 4 was turned on and all three ran for 94 more hours. Approximately 97,500 gallons of sludge-slurry was then transferred to Tank 15H. An estimated 37,000 gallons of sludge had been removed leaving approximately 12,900 gallons of sludge in the waste tank. This test increased the cumulative percentage of sludge removed during the single pump experiment from 35% to 83%. After MSR Campaign 3, a sludge mound remained in an area located 40 feet from Riser 2, and 28 feet from Riser 4A. This mound covered approximately 450 square feet of the tank floor and contained approximately 3,600 gallons of the estimated 12,900 gallons of sludge remaining in the waste tank. Another mound was visible under the valve house located 30 feet from any pump. The volume of this second mound could not be determined because the valve house piping obstructions prevented a full inspection of the area. [DPSP-79-17-17]

*Mechanical Sludge Removal Campaign 4*

In preparation for MSR Campaign 4, 38,000 gallons of supernate from Tank 22H were added to the Tank 16H primary tank. [DPSP-79-17-17] For this campaign, the pumps were alternately run in indexing mode which involved targeting the specific sludge mounds remaining from MSR Campaign 3. The SLPs in Risers 2 and 4A were alternately indexed towards the mound near these risers with the SLP in Riser 8 indexed toward the mound under the valve house. All three pumps were allowed to operate for 76 hours. A slurry of 75,100 gallons was transferred to Tank 15H, removing 89% of the solids left after MSR Campaign 3 for a total of 98.2% removal of the original sludge volume. Only small mounds located under Riser 3 were visible after MSR Campaign 4. These mounds held approximately 150 gallons of the estimated 1,390 gallons of sludge that remained on the floor of Tank 16H at the conclusion of MSR Campaign 4. [DPSP-79-17-17]

*Mechanical Sludge Removal Campaign 5*

In preparation for the next waste removal phase, Phase 3: Heel Removal Using OA, the SLP in Riser 8 was relocated to Riser 6. MSR Campaign 5, the last campaign in Phase 2, took place in November 1979 to specifically target the mounds under Riser 3 remaining after MSR Campaign 4. After adding 58,200 gallons of supernate from Tank 22H to provide a slurrying medium, the SLPs in Risers 2, 4A, and 6 were started. The SLP discharges in Risers 2 and 4A were indexed alternately towards the mounds. The pump motor bearing failed on the SLP in Riser 4A after 56 hours and the pump was shut down. The remaining SLPs were run for a total of 72 hours. A slurry of 81,000 gallons was then transferred to Tank 21H leaving a sludge-slurry heel estimated at 5,250 gallons. [DPSP-80-17-23] This apparent increase in heel volume may be the result of underreporting at the end of MSR Campaign 4 or because the MSR Campaign 5 volume estimate includes both sludge solids and residual slurry liquid.

#### *3.1.2.4 Phase 2: Summary of Bulk Solids Waste Removal with Slurry Pumps*

The five MSR campaigns beginning in December 1978 and ending in November 1979 reduced the Tank 16H residual volume from approximately 77,000 gallons to approximately 5,250 gallons. Overall, the MSRs campaigns were effective at removing sludge solids from the waste tank. Details of the Phase 2 MSR campaign results are summarized in Table 3.1-2. Figure 3.1-9 shows the Tank 16H liquid and solids removal history during the MSR campaigns.

### Table 3.1-2: Waste Removal Details for the Phase 2 Tank 16H MSR Campaigns

| MSR Campaign | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Dates of Run** | 12/78 | 1/79 | 1/79 | 2/79 | 11/79 |
| **SLP Locations** | Riser 2 | Riser 2 | Risers 2, 4A, 8 | Risers 2, 4A, 8 | Risers 2, 4A, 6 |
| **Operating Time, hours** | | | | | |
| **SLP 2** | 86 | 208 | 168 | 76 | 72 |
| **SLP 4A** | NA | NA | 94 | 76 | 56 |
| **SLP 6** | NA | NA | NA | NA | 72 |
| **SLP 8** | NA | NA | 169 | 76 | NA |
| **Flush Water Added, gallons** | 8,000 | 27 | 172 | 297 | NA |
| **Bearing Water Added, gallons** | 9,000 | 12,800 | 49,300 | 29,300 | 25,700 |
| **Supernate Added, gallons** | NA | 29,500 | 16,200 | 38,000 | 58,200 |
| **Slurry Transferred, gallons** | 22,100 | 56,500 | 97,500 | 75,100 | 81,000 |
| **Sludge Remaining, gallons** | 65,500 | 49,900 | 12,900 | 1,390[a] | 5,250[b] |
| **Solids Removed, %** | 15 | 24 | 74 | 89 | NA |
| **Cumulative Solids Removed, %** | 15 | 35 | 83 | 98 | NA |

Note: Due to inconsistencies in reporting, slurry, sludge and solids removed numbers have been rounded.

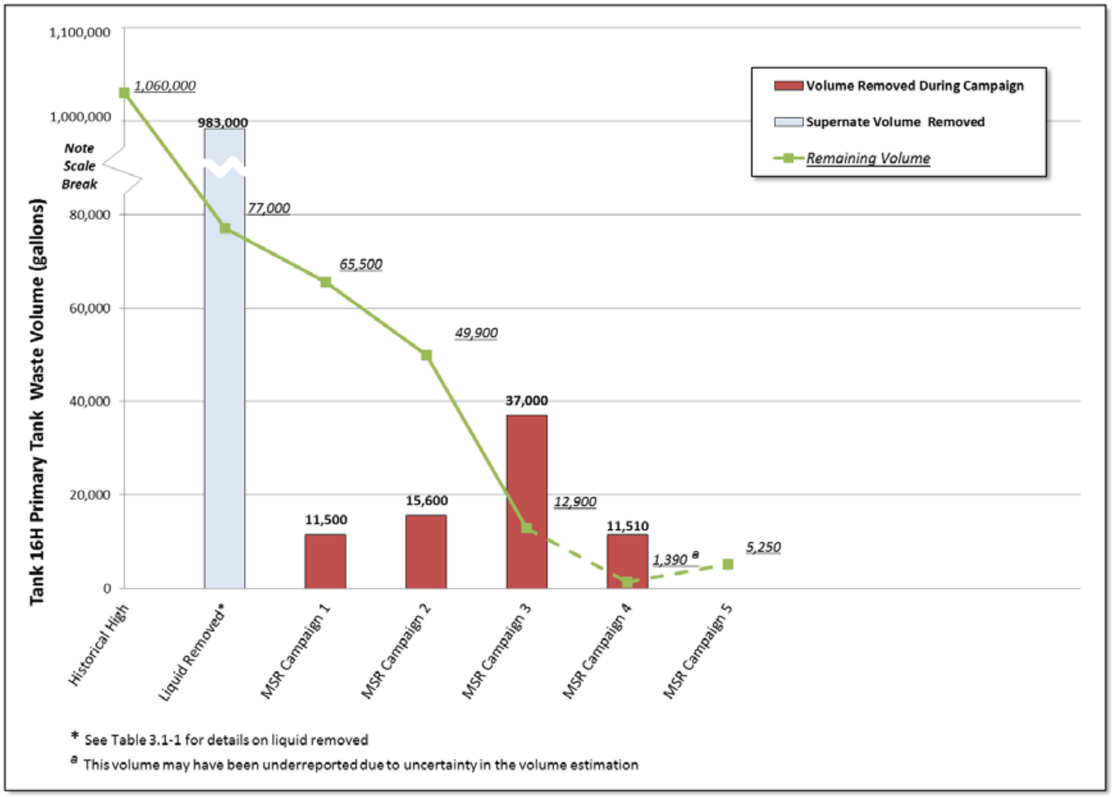
a This volume may have been underreported due to uncertainty in the volume estimation.

b This heel volume includes sludge solids plus remaining liquid slurry medium.

NA Not Applicable

[DPSP-79-17-17, DPSP-80-17-23]

**Figure 3.1-9: Summary of Tank 16H Primary Tank Liquid and Solids Waste Removal During the MSR Campaigns**

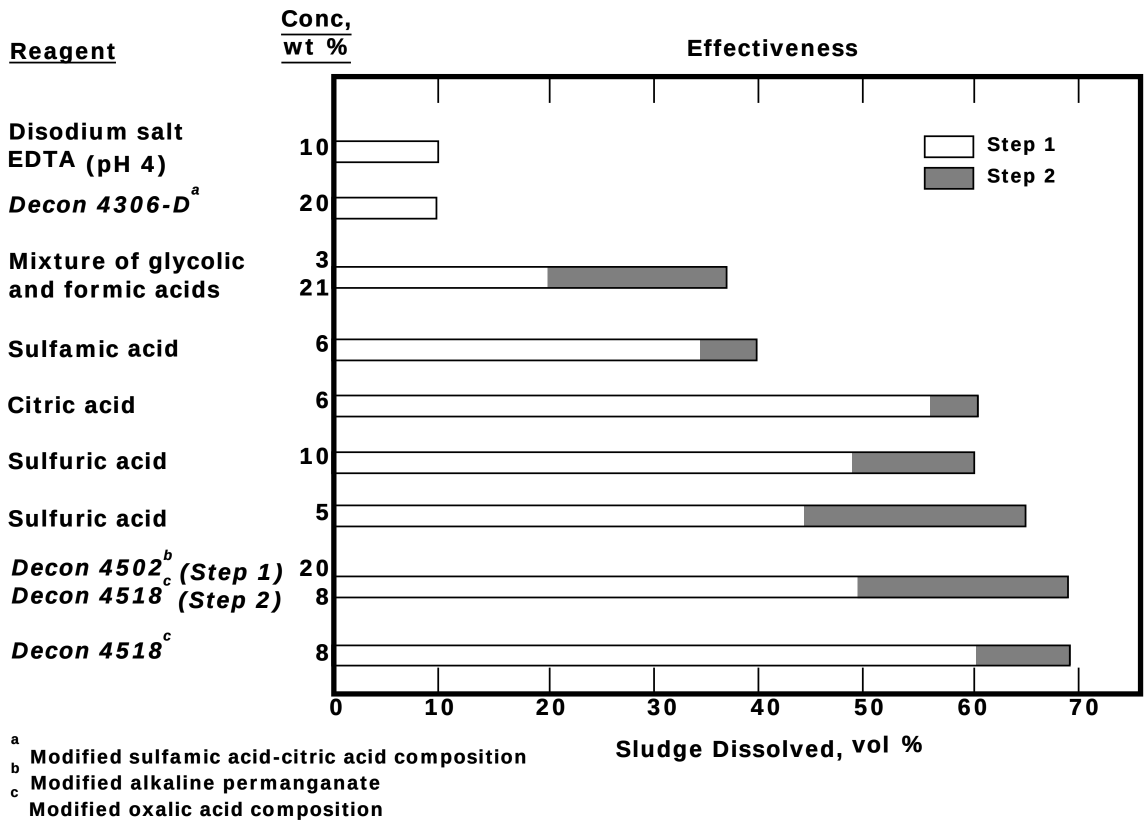



## 3.1.3 Tank 16H Primary Tank Waste Removal Phase 3: Heel Removal Using Oxalic Acid

### *3.1.3.1 Technology Selection for Phase 3: Primary Tank Heel Removal Using Oxalic Acid*

Tests conducted by SRNL in 1977 showed that sludge from high activity waste could be dissolved in concentrated mineral acids such as hydrochloric, nitric, hydrofluoric, and sulfuric at high temperatures. However, using these acids is not feasible because these reagents will attack the carbon steel of the primary tank. To evaluate alternative dissolution options, other chemicals were tested on sludge samples from Tank 16H and a summary of the results are shown in Figure 3.1-10. [DP-1471]

**Figure 3.1-10: Reagent Effectiveness Comparison for Dissolving Tank 16H Sludge**




[DP-1471]

The testing concluded that *Decon 4518* OA would be the best reagent for chemical cleaning. OA is a solid white crystal in its pure state and is readily soluble in water. [MSDS-43759] OA is one of the strongest of the organic acids and readily oxidizes (combines with metal ions such as iron, calcium, or magnesium) to form oxalates, which are less soluble in water than OA.

The results of all of the tests conducted during the 1977 study showed the dissolution rate of sludge increased with increased OA temperature, agitation, OA concentration, amount of OA addition, frequency of OA addition and amount of sludge surface exposed. The highest rate of corrosion measured during test strip corrosion testing was 0.0006 inches per week using 12 wt% OA at 95°C. This indicated that using 8 wt% solutions of either OA or *Decon 4518* would not cause significant corrosion damage to either the carbon steel waste tanks or to stainless steel equipment. [DP-1471]

Unlike the MSR campaigns, the chemical sludge removal (CSR) campaigns would remove, at varying degrees, the various chemical species comprising the waste. Another result of the 1977 study was that Sr-90 dissolved in OA at about the same rate as the total sludge volume. This was important because Sr-90 makes up a large percentage of the radioactivity in sludge. Testing also showed that Pu-239 in the sludge was largely insoluble, but small sample sizes made this testing difficult. [DP-1471]

Further testing showed that adding 1 wt% OA at an acid-to-sludge ratio of greater than 20:1 would be effective at removing the solids from the Tank 16H primary tank. At least one treatment of OA at 4 wt% would also be needed for maximum sludge dissolving efficiency. [DPST-79-538]

All of these results were used to determine that BOA CSR campaigns would be used to chemically clean Tank 16H following completion of MSR campaigns.

#### *3.1.3.2 Tank 16H Primary Tank Heel Removal Campaigns Using Oxalic Acid*

<u>*Chemical Sludge Removal Campaign 1 (Two Water Washes)*</u>

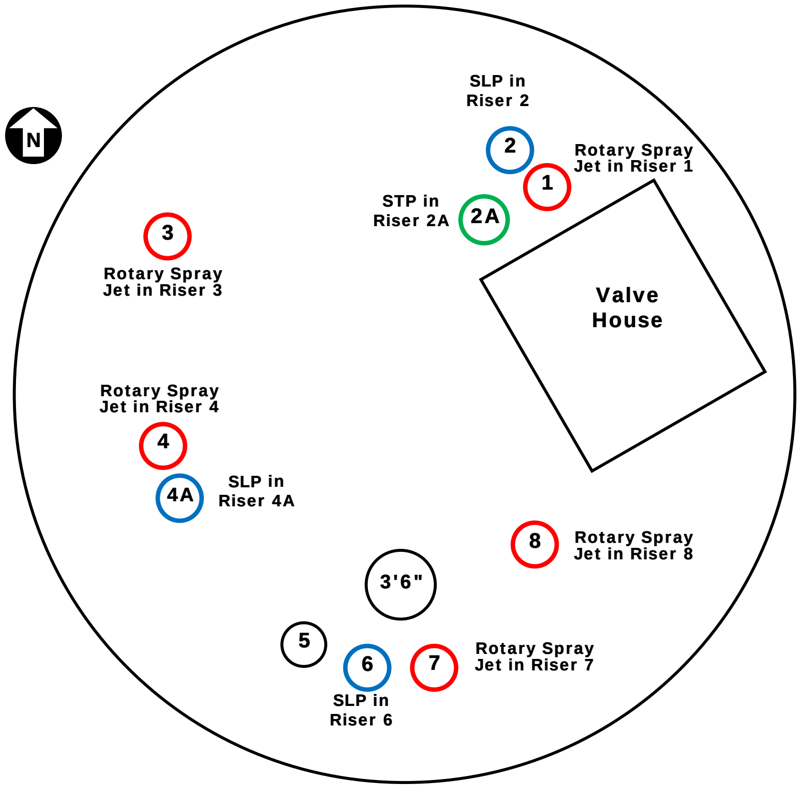
In preparation for BOA additions, water washes were performed in November 1979 and in December 1979 to dissolve some small, water soluble salt deposits adhering to the upper portions of a few vertical cooling coils, and to remove residual caustic in the sludge, thus minimizing neutralization of the OA added during the next CSR campaign. [DPSP-80-17-23]

To perform the water washes, rotary spray jets were installed in Risers 1, 3, 4, 7 and 8. For this type of jet, liquid was pumped through the jet and out of the spray nozzles, causing them to rotate in a vertical plane. Figure 3.1-11 shows the layout of the equipment for the CSR campaigns. For the November 1979 water wash, 63,000 gallons of $90^{o}$C heated water were alternately sprayed through each of the five spray jets. When the water level in the waste tank reached 16 inches, the SLPs in Risers 2, 4A and 6 were turned on. After 42 hours, the SLP in Riser 6 was shut down due to excessive vibration. A sludge-slurry of approximately 82,500 gallons was then transferred to Tank 21H.

The second water wash demonstration in December 1979 added 70,000 gallons of $90^{o}$C heated water alternately through the five spray jets. The SLPs were started when the liquid level covered the discharge nozzles. After running all three pumps simultaneously for 50 to 57 hours, a sludge-slurry of 104,500 gallons was transferred to Tank 21H. An estimated 3,500 gallons of sludge and liquid remained in the tank after these washes. [DPSP-80-17-23]

During this second water wash, the water flow to the Riser 1 spray jet was increased for better contact with a salt deposit on the upper portion of the cooling coils beneath the valve house that had not dissolved during the first water wash. Inspection after the second water wash revealed only partial dissolution of that salt deposit. [DPSP-80-17-23]

**Figure 3.1-11: Equipment Locations for the Tank 16H Solids Removal Using CSR**




[NOT TO SCALE]

*Chemical Sludge Removal Campaign 2 (OA Addition No. 1)*

Prior to the first OA addition in February 1980, approximately 37,000 gallons of 90°C heated water were sprayed through the rotary spray jet in Riser 1, reducing the volume of the salt deposit under the valve house by half.

Then 12,600 gallons of 4 wt% OA heated to 90°C were pumped directly to the Tank 16H primary tank floor to dissolve residual sludge, so that the activity removed from the sludge could be distinguished from activity removed from the coils and waste tank walls later by other acid sprays. The acid system was flushed with approximately 4,500 gallons of 90°C heated water, further diluting the OA to 1 wt%. The SLPs were turned on and continued to run for 2 days. A sludge-slurry of 80,200 gallons was then transferred to Tank 21H, leaving a heel of approximately 3,500 gallons, the same value reported after CSR Campaign 1. [DPSP-80-17-23] However, the similar volumes reported may be a reflection of a much lower wt% solids in the heel material (less than 1.0 wt%) after CSR Campaign 2 than after CSR Campaign 1 (3.1 wt%) rather than no material removed.

*Chemical Sludge Removal Campaign 3 (OA Addition No. 2)*

For the second OA addition in late February 1980, 41,600 gallons of 90°C heated water were introduced through the Riser 1 rotary spray jet. Then 1,800 to 2,000 gallons (each jet receiving a different amount) of 4 wt% OA heated to 90°C were sprayed through each of the five rotary spray jets for a total of approximately 9,870 gallons. The spray system was flushed with 5,400 gallons of water, further diluting the OA to 1 wt%. After the SLP nozzles became submerged, the SLPs were turned on and the waste tank contents were mixed for 40 hours before 82,800 gallons of sludge-slurry were transferred to Tank 21H. After this acid addition, inspection of the salt deposit under the valve house near Riser 1 showed that it had been reduced down to a volume of about 1 cubic foot. [DPSP-80-17-23] The heel volume after CSR Campaign 3 was estimated at 2,800 gallons. [DPSP-80-17-23]

*Chemical Sludge Removal Campaign 4 (OA Addition No. 3)*

The final OA addition began in March 1980 with 9,000 to 12,000 gallons of 4 wt% OA heated to 90°C sprayed through each of the five rotary spray jets for a total of approximately 50,500 gallons to ensure the total weight percent of OA in the Tank 16H primary tank stayed constant.

The spray system was then flushed with 5,800 gallons of water and the solution in the primary tank was agitated by the SLPs for 48 hours before 77,300 gallons of sludge-slurry was transferred to Tank 22H. [DPSP-80-17-23] The heel volume after CSR Campaign 4 was estimated at 3,680 gallons. [DPSP-80-17-23] The apparent volume increase from the CSR Campaign 3 volume of 2,680 gallons was thought to be due to uncertainty in the volume estimation or the precipitation of oxalates.

A photographic inspection through Riser 8 after CSR Campaign 4 revealed a mound containing an estimated 100 gallons. Twenty-two thousand gallons of 90°C heated water were sprayed into the Riser 8 rotary spray jet to rinse the coils and the primary tank wall in this vicinity. The spray jet was then removed and the SLP from Riser 6 was relocated to Riser 8 to prepare for Phase 4: Heel Removal Using a Water Rinse. [DPSP-80-17-23]

#### *3.1.3.3 Summary of Tank 16H Primary Tank Waste Removal Phase 3: Heel Removal Using Oxalic Acid*

The four CSR campaigns reduced the estimated residual heel volume in Tank 16H from approximately 5,250 gallons to approximately 3,680 gallons. [DPSP-80-17-23] Both of these heel volume estimates included sludge solids along with residual liquid. Details of the Phase 3 CSR campaigns are summarized in Table 3.1-3. Figure 3.1-12 provides a summary of the sludge solids and liquids removed during the CSR campaigns.

### Table 3.1-3: Waste Removal Details for Tank 16H Phase 3: CSR Campaigns

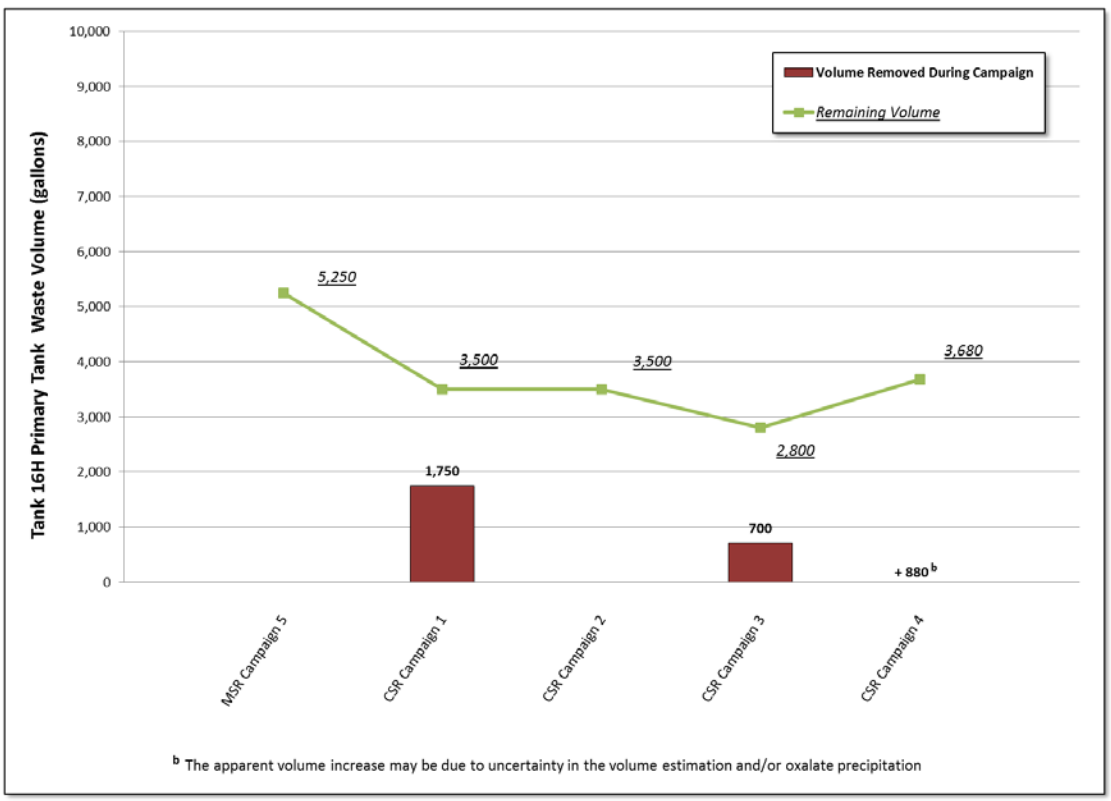
| Campaign | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Dates of Run | 11-12/79 | 2/80 | 2/80 | 3/80 |
| SLP Locations | Risers 2, 4A, 6 | Risers 2, 4A, 6 | Risers 2, 4A, 6 | Risers 2, 4A, 6 |
| Operating Time, hours | | | | |
| SLP 2 | 140 | 48 | 46 | 48 |
| SLP 4A | 121 | 48 | 46 | 48 |
| SLP 6 | 100 | 39 | 44 | 48 |
| Bearing Water Added, gallons | 55,000 | 22,900 | 27,200 | 20,300 |
| Spray Water Added, gallons | 133,000 | 41,600 | 46,500 | 5,800 |
| 4 wt% OA Added, gallons | 0 | 12,600 | 9,870 | 50,500 |
| Slurry Transferred, gallons | 187,000 | 80,200 | 82,800 | 77,300 |
| Heel Volume Remaining, gallons[a] | 3,500 | 3,500 | 2,800 | 3,680[b] |

[a] This heel volume includes sludge solids plus remaining liquid slurry medium. No apparent change from CSR Campaign 1 to CSR Campaign 2 may be a reflection of a change in the wt% solids of the material rather than a change in volume.

[b] Note the increase in heel volume between CSR Campaigns 3 and 4 may be due to uncertainty in the volume estimation and/or oxalate precipitation.

[DPSP-80-17-23]

### Figure 3.1-12: Summary of Tank 16H Waste Removal During the CSR Campaigns



### 3.1.4 Tank 16H Primary Tank Waste Removal Phase 4: Heel Removal Using a Water Rinse

In August 1980, 34,000 gallons of 90°C heated water were sprayed through the four rotary sprayers remaining in Risers 1, 3, 4, and 7 and 22,000 gallons of 90°C heated water were sprayed through Riser 8. The SLPs were turned on and the pump in Riser 8 was indexed toward the mound that was observed after CSR Campaign 4. After four days of mixing, a sludge-slurry of 195,000 gallons was transferred to Tank 15H. An additional 56,000 gallons of water at 25°C were passed through the rotary spray jets to enable the SLPs to continue suspending the fast-settling sludge particles during the transfer. [DPSP-80-17-23]

#### *3.1.4.1 Summary of Tank 16H Phase 4: Heel Removal Using a Water Rinse*

After this cleaning phase, the liquid in the primary tank was allowed to evaporate. Waste tank inspections in 1980 estimated 1,000 gallons of sludge remained in the Tank 16H primary tank. [DPSP-80-17-23] In January 2013, the primary tank residual solids volume was re-evaluated using high-definition photographs and a new mapping process developed for the waste tank closure project. This preliminary mapping estimated that 300 gallons of solids remained in the primary tank. [SRR-LWE-2012-00224] During characterization sampling later in 2013, additional photographs and video footage were collected and the final primary tank residuals volume was subsequently determined to be 330 gallons. [U-ESR-H-00113]

The Phase 4: Heel Removal Using a Water Rinse results are presented in Table 3.1-4.

**Table 3.1-4: Waste Removal Details for the Tank 16H Phase 4: Water Rinse Campaign**

| | |
|---|---|
| **Dates of Run** | 8/80 |
| **SLP Locations** | Risers 2, 4A, 8 |
| **Operating Time, hours** | |
| **SLP 2** | 106 |
| **SLP 4A** | 128 |
| **SLP 8** | 134 |
| **Bearing Water Added, gallons** | 72,500 |
| **Spray Water Added, gallons** | 112,000 |
| **Slurry Transferred, gallons** | 195,000 |
| **Sludge Remaining, gallons** | 330[a] |

[a] The original 1,000 gallon estimate made in 1980 was revised during the final volume determination in 2013.

[DPSP-80-17-23, U-ESR-H-00113]

### 3.1.5 Tank 16H Primary Tank Waste Removal Summary

A summary of the solids removed during the MSR and CSR campaigns is shown on Figure 3.1-13. The final residual heel in the Tank 16H primary tank in December 1980 is shown on Figure 3.1-14. This photo was taken from Riser 7 at an elevation near the tank floor. The SLP from Riser 8 can be seen in the background.

As mentioned earlier, the multiple campaigns performed were not planned to expedite waste removal from Tank 16H, but to provide maximum data and experience to evaluate various options available for waste removal from other tanks. After the cleaning demonstrations ended in late 1980, no additional cleaning evaluation to explore options for additional waste removal have been performed due to the small amount of waste remaining.

As described in more detail in Section 3.0, the extraordinary success for primary tank cleaning following its early RFS may not be indicative, or possible, for future waste removal efforts on other tanks.

**Figure 3.1-13: Summary of Tank 16H Primary Tank Waste Removal by Campaign**

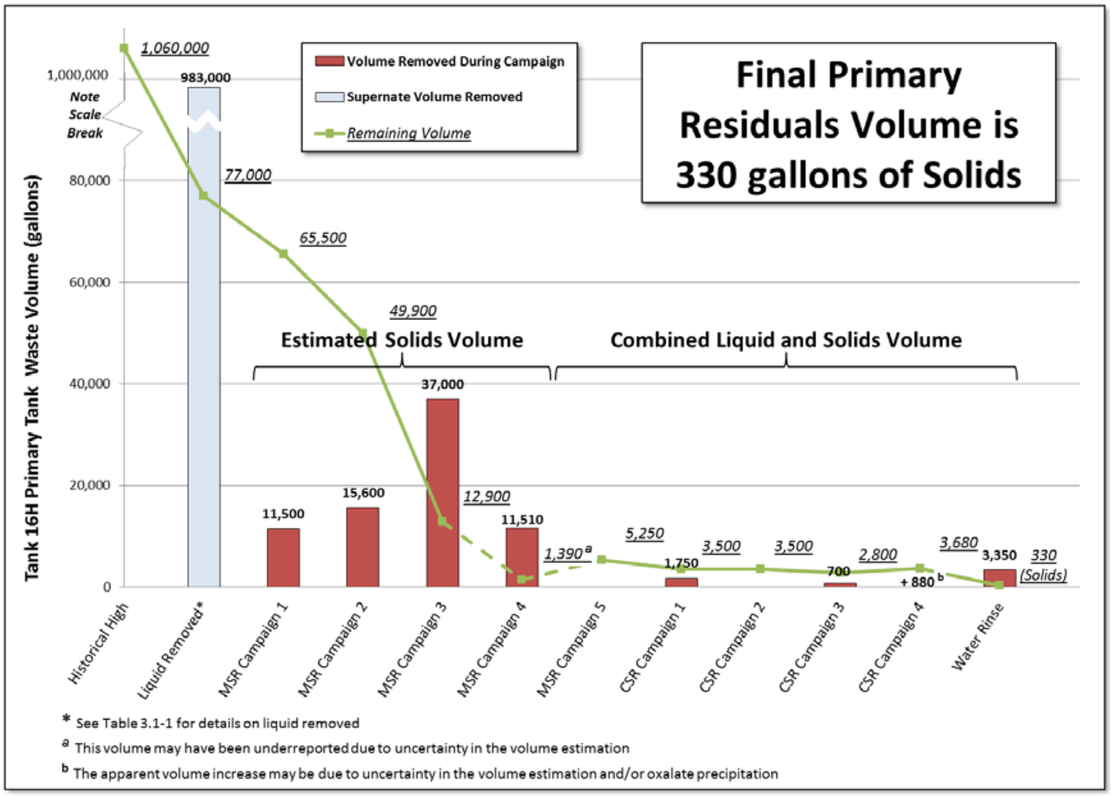
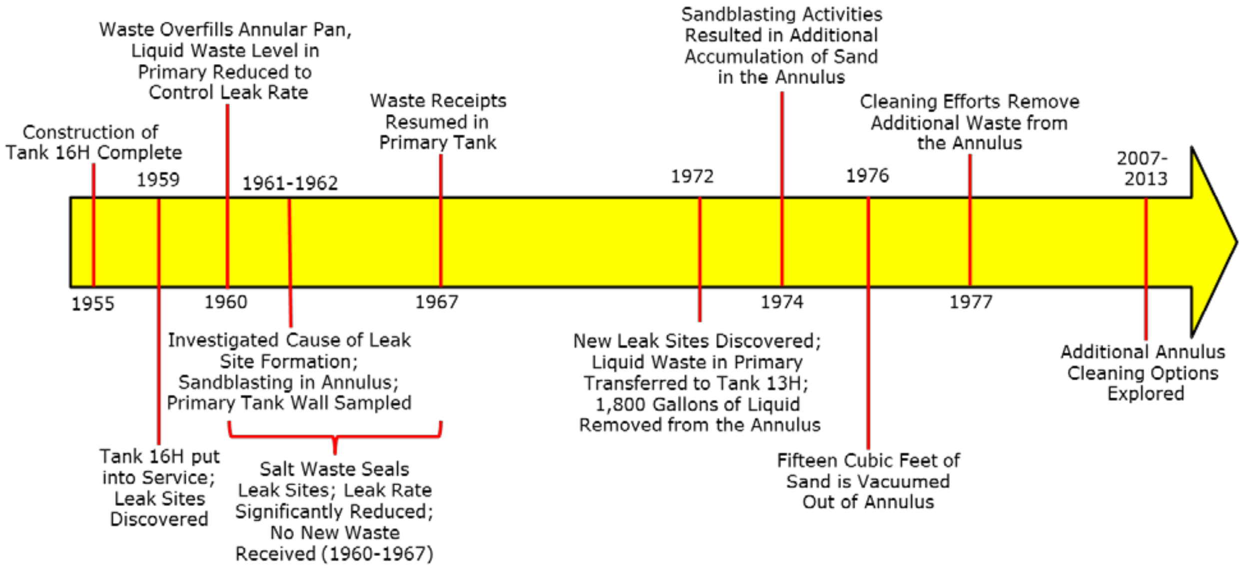


**Figure 3.1-14: Photograph of Tank 16H Primary Tank Post Phase 4 Cleaning (December 1980)**

## 3.2 Tank 16H Annulus Cleaning

Figure 3.2-1 shows the Tank 16H annulus historical timeline. The key events and activities on this timeline are described in this section.

**Figure 3.2-1: Tank 16H Annulus Historical Timeline**



### 3.2.1 Tank 16H Annulus Waste Removal Overview

As presented in Section 2.2.1, soon after Tank 16H was put into service, leakage from the primary tank into the annulus was discovered. In September 1960, the annulus pan overflowed and an estimated "tens of gallons" escaped the concrete encasement (presumably through a construction joint near the top of the annulus pan) and entered the surrounding soil. [DP-1358] Between September and October 1960, an estimated 185,000 gallons of waste had leaked from the primary tank into the annulus and was subsequently transferred out to Tank 14H. Leakage to the annulus stopped when the liquid level in the primary tank was lowered to 147 inches, a height just below the 150-inch elevation of the middle horizontal tank wall weld. [U-ESR-H-00107, DP-1358]

In October 1961, studies were started to determine the cause of the primary tank wall cracking. New IPs were installed in the annulus, and sections of the primary tank wall in the annulus were sandblasted in preparation for inspections, tank wall sampling, and dye-penetrant testing. [U-ESR-H-00107]

Tank 16H was returned to limited service in October 1967 to accept a combination of fresh waste receipts from H-Canyon and supernate from other HTF tanks, and by June 1968, the tank was refilled to a reduced liquid level operational capacity of 252 inches. In January and February 1972, inspection of the annulus revealed new leak sites and enlarged salt deposits on the waste tank wall and annulus floor. By March 1972, the use of the Tank 16H for additional waste receipts had ceased; liquid removal from the primary tank was initiated, and plans to remove the waste tank from service began.

In March 1972, core holes were drilled through the salt crust that had formed atop the waste on the annulus floor and 1,000 gallons of liquid were extracted from the salt cake and transferred to Tank 14H. [DPSPU 77-11-17]

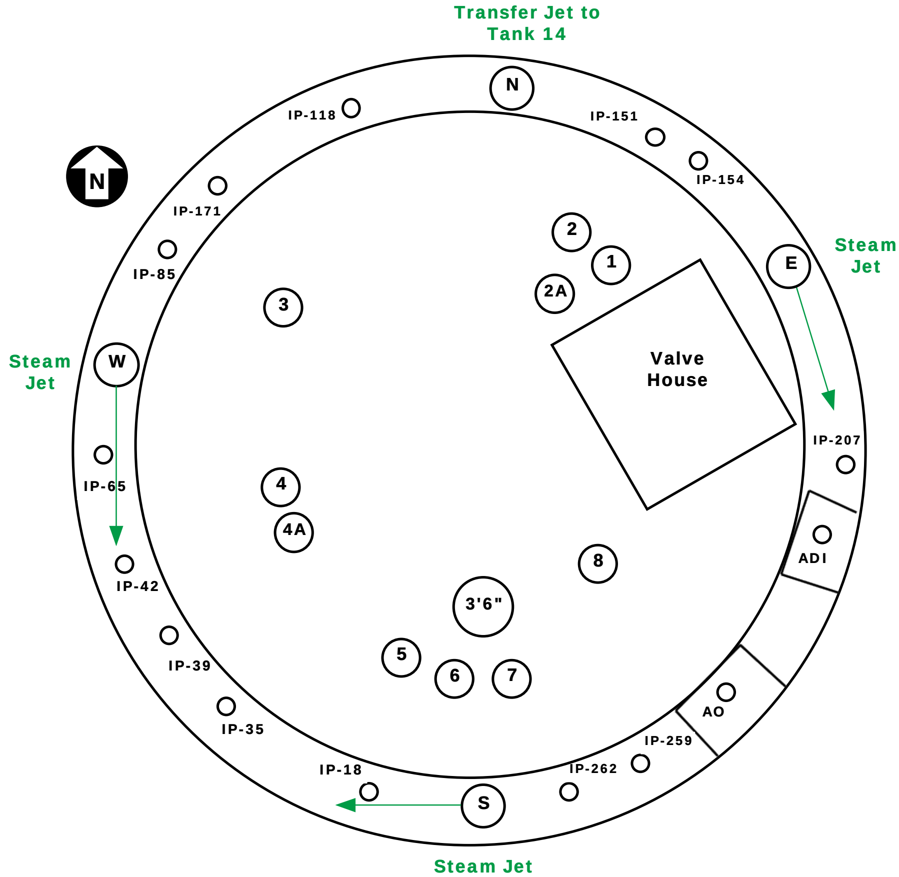
In September 1972, 800 gallons of liquid were jetted out of the annulus. In October 1973, another attempt was made to remove liquid with a dewatering jet. However, no appreciable waste was removed. [DPSPU 77-11-17]

The sandblasting activities in 1961 near IP-262 and South annulus riser, and in 1962 and 1973 near IP-151, resulted in the accumulation of several tons of sand on the annulus floor. To prepare for annulus cleaning, an estimated 15 cubic feet (112 gallons) of sand was vacuumed out of the annulus in June 1976.

*Annulus Waste Removal Campaigns*

In early 1977, an estimated 6,000 gallons of waste salt cake (crust and sludge) and sand remained in the annulus and a removal campaign was planned to dissolve and transfer the annulus salt waste to Tank 14H. [DPSPU-77-272-135] The waste removal efforts began in May 1977, when 14,000 gallons of low heat waste supernate from Tank 22H were transferred to the Tank 16H primary tank as ballast to prevent the waste tank bottom from bowing when water was added to the annulus. Steam mixing jets (25 gallons per minute) were installed in the East and South annulus risers to promote mixing and dissolution, and a transfer pump was installed in the North annulus riser. Water was then added to the Tank 16H annulus to dissolve the salt cake into solution and facilitate waste transfer out of the annulus. When the liquid level in the annulus reached 18 inches, the South and East riser steam jets were turned on to start a clockwise circulation. Steam was also sprayed into the top of the annulus to dissolve salt deposits on the primary tank wall. After 190 hours of steam jet operation, the West riser jet was turned on at 75 gallons per minute, to produce a counter-clockwise circulation. The West riser jet ran for a total of 32 hours, alternating with the East and South riser jets. The total operating time for the East and South riser jets was 600 hours. [DPSP-80-17-21] Figure 3.2-2 shows the placement of the jets in the Tank 16H annulus and the circulation direction for each.

**Figure 3.2-2: Steam Jet Configuration for Tank 16H Annulus Cleaning**




After three transfers totaling approximately 4,800 gallons of salt solution to Tank 14H via the transfer pump in the North annulus riser, an estimated 1,400 gallons of salt cake had been removed leaving an estimated 4,600 gallons in the Tank 16H annulus. [IOM-7914] Sample analysis of the waste remaining under IP-118, -151, -207 and -262 indicated that the waste contained mainly a water-insoluble sodium aluminosilicate mineral (natrodavyne) and sand. [DPSP-80-17-21] The remaining sodium aluminosilicate mineral was a result of high sodium salt waste that had leaked into the annulus interacting with the silica sand from sandblasting activities. Additional removal of this mostly insoluble material using the current method would be difficult. In July 1977, further annulus cleaning activities were suspended to avoid delaying the Tank 16H primary tank sludge removal demonstration. [IOM-20506]

As in the cleaning campaigns for the Tank 16H primary tank, no one-to-one volume correspondence exists for liquid gallons added and gallons of solids removed for material additions or transfers out of the annulus. The volumes estimated at various times for the annulus material are described below and summarized in Table 3.2-1.

**Table 3.2-1: Tank 16H Annulus Volumes**

| Date | Tank Condition | Net Change (gallons) | Estimated Waste Volume (gallons) |
|---|---|---|---|
| **September 1960** | Leakage into the annulus raises the liquid level in the annulus an estimated 2 inches (approximately 700 gallons) above the pan height before a transfer jet assembly can be fabricated and installed. [DPSPU 77-11-17] | — | 25,700 |
| **September 1960 to 1977** | Numerous transfers made to Tank 14H. Sandblasting and limited sand removal also occurred during this period. | A total of 185,000 gallons transferred. Final volume in annulus not estimated. | Monitored, but specific volumes not determined |
| **1977** | Waste estimated for salt removal planning after sand removal effort completed. [DPSP-77-272-135] | — | 6,000 |
| **May 1977** | Annulus cleaning with steam jets. | -1,400 | 4,600 |
| **March 2007** | Volume estimated after annulus inspection using a magnetic wall crawler. [LWO-LWE-2007-00085] | — | 4,760 |
| **February 2012** | Volume estimated using information gathered during collection of four samples for annulus cleaning evaluation study. [SRR-LWE-2012-00039] | — | 3,300 |
| **November 2013** | Final volume determination made using information gathered during collection of 11 characterization samples. [U-ESR-H-00113] | — | Inside duct = 410<br>Outside duct = 1,500<br>**Final Total = 1,910** |

— Not Applicable

In March 2007, the Tank 16H annulus was inspected using a magnetic wall crawler. Based on this inspection, an estimated 4,760 gallons of waste remained in the annulus. However it was recognized that this volume was probably biased high due to the conservative assumption that the waste height inside the dehumidification duct was equal to the height of the waste outside the duct. [LWO-LWE-2007-00085]

In 2011 as part of the annulus cleaning evaluation described in Section 3.2.2, samples of the annulus waste were collected under the North, South, East, and West annulus risers. Based on waste depth information obtained at the four sample locations, the annulus waste volume estimate was revised to 3,300 gallons in February 2012. [SRR-LWE-2012-00039]

During Tank 16H annulus characterization sampling in 2013, a total of 11 new samples were collected from inside and outside the ductwork and the waste depth were measured at those locations. Additional photographs and video footage were also collected. High resolution images taken during the sampling enabled a more precise estimate for material heights (thicknesses) both inside and outside the ductwork. The final annulus waste volume was determined to be 1,910 gallons, with 410 gallons inside the dehumidification duct and 1,500 gallons outside the duct on the floor. [U-ESR-H-00113]

### 3.2.2 Tank 16H Annulus Cleaning Options Evaluation

In March 2007, an in-depth study of annulus cleaning alternatives was performed. A preliminary scope of work and expression of interest (EOI) outlining the requirements for Tank 16H annulus cleaning were issued to engineering and technical companies that expressed interest in nuclear waste tank cleaning. The responses to the EOI included information on the proposed equipment and process.

Eight companies and technologies from a potential bidders list were selected and provided with a request for proposal (RFP). The RFP required:

- A scaled demonstration at the vendor's site of choice
- A full scale demonstration *in situ*
- Cleaning the Tank 16H annulus
- The cost to procure any equipment susceptible to radiological contamination.

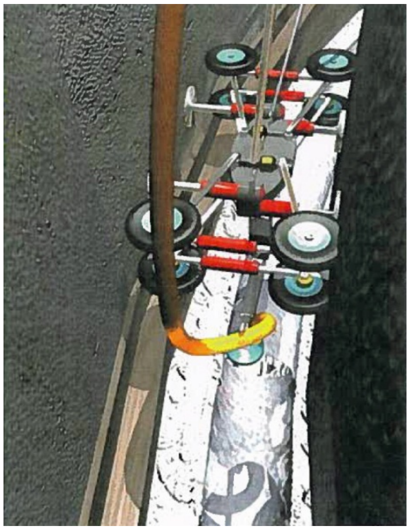
The RFP scope was to provide labor, material, and services for the design, fabrication, installation, and operation of annulus cleaning equipment to remove waste from a tank annulus and provide the interface necessary for the waste transfer to a designated tank. The work scope was divided into three proposal phases: 1) full-scale mockup, 2) in-tank demonstration, and 3) full annulus cleaning. The proposals were evaluated on best value using price, schedule, technical and organization approach, equipment functionality, and past performance.

Three of the seven vendor teams solicited responded to the RFP. The vendors were AREVA Federal Services, PaR Systems, and Safety and Ecology Corporation (SEC). The SEC proposal was chosen as the best value.

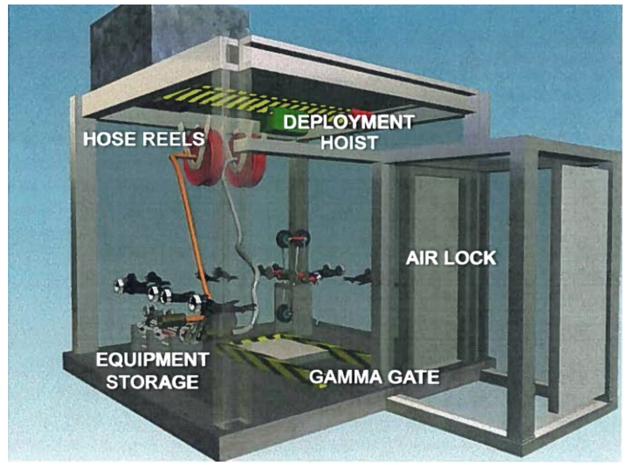
*Mechanical Cleaning*

The SEC system was a mechanical cleaning system. The system consisted of three equipment groups: a manipulator system, a pipe crawler, and a process system for retrieval, material size reduction, and material transport (Figure 3.2-3). The manipulator system would be mounted on a wall crawler. The electromechanical manipulator arm would support various tooling (rotating machine heads, wire brush head and cutoff wheels) for removing the waste and cutting ductwork. The interior duct cleaning would use an electromechanical pipe crawler with interchangeable tooling as well. SEC proposed vacuuming the dry material out of the tank to a process system skid that included a pulverizer. The processed material would then be blown into a dense-phase transfer hopper to be prepared for transport. A 50:50 water to dry media mix would be used for transport. The project team proposed that the dry retrieval approach could reduce environmental risks (from process leakage) and minimize secondary waste transfer. The estimated cost for implementing this program was $16.6M (adjusted to 2012 dollars). [LWO-CES-2007-00012]

**Figure 3.2-3: SEC Proposed Tank 16H Annulus Cleaning Components**

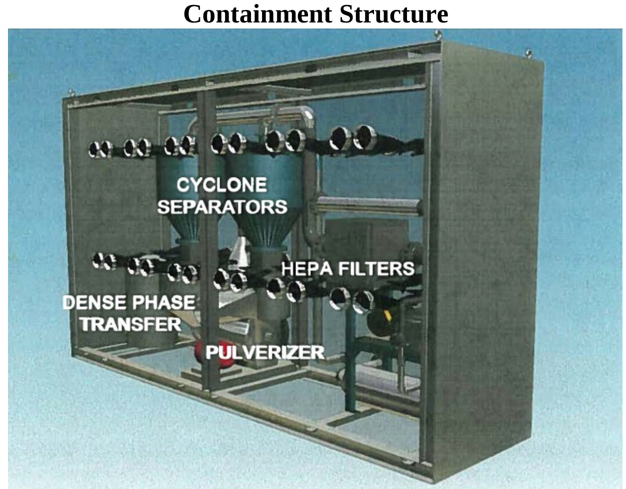


**Manipulator Cleaning Tank Annulus**




**Containment Structure**

**Pipe Crawler Installed in Pipe**




**Proposed Process Skid**

[U-ESR-H-00107]

A proof of principle test was successfully completed in 2007 at the vendor's facility. The test results and information gained were to be used as input for continued design and operating plan development. However, before this could take place, the project was suspended due to fiscal year funding constraints. When funding was reestablished in 2010, the projected cost to design, procure and implement the project was much higher than expected and the new schedule for implementation was extended many months longer than originally forecast. Also, new operability risks were identified based on real-time experience using crawlers in similar radiological applications and the assumed heterogeneity of the annulus waste material. In summary, the vendor proposal would be more difficult to implement, cost more to execute, and take longer than originally planned. Therefore, alternative methods to clean the Tank 16H annulus were re-examined. [SRR-WRC-2012-0018]

Based on available information, Savannah River Remediation LLC (SRR) developed an approach to evaluate two alternate methods for mechanical cleaning. The two methods were: 1) water dissolution/sluicing and 2) chemical cleaning with OA. Data was then developed to investigate additional annulus cleaning options by integrating the following activities:

1) Samples were retrieved from the four annulus risers in 2011;
2) Water and OA dissolutions were performed at the SRNL using the 2011 samples to provide data for the recommendation;
3) A process simulation software was used to develop a flowsheet using the best available information from all of the samples taken to predict solubility of the residual annulus waste; and
4) A conceptual design was prepared, including cost and schedule information.

*Water Dissolution and Sluicing*

Water dissolution and sluicing would involve using high-pressure nozzles, water circulating jets, and pumps to agitate clean, warm water throughout the annulus, including the space inside the dehumidification duct. The method would dissolve the majority of soluble components and remove some of the insoluble material through sluicing and mixing action. The slurry solution would be transferred to Tank 13H through an above-grade transfer line. The Tank 16H primary tank would have to have clean water added as ballast to prevent lifting (because of buoyant forces created when the annulus is filled with liquid). This option would have added approximately 150,000 gallons to Tank 13H.

Solubility studies at SRNL on the Tank 16H annulus samples collected in 2007 and the four samples collected in 2011 showed that about 35% of the total material outside the duct could be dissolved while 81% of the material inside the duct could be dissolved. Sample analysis found the four samples to be predominantly water-insoluble sodium aluminosilicate compounds and sand. The majority of the radionuclides were insoluble. The total material that could be dissolved per the flowsheet was about 57%. [SRNL-STI-2012-00178]

*Chemical Cleaning with Oxalic Acid*

Chemical cleaning with OA was evaluated as an improvement to the water dissolution/sluicing, focusing on annulus cleaning external to the duct. Chemical cleaning with OA would use the same equipment involved for water dissolution and sluicing except a heated solution of OA (4 to 8 wt%) would be substituted for warm water. The OA would improve the effectiveness of insoluble component removal.

The SRNL analysis results for OA cleaning showed that the solids remaining after drying were sticky and formed large clumps. [SRNL-STI-2012-00178] This could pose potential processing problems with transferring and storing the material. The formation of a gel using 4 wt% OA for cleaning was also identified in 1980. [DPST-80-377] This issue would require resolution and testing before implementing OA cleaning. Furthermore, a preliminary documented safety analysis evaluation showed that adding OA to the annulus would present additional safety concerns and would require safety basis modifications, that involve hazards assessments, expanded project safety documentation, readiness assessments, and a nuclear criticality safety evaluation. Though not insurmountable, a safety basis modification is non-trivial and would be time intensive and costly.

#### *3.2.2.1 Annulus Cleaning Alternatives Comparison*

Water dissolution and sluicing was compared to mechanical cleaning. Chemical cleaning with OA was evaluated as an improvement to water dissolution/sluicing, since water washing improves the effectiveness of OA dissolution by removing sodium and limiting the formation of sodium oxalate. However, chemical cleaning using OA was discounted as an option because of the technology development hurdles and safety basis modifications needed to make it viable. The slight possible advantage in performance did not outweigh the cost and schedule investment. Therefore, two options were studied for comparison. Water dissolution and sluicing was compared to the mechanical cleaning option presented in 2007.

Each method was assessed for certain areas of performance:

- **Removal Rate.** SRR predicted that water dissolution and sluicing and mechanical cleaning would be equally effective in radionuclide removal because the solids removed by mechanical cleaning (via vacuum) are roughly the same volume of solids dissolved by the water method. ***Advantage**: none.*
- **Operations.** In spite of the optimistic predictions for mechanical cleaning, recent experience with crawlers in tanks having cooling coils and other obstructions demonstrated that robotic equipment can easily be entangled, prone to in-tank failure, and difficult to repair in place, which gives a preference to water dissolution and sluicing in the area of reliability. The water method simply has fewer moving parts and involves fewer *in situ* actions. ***Advantage**: water dissolution and sluicing.*
- **Plant Interactions.** Mechanical cleaning has an advantage over water dissolution and sluicing for plant interactions because it does not require the addition of ballast water to the primary tank. Furthermore, there is less waste generated for mechanical cleaning because water is not added during the material processing. ***Advantage**: mechanical cleaning.*
- **Radiation Exposure.** At the time of evaluation, SRR judged both methods to be equal in the area of radiation exposure because operating the equipment for each option is labor intensive requiring work over open risers and IPs. ***Advantage**: none.*
- **Cost and Schedule.** The real discriminators in this comparison are in the areas of cost and schedule. The total costs for mechanical cleaning were estimated at $16.6M (vendor costs plus plant operations support). Preliminary estimates for water dissolution and sluicing were estimated at about $4M. Water dissolution and sluicing also has the advantage on schedule: 11 months for water dissolution and sluicing compared to 39 months for mechanical cleaning. ***Advantage**: water dissolution and sluicing.*
- **Safety Basis**. A Consolidated Hazard Analysis (CHA) for Tank 16H mechanical cleaning was completed in 2008. This CHA did not generate any new controls already credited in the current Documented Safety Analysis. ***Advantage:** mechanical cleaning.*

With overall waste removal performance relatively equal between the two options, water dissolution and sluicing was chosen as the preferred alternative based on operational simplicity, lower cost and a favorable schedule.

#### *3.2.2.2 Water Dissolution/Sluicing Demonstration*

After selection of water dissolution/sluicing as the preferred alternative, SRR continued design and processing strategy development for this option. To inform final design and the processing strategy, a mockup of the water dissolution/sluicing option was performed in October 2012. The demonstration would also provide information of whether the proposed cleaning method with high-pressure sluicing nozzles would potentially breach the containment boundary and adversely impact personnel safety.

The demonstration used vendor-furnished equipment (high pressure pump, hoses, and nozzles) to remove a non-radioactive simulant from the inside and outside of a full scale ventilation duct. Generally, the demonstration revealed that solids removal was likely to be less than forecasted and aerosolization of the waste is a possibility. Because of this potential, precautionary administrative and engineered controls would have to be installed to ensure the safety of Site workers and the public. [SRR-LWP-2012-00068]

Although a Consolidated Hazard Analysis (CHA) was not completed for water dissolution and sluicing, the mockup for this activity, described in *Tank 16 Annulus Cleaning Demonstration* [SRR-LWP-2012-00068], clearly showed that Safety Significant/Safety Class controls for aerosolization would be required.

The demonstration was also used to provide sufficient information to establish an estimated project dose projection for the workers executing the activities. Assuming no adverse incidents or unexpected releases, the total job dose would be approximately 14 person-rem, or approximately 10 mrem/hour per worker. [SRR-RPE-2013-00003]

#### *3.2.2.3 Basis for Not Removing Additional Annulus Waste*

The mockup demonstration disclosed two discoveries:

- Waste could get aerosolized and become airborne during removal operations. Because of the aerosolization potential, Site operations would have to invoke administrative and engineered controls to limit radioactive releases. These controls would have the project incur additional and unanticipated costs and program delays.
- The technique would be less effective; projecting less than 50% of waste removed due to the inability to fully break up the material along with the difficulty of moving the solid material toward the transfer pump.

Concurrently, SRR began running dose modeling for the HTF PA. A preliminary source term was established in May 2012 (based on the sample results from the 2011 samples). The PA was completed for HTF, using multiple release point scenarios and sensitivity cases, in November 2012. The HTF PA projected that the Tank 16H remaining waste contributed a small, nearly inconsequential, dose to a hypothetical future member of the public (MOP) (less than 0.2 mrem/year total effective dose equivalent [TEDE]). Therefore, implementation of the above strategy, with an expected efficiency of less than 50%, and an estimated 14 person-rem job dose would result in a projected dose reduction of less than 0.1 mrem/year. [SRR-RPE-2013-00003, SRR-CWDA-2010-00128]

Based on the results of the mockup demonstration, and information from the HTF PA, the decision was made that the benefits of additional cleaning did not outweigh the associated risks. [U-ESR-H-00107] The recommendation is based on the following two key points:

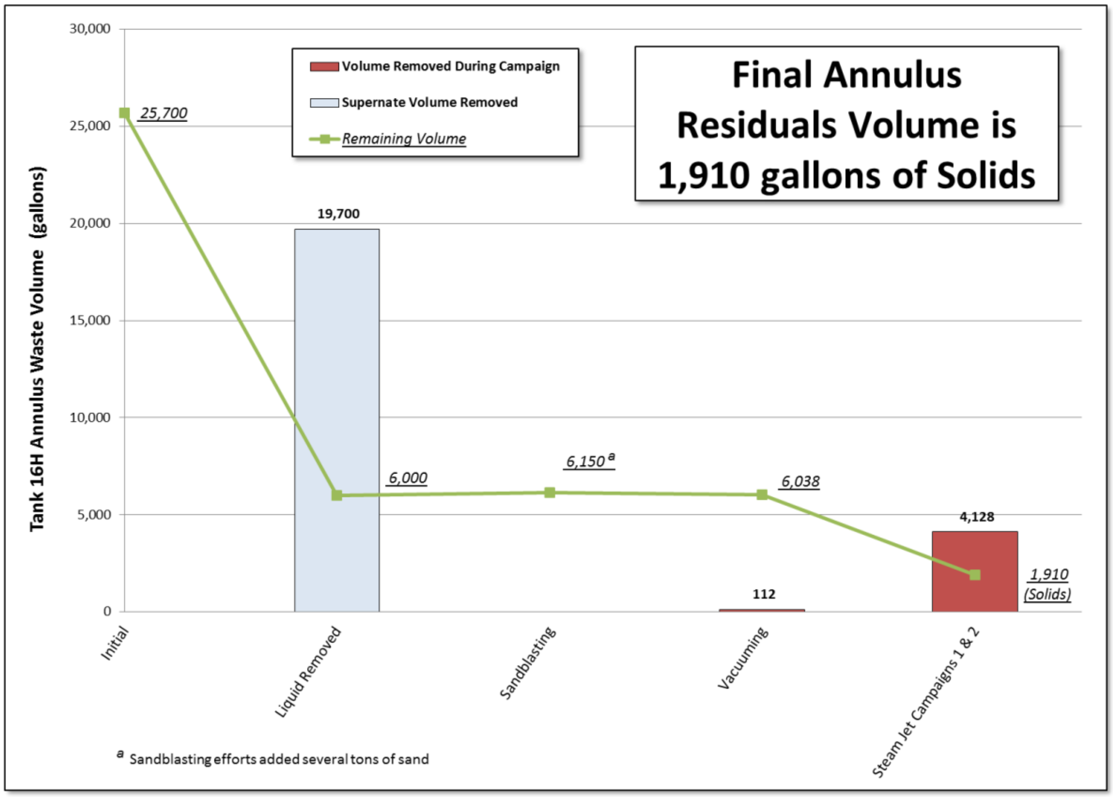
- The 14 person-rem job dose to implement the annulus cleaning program far exceeds the marginal improvement realized if annulus waste removal activities continue. Furthermore, the potential safety risks of executing the program (airborne release of aerosolized waste, high pressure line hazards, etc.) are greater than the risks of leaving the residual material in place. [U-ESR-H-00107]
- The cost to benefit ratio appears unwarranted. A detailed cost-benefit analysis substantiates this conclusion that a rough order of magnitude estimate of $7M to reduce the peak dose by approximately 0.1 mrem/year is not prudent. [U-ESR-H-00107]

Additional concerns were the difficulties anticipated in mobilizing the solids for removal and the low overall solubility (less than 35%) of the sodium aluminosilicate (natrodavyne)-waste mixture that would limit additional waste removal.

#### *3.2.2.4 Annulus Waste Removal Summary*

Tank 16H annulus waste removal began soon after leaked waste was discovered. Between 1960 and 1978, waste removal and leak site investigation activities added and removed liquids and solids. Beginning with a historical high level of 25,700 gallons (liquid level 2 inches above the annulus pan), the final total waste volume determined for the annulus waste was 1,910 gallons, with 410 gallons inside the ductwork and 1,500 gallons on the annulus floor. [U-ESR-H-00113] Figure 3.2-4 shows the annulus waste removal annulus by cleaning campaign.

**Figure 3.2-4: Summary of Tank 16H Annulus Waste Removal by Campaign**

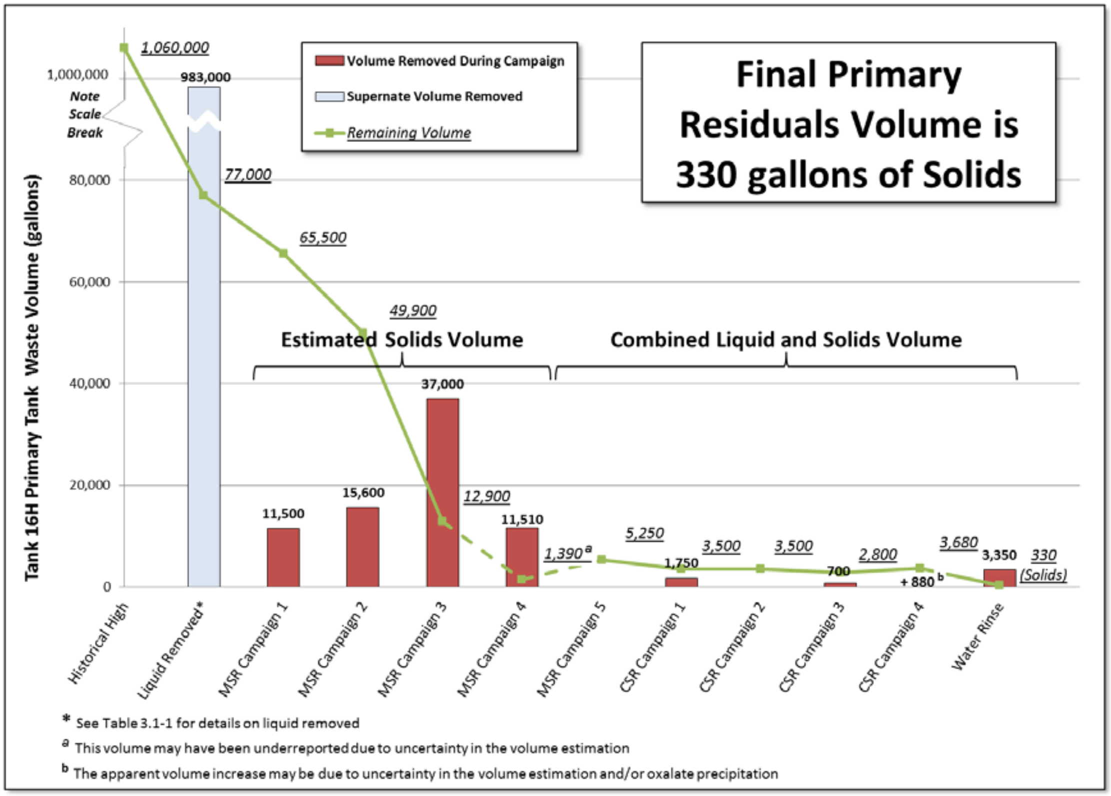



## 3.3 Overall Tank 16H Waste Removal Summary

Waste removal details for the primary tank are presented in Section 3.1. Figure 3.3-1 shows the Tank 16H primary tank after waste removal. The overall waste removal effectiveness for the primary tank is summarized on Figure 3.3-2. The percentage of total waste volume removed from the primary tank was calculated at greater than 99.9%. As described in more detail in Section 3.0, the extraordinary success for primary tank cleaning following its early RFS may not be indicative, or possible, for future waste removal efforts on other tanks.

**Figure 3.3-1: View of the Tank 16H Primary Tank After Waste Removal**

**Figure 3.3-2: Tank 16H Primary Tank Total Volume Removal by Phase**




Waste removal details for the annulus are presented in Section 3.2. Figure 3.3-3 shows the typical appearance of the annulus residual material as seen during characterization sampling in 2013. Figure 3.3-4 is a closer view of the material inside and outside the ductwork seen during sampling. The waste removal effectiveness for the annulus is shown on Figure 3.2-4. The percentage of total waste volume removed from the annulus was calculated at 92.6%.

The percentage of overall waste volume removed from Tank 16H was calculated at 99.8%. The Tank 16H primary tank and annulus waste removal details are summarized in Table 3.3-1.

**Figure 3.3-3: View of the Tank 16H Annulus during Sampling at IP-35**


Note: Round holes on top of duct (just above photo date stamp) were cut to sample the inner duct material.

**Figure 3.3-4: View of the Tank 16H Annulus during Sampling at IP-207**

**Table 3.3-1: Tank 16H Primary Tank and Annulus Waste Removal Details**

| | Primary Tank | Annulus | Total |
|---|---|---|---|
| Total Starting Volume (gallons)[a] | 1,060,000 | 25,700 | 1,085,700 |
| Total Pump/Jet Run Time (hours) | 2,297 | 632 | 2,926 |
| Total Liquid Introduced into the Tank (gallons) | 872,000 | 14,400 | 886,400 |
| Total Solids Removed (gallons) | 76,670 | 4,090 | 80,760 |
| Total Solids Remaining (gallons) | 330 | 1,910 | 2,240 |
| **Percent of Total Waste Volume Removed (%)** | **>99.9** | **92.6** | **99.8** |

[a] Starting volumes are based on historical high waste volumes in the tank.

## 3.4 Basis to Proceed with Sampling and Analysis Activities in Tank 16H

Heel removal operations were completed in both the primary tank and annulus as described in Sections 3.1 and 3.2, respectively. The following factors were used in making a qualitative determination to suspend waste removal operations:

*Primary Tank*

For the Tank 16H primary tank, the qualitative determination to suspend heel removal activities was primarily based on the visual observation. Visual inspections inside the primary tank, utilizing remotely operated cameras, showed there was a significant reduction in residual material volume as a result of the waste removal efforts. At the time of the decision to proceed with sampling, the volume of residual material was estimated to be approximately 300 gallons in the primary tank. Based on the final volume determination, Tank 16H has 330 gallons remaining in the primary tank. [U-ESR-H-00113]

*Annulus*

As described in Section 3.2.2.3, the qualitative determination to suspend removal operations in the Tank 16H annulus was based primarily on the benefits versus cost/risk of implementing an additional removal technology. In determining the potential consequences of leaving the remaining material in the annulus and the benefit of removing additional material, DOE examined the results of the HTF PA modeling that was being conducted in 2012. The HTF PA projected that the remaining residuals in Tank 16H contributed a small, nearly inconsequential, dose to a hypothetical future MOP (less than 0.2 mrem/year). Therefore, implementation of the water dissolution and sluicing strategy, with an expected efficiency of less than 50% and estimated 14 person-rem job dose, would result in a projected dose reduction of less than 0.1 mrem/year. [SRR-CWDA-2010-00128] Based on the final volume determination, Tank 16H has 1,910 gallons remaining in the annulus. [U-ESR-H-00113]

### 3.5 Agreement to Proceed with Sampling and Analysis

The FFA requires DOE to notify EPA and SCDHEC when DOE considers waste removal to be complete and to provide any supporting documentation to SCDHEC and EPA for review. DOE, SCDHEC, and EPA shall mutually agree that waste removal activities may cease.

DOE briefed officials of SCDHEC and EPA on January 28, 2013, regarding challenges related to additional waste removal in the Tank 16H annulus, and again on March 12, 2013 regarding the status of Tank 16H. [SRR-CWDA-2013-00041]

The briefing demonstrated that:

- The mechanical and chemical cleaning technologies had been effective in Tank 16H and had reached the extent of the technologies to remove significant additional waste.
- 99.8% of the waste by volume and the associated hazardous constituents and radionuclides in this waste tank had been removed.
- A qualitative assessment of additional cleaning options indicates that additional waste removal efforts are not practicable. Additional removal efforts would have a high cost and a high potential for dose to workers and members of the public. The benefit of additional removal efforts would be very small.
- A qualitative assessment indicates that at the current tank status, 10 Code of Federal Regulations (CFR) 61, Subpart C performance objectives would be met.

Following the briefing DOE requested concurrence to proceed to the sampling and analysis phase of the waste tank closure process for Tank 16H. [WDPD-13-40]

Agreement was reached between the three agencies that waste removal efforts could be suspended and DOE could proceed with sampling and analysis activities for Tank 16H to characterize the residual waste. SCDHEC and EPA submitted letters to DOE stating:

> "*…based upon the qualitative information provided, there is reasonable assurance that it is appropriate to enter the sampling and analysis phase of the closure process for Tank 16H. Full sampling and analysis of the residuals in support of the Closure Module for this tank will be needed before a final decision can be made by the Department regarding completion of waste removal operations for Tank 16H.*" [DHEC_04-11-2013]
>
> and
>
> "*Based on the information provided in the two briefings and in DOE's letter, EPA concurs with DOE's request to cease waste removal activities in Tank 16H and proceed with the sampling and analysis phase of the project.*" [EPA_04-10-2013]

# 4.0 RESIDUAL WASTE CHARACTERIZATION

After receiving letters from EPA and SCDHEC agreeing with DOE to suspend waste removal, DOE characterized the Tank 16H residual materials to determine the actual inventory of chemical and radiological constituents and validate the performance assessment modeling. The residuals characterization is not meant to demonstrate compliance with the GCP performance objectives but rather to determine through the special analysis if the source term left in the waste tank provides reasonable assurance that the GCP performance objectives will be met throughout the evaluation period.

Tank 16H is the first waste tank sampled and characterized under the conditions and requirements of the *Liquid Waste Tank Residuals Sampling and Analysis Program Plan* (LWTRSAPP) and *Liquid Waste Tank Residuals Sampling - Quality Assurance Program Plan* (LWTRS-QAPP) that were reviewed and approved by the SCDHEC and EPA. [SRR-CWDA-2011-00050, SRR-CWDA-2011-00117] No separate Data Quality Summary Report, like those prepared for Tanks 18, 19, 5, and 6 is planned to demonstrate the acceptability of the Tank 16H analytical data.

The steps associated with residual waste characterization are described in the following sections:

- Residuals Volume Determination – Section 4.1 discusses how the volumes of residual material were determined for the primary tank and the annulus.
- Residual Waste Characterization – Section 4.2 discusses the approaches used for the residual materials characterization, the sample collection techniques, and the final sample locations.
- Derivation of Constituents of Concern and Analytes – Section 4.3 describes the process for determining the chemical and radiological constituents of concern and the screening process for the final analyte lists used to characterize the residual materials.
- Sample Analyses – Section 4.4 briefly describes the residual material sample analyses and references the laboratory report for details. The results of the data quality assessment are discussed.
- Inventory Determination – Sections 4.5.2 through 4.5.7 describe how the residual volumes and the sample analysis results are used to determine the inventories of the primary tank, the annulus, sand layers, cooling coils and walls, and residuals hold-up in the remaining equipment. Section 4.6 and Tables 4.6-1 and 4.6-2 provide the final inventories determined for the Tank 16H residual materials.

## 4.1 Residuals Volume Determinations

The final Tank 16H primary tank and annulus residual volume determinations and uncertainty estimates were developed during the sample collection using additional photographs and video coverage from the on-board robotic crawler optical system, cameras lowered to record sampling, and waste thickness measurements made during annulus sampling. The personnel performing the residual material mapping in the primary liner and annulus were trained as described in the LWTRS-QAPP. [SRR-CWDA-2011-00117] The primary tank residual material mapping used the processes described in *Tank Mapping Methodology*. [SRR-LWE-2010-00240] The final annulus residual material volumes were determined using the methodology described in *The Tank 16 Final Residual Solids Determination and Uncertainty Estimate*. [U-ESR-H-00113]

### 4.1.1 Primary Tank Residuals Volume Determination

In January 2011, high resolution photographs were taken of the Tank 16H primary tank interior. These photographs were taken from Risers 2, 3, 6, and 8 and gave a 360 degree view of the waste tank at the high, middle, and lower elevations. [U-ESR-H-00113]

In May 2013, robotic crawlers were deployed in Risers 3 and 6 to collect residual materials for analysis and obtain close-up video coverage of the primary tank floor. Following sample collection, the crawlers were driven as far as possible around the tank floor to collect additional video footage to support the final residuals mapping and volume determination. The additional video footage collected during the sampling process was used to augment the photographs. The pictures and video were evaluated by a mapping team to determine the height of the residual material and refine the preliminary volume estimate.

Type II tanks have several internal features with known dimensions that can be used to estimate residual material height (thickness) on the tank floor. These features include horizontal cooling coils, regularly spaced vertical cooling coils, vertical support struts for the cooling coils, and the base plate for the central roof support column. In addition, the sample crawler dimensions are known and can be used for comparison to residual material height in the crawler vicinity. These features were used as landmarks for residual material mapping.

The mapping team used a widescreen high definition monitor and picture enhancement software to adjust color, contrast, and brightness to provide the best visuals possible. The criteria in Table 4.1-1 were used to assign heights to residual material areas. Known landmark dimensions also aided in determining residual material height. The thicknesses of the residual material regions were determined and plotted onto a gridded map of the tank floor. Figure 4.1-1 is the final residual material thickness and distribution map for the Tank 16H primary tank.

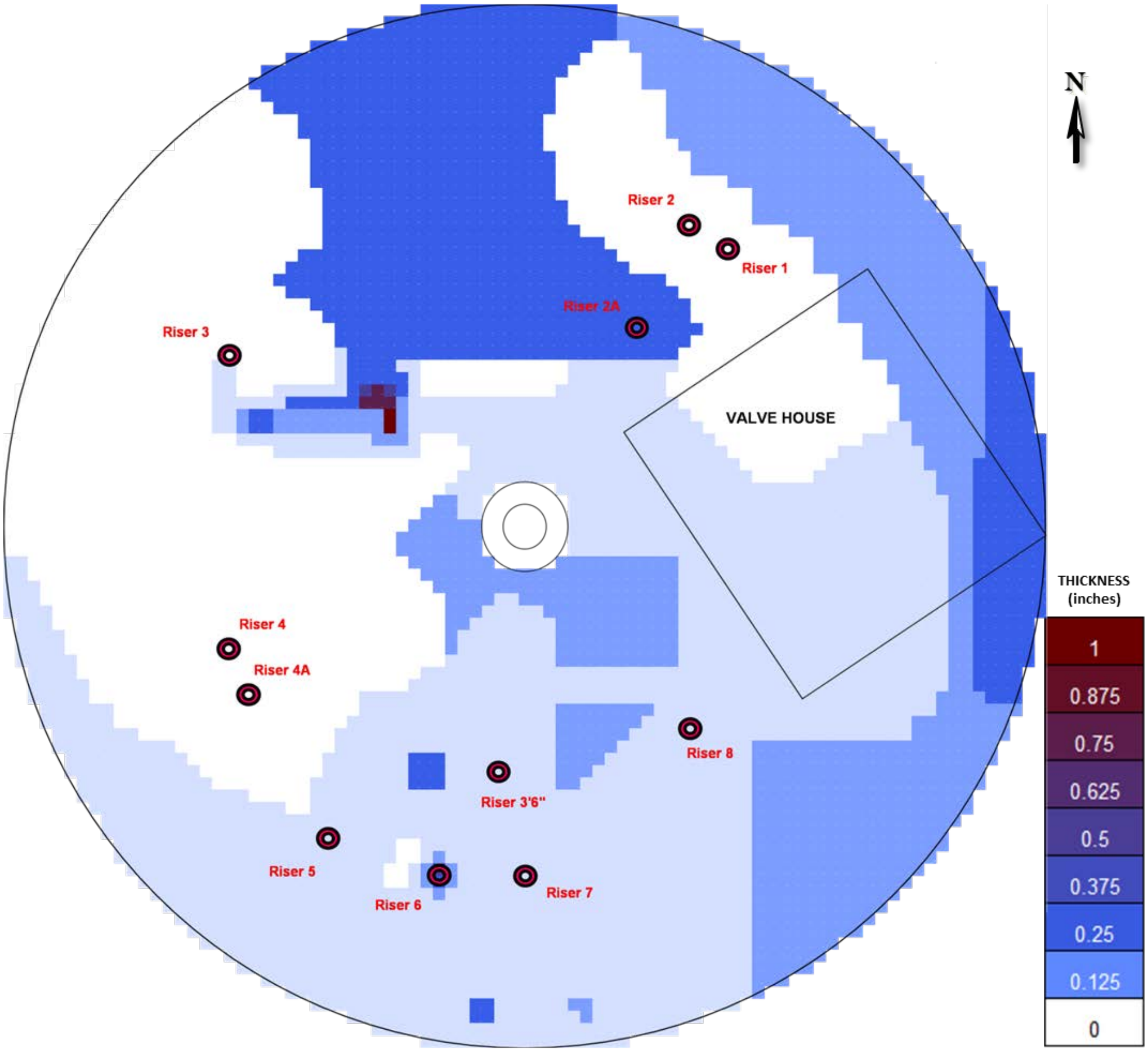
Based on the final mapping, the final primary tank residuals volume was determined to be 330 gallons. [U-ESR-H-00113]

**Table 4.1-1: Primary Tank Residual Material Height Criteria**

| Height (inch) | Criteria |
|---|---|
| 1/32 | Bare floor with minimal dusting |
| 1/16 | A dusting of material on the waste tank floor |
| 1/8 | Areas of thicker material where depth becomes apparent |
| >1/8 | Depth referenced against waste tank landmarks with known heights such as lifting plates (1/2 inch), welds for cooling coil supports and tie down rods (1/4 inch), and the bottom of lower horizontal cooling coils (13/16 inch). |

[U-ESR-H-00113]

**Figure 4.1-1: Tank 16H Primary Tank Residual Solids Map**




[U-ESR-H-00113]

### 4.1.2 Annulus Residuals Volume Determination

In November 2011, SRR Engineering inspected the Tank 16H annulus and collected four residual material samples from the North, South, East, and West annulus risers. Based on the visual inspection and waste thickness information collected at the four specific sample locations, a spreadsheet using the estimated height (thickness) of material inside and outside of the dehumidification duct was used to estimate the total annulus material volume. [SRR-LWE-2013-00010] A profile of the material height was also prepared to show where material accumulations were present with respect to sampling access points. [SRR-CWDA-2012-00179] The preliminary annulus residuals volume estimate was 3,300 gallons (total) for material inside the annulus. [SRR-LWE-2013-00010]

When annulus sampling was conducted in June through November 2013, the actual waste thickness at the 11 new sample locations inside and outside the dehumidification duct was measured using the sampling tool. Video footage and photographs taken during the sampling were also used to estimate the waste thickness at other locations using visual landmarks (Table 4.1-2). Where cameras were unable to visually inspect areas, the thickness was extrapolated from the nearest known area.

**Table 4.1-2: Tank 16H Annulus Residual Material Height Criteria**

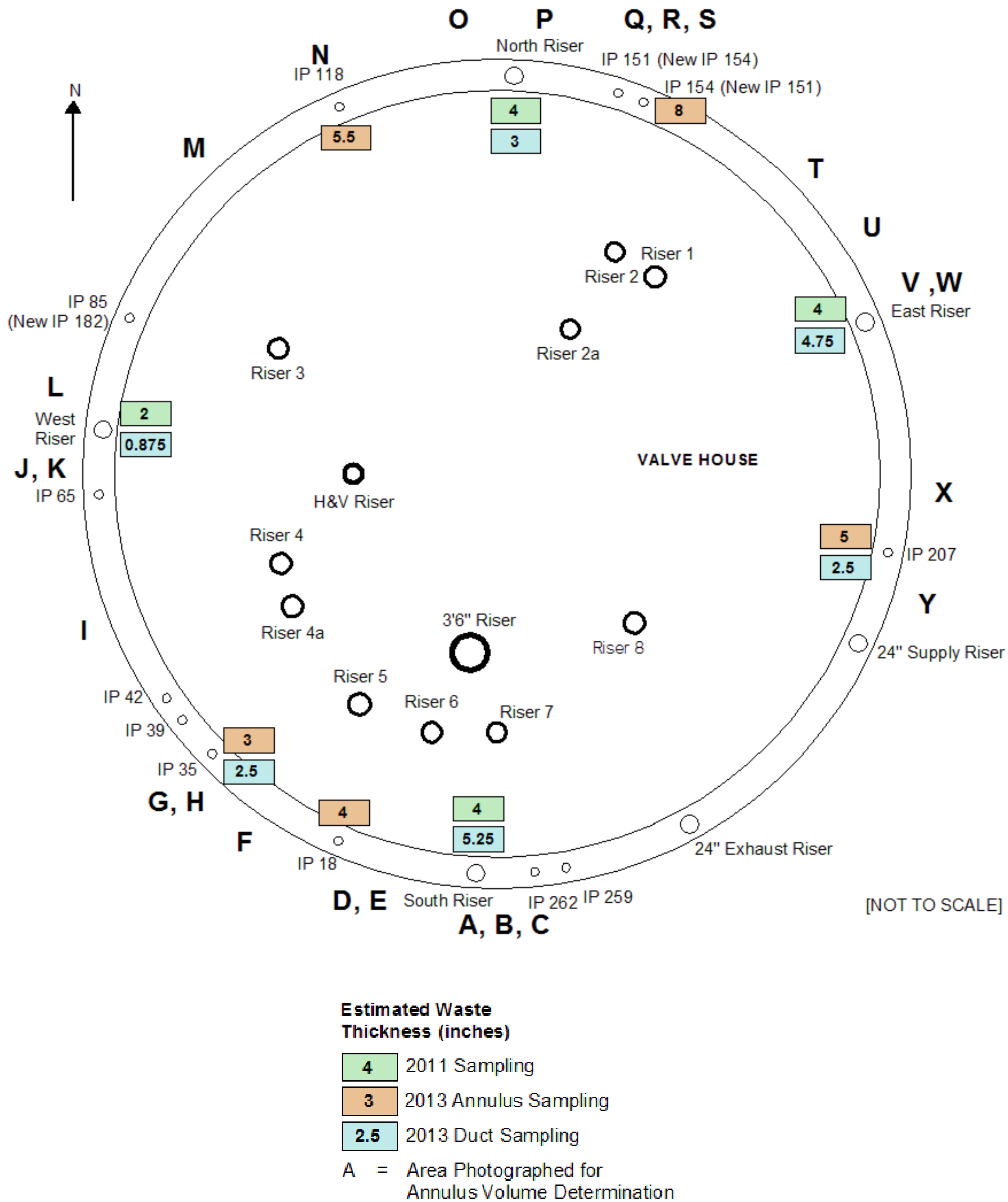
| Dimension (inch) | Landmark |
|---|---|
| 24 | Annulus wall weld height |
| 12, 15, 18, and 20 | Annulus duct diameters |
| 3/32 by 1 | Duct anchor strap |
| 12 | Annulus wall knuckle radius |
| 14 by 6 | Duct air supply openings (16) |

[U-ESR-H-00113]

The measurements were entered into a spreadsheet that calculated the volume of residual material inside and outside the duct. The volume was determined by dividing the annulus into sections and summing the material volumes calculated for each section. [U-ESR-H-00113] The colored boxes on Figure 4.1-2 contain the waste thickness measurements recorded during the 2011 and 2013 annulus samplings while the letters around the tank perimeter indicate areas photographed during the 2013 sampling that were used for the final volume determination. [U-ESR-H-00113, SRR-LWE-2014-00151]

The final annulus volume determination was 410 gallons for residual material inside the dehumidification duct and 1,500 gallons for residual material on the annulus floor for a total of 1,910 gallons. [U-ESR-H-00113]

**Figure 4.1-2: Tank 16H Annulus Residual Solids Thickness**



## 4.2 Tank 16H Residual Waste Characterization

As described in Section 3.0, Tank 16H is unique because its operational service history included limited waste receipts and extensive leakage from the primary tank into the annulus. Also, the early initiation of waste removal campaigns in the primary tank, as part of a demonstration project, was extraordinarily successful.

Sandblasting in the annulus to study the failure mechanism of the primary tank liner added tons of sand, and over time, the sand combined with the waste present in the annulus to form water-insoluble sodium aluminosilicate compounds such as natrodavine. As presented in Section 3.2.1, the dissimilar histories and cleaning methodologies produced differences in the residual material compositions and volumes between the primary tank and annulus.

### 4.2.1 Residuals Characterization Approaches

Because of the material and volume differences in the primary tank and annulus, various sampling approaches for the waste tank characterization were evaluated. In December 2012, as a first step towards designing the sampling plan, a statistical evaluation of the sampling uncertainties associated with six possible sampling options was performed by the Applied Computational and Statistics Division of the SRNL.

The Tank 16H residual material volume estimates and material distributions (segments) assumed for the primary tank and annulus were used as statistical evaluation inputs. A formula was developed for the variance of the mean concentration measurements of a theoretical analyte from tank residual material samples based on components of spatial and measurement variability. [SRNL-STI-2013-00100] The evaluation focused on the impacts to the expected 95% Upper Confidence Limit (UCL95) for the mean analyte concentration for the annulus and the primary residuals characterizations. The six sampling options evaluated in the statistical analysis were:

1. **Baseline Compositing –** 15 samples from the primary (composited into 3 samples for analysis) and 15 samples from the annulus (composited into 3 samples for analysis).
2. **Combined Compositing –** 15 samples total from the primary and annulus (composited into 3 samples for analysis).
3. **Reduced Baseline Compositing –** Similar to Option 1, but with less than 15 samples in the primary (composited into 3 samples for analysis) and less than 15 samples in the annulus (composited into 3 samples for analysis).
4. **Composited and Discrete Analysis –** Similar to Option 2, but with some limited number of discrete samples individually measured for key constituents.
5. **Discrete Primary and Composited Annulus –** 3 to 5 discrete samples analyzed from the primary and 15 samples from the annulus (composited into 3 samples for analysis).
6. **Discrete Primary and Discrete Annulus Sampling and Analysis –** Approximately 5 discrete samples from the primary and at least 5 discrete samples from the annulus.

In January 2013, a team of SRR Management, SRR Engineering, Closure & Waste Disposal Authority (C&WDA), and Tank Farm Operations personnel met to discuss the six Tank 16H sampling options. The evaluation used the available information on the residual material distributions (segments) and volumes in the tank primary and annulus, accessibility for sampling, the SRNL statistical evaluation of the uncertainty associated with each sampling option, and applicability of the sampling options. [SRR-CWDA-2013-00035]

The team recommended Option 5; the collection and analysis of 3 to 5 discrete samples from the primary tank and the collection of 15 samples from the annulus to create three composite samples for analysis. The recommendation also included using the material remaining from four annulus samples collected in November 2011 as part of the 15 annulus samples for analytical sample compositing. [SRR-CWDA-2013-00035]

The sample locations selected in the primary tank and annulus are discussed in Section 4.2.3 and documented in the *Tank 16 Sample Location Determination Report* (SLDR). [SRR-CWDA-2013-00018] The SLDR was then used to prepare the *Tank 16 Sampling and Analysis Plan*. [SRR-LWE-2013-00057]

The characterization approaches recommended were consistent with those developed and described in the LWTRSAPP. [SRR-CWDA-2011-00050] The LWTRSAPP and associated LWTRS-QAPP were approved by SCDHEC and the EPA and were fully implemented for the first time for the Tank 16H sampling and analysis.

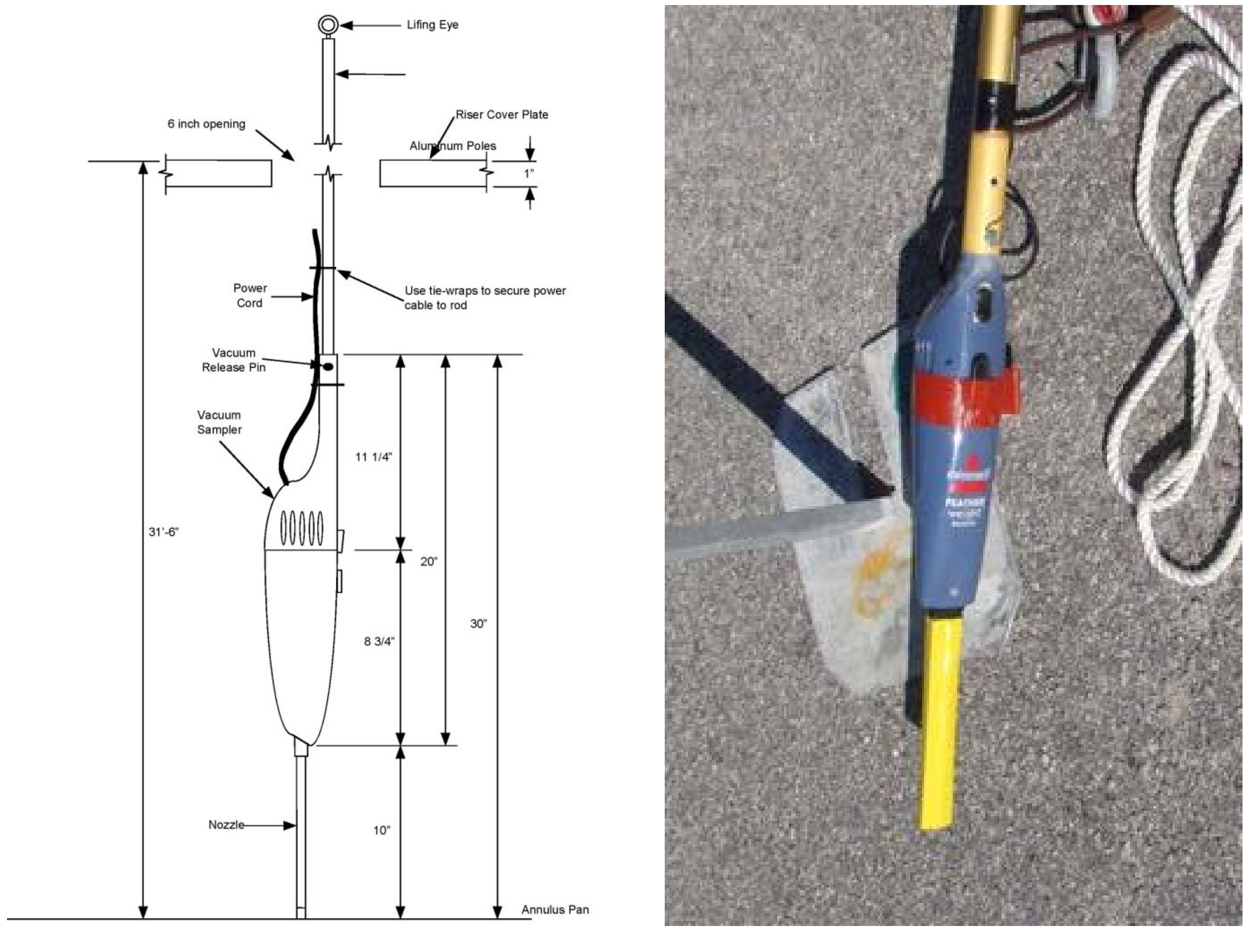
### 4.2.2 Sample Collection Techniques

As a result of the difficulties experienced when sampling the loose, granular residual material in Tanks 5F and 6F, new sample collection techniques were developed by SRR Engineering for sampling in the Tank 16H primary tank and annulus. Instead of using scrape samplers for sample collection, small diameter, and commercially-available vacuum cleaners were modified for use with pole samplers and by the robotic crawler. These vacuums were used for sample collection in both the primary tank and annulus. A special augering tool was used to disaggregate the annulus material before sample collection with a vacuum.

#### *4.2.2.1 Vacuum Sample Collection in the Primary Tank*

Testing showed that the sample collection vacuum suction was sufficient to collect loose residual material of the sizes anticipated in the primary tank and annulus. The vacuums were first used on a pole and by the robotic crawler to sample inside the Tank 16H primary tank. Lessons learned during the primary tank sampling led to several vacuum modifications for vacuum sample collection in the annulus. A clear, plastic window was added to the collection chamber for the visual verification of material retrieval. The one-way flap of the internal vacuum collection chamber was also modified to minimize material loss after vacuum shut off and transport. Figure 4.2-1 shows a drawing and photograph of the vacuum sampling tool.

**Figure 4.2-1: Line Drawing and Picture of Vacuum Sampling Tool**

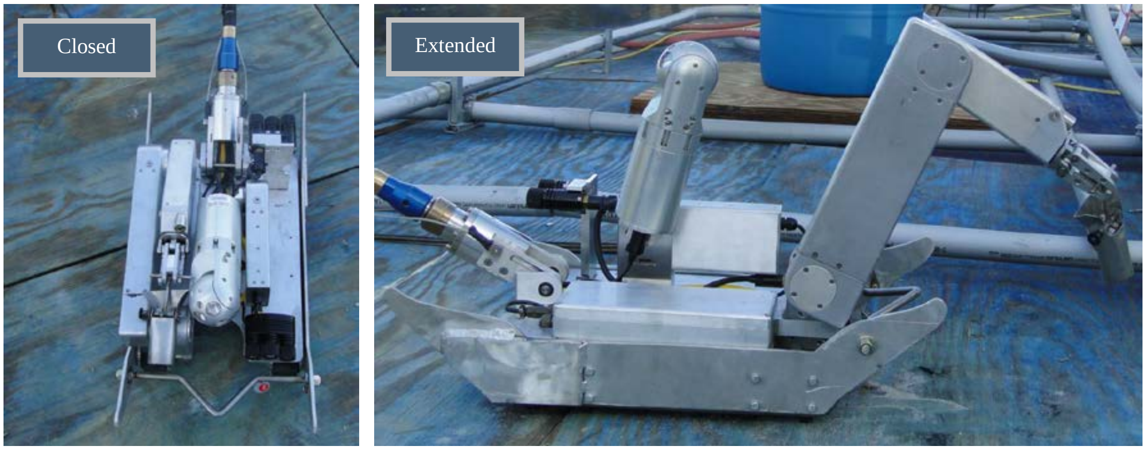



Note: The yellow nozzle extension was used for sampling inside the annulus.

Based upon previous sampling success in Tanks 5F and 6F, the crawler was chosen to collect some of the samples on the Tank 16H primary tank floor. The modified crawler was capable of traveling into areas not directly beneath a riser and collecting either scrape samples (samples obtained by scraping the floor surface) or with the vacuum.

The crawler is equipped with 20-inch long minitracs, a spectrum 90 camera, a four function manipulator arm, a mini crystal-cam, and front/rear auxiliary lights. The power is supplied via a cord inside the tether, which connects to the back end of the crawler through an extended spring loaded tether relief and control swivel. The crawler weighs 130 pounds. Figure 4.2-2 shows the crawler with the manipulator arm extended and the crawler fully compacted. The manipulator arm has very limited reach backward. The crawler can be fully compacted when driving around the waste tank to increase its mobility. By accessing and inspecting other areas of the waste tank, the residuals volume estimate was refined and finalized. [U-ESR-H-00113]

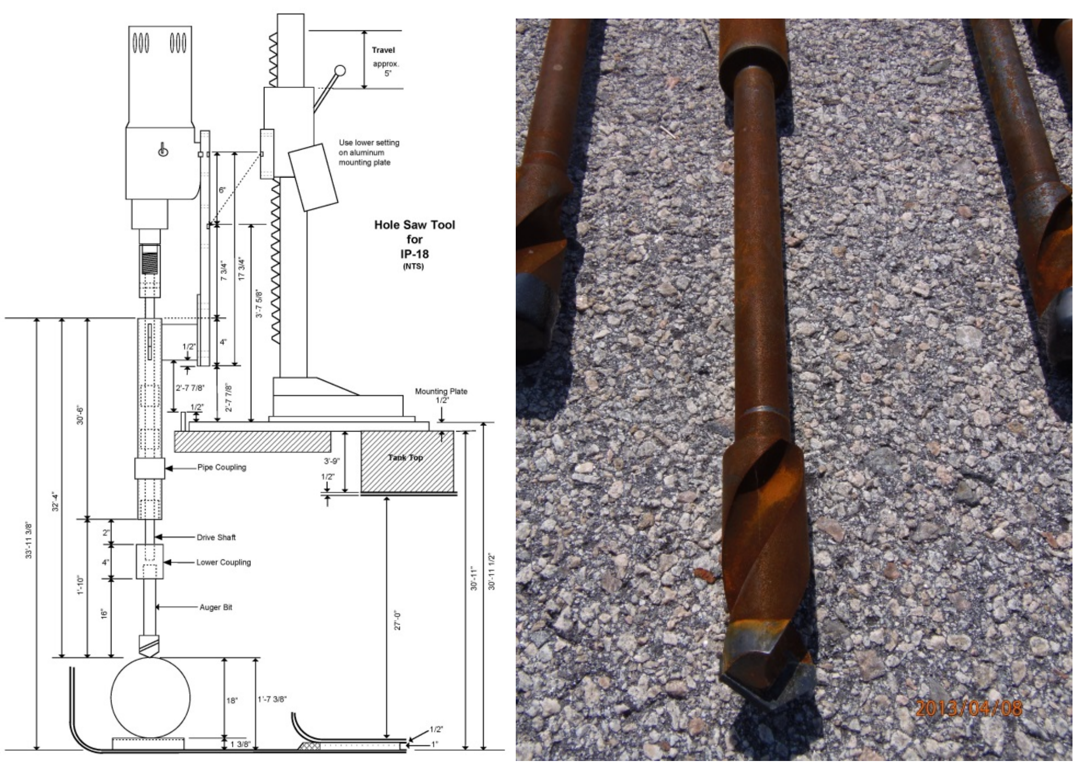
**Figure 4.2-2: Modified Sample Crawler With Arm Closed and Fully Extended (Mockup)**




#### *4.2.2.2 Vacuum Sample Collection in the Annulus*

Because the residual material on the annulus floor was a mixture of dried, water-insoluble sodium aluminosilicate compounds and sand, the material required mechanical disaggregation before sample collection using a vacuum. A special auger tool was developed for use with a modified drill press to penetrate the material (Figure 4.2-3).

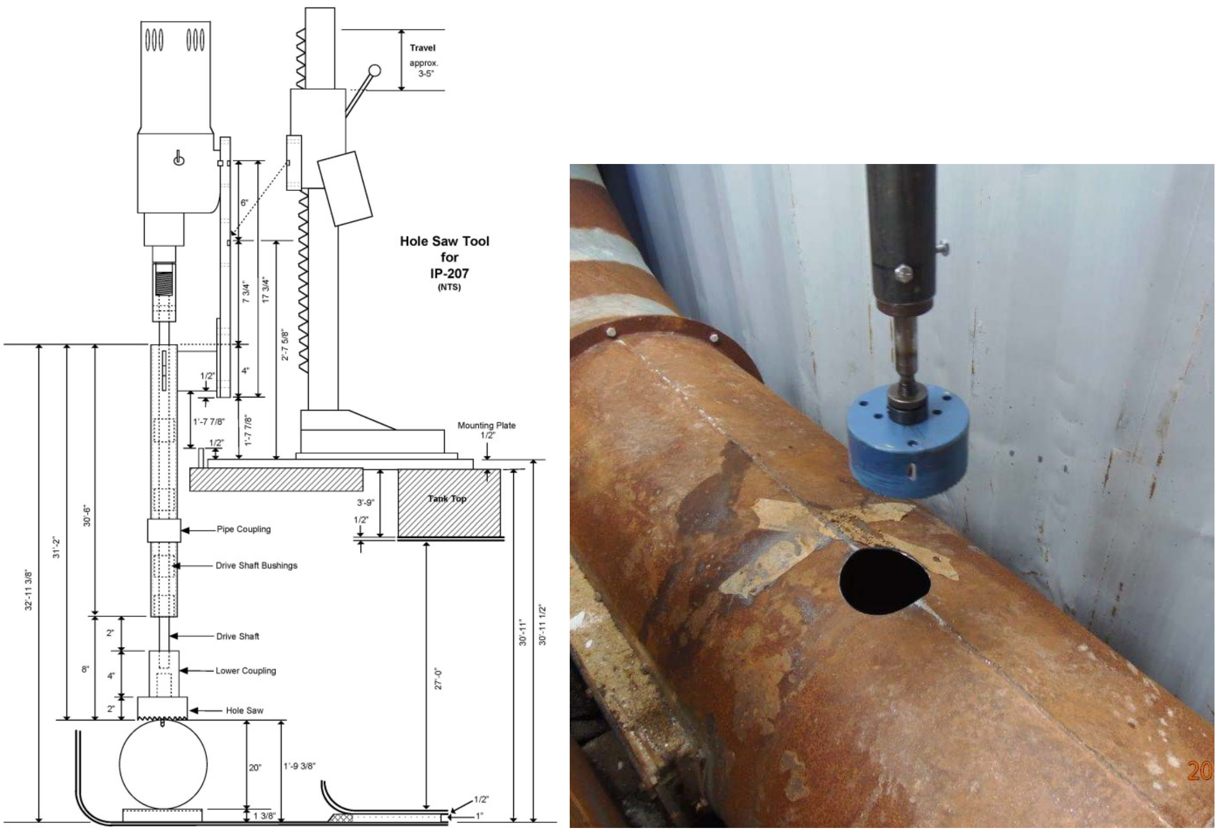
**Figure 4.2-3: Auger Sampling Tool and Auger Bit**



By measuring the height of the waste at the start of drilling, and the height when auger bit speed increased (indicating the material had been disaggregated) and penetration stopped (indicating the presence of a hard surface such as the annulus pan or duct bottom) the waste thickness was determined.

For sampling residuals inside the ductwork, a special tool was developed to cut a hole in the top of the ductwork. After the hole was cut, the material on the ductwork floor was disaggregated by augering and then sampled using a vacuum. The residual material thickness was also measured during the augering. The diameter of the cut hole was sufficient for insertion of the vacuum to collect residual material. Figure 4.2-4 shows a diagram of the hole cutting tool assembly and test results on a ductwork mockup.

**Figure 4.2-4: Hole Saw Tool for Sampling Access Inside the Annulus Ductwork**




### 4.2.3 Tank 16H Sample Locations and Sampling and Analysis Plan

Details on the sample location selection for the primary tank and annulus and the planned sampling and analysis are presented in the *Tank 16 Sample Location Determination Report* and the *Tank 16 Sampling and Analysis Plan*, respectively, and are summarized below. [SRR-CWDA-2013-00018, SRR-LWE-2013-00057]

#### *4.2.3.1 Primary Tank Sample Locations*

Because the primary tank contained only an estimated 330 gallons of residual material, the discrete sample collection and analysis option was implemented. This approach was consistent with Section 4.1.2.5 of the LWTRSAPP for the "low-volume" case where waste removal leaves only minimal material for characterization and the volume-proportional compositing sampling approach cannot be implemented. [SRR-CWDA-2011-00050] During the Tank 16H sampling option discussion meeting, the recommendation and decision was made to initially collect three discrete residual material samples from the primary tank floor. [SRR-CWDA-2013-00035]

Three initial sample locations were selected with three alternate locations identified in case insufficient material was recovered at the initial sample locations. In addition, contingencies for reduced analyte lists and higher detection limits were developed in case sample analyses using less than the desired 40 grams of recovered material were required. [SRR-LWE-2013-00057] Because the vacuum sampling technique was so successful, the alternate locations did not require sampling.

The sample identifications are listed in Table 4.2-1 and shown on Figure 4.2-5. Beneath Riser 8, floor residual material was collected using a vacuum on a pole. A robotic crawler equipped with a vacuum was used for floor sampling beneath Risers 3 and 6.

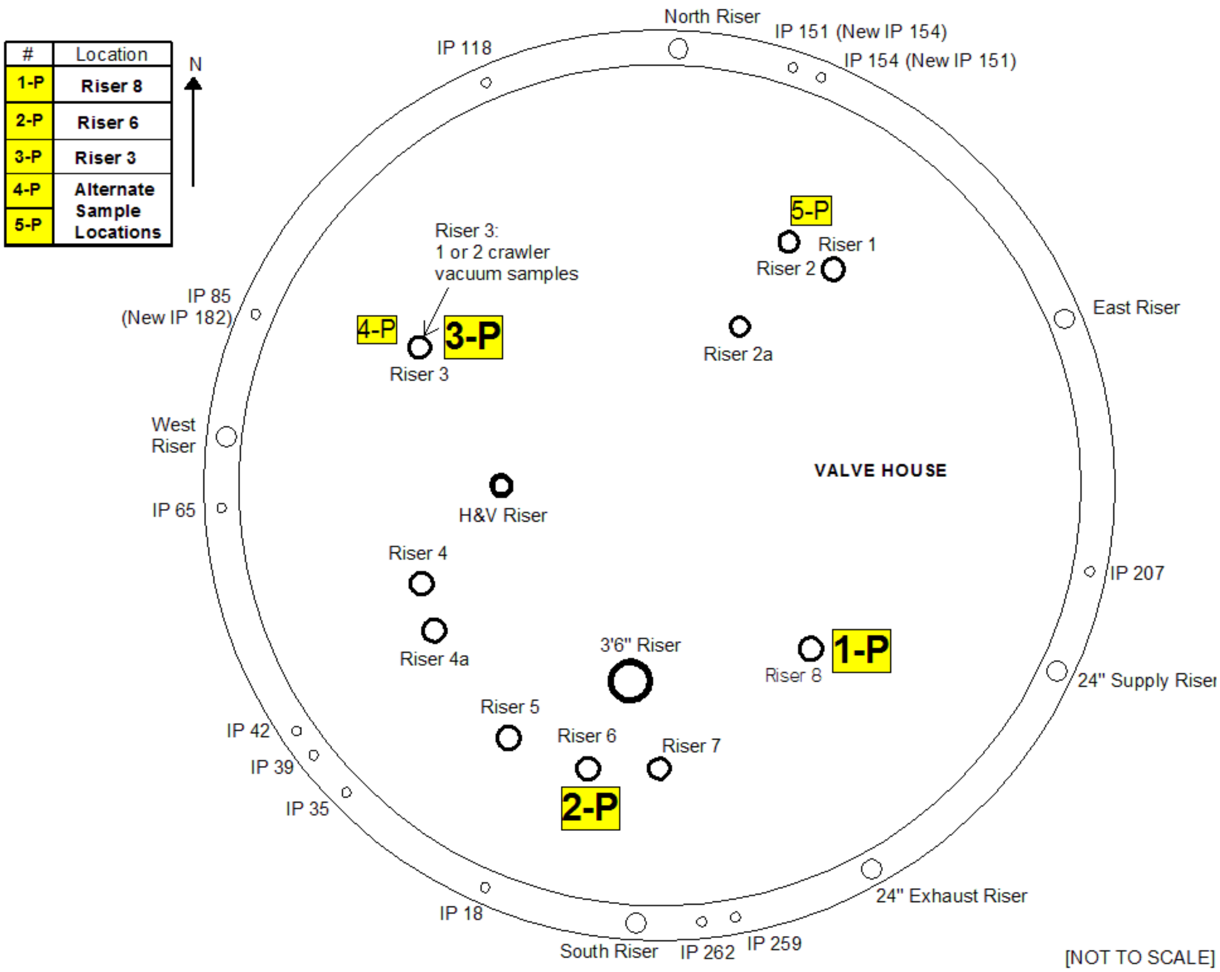
**Table 4.2-1: Tank 16H Primary Tank Sample Identifications**

| Primary Tank Location | Sample Identifications |
|---|---|
| Riser 8 | 1-P |
| Riser 6 | 2-P |
| Riser 3 | 3-P |
| Riser 3 | 4-P[a] |
| Riser 2 | 5-P[a] |

[a] Alternate primary tank floor location that did not require sampling.

Samples were collected and shipped to SRNL under chain-of-custody per the requirements of the LWTRSAPP. [SRR-CWDA-2011-00050] Sample collection was documented with photographs and video footage and reported in the *Tank 16 Sample Location Verification Document*. [SRR-LWE-2013-00027]

**Figure 4.2-5: Tank 16H Primary Tank Risers and Sample Locations**




### *4.2.3.2 Annulus Sample Locations*

As described in Section 2.0, Type II waste tanks have four risers for access to the North, East, South, and West areas of the tank annulus. Due to leakage from the Tank 16H primary tank into the annulus pan, 13 additional annulus IPs were added later to permit 100% annulus inspections. Leakage into the annulus, sandblasting, and other waste removal activities as described in Section 3.2, produced a complex mixture of waste, water-insoluble sodium aluminosilicate compounds, and sand in the annulus for characterization.

For the stratified random sampling plan design used in the annulus, three general material segments were delineated in the annulus residuals based on physical appearance and analytical results for the process samples collected in 2011. [SRR-CWDA-2013-00018, SRNL-STI-2012-00178, SRNL-STI-2012-00309] Northern and southern segments were defined for the material outside the annulus ductwork based on the limited chemical analyses of the 2011 annulus material samples. The material inside the ductwork was different in appearance than the material on the annulus floor, and was defined as the third segment.

Prior to sampling, the residuals volume in the Tank 16H annulus was estimated at approximately 3,300 gallons (total). [SRR-LWE-2013-00010] The residual material is present inside the dehumidification duct and outside the duct on the annulus pan floor. Using thickness measurements taken during the annulus sampling the final residuals volume was determined to be 1,910 gallons. [U-ESR-H-00113] The segments, distributions, and estimated volumes used for the sampling plan design are shown in Table 4.2-2. The sample locations and segments (populations) are shown on Figure 4.2-6.

**Table 4.2-2: Tank 16H Annulus Residual Material Segments for Sampling**

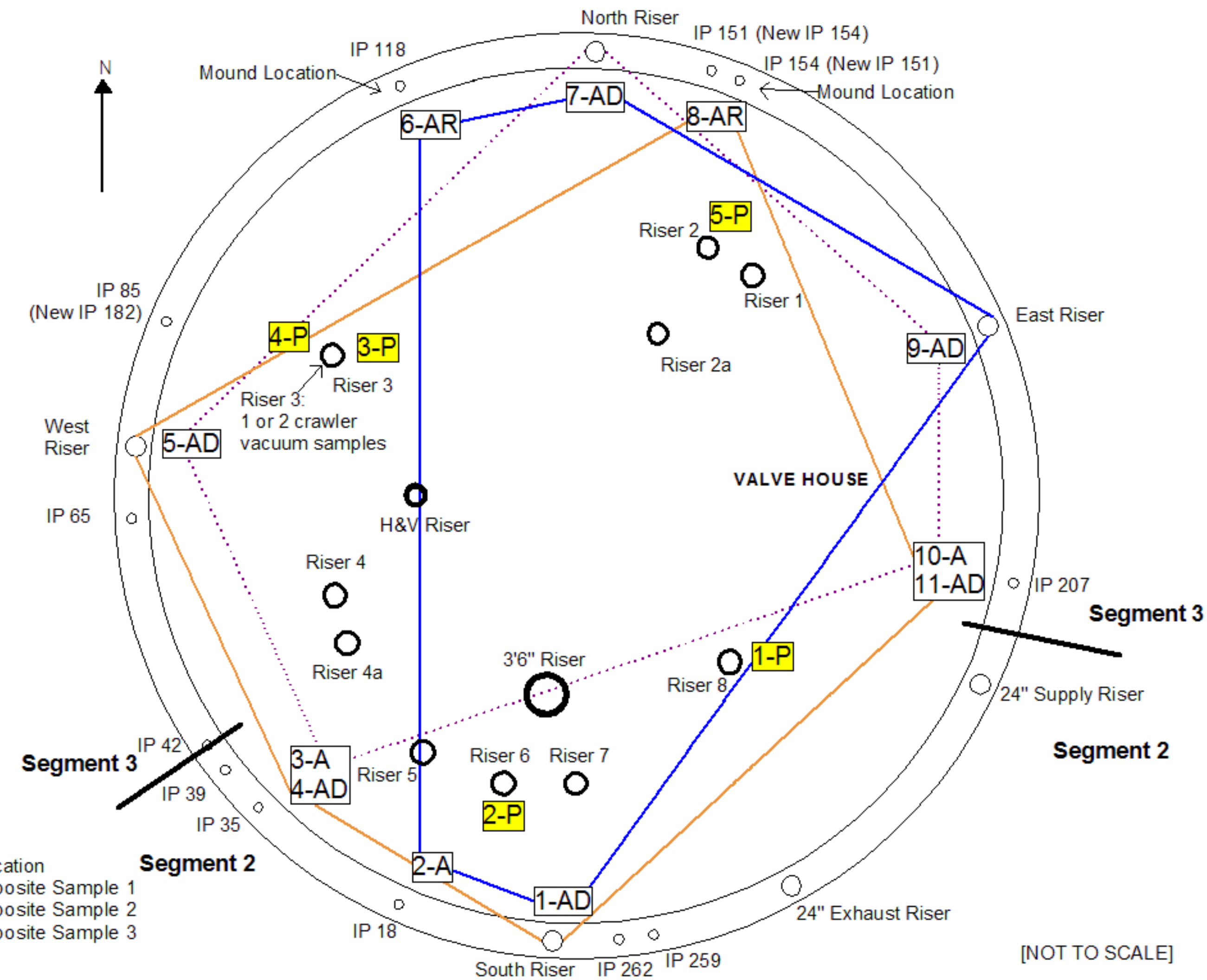
| Segment | Location | Material Characteristics | Final Volume (gallons) |
|---|---|---|---|
| 1 | Material inside the dehumidification duct | Visually consistent with dried salt (supernate) material | 410 |
| 2 | Material outside the dehumidification duct in the southern annulus sector | Sample analysis and visual observations show the material is generally consistent with sand (silica) with insoluble sodium-aluminum silicates | 500 |
| 3 | Material outside the dehumidification duct in the northern annulus sector | Sample analysis and visual observations show the material is generally consistent with sand (silica) with less sodium aluminum silicate content than the southern annulus sector | 1,000 |

[SRR-LWE-2013-00010, U-ESR-H-00113]

**Figure 4.2-6: Tank 16H Annulus Sample Locations**

| # | Location |
|---|---|
| 1-P | Riser 8 |
| 2-P | Riser 6 |
| 3-P | Riser 3 |
| 4-P | Alternate Sample Locations |
| 5-P | |
| 1-AD | South Riser |
| 2-A | IP 18 |
| 3-A | IP 35 |
| 4-AD | IP 35 |
| 5-AD | West Riser |
| 6-AR | IP 118 |
| 7-AD | North Riser |
| 8-AR | IP 154 (New IP 151) |
| 9-AD | East Riser |
| 10-A | IP 207 |
| 11-AD | IP 207 |

Notes:
P: Primary Tank
A: Annulus Floor
D: Inside the Duct
R: Resample at Original Location
Sample Array for Composite Sample 1
Sample Array for Composite Sample 2
Sample Array for Composite Sample 3



The stratified random sampling approach uses three arrays, each with five sample points. The northern and southern segment boundaries and sample arrays for the Table 16H annulus sampling are shown on Figure 4.2-6. As mentioned earlier, SRNL had retained custody of excess material remaining from the analysis of the four (4) annulus process samples collected in 2011. As discussed in the Tank 16H SLDR, the sample collection, transport, storage, and control documentation were evaluated and the samples were determined to be acceptable for use in the current characterization effort. [SRR-CWDA-2013-00018] Therefore, only 11 new samples were planned in the annulus. The sample locations and identifications are shown in Table 4.2-3. Due to no material recovery, samples were recollected at locations IP-118 and IP-151. An "R" was added to the sample identifications to indicate they are resamples.

**Table 4.2-3: Tank 16H Annulus New Sample Locations and Sample Identifications**

| Sample Location | Sample Identification |
|---|---|
| South Riser | 1-AD |
| IP-18 | 2-A |
| IP-35 | 3-A |
| IP-35 | 4-AD |
| West Riser | 5-AD |
| IP-118 | 6-AR* |
| North Riser | 7-AD |
| IP-151 (Old IP 154) | 8-AR* |
| East Riser | 9-AD |
| IP-207 | 10-A |
| IP-207 | 11-AD |

A = Annulus Sample
D = Sample collected from inside dehumidification duct
*R = Resample (due to no material recovery on first attempt)

#### *4.2.3.3 Annulus Sample Compositing*

Using the methodology described in the LWTRSAPP, the annulus sample densities and segment volumes were used to develop the sample compositing instructions to create the analytical samples.

To address the uncertainty associated with the final annulus residual volume estimate, the individual sample proportions used for the composite samples were varied based on the volumetric uncertainty. Thus, the analytical results reflected the volumetric uncertainty as well as the measurement, sampling, and material uncertainties. This compositing method was reviewed and supported by statistical experts in the Applied Computational and Statistics Group at SRNL. [SRNL-STI-2011-00323] The analytical results for the three composite samples allowed the overall uncertainty to be reflected in the confidence limits on the mean concentrations. The sample locations within each of the three segments were chosen to ensure a good representation of the material distribution.

The samples used for the compositing are shown on Figure 4.2-6 and listed in Table 4.2-4.

**Table 4.2-4: Tank 16H Annulus Samples Used for Compositing**

| Composite Sample | Material Segment Used for Compositing and Location | Sample Identification |
|---|---|---|
| 1 | 3-North, outside duct, on floor | 8-AR* |
| | 3-North, outside duct, on floor | West Riser |
| | 2-South, outside duct on floor | South Riser |
| | 1-Inside Duct | 4-AD |
| | 1-Inside Duct | 11-AD |
| 2 | 3-North, outside duct, on floor | 6-AR* |
| | 3-North, outside duct, on floor | East Riser |
| | 2-South, outside duct on floor | 2-A |
| | 1-Inside Duct | 1-AD |
| | 1-Inside Duct | 7-AD |
| 3 | 3-North, outside duct, on floor | 10-A |
| | 3-North, outside duct, on floor | North Riser |
| | 2-South, outside duct on floor | 3-A |
| | 1-Inside Duct | 5-AD |
| | 1-Inside Duct | 9-AD |

*R = Resample (due to no material recovery on first attempt)

#### *4.2.3.4 Sample Location Documentation and Shipping*

Sample collection was documented with photographs and video footage and reported in the *Tank 16 Sample Location Verification Document*. [SRR-LWE-2013-00027] The sample locations in the Tank 16H annulus are shown on Figure 4.2-6.

Samples were collected and shipped to SRNL under chain–of-custody per the requirements of the LWTRSAPP. [SRR-CWDA-2011-00050]

## 4.3 Derivation of Constituents of Concern and Analytes

Chemical and radiological constituents in the waste tanks are known by tracking waste data based on sample analysis, process histories, composition studies, and theoretical relationships. The most current listing of the chemical and radiological constituents found in tank waste is in *Information on the Radiological and Chemical Characterization of the Savannah River Site Tank Waste as of July 5, 2011* (SRR-LWE-2011-00201), which includes constituents that were received into the FTF or HTF over the facility history as well as any constituents that could have formed in the tank sludge, salt, or supernate phases. The report was used to develop the initial list of chemical constituents in the tank residuals. The radiological analyte list development is discussed in Section 4.3.3. The chemical inventories reported in the report are best available information or estimated values used to support liquid waste management safety and operational decisions. Because this information is used for safety purposes (e.g., nuclear criticality evaluations, corrosion evaluations), the estimates are approximate (i.e., may be conservative) and may overestimate or underestimate the actual inventories for constituents not involved in safety basis calculations. [SRR-LWE-2011-00201]

Because the original source of the annulus material was leakage from the primary tank, the analyte list for primary residuals characterization was used. However, analyte concentrations were expected to differ due to the differences in the cleaning histories for the primary tank and annulus. The derivation of the chemical and radionuclide constituents of concern is described below.

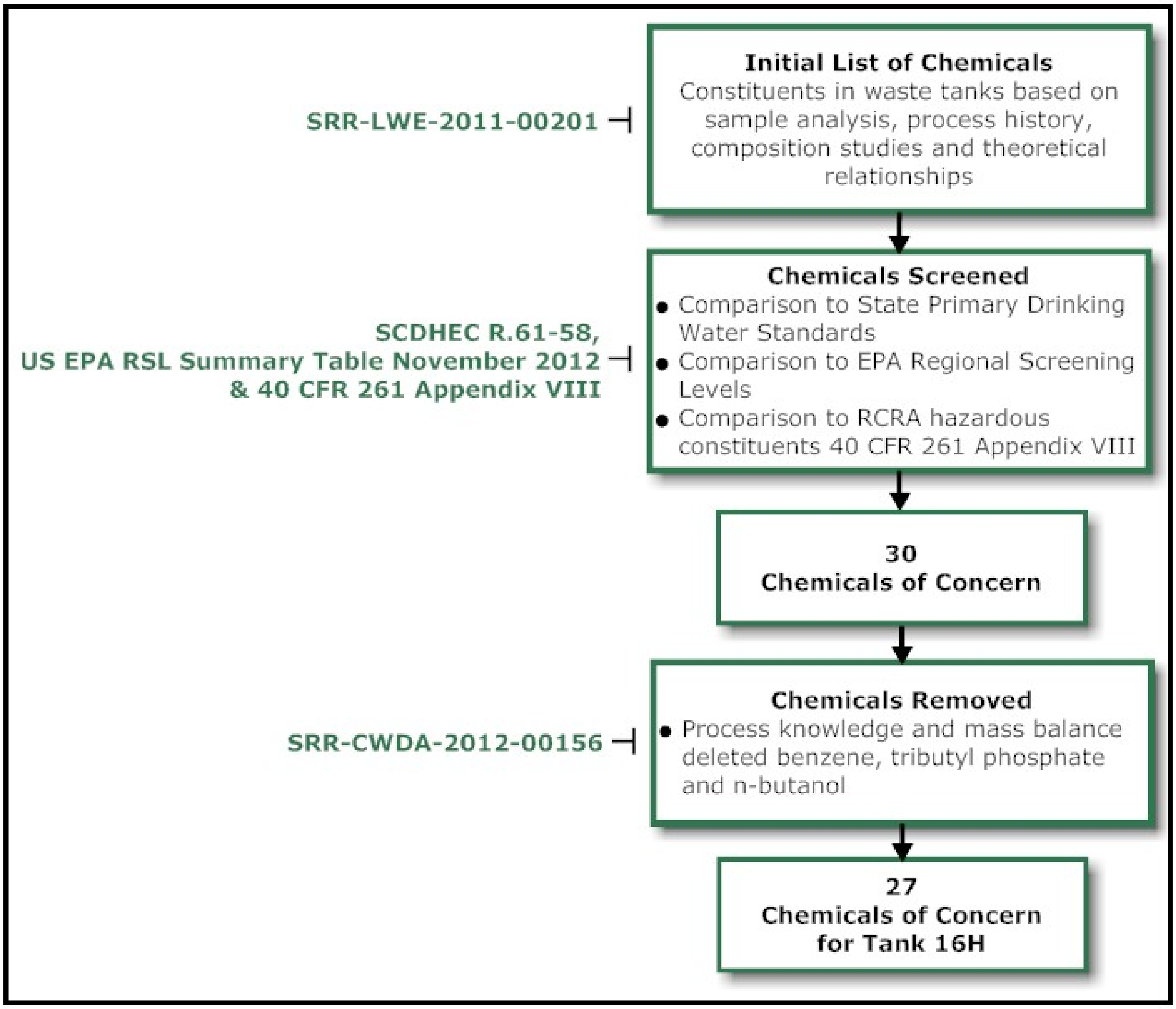
### 4.3.1 Chemical Constituent Screening and Analyte List

The chemical constituents of interest were identified through a screening process using EPA Regional Screening Levels (RSLs) (EPA_RSL Tbl_11-2011), maximum contaminant levels (MCLs) from the *State Primary Drinking Water Regulation* for inorganic contaminants specified in SCDHEC R.61-58, and hazardous constituents from 40 CFR 261 Appendix VIII. The chemical constituents expected to be present in the waste tanks were compared to the list of chemicals that had RSLs, MCLs or hazardous characteristics and if any of the tank farm chemicals were present on any of the lists, the chemical was added to the list of chemicals of concern.

The chemicals of concern list was further evaluated to determine which constituents could be present in Tank 16H. Tributyl phosphate, benzene, and n-butanol were removed based on process knowledge. [SRR-CWDA-2012-00156]

The overall screening process yielded a list of 27 chemical constituents for Tank 16H that will have an assigned inventory based either on sample analysis and/or process knowledge. The screening determination process is shown on Figure 4.3-1 and the Tank 16H chemical analytes are listed in Table 4.3-1.

**Figure 4.3-1: Screening Determination Process for Tank 16H Chemical Analytes**




[SRR-CWDA-2012-00156]

**Table 4.3-1: Chemical Analyte List for Tank 16H Samples**

| Chemical Analytes | | |
|---|---|---|
| Aluminum | Fluoride | Phosphate |
| Arsenic | Iodine | Selenium |
| Antimony | Iron | Silver |
| Barium | Lead | Strontium |
| Boron | Manganese | Sulfate |
| Cadmium | Mercury | Uranium |
| Chloride | Molybdenum | Zinc |
| Chromium | Nickel | |
| Cobalt | Nitrate | |
| Copper | Nitrite | |

### 4.3.2 Radiological Constituent Screening and Analyte List

The screening process to determine potential radionuclide contaminants is described in Section 5.1 of the HTF GCP. [SRR-CWDA-2011-00022] The analytes included potential radionuclides and any radionuclide daughters that may be present in the waste tank. The initial screening evaluated 849 radionuclides. Of the original 849 radionuclides, 159 remained on the list and 690 were excluded from further consideration for various reasons (e.g., short half-life, no HTF associated production history, low risk) as explained in *Savannah River Site High-Level Waste Tank Farm Closure, Radionuclide Screening Process (First-Level), Development and Application*. [CBU-PIT-2005-00228] Additional screening was performed for the remaining 159 isotopes in Section 3.3.2 (Evaluation of Remaining Radionuclides) of the HTF PA based on the presence/absence of parent radionuclides and the expectation of waste tank inventory. The result of these two screening processes yielded a list of 54 radionuclides for the HTF.

The starting point for the radionuclide screening for Tank 16H was the 54 radionuclide analytes identified for the HTF. These were the same radionuclides analyzed in the Tank 5F, 18F, and 19F samples with the following exceptions: three radionuclides were added; Cf-251, Th-232, and Ra-228, and three radionuclides were deleted; Nb-93m, Sb-126, and Sb-126m. Cf-251 and Th-232 were added due to special campaigns in H-Canyon that involved these radionuclides. Ra-228 is believed to be present in HTF waste at a minimal concentration. [SRR-CWDA-2010-00023] It was not believed to be present in FTF. [SRR-CWDA-2009-00045] The three radionuclides were deleted since they are daughters of Zr-93 and Sn-126 and can be accounted for by analysis for the parent radionuclides.

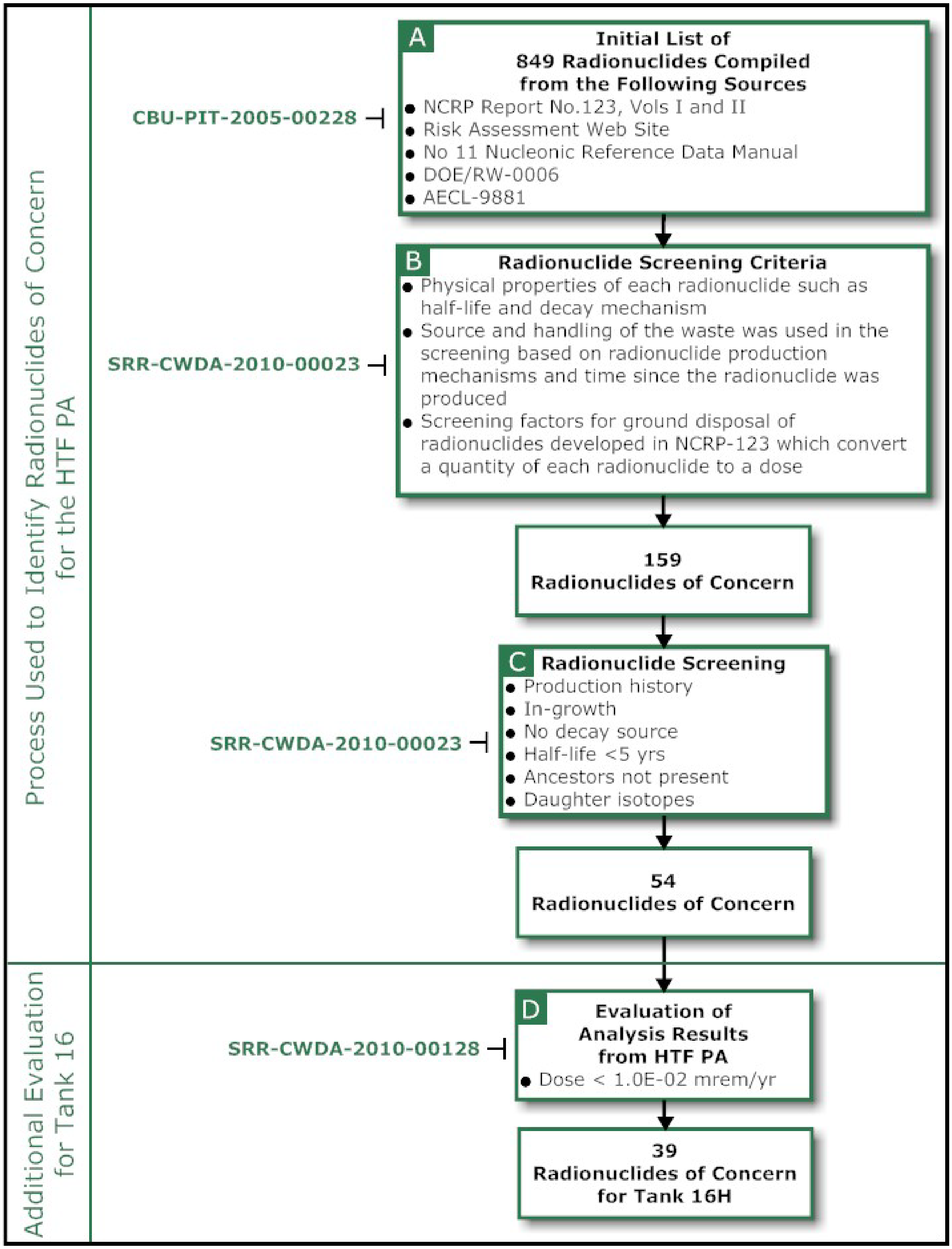
The radionuclide list was also screened based on the actual residuals sample results of Tanks 5F, 6F, 18F, and 19F and output information from the HTF PA modeling. The HTF PA used residual inventory estimates, with other parameter estimates, to project future dose impacts.

This additional screening effort (Box D on Figure 4.3-2) was aimed at eliminating those radionuclides that resulted in an estimated peak TEDE of less than 1.0E-02 mrem/year in the HTF PA model. The 1.0E-02 mrem/year criterion was chosen since this represents a reasonably conservative dose limit such that there would be a conservative factor of 2,500 less than the 25 mrem/year performance objective. [SRR-CWDA-2012-00156] The results of the latest HTF PA modeling identified the following 17 radionuclides that met the criterion: Ac-227, Al-26, Eu-152, Eu-154, H-3, Pd-107, Pt-193, Ra-228, Se-79, Sm-151, Sn-126, Th-229, Th-230, Th-232, U-232, U-236, and U-238. [SRR-CWDA-2010-00128]

Each of these 17 screened radionuclides were then assessed to determine if any daughter radionuclide inventory could be responsible for producing an impact on the future dose. Two radionuclides, U-238 and Th-230, were added back to the analyte list due to their decay product, Ra-226.

The screening process and criteria used are described in detail in *Tank 16 Radionuclide and Chemical Screening for Residual Inventory Determination* and shown on Figure 4.3-2. [SRR-CWDA-2012-00156] The final 39 radionuclides recommended for the Tank 16H residual material sample analyses are listed in Table 4.3-2.

**Figure 4.3-2: Screening Determination Process for Tank 16H Radionuclide Analytes**




[SRR-CWDA-2012-00156]

**Table 4.3-2: Radionuclide Analyte List for Tank 16H Samples**

| **Radionuclides** | | | |
|---|---|---|---|
| Am-241 | Cm-245 | Ni-63 | Sr-90 |
| Am-242m | Cm-247 | Np-237 | Tc-99 |
| Am-243 | Cm-248 | Pa-231 | Th-230 |
| Ba-137m | Co-60 | Pu-238 | U-233 |
| C-14 | Cs-135 | Pu-239 | U-234 |
| Cf-249 | Cs-137 | Pu-240 | U-235 |
| Cf-251 | I-129 | Pu-241 | U-238 |
| Cl-36 | K-40 | Pu-242 | Y-90 |
| Cm-243 | Nb-94 | Pu-244 | Zr-93 |
| Cm-244 | Ni-59 | Ra-226 | |

Based on the screening processes used for chemical and radiological constituents described above, the Tank 16H composite samples were analyzed to quantify the constituents listed in Tables 4.3-1 and 4.3-2.

## 4.4 Sample Analyses

SRNL analyzed the residual material samples for the constituents listed in Tables 4.3-1 and 4.3-2. Most of the samples were analyzed in triplicate for the requested constituents. New or modified analytical methods and/or additional sample material were required to achieve the requested minimum detection limit values. Special emphasis was placed on achieving these target detection limits (TDLs) for at least one sample. Another purpose of the analyses was to confirm that either the constituent was absent or present in extremely low concentrations. These analyses were expected to be challenging due to the low requested detection limits and the difficult separations required. Only one replicate per sample was required to be performed for these analytes. For details of the analyses and results, refer to the *Tank 16H Residual Sample Analysis Report*. [SRNL-STI-2014-00321]

A statistical study of the sampling results was performed and provided the means, standard deviations, and UCL95 on the mean for those analytes with measured concentration values. For those analytes where the concentration was non-detected or less than the TDL, the lowest and highest minimum detectable concentrations (MDCs) were used to bound the concentration values for the analyte. The statistical study refers to these analytes as having concentrations less than their MDC. For those analytes with a mixture of detected and non-detected concentrations, the analytes were treated as either those with measured values or those with non-detected values. Additional details on how the analytes with a mixture of detected and non-detected concentrations were treated are presented in the *Tank 16H Residual Sample Analysis Report.* [SRNL-STI-2014-00321]

### 4.4.1 Data Quality Assessment

A Data Quality Assessment was performed to assess the data quality of the Tank 16H sampling and analyses. The sampling plan and compositing scheme was shown to be sufficient to representatively characterize the tank residual materials. For the primary tank samples, Sample 2-P was different than the other two samples with most analyses at less than the MDC. The three composite annulus samples appeared to be uniform with minor statistical differences. The reviews of precision, accuracy, representativeness, comparability, completeness, and the statistical analysis indicated the data are sufficient to characterize the residual materials. [SRR-CWDA-2014-00090]

## 4.5 Establishing Inventories Based on Results

For Tank 16H, inventories were developed for each of the residual material portions remaining in the primary tank, the annulus, and sand layers underlying the primary tank and annulus pans. The sum of the inventory portions was the total Tank 16H inventory.

### 4.5.1 Quantification of Residual Contaminants

The methodology used to develop the total Tank 16H inventory sums the inventories from each contributing portion of the waste tank. The contributing portions determined are:

- Primary tank floor
- Waste tank annulus
- Primary and secondary sand layers
- Cooling coils and tank wall
- Equipment hold-up (e.g., residual material remaining in the interior of spray jets, a transfer pump, dip tubes, etc. remaining in the waste tank)

The inventory for each analyte was determined by taking the measured concentration and multiplying it by the associated primary tank, annulus, or sand layer volume (or surface area). This was repeated for each radionuclide and chemical constituent.

### 4.5.2 Primary Tank Floor Residual Inventory

The primary tank floor inventory was determined by multiplying the residuals floor volume by the concentration for each constituent. Discrete residual material samples were collected and analyzed to determine the concentrations. [SRR-CWDA-2014-00071] These concentrations were reported in terms of dried solids mass and converted to a volume basis using the sample density and solids content (dry solids to wet solids). The Tank 16H sample analysis results are presented in the *Tank 16H Residual Sample Analysis Report*. [SRNL-STI-2014-00321]

It should be noted that one of the Tank 16H floor samples (Sample 2-P) had more analytes with non-detected concentrations than the other two samples. Consideration was given to excluding Sample 2-P from the sample analysis report statistical analysis, but the sample was included in the final analysis because:

1. The residual material represented by Sample 2-P is part of the floor material volume, and

2. Including the Sample 2-P non-detected concentrations tended to skew the inventory values conservatively (e.g., including the non-detected values increased the UCL95 values upon which the Best Estimate Inventory values are based).

Using the reported analyte concentrations and final primary tank floor residuals volume, the radiological and chemical residual material inventories were determined for the primary tank. These inventories are presented in Table 4.5-1 and Table 4.5-2, respectively.

**Table 4.5-1: Tank 16H Primary Tank and Annulus Residual Material Radionuclide Inventories**

| Constituent | Units | Primary Tank Assigned Inventory (2014) | Primary Tank Assigned Inventory (2032) | Annulus Assigned Inventory (2014) | Annulus Assigned Inventory (2032) |
|---|---|---|---|---|---|
| Am-241 | Ci | 1.5E+00 | 1.6E+00 | 7.7E+00 | 7.5E+00 |
| Am-242m | Ci | <2.5E-05 | <2.5E-05 | <4.1E-03 | <3.8E-03 |
| Am-243 | Ci | <2.0E-04 | <2.1E-04 | <8.0E-03 | <8.0E-03 |
| Ba-137m | Ci | <2.1E-02 | <1.5E-02 | 5.4E+03 | 3.5E+03 |
| C-14 | Ci | <1.5E-03 | <1.6E-03 | <4.9E-03 | <4.9E-03 |
| Cf-249 | Ci | <4.8E-05 | <5.0E-05 | <6.5E-03 | <6.3E-03 |
| Cf-251 | Ci | <1.2E-04 | <1.3E-04 | <1.7E-02 | <1.7E-02 |
| Cl-36 | Ci | <4.4E-06 | <4.7E-06 | <3.1E-03 | <3.1E-03 |
| Cm-243 | Ci | <1.4E-04 | <9.9E-05 | <2.2E-02 | <1.4E-02 |
| Cm-244 | Ci | <8.1E-03 | <4.3E-03 | <8.0E-01 | <3.9E-01 |
| Cm-245 | Ci | <5.8E-06 | <6.2E-06 | <7.4E-05 | <7.4E-05 |
| Cm-247 | Ci | <2.8E-09 | <3.0E-09 | <4.8E-09 | <4.8E-09 |
| Cm-248 | Ci | <1.3E-07 | <1.4E-07 | <5.4E-06 | <5.4E-06 |
| Co-60 | Ci | <9.6E-04 | <8.8E-05 | 2.2E-02 | 1.9E-03 |
| Cs-135 | Ci | <4.9E-05 | <5.3E-05 | 2.0E-02 | 2.0E-02 |
| Cs-137 | Ci | <2.2E-02 | <1.5E-02 | 5.7E+03 | 3.7E+03 |
| I-129 | Ci | 1.2E-03 | 1.3E-03 | 7.9E-03 | 7.9E-03 |
| K-40 | Ci | <3.8E-05 | <4.1E-05 | <1.7E-04 | <1.7E-04 |
| Nb-94 | Ci | <8.2E-03 | <8.9E-03 | <2.6E-03 | <2.6E-03 |
| Ni-59 | Ci | <1.2E-03 | <1.3E-03 | <9.3E-03 | <9.3E-03 |
| Ni-63 | Ci | <1.6E-03 | <1.5E-03 | <4.1E-01 | <3.6E-01 |
| Np-237 | Ci | <1.4E-03 | <1.5E-03 | 2.0E-02 | 2.0E-02 |
| Pa-231 | Ci | <5.8E-03 | <6.2E-03 | <1.6E-03 | <1.6E-03 |
| Pu-238 | Ci | 4.9E+00 | 4.6E+00 | 3.5E+01 | 3.0E+01 |
| Pu-239 | Ci | 2.0E-01 | 2.2E-01 | 4.7E+00 | 4.7E+00 |
| Pu-240 | Ci | 8.8E-02 | 9.5E-02 | 2.1E+00 | 2.1E+00 |
| Pu-241 | Ci | <8.0E-02 | <3.5E-02 | 1.4E+01 | 5.8E+00 |
| Pu-242 | Ci | <1.8E-05 | <2.0E-05 | 8.4E-04 | 8.4E-04 |
| Pu-244 | Ci | <2.0E-07 | <2.1E-07 | <7.0E-07 | <7.0E-07 |
| Ra-226 | Ci | <6.8E-04 | <7.3E-04 | <1.1E-03 | <1.0E-03 |
| Sr-90 | Ci | 1.4E+04 | 9.4E+03 | 1.6E+04 | 1.0E+04 |
| Tc-99 | Ci | 1.6E+00 | 1.7E+00 | 1.9E+00 | 1.9E+00 |
| Th-230 | Ci | <2.2E-04 | <2.4E-04 | <3.7E-04 | <3.7E-04 |
| U-233 | Ci | 1.8E-02 | 1.9E-02 | <1.1E-02 | <1.1E-02 |
| U-234 | Ci | 1.1E-02 | 1.2E-02 | 1.2E-02 | 1.2E-02 |
| U-235 | Ci | 3.1E-06 | 3.3E-06 | 1.8E-04 | 1.8E-04 |
| U-238 | Ci | 1.1E-05 | 1.2E-05 | 7.9E-04 | 7.9E-04 |
| Y-90 | Ci | 1.4E+04 | 9.4E+03 | 1.6E+04 | 1.0E+04 |
| Zr-93 | Ci | <6.6E-03 | <7.1E-03 | <8.7E-01 | <8.7E-01 |

**Table 4.5-2: Tank 16H Primary Tank and Annulus Residual Material Chemical Inventories**

| Constituent | Units | Primary Tank Assigned Inventory (2014) and (2032) | Annulus Assigned Inventory (2014) and (2032) |
|---|---|---|---|
| Ag | kg | <2.7E-02 | <2.3E-01 |
| Al | kg | 1.5E+01 | 5.1E+02 |
| As | kg | 9.4E-02 | <1.8E-02 |
| B | kg | <3.9E-01 | <3.3E+00 |
| Ba | kg | 2.9E-01 | 1.5E+00 |
| Cd | kg | 5.5E-02 | <2.4E-01 |
| Cl | kg | <1.0E-01 | 4.6E+00 |
| Co | kg | 1.9E-01 | <2.0E+00 |
| Cr | kg | 7.1E-01 | 2.1E+00 |
| Cu | kg | 1.6E+00 | 1.0E+01 |
| F | kg | <1.0E-01 | <1.9E+00 |
| Fe | kg | 1.3E+03 | 2.3E+02 |
| Hg | kg | 5.6E+00 | 1.7E+01 |
| I | kg | 6.9E-03 | <2.6E-02 |
| Mn | kg | 1.3E+01 | 2.4E+00 |
| Mo | kg | <1.7E-01 | <2.5E+00 |
| Ni | kg | 6.1E-01 | <3.5E+00 |
| $NO_2$ | kg | <1.0E-01 | 4.4E+02 |
| $NO_3$ | kg | 1.2E+00 | 3.8E+02 |
| Pb | kg | 2.2E+01 | <8.9E+00 |
| $PO_4$ | kg | <1.0E-01 | <1.9E+00 |
| Sb | kg | <5.9E-01 | <4.9E+00 |
| Se | kg | <1.1E-02 | 8.7E-02 |
| $SO_4$ | kg | <1.0E-01 | 6.7E+01 |
| Sr | kg | 7.1E-01 | <4.4E-01 |
| U | kg | <4.4E+00 | <1.6E+01 |
| Zn | kg | 1.8E+00 | <3.2E+00 |

The Assigned Inventory (2032) column represents the radionuclide inventories that have been decay-corrected from 2014 to 2032 to provide a comparison to the 2032 inventory that was used for modeling in the HTF PA. No decay correction is necessary for the chemicals.

An in-depth description of the methodology and determination of the Tank 16H primary tank and annulus residual inventories for all of the analytes is provided in the *Tank 16H Inventory Determination*. [SRR-CWDA-2014-00071]

### 4.5.3 Tank 16H Annulus Residual Material Inventory

The annulus composite samples were analyzed by SRNL for the same analytes as the primary tank floor (Tables 4.3-1 and 4.3-2). The same analysis techniques used for the primary tank floor samples were also applied to the annulus samples to address reaching the TDLs. Additional details on the sample analyses are presented in the *Tank 16H Residual Sample Analysis Report*. [SRNL-STI-2014-00321]

The annulus inventory was determined by multiplying the residuals volume by the concentration (for each constituent). Composite residual material samples were created and analyzed to determine the concentrations. [SRR-CWDA-2014-00071] These concentrations were reported in terms of dried solids mass and converted to a volume basis using the sample density and solids content (dry solids to wet solids). The Tank 16H sample analysis results are presented in the *Tank 16H Residual Sample Analysis Report*. [SRNL-STI-2014-00321]

Using the reported analyte concentrations and final annulus residuals volume, the radiological and chemical residual material inventories were determined for the annulus. The radionuclide and chemical inventories for the annulus residuals are presented in Table 4.5-1 and Table 4.5-2, respectively.

The Annulus Assigned Inventory (2032) column represents the radionuclide inventories that have been decay-corrected from 2014 to 2032 to provide a comparison to the 2032 inventory that was used for modeling in the HTF PA. No decay correction is necessary for the chemicals.

An in-depth description of the methodology and determination of the Tank 16H primary tank and annulus residual inventories for all of the analytes is presented in the *Tank 16H Inventory Determination.* [SRR-CWDA-2014-00071]

### 4.5.4 Tank 16H Sand Layers Inventory

Type II tanks, such as Tank 16H have sand layers between the primary tank liner and the secondary liner (annulus pan), and between the secondary liner and the basemat. In 1960, as described in Section 2.2.1, leakage from the primary tank into the annulus overfilled the annulus pan escaped the concrete waste tank encasement, and waste would have entered both the primary and secondary sand layers.

Due to inaccessibility for sampling, it is assumed that the primary and secondary sand layers contain residual material having the same concentrations as the annulus material. The volume of the residual material within the primary sand layer is conservatively estimated at 1,300 gallons. [SRR-CWDA-2010-00023] The secondary sand layer is conservatively estimated to contain 2% of the residuals volume of the primary sand layer. This yields a residuals volume of 26 gallons in the secondary sand layer. [SRR-CWDA-2010-00023] The calculation of the inventory associated with the sand layers is presented in the *Tank 16 Inventory Determination*. [SRR-CWDA-2014-00071] The radionuclide and chemical inventories calculated and assigned to the sand layers are presented in Table 4.5-3 and Table 4.5-4, respectively.

### 4.5.5 Tank 16H Cooling Coil and Wall Inventory

To evaluate any inventory associated with tank metal surfaces that had been in contact with waste, a cooling coil sample was collected during the Tank 5F characterization. The cooling coil and wall surface inventories calculated using the analytical results were determined to be less than 1% of the floor residuals inventory (with the exception of U-233 which was less than the detection limit) and would have little impact on the overall tank inventory. [SRR-CWDA-2012-00027] Since the Tank 16H cleaning history is similar to Tank 5F, and photographs/video footage of the Tank 16H interior do not show an appreciable amount of residual material remaining on the interior support column, cooling coils, and primary tank

**Table 4.5-3: Tank 16H Primary and Secondary Sand Layer Radionuclide Inventories**

| Constituent | Units | Primary Sand Layer Assigned Inventory (2014) | Secondary Sand Layer Assigned Inventory (2014) |
|---|---|---|---|
| Am-241 | Ci | 5.2E+00 | 1.0E-01 |
| Am-242m | Ci | <2.8E-03 | <5.6E-05 |
| Am-243 | Ci | <5.4E-03 | <1.1E-04 |
| Ba-137m | Ci | 3.7E+03 | 7.4E+01 |
| C-14 | Ci | <3.3E-03 | <6.7E-05 |
| Cf-249 | Ci | <4.5E-03 | <8.9E-05 |
| Cf-251 | Ci | <1.2E-02 | <2.4E-04 |
| Cl-36 | Ci | <2.1E-03 | <4.2E-05 |
| Cm-243 | Ci | <1.5E-02 | <2.9E-04 |
| Cm-244 | Ci | <5.4E-01 | <1.1E-02 |
| Cm-245 | Ci | <5.0E-05 | <1.0E-06 |
| Cm-247 | Ci | <3.2E-09 | <6.5E-11 |
| Cm-248 | Ci | <3.7E-06 | <7.3E-08 |
| Co-60 | Ci | 1.5E-02 | 3.0E-04 |
| Cs-135 | Ci | 1.3E-02 | 2.7E-04 |
| Cs-137 | Ci | 3.9E+03 | 7.8E+01 |
| I-129 | Ci | 5.4E-03 | 1.1E-04 |
| K-40 | Ci | <1.2E-04 | <2.3E-06 |
| Nb-94 | Ci | <1.8E-03 | <3.5E-05 |
| Ni-59 | Ci | <6.3E-03 | <1.3E-04 |
| Ni-63 | Ci | <2.8E-01 | <5.6E-03 |
| Np-237 | Ci | 1.4E-02 | 2.8E-04 |
| Pa-231 | Ci | <1.1E-03 | <2.1E-05 |
| Pu-238 | Ci | 2.4E+01 | 4.7E-01 |
| Pu-239 | Ci | 3.2E+00 | 6.4E-02 |
| Pu-240 | Ci | 1.5E+00 | 2.9E-02 |
| Pu-241 | Ci | 9.8E+00 | 2.0E-01 |
| Pu-242 | Ci | 5.7E-04 | 1.1E-05 |
| Pu-244 | Ci | <4.8E-07 | <9.5E-09 |
| Ra-226 | Ci | <7.1E-04 | <1.4E-05 |
| Sr-90 | Ci | 1.1E+04 | 2.2E+02 |
| Tc-99 | Ci | 1.3E+00 | 2.6E-02 |
| Th-230 | Ci | <2.5E-04 | <5.0E-06 |
| U-233 | Ci | <7.7E-03 | <1.5E-04 |
| U-234 | Ci | 8.5E-03 | 1.7E-04 |
| U-235 | Ci | 1.2E-04 | 2.4E-06 |
| U-238 | Ci | 5.4E-04 | 1.1E-05 |
| Y-90 | Ci | 1.1E+04 | 2.2E+02 |
| Zr-93 | Ci | <5.9E-01 | <1.2E-02 |

**Table 4.5-4: Tank 16H Primary and Secondary Sand Layer Chemical Inventories**

| Constituent | Units | Primary Sand Layer Assigned Inventory (2014) | Secondary Sand Layer Assigned Inventory (2014) |
|---|---|---|---|
| Ag | kg | <1.5E-01 | <3.1E-03 |
| Al | kg | 3.5E+02 | 6.9E+00 |
| As | kg | <1.2E-02 | <2.4E-04 |
| B | kg | <2.2E+00 | <4.5E-02 |
| Ba | kg | 1.0E+00 | 2.1E-02 |
| Cd | kg | <1.6E-01 | <3.2E-03 |
| Cl | kg | 3.1E+00 | 6.3E-02 |
| Co | kg | <1.3E+00 | <2.7E-02 |
| Cr | kg | 1.4E+00 | 2.8E-02 |
| Cu | kg | 7.1E+00 | 1.4E-01 |
| F | kg | <1.3E+00 | <2.6E-02 |
| Fe | kg | 1.6E+02 | 3.2E+00 |
| Hg | kg | 1.2E+01 | 2.3E-01 |
| I | kg | <1.8E-02 | <3.6E-04 |
| Mn | kg | 1.6E+00 | 3.2E-02 |
| Mo | kg | <1.7E+00 | <3.4E-02 |
| Ni | kg | <2.4E+00 | <4.8E-02 |
| $NO_2$ | kg | 3.0E+02 | 6.0E+00 |
| $NO_3$ | kg | 2.6E+02 | 5.2E+00 |
| Pb | kg | <6.0E+00 | <1.2E-01 |
| $PO_4$ | kg | <1.3E+00 | <2.6E-02 |
| Sb | kg | <3.3E+00 | <6.7E-02 |
| Se | kg | 5.9E-02 | 1.2E-03 |
| $SO_4$ | kg | 4.6E+01 | 9.1E-01 |
| Sr | kg | <3.0E-01 | <5.9E-03 |
| U | kg | <1.1E+01 | <2.2E-01 |
| Zn | kg | <2.1E+00 | <4.3E-02 |

wall surface, any associated inventory is also expected to be insignificant compared to the overall waste tank inventory. Therefore, a separate Tank 16H interior surface inventory was not determined. [SRR-CWDA-2014-00071]

### 4.5.6 Tank 16H Internal Cooling Coil Inventory

Tank 16H has a total of 44 chromate water cooling coils inside the primary tank. As part of the Tank 16H closure these cooling coils may be flushed, and any residual chromate water may be introduced into the tank. An estimated 6.52 kilograms of chromium (Cr) may be added to the tank during the cooling coil flushing. [M-CLC-H-03244]

### 4.5.7 Tank 16H Equipment Hold-up Inventory

Various pieces of equipment used during the operational and the waste removal processes will remain in Tank 16H when it is removed from service. This equipment includes a pump, spray jets, dip tubes, and tubing. There is potential for residual material hold-up in some of these pieces and the amount of associated inventory has been estimated. For equipment remaining in the primary tank, any inventory on the exterior surfaces is expected to be minimal since any material build-up would have experienced similar treatment conditions (i.e., OA cleaning) as the residual material on the tank wall and cooling coils. The total internal hold-up volume is estimated at 26 gallons for equipment in the primary tank and 6 gallons for equipment in the annulus. [SRR-LWE-2014-00017]

The residual material concentrations for equipment hold-up in the primary tank were assumed equal to the floor residuals because this equipment would have been in contact with the residual material prior to completion of waste removal activities.

The annulus equipment hold-up inventory associated with the 6 gallons was assumed to be captured in the annulus volume uncertainty and was not calculated separately.

The equipment that will remain in Tank 16H is described in Section 7.0. The radionuclide and chemical inventories calculated and assigned to the equipment hold-up in the primary tank are presented in Table 4.5-5 and Table 4.5-6, respectively.

**Table 4.5-5: Tank 16H Equipment Hold-up Radionuclide Inventory**

| Constituent | Units | Equipment Hold-up Inventory (2014) |
|---|---|---|
| Am-241 | Ci | 1.2E-01 |
| Am-242m | Ci | <2.0E-06 |
| Am-243 | Ci | <1.6E-05 |
| Ba-137m | Ci | <1.7E-03 |
| C-14 | Ci | <1.2E-04 |
| Cf-249 | Ci | <3.9E-06 |
| Cf-251 | Ci | <9.7E-06 |
| Cl-36 | Ci | <3.5E-07 |
| Cm-243 | Ci | <1.1E-05 |
| Cm-244 | Ci | <6.4E-04 |
| Cm-245 | Ci | <4.6E-07 |
| Cm-247 | Ci | <2.2E-10 |
| Cm-248 | Ci | <1.0E-08 |
| Co-60 | Ci | <7.7E-05 |
| Cs-135 | Ci | <3.9E-06 |
| Cs-137 | Ci | <1.8E-03 |
| I-129 | Ci | 9.7E-05 |
| K-40 | Ci | <3.0E-06 |
| Nb-94 | Ci | <6.6E-04 |
| Ni-59 | Ci | <9.5E-05 |
| Ni-63 | Ci | <1.3E-04 |
| Np-237 | Ci | <1.1E-04 |
| Pa-231 | Ci | <4.6E-04 |
| Pu-238 | Ci | 3.9E-01 |
| Pu-239 | Ci | 1.6E-02 |
| Pu-240 | Ci | 7.0E-03 |
| Pu-241 | Ci | <6.4E-03 |
| Pu-242 | Ci | <1.5E-06 |
| Pu-244 | Ci | <1.6E-08 |
| Ra-226 | Ci | <5.4E-05 |
| Sr-90 | Ci | 1.1E+03 |
| Tc-99 | Ci | 1.2E-01 |
| Th-230 | Ci | <1.8E-05 |
| U-233 | Ci | 1.4E-03 |
| U-234 | Ci | 9.1E-04 |
| U-235 | Ci | 2.5E-07 |
| U-238 | Ci | 9.0E-07 |
| Y-90 | Ci | 1.1E+03 |
| Zr-93 | Ci | <5.3E-04 |

**Table 4.5-6: Tank 16H Equipment Hold-up Chemical Inventory**

| Constituent | Units | Equipment Hold-up Inventory (2014) |
|---|---|---|
| Ag | kg | <2.2E-03 |
| Al | kg | 1.2E+00 |
| As | kg | 7.5E-03 |
| B | kg | <3.1E-02 |
| Ba | kg | 2.3E-02 |
| Cd | kg | 4.4E-03 |
| Cl | kg | <8.0E-03 |
| Co | kg | 1.5E-02 |
| Cr | kg | 5.6E-02 |
| Cu | kg | 1.2E-01 |
| F | kg | <8.0E-03 |
| Fe | kg | 1.1E+02 |
| Hg | kg | 4.5E-01 |
| I | kg | 5.5E-04 |
| Mn | kg | 1.0E+00 |
| Mo | kg | <1.3E-02 |
| Ni | kg | 4.8E-02 |
| $NO_2$ | kg | <8.0E-03 |
| $NO_3$ | kg | 9.5E-02 |
| Pb | kg | 1.7E+00 |
| $PO_4$ | kg | <8.0E-03 |
| Sb | kg | <4.7E-02 |
| Se | kg | <8.9E-04 |
| $SO_4$ | kg | <8.0E-03 |
| Sr | kg | 5.6E-02 |
| U | kg | <3.5E-01 |
| Zn | kg | 1.5E-01 |

## 4.6 Tank 16H Final Residual Material Inventory

The inventories for the contributing residual material portions (primary tank floor, annulus, sand layers, coils/walls, and equipment hold-up) were determined as described in the *Tank 16 Inventory Determination*. [SRR-CWDA-2014-00071] Each inventory was evaluated and the cooling coil, wall, and equipment hold-up inventories were considered insignificant when compared to the tank floor, annulus, and sand layer inventories.

The final radiological inventories were decayed to support performance assessment modeling based on the 2014 analysis date for the samples and the October 1, 2032 start date of HTF PA modeling. The radionuclide inventories decayed to 2032 for the primary tank, annulus, and sand layers are considered the Tank 16H final radionuclide inventory and are shown in Table 4.6-1.

The final chemical inventories to support performance assessment modeling are based on the 2014 analysis date. The chemical inventories for the each of the contributing residual portions are considered the Tank 16H final chemical inventory and are shown in Table 4.6-2.

**Table 4.6-1: Tank 16H Final Residual Material Radionuclide Inventory**

| Constituent | Units | Primary Tank Assigned Inventory (2032) | Annulus Assigned Inventory (2032) | Primary Sand Layer Assigned Inventory (2032) | Secondary Sand Layer Assigned Inventory (2032) |
|---|---|---|---|---|---|
| Am-241 | Ci | 1.6E+00 | 7.5E+00 | 5.1E+00 | 1.0E-01 |
| Am-242m | Ci | <2.5E-05 | <3.8E-03 | <2.6E-03 | <5.1E-05 |
| Am-243 | Ci | <2.1E-04 | <8.0E-03 | <5.4E-03 | <1.1E-04 |
| Ba-137m | Ci | <1.5E-02 | 3.5E+03 | 2.4E+03 | 4.8E+01 |
| C-14 | Ci | <1.6E-03 | <4.9E-03 | <3.3E-03 | <6.6E-05 |
| Cf-249 | Ci | <5.0E-05 | <6.3E-03 | <4.3E-03 | <8.6E-05 |
| Cf-251 | Ci | <1.3E-04 | <1.7E-02 | <1.2E-02 | <2.3E-04 |
| Cl-36 | Ci | <4.7E-06 | <3.1E-03 | <2.1E-03 | <4.2E-05 |
| Cm-243 | Ci | <9.9E-05 | <1.4E-02 | <9.4E-03 | <1.9E-04 |
| Cm-244 | Ci | <4.3E-03 | <3.9E-01 | <2.6E-01 | <5.3E-03 |
| Cm-245 | Ci | <6.2E-06 | <7.4E-05 | <5.0E-05 | <1.0E-06 |
| Cm-247 | Ci | <3.0E-09 | <4.8E-09 | <3.2E-09 | <6.5E-11 |
| Cm-248 | Ci | <1.4E-07 | <5.4E-06 | <3.7E-06 | <7.3E-08 |
| Co-60 | Ci | <8.8E-05 | 1.9E-03 | 1.3E-03 | 2.6E-05 |
| Cs-135 | Ci | <5.3E-05 | 2.0E-02 | 1.3E-02 | 2.7E-04 |
| Cs-137 | Ci | <1.5E-02 | 3.7E+03 | 2.5E+03 | 5.1E+01 |
| I-129 | Ci | 1.3E-03 | 7.9E-03 | 5.4E-03 | 1.1E-04 |
| K-40 | Ci | <4.1E-05 | <1.7E-04 | <1.2E-04 | <2.3E-06 |
| Nb-94 | Ci | <8.9E-03 | <2.6E-03 | <1.8E-03 | <3.5E-05 |
| Ni-59 | Ci | <1.3E-03 | <9.3E-03 | <6.3E-03 | <1.3E-04 |
| Ni-63 | Ci | <1.5E-03 | <3.6E-01 | <2.4E-01 | <4.9E-03 |
| Np-237 | Ci | <1.5E-03 | 2.0E-02 | 1.4E-02 | 2.8E-04 |
| Pa-231 | Ci | <6.2E-03 | <1.6E-03 | <1.1E-03 | <2.1E-05 |
| Pu-238 | Ci | 4.6E+00 | 3.0E+01 | 2.0E+01 | 4.1E-01 |
| Pu-239 | Ci | 2.2E-01 | 4.7E+00 | 3.2E+00 | 6.4E-02 |
| Pu-240 | Ci | 9.5E-02 | 2.1E+00 | 1.5E+00 | 2.9E-02 |
| Pu-241 | Ci | <3.5E-02 | 5.8E+00 | 4.0E+00 | 7.9E-02 |
| Pu-242 | Ci | <2.0E-05 | 8.4E-04 | 5.7E-04 | 1.1E-05 |
| Pu-244 | Ci | <2.1E-07 | <7.0E-07 | <4.8E-07 | <9.5E-09 |
| Ra-226 | Ci | <7.3E-04 | <1.0E-03 | <7.1E-04 | <1.4E-05 |
| Sr-90 | Ci | 9.4E+03 | 1.0E+04 | 6.9E+03 | 1.4E+02 |
| Tc-99 | Ci | 1.7E+00 | 1.9E+00 | 1.3E+00 | 2.6E-02 |
| Th-230 | Ci | <2.4E-04 | <3.7E-04 | <2.5E-04 | <5.0E-06 |
| U-233 | Ci | 1.9E-02 | <1.1E-02 | <7.7E-03 | <1.5E-04 |
| U-234 | Ci | 1.2E-02 | 1.2E-02 | 8.5E-03 | 1.7E-04 |
| U-235 | Ci | 3.3E-06 | 1.8E-04 | 1.2E-04 | 2.4E-06 |
| U-238 | Ci | 1.2E-05 | 7.9E-04 | 5.4E-04 | 1.1E-05 |
| Y-90 | Ci | 9.4E+03 | 1.0E+04 | 6.9E+03 | 1.4E+02 |
| Zr-93 | Ci | <7.1E-03 | <8.7E-01 | <5.9E-01 | <1.2E-02 |

**Table 4.6-2: Tank 16H Final Residual Material Chemical Inventory**

| Constituent | Units | Primary Tank Assigned Inventory (2014) | Annulus Assigned Inventory (2014) | Primary Sand Layer Assigned Inventory (2014) | Secondary Sand Layer Assigned Inventory (2014) |
|---|---|---|---|---|---|
| Ag | kg | <2.9E-02 | <2.3E-01 | <1.5E-01 | <3.1E-03 |
| Al | kg | 1.6E+01 | 5.1E+02 | 3.5E+02 | 6.9E+00 |
| As | kg | 1.0E-01 | <1.8E-02 | <1.2E-02 | <2.4E-04 |
| B | kg | <4.3E-01 | <3.3E+00 | <2.2E+00 | <4.5E-02 |
| Ba | kg | 3.2E-01 | 1.5E+00 | 1.0E+00 | 2.1E-02 |
| Cd | kg | 5.9E-02 | <2.4E-01 | <1.6E-01 | <3.2E-03 |
| Cl | kg | <1.1E-01 | 4.6E+00 | 3.1E+00 | 6.3E-02 |
| Co | kg | 2.0E-01 | <2.0E+00 | <1.3E+00 | <2.7E-02 |
| Cr* | kg | 7.3E+00 | 2.1E+00 | 1.4E+00 | 2.8E-02 |
| Cu | kg | 1.7E+00 | 1.0E+01 | 7.1E+00 | 1.4E-01 |
| F | kg | <1.1E-01 | <1.9E+00 | <1.3E+00 | <2.6E-02 |
| Fe | kg | 1.4E+03 | 2.3E+02 | 1.6E+02 | 3.2E+00 |
| Hg | kg | 6.1E+00 | 1.7E+01 | 1.2E+01 | 2.3E-01 |
| I | kg | 7.5E-03 | <2.6E-02 | <1.8E-02 | <3.6E-04 |
| Mn | kg | 1.4E+01 | 2.4E+00 | 1.6E+00 | 3.2E-02 |
| Mo | kg | <1.8E-01 | <2.5E+00 | <1.7E+00 | <3.4E-02 |
| Ni | kg | 6.5E-01 | <3.5E+00 | <2.4E+00 | <4.8E-02 |
| $NO_2$ | kg | <1.1E-01 | 4.4E+02 | 3.0E+02 | 6.0E+00 |
| $NO_3$ | kg | 1.3E+00 | 3.8E+02 | 2.6E+02 | 5.2E+00 |
| Pb | kg | 2.4E+01 | <8.9E+00 | <6.0E+00 | <1.2E-01 |
| $PO_4$ | kg | <1.1E-01 | <1.9E+00 | <1.3E+00 | <2.6E-02 |
| Sb | kg | <6.3E-01 | <4.9E+00 | <3.3E+00 | <6.7E-02 |
| Se | kg | <1.2E-02 | 8.7E-02 | 5.9E-02 | 1.2E-03 |
| $SO_4$ | kg | <1.1E-01 | 6.7E+01 | 4.6E+01 | 9.1E-01 |
| Sr | kg | 7.6E-01 | <4.4E-01 | <3.0E-01 | <5.9E-03 |
| U | kg | <4.8E+00 | <1.6E+01 | <1.1E+01 | <2.2E-01 |
| Zn | kg | 2.0E+00 | <3.2E+00 | <2.1E+00 | <4.3E-02 |

* The chromium inventory has been adjusted to account for the possible addition of 6.52 kilograms of chromium from the cooling coil flushing. The primary tank assigned inventory (2032) adds the 7.1E-01 kilograms from the floor plus the 6.52 kilograms from the cooling coils for a chromium total of 7.2 kilograms.

# 5.0 PERFORMANCE EVALUATION

The HTF PA was prepared to support closure of the HTF underground radioactive waste tanks and ancillary structures. [SRR-CWDA-2010-00128] The purpose of the HTF PA is to evaluate the potential impact on human health and the environment by modeling the residual contaminant release from waste tanks and ancillary structures that have been stabilized with grout. Therefore, the assumed contaminant inventory is the starting point for modeling the contaminant release. A methodical approach was used to construct projections of HTF waste tank system closure inventories to be used in PA modeling. This approach considered current waste tank inventories, uncertainties in the effectiveness of tank cleaning technologies, laboratory detection limits, decay products, and half-lives of radionuclides. The HTF inventory projection for the HTF PA is provided in *H-Tank Farm Closure Inventory for use in Performance Assessment Modeling*. [SRR-CWDA-2010-00023, Revision 3]

The PA provided the technical basis and results to be used to evaluate residual contaminant status over time. An integrated conceptual model (ICM) was prepared for the PA to evaluate the performance of the HTF following RFS of all waste tanks and ancillary structures. This ICM is used to evaluate the migration of contaminants from the HTF over time. The ICM comprises three related conceptual flow models that represent the HTF and the environmental media through which contaminants may migrate: 1) closure cap model, 2) vadose zone model, and 3) saturated zone model.

The ICM simulates the release of radiological and chemical contaminants from the underground waste tanks and associated ancillary structures in the HTF as well as the migration of the contaminants through soil and groundwater. An independent waste release sub-model was used in the HTF PA to simulate the contaminant release from the stabilized waste tanks, based on various chemical phases in the waste tank controlling solubility and thereby affecting the timing and rate of release of the residual inventory. The ICM also considers the integrity of the waste tank steel liners and cementitious barriers in waste tank modeling, with the barriers degrading over time. As discussed in Section 4.2.2.2.6 of the HTF PA, Tanks 12H, 14H, 15H, and 16H are modeled as "degraded" (i.e., no liners or residual liner materials, such as iron oxides, are assumed to be present in the PA modeling for these tanks). The modeling assumption that no carbon-steel primary tank liner or five-foot high annulus pan exist is especially conservative for fast moving or short-lived contaminants such as I-129 and Sr-90, respectively, since infiltrating water would immediately transport the contaminants through the closed tank system (i.e., closure grout and tank vault) to the saturated zone. In the ICM, carbon steel liner failure triggers the contaminant release from the waste tanks. After failure, the liner is not assumed to exist, or otherwise retard flow. The flow into and out of the stabilized residual material is impacted by the material properties of the waste tank cementitious materials. The expected degradation rate and timing for the waste tank cementitious materials is modeled in the ICM. The ICM also simulates the impact of the cementitious materials and soil on contaminant transport. The waste tank ICM within the HTF PA that represents the most probable and defensible estimate of expected release and transport conditions based on currently available information is referred to as the Base Case.

As part of the Tank 16H RFS process, the final residual material inventory has been determined for Tank 16H. [SRR-CWDA-2014-00071] Based on the final residual material inventory for

Tank 16H and new process data (i.e., Tank 12H process sample results), the inventories for Tank 16H and the remaining HTF waste tanks and ancillary structures were adjusted to reflect updated residual material inventory information where applicable. [SRR-CWDA-2010-00023] The final residual material inventory from Tank 16H, along with the adjusted inventory assignments for the remainder of the waste tanks and ancillary equipment in HTF, were evaluated in a special analysis (hereinafter referred to as the Tank 16H Special Analysis [SA]). The purpose of a special analysis is to confirm that new and updated information (e.g., actual inventories and updated inventory projections) does not change the conclusions regarding the impact of the closure actions. [SRR-CWDA-2014-00106] The HTF ICM used in the Tank 16H SA was essentially the same as that used in HTF PA, with the transport model being slightly modified for the Tank 16H SA to better segment the annulus inventory from the sand layers inventories for applicable waste tanks. The modeling runs performed for the Tank 16H SA used the updated HTF inventories and updated distribution coefficients reflecting the most currently available test results from *Qualification and Management of $K_d$ Data for Use in C&WDA Performance Assessments* (SRR-CWDA-2011-00106).

In summary, the Tank 16H SA modeling used:

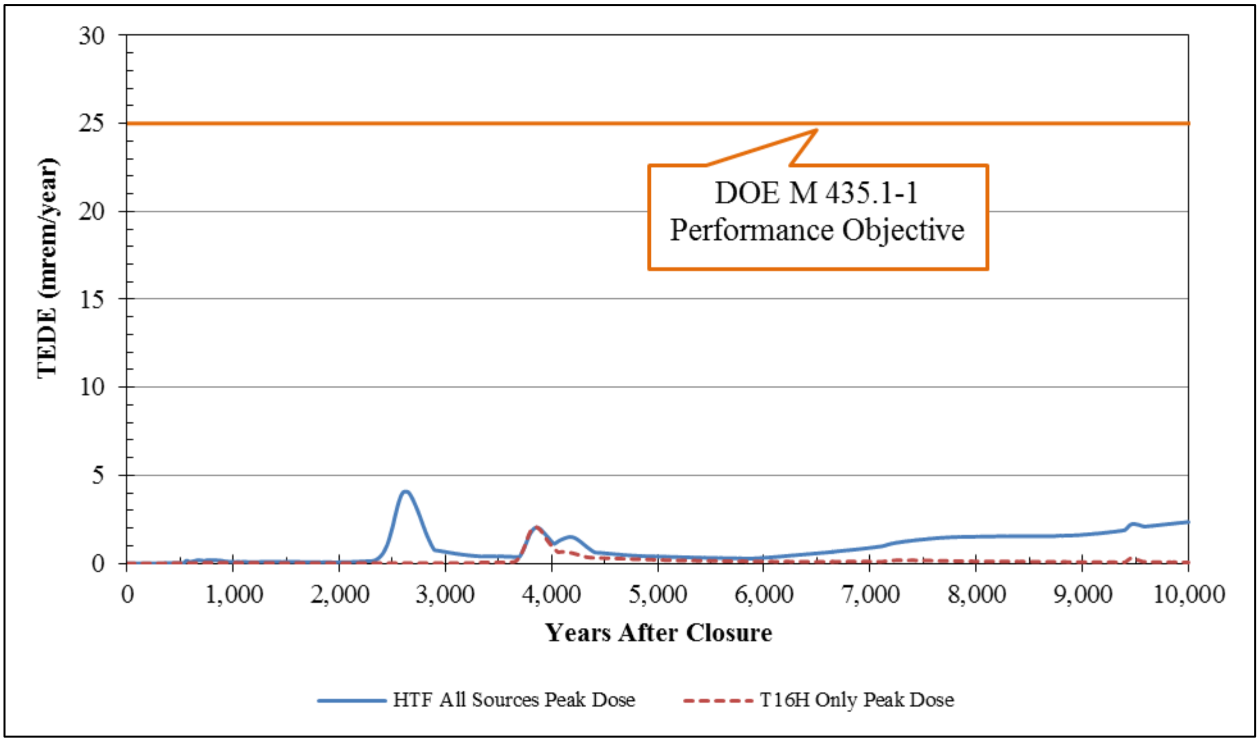
- The final residual inventory for Tank 16H
- Revised residual inventory assignments for remaining HTF waste tanks and ancillary structures to reflect updated residual material inventory information, where applicable [SRR-CWDA-2010-00023]
- The same deterministic (PORFLOW) and probabilistic (GoldSim) models that were developed for the HTF PA [SRR-CWDA-2010-00128] with modified inventory segmentation and updated distribution coefficients, where applicable

The Tank 16H SA provides peak groundwater concentration results within a 1,000-year time period. The *Radioactive Waste Management Manual* (DOE M 435.1-1) establishes a DOE compliance period of 1,000 years for quantitatively assessing whether there is reasonable assurance that performance objectives will be met. DOE has also evaluated groundwater concentrations beyond this 1,000-year DOE compliance period to qualitatively assess risk and evaluate the conclusions regarding reasonable assurance that performance objectives will be met within the 1,000-year period. DOE utilizes a MOP exposure pathway dose methodology to convert radionuclide concentrations to TEDE values for comparison against performance objectives utilizing the most recent dose conversion factors (DCFs), elemental transfer factors and individual consumption rates as documented in the HTF PA (Section 4.2.3.1, *Member of the Public Exposure Pathways*) and updated in the applicable SA. The TEDE methodology used in calculating TEDE for DOE M 435.1-1 assessment includes multiple dose pathways (e.g., water, vegetable, and beef ingestion), in comparison to the radiological beta-gamma dose calculated for the state drinking water standard (Tables 5.1-1 and 5.1-2), which is an effective dose equivalent (EDE) based solely on water ingestion. For the HTF Base Case model, Tank 16H does not contribute significantly to the modeled groundwater peak TEDE within 1,000 years or 10,000 years, as shown in Figure 5.0-1 and discussed in Section 6.0 of the Tank 16H SA. The TEDE contributions associated with Tank 16H only have peaks of 0.03 mrem/year within 1,000 years and approximately 2 mrem/year within 10,000 years. As can be seen in Figure 5.0-1, the TEDE contribution from Tank 16H does not coincide with the overall HTF peak dose, such that diminishing the Tank 16H contribution would not appreciably impact the overall HTF peak

TEDE of approximately 4 mrem within 10,000 years as calculated in the Tank 16H SA using the MOP TEDE exposure pathway methodology. [SRR-CWDA-2014-00106]

The HTF all sources peak TEDE and Tank 16H only peak TEDE are both well below the applicable *Radioactive Waste Management Manual* (DOE M 435.1-1) performance objective (i.e., dose to representative members of the public shall not exceed 25 mrem in a year TEDE from all exposure pathways) and the *Radiation Protection of the Public and the Environment* (DOE O 458.1) public dose limit of 100 mrem in a year. [DOE M 435.1-1, DOE O 458.1]

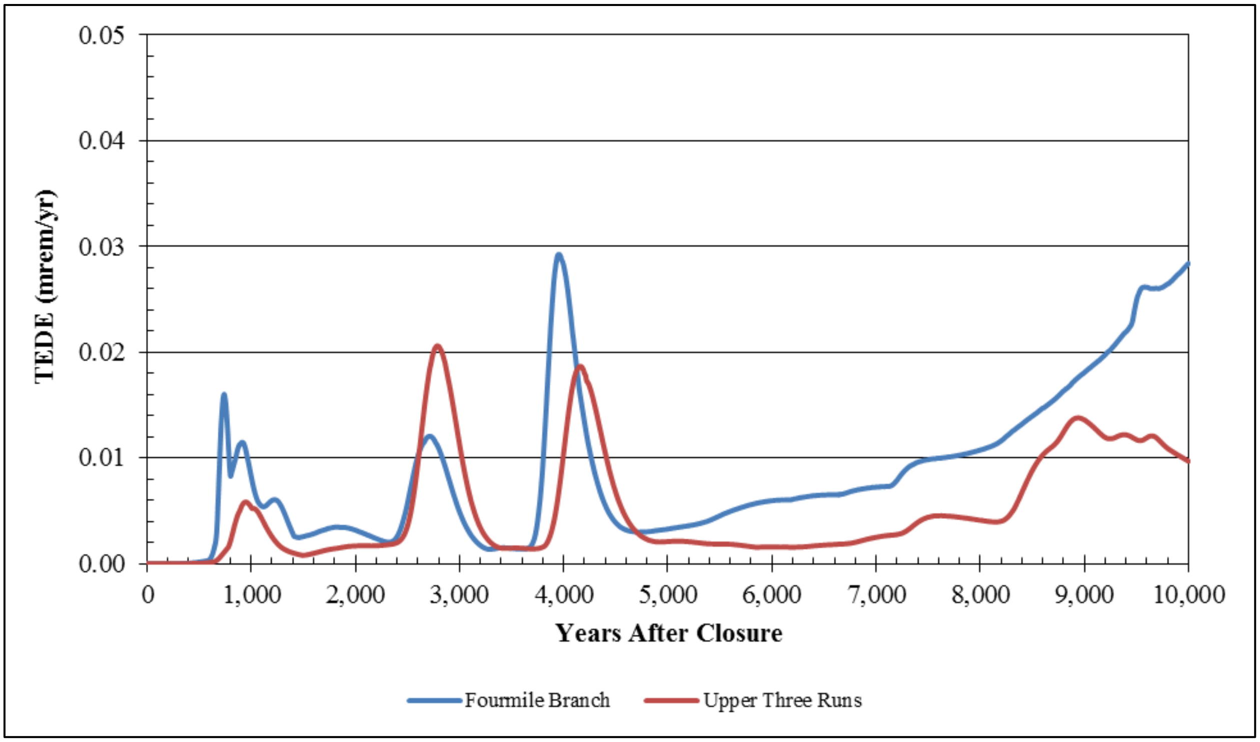
**Figure 5.0-1: MOP Peak Groundwater Pathway TEDE at 100-Meter Assessment Point within 10,000 Years Showing the Tank 16H Contribution**




[SRR-CWDA-2014-00106]

The HTF PA provided groundwater concentrations and radiological peak doses at different assessment points that can be utilized in the subsequent decision documents. The HTF PA provided groundwater radionuclide concentrations at 100 meters, and at the two seeplines downgradient from the HTF (Upper Three Runs [UTR] seepline approximately 2,400 meters northwest and Fourmile Branch [FMB] seepline approximately 1,200 meters southwest). These locations are shown in Figures 5.2-5 and 5.2-6 of the HTF PA. The groundwater radionuclide and chemical concentrations are provided at different aquifer depths in the HTF PA groundwater modeling. The Tank 16H SA assesses and documents the updated peak radionuclide and chemical concentrations at these same assessment points to reflect the replacement of the HTF PA assigned inventories in the ICM with the final Tank 16H and updated inventory information on other waste tanks. Figure 5.0-2 shows that the MOP TEDE peak at the seeplines are approximately two orders of magnitude less than the TEDE at the 100-meter assessment point within 10,000 years. As described in Section 5.1, the more plausible location for groundwater exposure to a future MOP would be at the UTR or FMB seeplines.

**Figure 5.0-2: HTF Base Case MOP Peak TEDE at the UTR and FMB Seeplines within 10,000 Years**




[SRR-CWDA-2014-00106]

The peak groundwater concentrations calculated in the HTF PA and Tank 16H SA are associated with specific locations and times. Since multiple inventory sources are modeled, there is significant temporal and spatial complexity inherent in the modeling system. Removal of any one inventory source term may reduce the concentrations (including the peak concentration, where applicable) associated with that source term, but the overall HTF peak concentrations will not necessarily be reduced by a corresponding amount. The overall HTF concentrations will merely shift to a different location and time. As a result, completely removing the entire inventory from a single source would not necessarily result in an equivalent corresponding concentration reduction, since another waste source (e.g., one of the other waste tanks) would then replace the affected source as the primary contributor to the peak concentration. For some contaminants there may not be a significant peak concentration decrease from the 100–meter assessment point to the seepline because the seepline peak concentration is influenced by multiple inventory sources rather than a single source. As presented in the HTF PA (Sections 4.2.2 and 4.4.4.1), the HTF is located over a groundwater divide between UTR and FMB, and contaminants can eventually discharge to both streams, depending on the contaminant origination point.

*HTF General Closure Plan Performance Objectives*

The *Industrial Wastewater General Closure Plan for H-Area Waste Tank Systems* (SRR-CWDA-2011-00022) performance objectives applied to groundwater concentrations for the HTF waste tank systems are:

- The SCDHEC *State Primary Drinking Water Regulation* for radionuclides (i.e., 4 mrem/year beta-gamma dose, 15 pCi/L total alpha concentration, and 5 pCi/L total Ra-228 + Ra-226) [SCDHEC R.61-58]
- The SCDHEC *State Primary Drinking Water Regulation* MCLs for nonradiological inorganic constituents [SCDHEC R.61-58]

These performance objectives are used only in the performance assessment process to provide reasonable assurance that during the interim period from tank grouting to final HTF FFA corrective/remedial actions, it can be concluded that groundwater concentrations derived from residual contamination in the waste tanks and ancillary structures will be within the performance objectives.

## 5.1 Tank 16H SA Modeling Results

The impacts from operationally closing Tank 16H were modeled using the final Tank 16H inventory and assigned inventory projections for the tanks that have not completed waste removal. The Tank 16H SA constituent modeling results are presented and compared in Table 5.1-1 to the state drinking water standards. [SCDHEC R.61-58] The results are provided at the UTR and FMB seeplines as discussed in Section 5.4 of *Industrial Wastewater General Closure Plan for H-Area Waste Tank Systems*, and at 100 meters from the HTF boundary. [SRR-CWDA-2011-00022] As described in Section 5.4 of the HTF GCP:

- *SRS will be owned and controlled by the Federal government in perpetuity,*
- *The property will be used only for industrial purposes,*
- *Site boundaries will remain unchanged, and*
- *Residential use will not be allowed on-site. [SRR-CWDA-2010-00128]*

> *Therefore, a scenario in which a future hypothetical MOP establishes a residence directly on the HTF and obtains drinking water from the water table below is extremely unlikely. A more plausible, although still highly unlikely, location for the future MOP to be exposed to the groundwater below the HTF would be at the UTR seepline or the Fourmile Branch seepline…*

In all cases, the modeling results demonstrate reasonable assurance that the respective peak concentrations or peak doses remain well below the state drinking water standards during the 1,000-year DOE compliance period following closure of all HTF sources. The results presented in this section are from the Tank 16H SA Base Case modeling and represent the best estimate or most probable and defensible scenario for modeling. For some constituents listed in Table 5.1-1 (e.g., Al, Sb, and Cr), the predicted concentrations are higher at the FMB seepline than at the 100-meter location due to the cumulative effect of multiple inventory sources and the complex HTF hydrogeology.

**Table 5.1-1: Tank 16H SA Modeling Results Within 1,000 Years Following HTF Closure**

| Constituent | Units | MCL[a] | Peak Groundwater Concentrations | | |
|---|---|---|---|---|---|
| | | | 100 meters | FMB Seepline | UTR Seepline |
| **Nonradiological** | | | | | |
| Aluminum (Al) | µg/L | 100 | 1.8E-27 | 1.2E-26 | 2.1E-31 |
| Antimony (Sb) | µg/L | 6 | 3.2E-33 | 1.5E-31 | 1.4E-36 |
| Arsenic (As) | µg/L | 10 | 4.3E-17 | 1.9E-19 | 4.2E-23 |
| Barium (Ba) | µg/L | 2,000 | 1.4E-04 | 1.2E-10 | 2.1E-12 |
| Boron (B) | µg/L | NA | 5.3E+01 | 7.1E-01 | 4.4E-01 |
| Cadmium (Cd) | µg/L | 5 | 4.4E-04 | 1.4E-10 | 2.4E-12 |
| Chloride (Cl) | µg/L | 250,000 | 2.6E-01 | 2.1E-02 | 3.8E-03 |
| Chromium[b] (Cr) | µg/L | 100 | 8.3E-28 | 2.5E-27 | 5.8E-32 |
| Cobalt (Co) | µg/L | NA | 7.3E-11 | 1.4E-15 | 7.1E-19 |
| Copper (Cu) | µg/L | 1,300 | 7.2E-11 | 2.8E-15 | 1.2E-18 |
| Fluoride (F) | µg/L | 4,000 | 1.7E-01 | 1.1E-02 | 3.9E-03 |
| Iodine (I) | µg/L | NA | 3.7E-03 | 3.1E-04 | 5.9E-05 |
| Iron (Fe) | µg/L | 300 | 1.3E-16 | 3.7E-18 | 4.1E-22 |
| Lead (Pb) | µg/L | 15 | 3.3E-31 | 8.0E-30 | 9.2E-35 |
| Manganese (Mn) | µg/L | 50 | 1.3E-03 | 2.3E-09 | 4.1E-11 |
| Mercury (Hg) | µg/L | 2 | 3.0E-25 | 4.8E-25 | 1.4E-29 |
| Molybdenum (Mo) | µg/L | NA | 5.8E-27 | 1.8E-26 | 4.1E-31 |
| Nickel (Ni) | µg/L | 100 | 5.0E-02 | 5.7E-07 | 4.2E-08 |
| $NO_2$ + $NO_3$ (as N) | µg/L | 10,000 | 1.2E+01 | 8.1E-01 | 2.4E-01 |
| Phosphate ($PO_4$) | µg/L | NA | 1.3E+01 | 1.9E-01 | 1.2E-01 |
| Selenium (Se) | µg/L | 50 | 8.5E-30 | 2.6E-29 | 6.0E-34 |
| Silver (Ag) | µg/L | 100 | 1.6E-03 | 6.1E-10 | 1.1E-10 |
| Strontium (Sr) | µg/L | NA | 2.8E-03 | 1.2E-06 | 2.6E-08 |
| Sulfate ($SO_4$) | µg/L | 250,000 | 1.2E+02 | 2.1E+00 | 1.5E+00 |
| Uranium (U) | µg/L | 30 | 1.6E-20 | 1.5E-21 | 1.1E-25 |
| Zinc (Zn) | µg/L | 5,000 | 1.5E-04 | 4.7E-11 | 7.9E-13 |
| **Radiological** | | | | | |
| Beta-gamma dose[c] | mrem/yr | 4 | 4.0E-01 | 3.3E-02 | 1.2E-02 |
| Alpha concentration | pCi/L | 15 | 2.5E-01 | 4.0E-03 | 1.3E-04 |
| Total Ra-226 + Ra-228 | pCi/L | 5 | 8.3E-09 | 8.0E-14 | 6.0E-17 |

NA Not Applicable

a SCDHEC R.61-58

b Total chromium (chromium III and VI)

c The state drinking water standard for beta particle and photon radioactivity is specified in the South Carolina State Primary Drinking Water Regulation which states that “The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water must not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year (mrem/year).” [SCDHEC R.61-58] This total body or organ dose equivalent comparison to the standard is calculated on the basis of two (2) liters per day drinking water intake. Rather than using the 168 hour data listed in *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure, NBS (National Bureau of Standards) Handbook 69 as amended August 1963, U.S. Department of Commerce*, the values are calculated using the most current DCFs from *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site* (SRR-CWDA-2013-00058). Because two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ is calculated. The calculated individual radionuclide concentrations are provided in the Tank 16H SA. [SRR-CWDA-2014-00106]

In addition, a 10,000-year qualitative evaluation was performed to evaluate system performance and future potential risks associated with HTF closure activities. This 10,000-year evaluation indicated that the 100 meter results for the manganese (Mn) concentration and beta-gamma EDE would be above the state drinking water standard. Mn was the only non-radiological contaminant migration constituent of concern (CMCOC) identified with a modeled peak concentration above the MCL value within 10,000 years. The modeled Mn concentration of 250 µg/L is above the 50 µg/L MCL at the 100-meter assessment point, but is below the MCL at both seeplines (Table 5.1-2). Similarly the 11 mrem/year modeled beta-gamma EDE at 10,000 years is also above the 4 mrem/year state drinking water standard at the 100-meter assessment point, but is below the state drinking water standard at both seeplines (Table 5.1-2).

The modeled beta-gamma concentration at 100 meters within 10,000 years is above the 4 mrem/year state drinking water standard primarily due to I-129, which constitutes approximately 75% of the calculated 11 mrem peak. The modeling assumptions inherent in the I-129 contribution to the beta-gamma peak (e.g., low distribution coefficients allowing fast contaminant transport) are such that the beta-gamma peak is not expected to move forward in time (i.e., into the 1,000 year DOE compliance period). [SRR-CWDA-2014-00106, Appendix B]

The Mn and beta-gamma results are discussed in Section 5.1.1.

To determine the peak alpha concentration, within 10,000 years, the sum of the concentrations of alpha-emitting isotopes, with the exception of uranium and radon, is determined for each year. In the Tank 16H SA, the modeled peak alpha concentration in the groundwater at the 100-meter assessment point occurs approximately 10,000 years following closure of the HTF. The primary contributors are Ra-226 and Np-237. The modeled peak total radium concentration occurs approximately 10,000 years following closure of the HTF. [SRR-CWDA-2014-00106, Appendix B] The modeled peak alpha and total radium concentrations are below the state drinking water standard at both seeplines and at the 100-meter assessment point.

The peak beta-gamma total body or internal organ dose is calculated using the most current water ingestion DCFs from *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site* (SRR-CWDA-2013-00058). Because two or more radionuclides are present, the sum of their annual dose equivalents to the total body or to any organ is calculated. This total body or internal organ dose equivalent is calculated on the basis of two (2) liters per day water intake, and is provided in the Tank 16H SA. [SRR-CWDA-2014-00106]

For the purpose of the 1,000-year DOE compliance period, the peak beta-gamma EDE at the 100-meter assessment point and at the seeplines is conservatively calculated by adding the peaks of all contributors, regardless of when the peak occurs. For both the 100-meter assessment point and the seepline evaluations, the contributing peak sources are the ancillary structures and waste tanks modeled with initially failed liners (Tanks 12H, 14H, 15H, and 16H) since this peak EDE occurs prior to the time associated with tank liner degradation for all other HTF waste tanks in the Base Case modeling. [SRR-CWDA-2014-00106, Appendix B]

**Table 5.1-2: Tank 16H SA Modeling Results Within 10,000 Years Following HTF Closure**

| Constituent | Units | MCL[a] | Peak Groundwater Concentrations | | |
|---|---|---|---|---|---|
| | | | 100 meters | FMB Seepline | UTR Seepline |
| **Nonradiological** | | | | | |
| Aluminum (Al) | µg/L | 100 | 1.3E-11 | 2.4E-15 | 7.3E-19 |
| Antimony (Sb) | µg/L | 6 | 4.7E-18 | 5.9E-19 | 8.1E-24 |
| Arsenic (As) | µg/L | 10 | 1.9E-04 | 7.5E-07 | 3.3E-08 |
| Barium (Ba) | µg/L | 2,000 | 1.8E+00 | 4.4E-02 | 7.5E-03 |
| Boron (B) | µg/L | NA | 5.3E+01 | 7.1E-01 | 4.4E-01 |
| Cadmium (Cd) | µg/L | 5 | 5.1E-01 | 1.0E-02 | 1.6E-03 |
| Chloride (Cl) | µg/L | 250,000 | 1.5E+02 | 2.6E+00 | 6.6E-01 |
| Chromium[b] (Cr) | µg/L | 100 | 2.8E-11 | 1.7E-13 | 2.1E-18 |
| Cobalt (Co) | µg/L | NA | 1.0E-02 | 5.4E-06 | 4.1E-07 |
| Copper (Cu) | µg/L | 1,300 | 4.6E-02 | 7.1E-05 | 6.9E-06 |
| Fluoride (F) | µg/L | 4,000 | 5.2E+01 | 1.2E+00 | 3.4E-01 |
| Iodine (I) | µg/L | NA | 1.0E+00 | 2.2E-02 | 4.6E-03 |
| Iron (Fe) | µg/L | 300 | 5.1E-02 | 2.8E-06 | 3.5E-08 |
| Lead (Pb) | µg/L | 15 | 4.0E-16 | 4.4E-17 | 4.9E-22 |
| Manganese (Mn) | µg/L | 50 | 2.5E+02[c] | 1.6E+00 | 1.3E+00 |
| Mercury (Hg) | µg/L | 2 | 6.7E-09 | 2.6E-12 | 4.4E-17 |
| Molybdenum (Mo) | µg/L | NA | 1.0E-10 | 2.3E-14 | 1.1E-18 |
| Nickel (Ni) | µg/L | 100 | 3.9E-01 | 1.2E-02 | 2.6E-03 |
| $NO_2$ + $NO_3$ (as N) | µg/L | 10,000 | 4.5E+03 | 9.7E+01 | 3.1E+01 |
| Phosphate ($PO_4$) | µg/L | NA | 4.5E+01 | 8.5E-01 | 2.0E-01 |
| Selenium (Se) | µg/L | 50 | 1.5E-13 | 9.7E-18 | 1.8E-21 |
| Silver (Ag) | µg/L | 100 | 3.8E-01 | 7.6E-03 | 2.2E-03 |
| Strontium (Sr) | µg/L | NA | 2.3E+00 | 4.4E-02 | 9.9E-03 |
| Sulfate ($SO_4$) | µg/L | 250,000 | 1.2E+02 | 2.1E+00 | 1.5E+00 |
| Uranium (U) | µg/L | 30 | 1.1E-04 | 3.8E-10 | 3.1E-13 |
| Zinc (Zn) | µg/L | 5,000 | 2.9E+00 | 5.2E-02 | 6.0E-03 |
| **Radiological** | | | | | |
| Beta-gamma dose[d] | mrem/yr | 4 | 1.1E+01[c] | 9.5E-02 | 6.4E-02 |
| Alpha concentration | pCi/L | 15 | 4.8E+00 | 6.5E-02 | 1.1E-02 |
| Total Ra-226 + Ra-228 | pCi/L | 5 | 3.3E+00 | 2.4E-02 | 2.9E-04 |

[a] SCDHEC R.61-58
[b] Total chromium (chromium III and VI)
[c] Additional discussion is presented in Section 5.1.1.
[d] The state drinking water standard for beta particle and photon radioactivity is specified in the South Carolina State Primary Drinking Water Regulation which states that "The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water must not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year (mrem/year)." [SCDHEC R.61-58] This total body or organ dose equivalent comparison to the standard is calculated on the basis of two (2) liters per day drinking water intake. Rather than using the 168 hour data listed in *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure, NBS (National Bureau of Standards) Handbook 69 as amended August 1963, U.S. Department of Commerce*, the values are calculated using the most current DCFs from *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site* (SRR-CWDA-2013-00058). Because two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ is calculated. The calculated individual radionuclide concentrations are provided in the Tank 16H SA. [SRR-CWDA-2014-00106]

At the 100-meter assessment point, the primary contributor during the 1,000-year DOE compliance period is Tc-99 with the peak EDE occurring approximately 780 years following HTF closure.

At the FMB seepline within the 1,000-year DOE compliance period, the primary contributor during the 1,000-year time period is Tc-99. The Tc-99 peak occurs approximately 740 years following HTF closure. The UTR seepline results are even lower.

The state drinking water standards represent the allowable dose or MCLs from drinking water directly from a free-flowing tap (e.g., kitchen sink faucet). In developing the state drinking water standards, the following must be considered:

> *(a) incremental costs and benefits associated with a range of MCL values, (b) health effects to the general population and sensitive sub-populations, and (c) any increased health risk to the general population that may occur as a result of the new MCL. EPA may adjust the MCL for particular class or group of systems to a level that "maximizes health risk reduction benefits at a cost that is justified by the benefits."* [EPA_MCL_11-2012]

In the establishment of the state drinking water standards, the associated costs and benefits were considered. Comprehensive modeling in the Tank 16H SA, including uncertainty and sensitivity analyses, has demonstrated reasonable assurance that during the next 1,000 years following HTF closure, groundwater concentrations derived from residual contamination in the tanks and ancillary structures will be less than the state drinking water standards. Therefore, it may be concluded that there is reasonable assurance that, at the time of final FFA corrective/remedial actions for the HTF, groundwater concentrations will be below the state drinking water standards.

### 5.1.1 Groundwater Concentration Discussion

As shown in Table 5.1-2, within the 10,000-year time period following HTF closure, no constituents modeled are above the state drinking water standards at the UTR and FMB seeplines. Table 5.1-2 also presents the 100-meter modeling results within the 10,000-year time period following HTF closure. Within this 10,000-year time period following HTF closure, two constituents are above the state drinking water standards at the 100-meter assessment point (Table 5.1-2). The 250 µg/L modeled Mn peak, approximately 7,300 years following HTF closure, is above the state drinking water standard due to a change in the forecasted inventory for Tank 12H from the inventory modeled in the HTF PA. Tank 16H is not the primary contributor to the groundwater Mn concentration. As final characterization data are not yet available for Tank 12H residuals, the Tank 12H forecasted inventory was increased to account for uncertainties in residual Mn mass. As a result, the Mn inventory was increased approximately six times the value used in the HTF PA as described in the *H-Tank Farm Closure Inventory for use in Performance Assessment Modeling* (SRR-CWDA-2010-00023). The final characterization of the Tank 12H residuals will be used in the Tank 12H SA and Tank 12H Closure Module Addendum supporting operational closure of Tank 12H. The 50 µg/L Mn MCL is a secondary state drinking water standard for aesthetic or nuisance effects (above the MCL, the noticeable effects are black to brown water color, black staining on surfaces, and a bitter metallic taste). Mn is not a primary state drinking water standard established for potential human health effects.

Similarly, the 11 mrem/year modeled beta-gamma EDE at 100 meters, approximately 2,600 years following HTF closure, is above the 4 mrem/year state drinking water standard due to a change in the forecasted inventory for Tank 12H from the inventory originally modeled in the HTF PA. The peak is driven by the contribution from I-129 which constitutes the majority (approximately 75%) of the beta-gamma EDE. The peak I-129 groundwater concentration associated with only Tank 16H (13 pCi/L at year 3,850) is half of the I-129 groundwater concentration associated with Tank 12H (26 pCi/L). [SRR-CWDA-2014-00106]

As final characterization data are not yet available for Tank 12H residuals, the Tank 12H forecasted inventory was increased to account for uncertainties in residual I-129 inventory. As a result the I-129 inventory was increased by approximately 90 times the value used in the HTF PA as described in the *H-Tank Farm Closure Inventory for use in Performance Assessment Modeling* (SRR-CWDA-2010-00023). The final characterization of the Tank 12H residuals will be used in the Tank 12H SA and Tank 12H Closure Module Addendum supporting operational closure of Tank 12H to reflect the actual risk associated with I-129.

## 5.2 Assessment Evaluation

As described in this section, there is reasonable assurance that the groundwater concentrations derived from residual contamination in the HTF tanks and ancillary structures will be within the state drinking water standards, based on the groundwater modeling performed within the Tank 16H SA. These modeling results provide assurance that human health and the environment will continue to be protected after the HTF waste tank systems have been stabilized with grout and removed from service.

# 6.0 ASSESSMENT OF THE IMPACT OF DEPLOYING ADDITIONAL REMOVAL TECHNOLOGY

An evaluation was completed to determine if it is useful (e.g., that the costs, such as monetary costs, delays in higher risk reducing activities, or occupational exposure of site workers to hazardous, potentially hazardous, or radioactive materials, outweigh the potential benefits associated with further waste removal efforts) to develop and deploy another cleaning technology in Tank 16H assuming such a technology could be identified and safely deployed. This cost-benefit analysis considered a broad range of costs including resultant schedule impacts on other on-going cleaning activities and waste disposition activities, and also the current state of waste removal capabilities and technologies. As described below, the analysis shows that removing additional residual material from Tank 16H does not justify the costs of implementation or the impacts to on-going and future risk-reduction activities associated with waste removal and stabilization.

As described in Section 3.0, waste removal was performed in the Tank 16H primary tank from 1972 through 1980 using a series of mechanical mixing and chemical cleaning campaigns. The waste removal efforts successfully reduced the volume of residual solids to 330 gallons because they were initiated soon after fresh waste receipts were stopped and many of the current safeguards related to nuclear safety were either not in place or were not as restrictive at that time. Due to the small amount of waste remaining in the primary tank, no evaluation to explore additional waste removal options in the primary tank was performed.

Waste removal was performed in the Tank 16H annulus in 1977. As described in Section 4.1.2, the final annulus residuals volume determination was 410 gallons for material inside the dehumidification duct and 1,500 gallons for residual material on the annulus floor for a total of 1,910 gallons. [U-ESR-H-00113] The 330 gallons of residual solids on the primary tank floor are relatively small compared to the 1,910 gallons in the annulus. Therefore, the assessment in this closure module of the impact of deploying additional waste removal technology is limited to the Tank 16H annulus.

As described in Section 2.2.1, when the annulus pan overflowed, waste escaped the concrete vault encasement and was assumed to have also migrated into the one-inch thick sand layer between the bottom of the primary tank liner and annulus steel pan and into the sand layer between the bottom of the annulus steel pan and the concrete base slab. Due to inaccessibility for sampling, it is assumed that the primary and secondary sand layers contain residual material with the same concentrations as the annulus material. The volume of the residual material within the primary sand layer is conservatively estimated at 1,300 gallons. [SRR-CWDA-2010-00023] The secondary sand layer is conservatively estimated to contain 2% (26 gallons) of the residuals volume of the primary sand layer. Due to inaccessibility for waste removal from the sand layers and the limited inventory assigned to the sand layers, a cleaning evaluation to explore options for waste removal from the sand layers was not performed.

## 6.1 Analysis of Potential Annulus Cleaning Technologies

DOE has developed a robust process to assess the technical readiness of new technologies as described in *Technology Readiness Assessment Guide* (DOE G 413.3-4A). The process evaluates technology maturity using the Technology Readiness Level scale that was pioneered by the National Aeronautics and Space Administration in the 1980s. Through this process DOE is able to validate that technologies have reached a level of maturity ensuring a high probability of success before they are fully funded and deployed. As required by the HTF GCP, DOE continues to provide an annual technology briefing to SCDHEC. The most recent review is provided in the *Annual SCDHEC Technology Briefing* given in April 2014. [SRR-LWE-2014-00055]

As described in Section 3.2.2, there are three categories of cleaning technologies that could be deployed for additional annulus cleaning in Tank 16H. These include mechanical removal, water dissolution and sluicing, and chemical cleaning with OA. The following subsections summarize and augment information in Section 3.2.2 on these technologies and their viability for removing additional Tank 16H annulus material.

### 6.1.1 Mechanical Cleaning Technologies

As described in Section 3.2.1, in early 1977 steam mixing jets (25 gallons per minute) were installed in the Tank 16H East and South annulus risers, and a third steam mixing jet (75 gallons per minute) was installed in the West annulus riser. Water was added to the annulus to dissolve the salt cake into solution and facilitate waste transfers out of the annulus. When the liquid level in the annulus reached 18 inches, the East and South riser steam jets were turned on to start a clockwise circulation. Steam was also sprayed into the top of the annulus to dissolve salt deposits on the primary tank exterior wall surface. The East and South riser steam jets were turned off, and the West riser steam jet was subsequently turned on to produce a counter-clockwise circulation. This sequence was repeated alternating between the East and South riser jets and the West riser jet. Transfers out of the annulus utilized the transfer jet in the North annulus riser. Sample analysis indicated that the residual waste contained a complex mixture of water-insoluble sodium aluminosilicate compounds and sand. Further annulus cleaning activities were suspended in July 1977 to avoid delaying the Tank 16H primary tank sludge removal demonstration. No additional waste removal has been performed in the Tank 16H annulus.

Evaluation of further waste removal from the annulus was initiated in 2007. A preliminary scope of work and expression of interest were issued to 46 vendors. Eight companies and alternative technologies were selected from the potential bidders list and provided a request for proposal. Three vendors provided proposals to perform additional waste removal from the Tank 16H annulus. A mechanical cleaning system using robotic technology proposed by SEC was chosen as the best option. Various tools for removing the waste and cutting the dehumidification duct open would be deployed on a wall crawler, and a separate pipe crawler would be deployed to clean inside the duct. The SEC system would vacuum the dry material out of the annulus and dehumidification duct to a process system skid that would include a pulverizer. The material would then be blown into a dense phase transfer hopper to be prepared for transport. A 50:50 water to dry mix would be used for transport. A proof of principle test of the SEC system was completed in 2007, but the project was suspended at that time due to funding constraints. When the project was reestablished in 2010, the cost was higher than previously estimated (i.e., greater than $16.6M), and the new schedule for implementation approached 39 months. Worker radiation exposure was judged to be 14-person-rem due to work over open risers and inspection ports. Additionally, new operability risks were identified based on real-time experience with crawlers in similar applications. In summary, it was determined that the SEC proposal would be more difficult to implement, cost more to execute, and take longer than originally planned. Therefore, additional alternatives (i.e., water dissolution and sluicing and chemical cleaning with OA) were evaluated. [SRR-WRC-2012-0018, U-ESR-H-00107]

### 6.1.2 Water Dissolution and Sluicing Technology

The proposed strategy for water dissolution and sluicing included the use of water jets installed in annulus inspection ports and several pumps to clean the annulus with warm water. High pressure nozzles would be used to clean inside the dehumidification duct. A final soak and rinse would potentially be performed at the end of cleaning. Water, as ballast, would be added into the Tank 16H primary tank to prevent damage to the primary tank due to the hydrostatic lifting force of liquid in the annulus. The combined ballast and annulus cleaning solutions would add about 150,000 gallons of new waste to the tank farm system. Tank farm personnel would operate the jets and pumps using video cameras mounted inside the annulus, while a vendor experienced in tank farm operations would perform dehumidification duct cleaning with high pressure nozzles. Material removed from the annulus and duct would be transferred to a receipt tank through an above ground hose-in-hose transfer line with radiation shielding and connections to facilitate transfer line flushing to prevent waste hold-up after transfers are complete. A rough order of magnitude estimate of $7M was assigned to additional annulus material removal activities using water dissolution and sluicing. [SRR-WRC-2012-0018, U-ESR-H-00107] The total dose estimate for personnel to perform demolition and removal work, annulus cleaning using water dissolution and sluicing, and post annulus cleaning sampling was approximately 14-person-rem. [SRR-RPE-2013-00003]

Solubility studies estimated that about 35% of the total material outside the dehumidification duct and 81% of the material inside the duct could be dissolved. In addition to dissolution, sluicing was estimated to be capable of removing approximately 30% of the insoluble solids. An assessment indicated that the combined efforts of dissolution and sluicing would remove 53% to 67% of the total annulus material volume. [SRR-WRC-2012-0018] As discussed in detail in Section 3.2.2.2, a subsequent full scale mockup demonstration was performed for the water dissolution and sluicing option. The mockup demonstration projected that 70% to 80% of the material inside the duct would be removed, but only 50% of the annulus material outside the duct would be removed.

The volume of water required for mobilizing the solids was considerably greater than initially estimated, and the time to move the solids slurry to the transfer pump was longer than predicted. The most significant observation during the mockup was the significant water vapor produced by the water jets. The water vapor aerosolization was significant enough to impair visibility with the camera making it difficult to aim the water jets. The mockup also demonstrated that waste could get aerosolized and become airborne during annulus cleaning operations utilizing this removal technology. This presented a significant challenge to control contamination and protect the worker. Administrative and engineering safety significant/safety class controls (i.e., safety basis modifications) would be required in case aerosolization did occur and would result in additional cost and delays. Based on lessons learned from the mockup demonstration, primarily reduced cleaning effectiveness and waste aerosolization concerns, it was decided not to implement water dissolution and sluicing to attempt further cleaning in the Tank 16H annulus. [SRR-LWP-2012-00068]

### 6.1.3 Chemical Cleaning Technology

Chemical cleaning with OA was evaluated as an improvement to water dissolution and sluicing. The same equipment used in water dissolution and sluicing would be used to add OA to dissolve additional material. In 2012, SRNL OA leaching tests on Tank 16H annulus material showed that an additional 1% to 12% of material, above what would be removed by water dissolution, could be dissolved with OA. However, the solids remaining formed large sticky clumps which would pose potential processing problems during subsequent transfers and storage. [SRNL-STI-2012-00178] The formation of gel-like clumps was also observed during OA testing on water-insoluble sodium aluminosilicate compounds in 1980. More testing would be required to resolve this issue. Since the same equipment and operations used in water dissolution and sluicing would be used for this chemical cleaning technology, the worker dose (14-person-rem) would be comparable, and the cost would be at least as much as water dissolution and sluicing (i.e., greater than or equal to $7M).

The use of OA to remove additional waste from the Tank 16H annulus would require a documented safety basis modification and other potential "major modification" activities such as a CHA, project safety documentation, a readiness assessment, a nuclear criticality safety evaluation, and evaluation of downstream impacts to the liquid waste system. [U-ESR-H-00107]

## 6.2 Estimated Dose Reduction

As discussed in Section 3.2.2.3, SRR began dose modeling for the HTF PA using updated source term projections established in May 2012 (based on the analytical results from the 2011 samples). The HTF PA was completed using multiple release point scenarios and sensitivity cases in November 2012. The HTF PA projected that the remaining Tank 16H waste contributed a nearly inconsequential, less than 0.2 mrem/year TEDE to a hypothetical future MOP. Therefore, the benefit of implementing additional cleaning strategies to reduce this small dose did not outweigh the associated worker dose and contamination risks. [SRR-RPE-2013-00003, SRR-CWDA-2010-00128]

As described in Section 4.0, a final residual volume determination and sampling and analysis were performed to characterize the Tank 16H residual material. [SRR-CWDA-2014-00071] As described in Section 5.0, the Tank 16H SA evaluated the impact of closure actions. Where applicable, the Tank 16H SA fate and transport modeling used:

- The final Tank 16H residual inventory
- Revised residual inventory assignments for the remaining HTF waste tanks and ancillary structures to reflect updated residual material inventory information [SRR-CWDA-2010-00023]
- The same deterministic (PORFLOW) and probabilistic (GoldSim) conceptual models that were developed for the HTF PA (SRR-CWDA-2010-00128) with updated distribution coefficients

The inventories developed for use in the Tank 16H SA were compared to the inventories used in the HTF PA. The results of the Tank 16H SA were compared to the results in the HTF PA to confirm that this updated information did not adversely impact the HTF PA results.

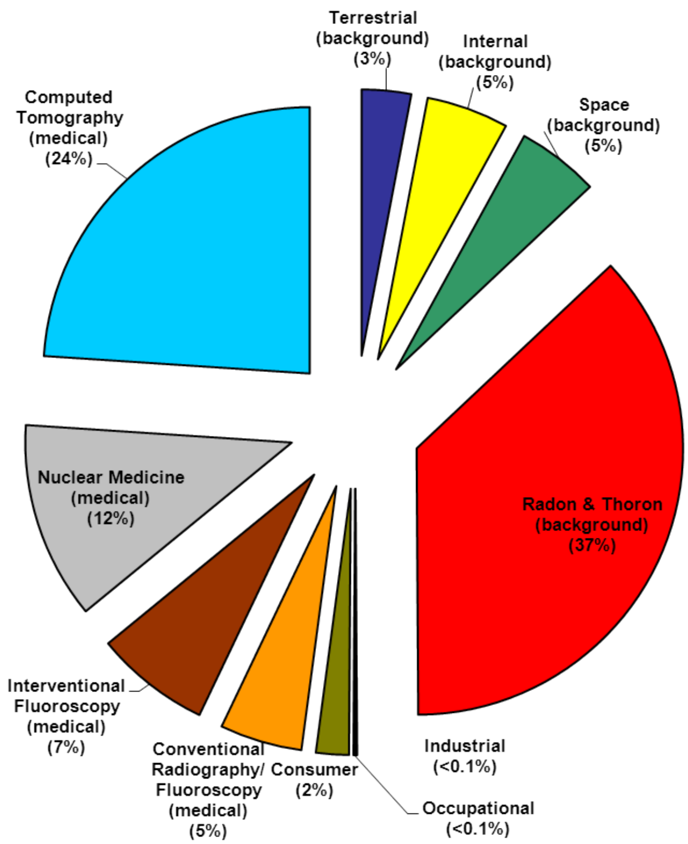
As discussed in Section 5.0 and shown in Table 5.1-1, using the actual Tank 16H inventories and updated HTF waste tank inventories, there remains reasonable assurance that the projected peak groundwater concentrations at the assessment point remain below the MCLs for the initial 1,000 years after closure of HTF. DOE M 435.1-1 establishes a DOE compliance period of 1,000 years for quantitatively assessing whether there is reasonable assurance that performance objectives will be met. DOE has also evaluated beyond this 1,000-year time period (i.e., for 10,000 years) to qualitatively assess risk and further inform the conclusions regarding reasonable assurance within the 1,000-year DOE compliance period. The Tank 16H SA provides reasonable assurance that the groundwater contaminant concentrations derived from residual contamination in the waste tanks and ancillary structures following removal from service will be below the MCLs.

Although not prescribed by the HTF GCP, the peak all-pathway radiological dose impacts were evaluated in the Tank 16H SA and showed that the all-pathways radiological dose to a MOP living 100 meters from the HTF boundary at any point in time for the initial 1,000 years following HTF closure is 0.2 mrem/year (TEDE). In the initial 10,000-year period the peak all-pathways dose is 4 mrem/year. As shown on Figure 5.0-1, the peak TEDE contributions associated only with Tank 16H are 0.03 mrem/year in 1,000 years and 2.1 mrem/year in 10,000 years. [SRR-CWDA-2014-00106] It should be noted that the peak all-pathways dose cannot be directly compared to the gross beta-gamma MCL value shown in Table 5.1-1 (i.e., 4 mrem/year) nor to the value calculated for comparison purposes versus the gross beta-gamma MCL (i.e., 0.72 mrem/year) at 1,000 years. The MCL was derived to establish acceptable concentrations in drinking water. The assumptions used to calculate the MCL value differ from those used to calculate an all-pathways peak TEDE. While the MCL only assesses hazards associated with drinking water, the all-pathways dose considers much broader resident scenarios involving drinking and showering with water from a contaminated well and also using the contaminated water to grow livestock and crops that are consumed by the hypothetical individual. The HTF PA Section 5.5.3 provides a detailed description of the exposure pathways associated with the all-pathways TEDE. [SRR-CWDA-2010-00128]

As discussed in Section 5.0, for the HTF PA Base Case model, the residual waste in the Tank 16H primary, annulus, and sand layers does not contribute to the HTF peak all-pathways TEDE within the 1,000-year or 10,000-year period after HTF closure as demonstrated in the Tank 16H SA. [SRR-CWDA-2014-00106] Therefore, it may be concluded that removal of additional residual waste from the Tank 16H annulus does not provide the benefit of additional dose reduction to a hypothetical future MOP.

All human beings are exposed to sources of ionizing radiation that include naturally occurring and man-made sources. To put the estimated doses in perspective, a person living in the United States receives an annual radiation dose on average of approximately 620 mrem/year. Figure 6.2-1 provides a breakdown of this exposure. The 0.2 mrem/year in the initial 1,000 years and 4 mrem/year within the initial 10,000 years TEDE to a MOP living 100 meters from the closed HTF is insignificant compared to the annual dose.

**Figure 6.2-1: Major Sources of Radiation Exposure Near SRS**




The major source of radiation exposure to an average MOP in the Central Savannah River Area is attributed to naturally occurring radiation (311 mrem/year) and medical exposure (300 mrem/year). This naturally occurring radiation is often referred to as natural background radiation and includes dose from background radon and its decay products (37%), cosmic radiation (5%), internal radionuclides occurring naturally in the body (5%), and natural radioactive material in the ground (3%). The dominant medical sources include dose from computed tomography (24%), nuclear medicine (12%), and radiography/fluoroscopy (12%). The remainder of the dose is from consumer products (2%), industrial/educational/research activities (less than 0.1%), and occupational exposure (less than 0.1%). [NCRP-160]

Using the actual residual materials inventory in Tank 16H and the updated inventory projections for remaining HTF waste tanks and ancillary structures, the all-pathways HTF peak TEDE (i.e., the highest single year dose in the years following closure of HTF) is estimated to be 0.2 mrem within 1,000 years and 4 mrem within 10,000 years. [SRR-CWDA-2014-00106] These peak doses are approximately 0.1 and 1%, respectively, of the naturally occurring background radiation (311 mrem/year) in this area, and even less when considering all sources of radiation exposure to the average person living in the United States.

### 6.3 Assessment Conclusion

Based on this evaluation of technology capability, schedule, and quantified cost/benefit analysis, deployment of additional waste removal technology to clean the Tank 16H annulus would not be practicable for the following reasons:

*Technology Evaluation Summary*

No new practicable technology has been identified that has reached a level of maturity for deployment to remove a significant additional concentration of constituents of concern from the Tank 16H annulus. The three broad categories of cleaning technologies (i.e., mechanical, water dissolution and sluicing, and chemical) which have been used at SRS were evaluated for viability in removing additional waste.

- A vendor-proposed mechanical cleaning system was previously chosen in 2007 as the best option of three submitted proposals for cleaning the Tank 16H annulus. This system would deploy robotic technology with various tools for removing waste with a vacuum system and cutting into the dehumidification duct for access. A pipe crawler would be deployed to clean inside the duct. This technology was re-assessed in 2010, and it was determined that the cost was higher than previously estimated (i.e., greater than $16.6M), more difficult to implement, and would take longer than originally planned to execute.
- A cleaning approach using water dissolution and sluicing technology would install water jets in annulus inspection ports to clean the annulus with warm water. Several pumps would be employed to remove the waste through an above grade hose-in-hose transfer line. Additionally, high pressure nozzles would be operated by a vendor to clean the inside of the dehumidification duct. A final soak and rinse could also be performed for potential additional cleaning. An initial assessment indicated that the combined efforts of dissolution and sluicing would only remove 53% to 67% of the material from the annulus. A subsequent full scale mockup demonstration projected that 70% to 80% of the material inside the duct would be removed, but only remove 50% of the annulus material outside the duct. The mockup also demonstrated that airborne release of aerosolized waste was a significant concern requiring extensive previously unplanned safety features and controls.
- Chemical cleaning with OA was evaluated as an improvement to water dissolution and sluicing. The same equipment used in water dissolution and sluicing would be used to add OA to dissolve additional waste. Testing on actual Tank 16H annulus material showed that 1% to 12% additional material, beyond that removed by water dissolution and sluicing, could be dissolved with this approach. However, more testing would be required to address the formation of gel-like clumps that were previously observed during OA testing. A documented safety basis modification, along with other assessments and safety evaluations, would be required prior to implementing chemical cleaning with OA.

*Cost/Benefit Analysis Summary*

The costs and benefits of potential risk reduction from removing additional residual material from Tank 16H were evaluated. The impact to the performance objectives outlined in the HTF GCP from the residuals in Tank 16H was quantified through use of the special analysis process. The final estimated residual inventory in Tank 16H was determined through final volume determinations and sampling and analysis. [SRR-CWDA-2014-00071] The impact of these final inventories on the performance objectives was then determined by performing fate and transport modeling through development of an SA. It should be noted that the TEDE results represent release of all Tank 16H inventories (primary, annulus, and sand layers), not just the annulus inventory.

- The financial costs associated with deployment of additional annulus material removal activities was estimated to be about $7M for the lowest cost technology of water dissolution and sluicing. The vendor-proposed mechanical cleaning technology costs over $16.6M, and chemical cleaning with OA requires more study and safety basis modifications and would cost at least as much as water dissolution and sluicing given the same equipment utilized. The expected potential radiological dose to the workers to deploy and operate each of the additional annulus material removal activities would be approximately 14-person-rem.
- Deployment of additional annulus material removal technologies would have resulted in impacts to other risk reduction activities including waste removal activities associated with Type I, II, and IV tanks, and preparation of DWPF sludge batches.
- In the HTF PA Base Case model, further removal of the residuals in Tank 16H does not impact performance objectives within the 1,000-year DOE compliance period after HTF closure.

No new practicable technology for removing additional residual material from Tank 16H was identified in the technology evaluation. Nevertheless, even if a technology could be identified and deployed, the limited benefit associated with further removal of residuals from Tank 16H does not justify the associated additional costs including the resulting delays in other risk-reducing activities in the Liquid Waste System. Therefore, it may be concluded that further residual removal is not technically practicable from an engineering perspective.

# 7.0 WASTE TANK SYSTEM ISOLATION PROCESS AND STABILIZATION STRATEGY

This section summarizes the planned waste tank system isolation process and subsequent stabilization strategy to be implemented on Tank 16H after waste removal is complete. In particular, the following attributes will be described:

- Waste tank system isolation process and system final configuration
- Description of structures and equipment that are part of this RFS activity including any equipment that will remain in Tank 16H at the time of RFS
- Stabilization strategy including type and characteristics of the grout fill material

## 7.1 Waste Tank System Isolation Process

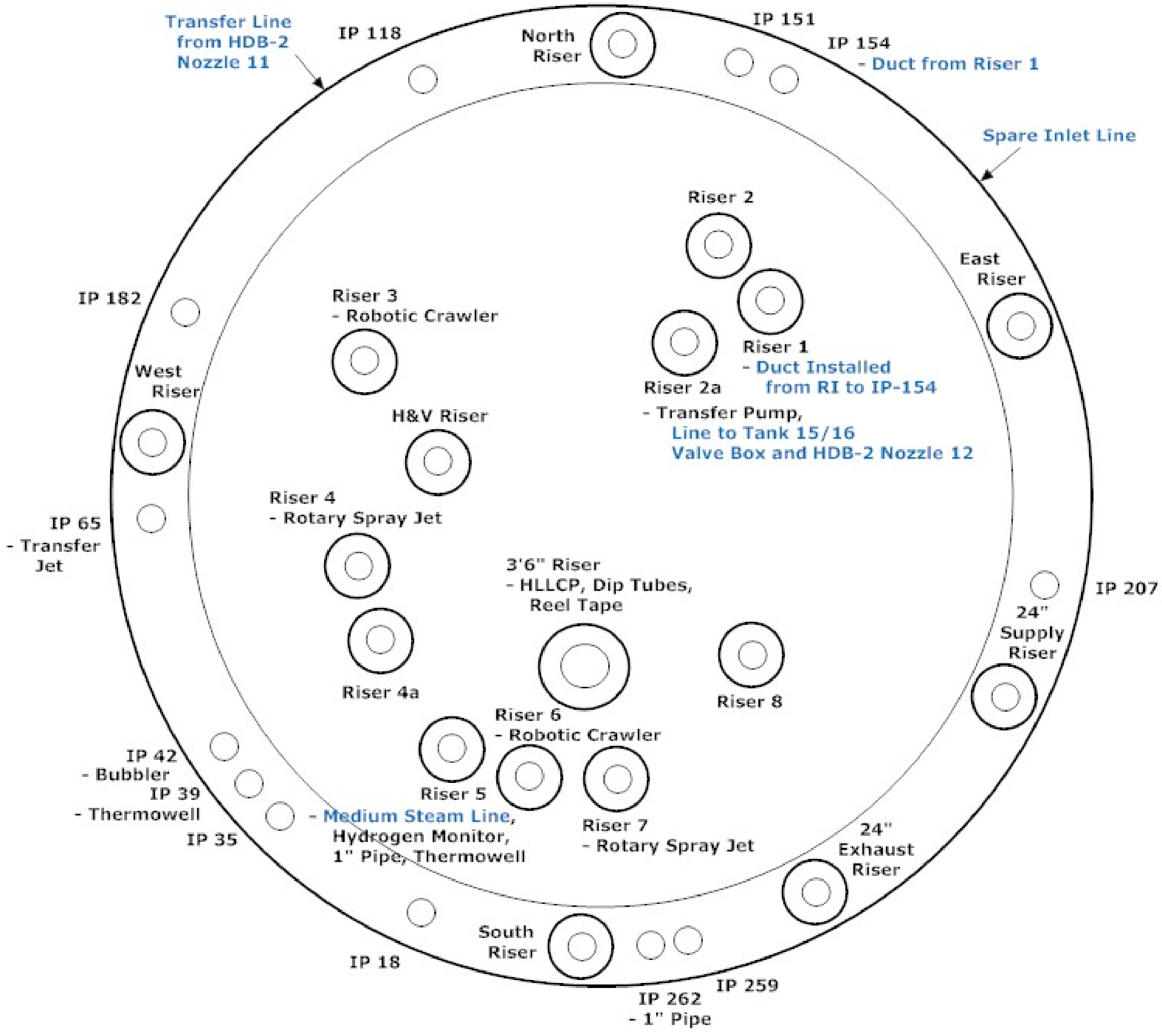
The isolation process for Tank 16H separates the waste tank from the HTF Waste Transfer System (WTS) and the HTF support systems. Implementation of the process consists of identification and isolation of transfer lines, drain lines, water, air, and steam supply lines, ventilation lines, power and instrumentation lines, and all other penetrations into, or out of, the waste tank. Isolation of these systems will be performed at the electrical control rooms or at the field location for electrical services and instrumentation for mechanical systems. Isolation for mechanical systems will be at the system supply headers located away from the tank top. Where practical, accessible piping and conduit will be removed creating a physical break from the waste tank. Other pipes will be plugged or capped to isolate them from the HTF systems. Isolating all waste tank systems will render the tank closed to waste processing activities. [M-CTP-H-00001]

### 7.1.1 Tank 16H System Isolation

As Tank 16H is filled with grout, grout material will flow into the waste tank, risers, and waste tank penetrations, thereby effectively sealing the abandoned transfer lines. This will eliminate the possibility of transferring waste into, or out of, the waste tank through the transfer lines. Though the grout will seal the transfer lines at the waste tank penetrations, there are no current plans to fill the abandoned HTF transfer lines exterior to the waste tank with grout. The waste transfer lines were modeled with no grout in the HTF PA and the results predicted compliance with the required performance objectives. [SRR-CWDA-2010-00128] Because any residual waste would be on the interior wall of the transfer lines and grouting would not significantly influence the leaching rate, there is no environmental benefit to grouting these small diameter transfer lines. In addition, there is no long-term subsidence issue requiring stabilization of the lines due to the small diameter of the transfer piping. Additional details on the isolation plans for the Tank 16H systems from the HTF WTS and support systems is in the Tank 16H Isolation Strategy. [M-CTP-H-00001] As new information is made available from field walkdowns and waste tank inspections, any necessary changes will be documented.

The six penetrations into the waste tank or tank risers, to be isolated during RFS, are shown on Figure 7.1-1 and described in Table 7.1-1.

## Figure 7.1-1: Tank 16H Riser Diagram




Note: Blue text indicates penetrations as reflected in Table 7.1-1.

[NOT TO SCALE]

[HTF-SKM-2014-00029]

**Table 7.1-1: Tank 16H Line Penetrations**

| Line Description | Size | Location |
|---|---|---|
| Transfer Line from H-Tank Farm Diversion Box (HDB)-2 Nozzle 11 | 3-inch inner pipe, 4-inch outer jacket | Penetrates the waste tank northwest wall and is approximately 25.8 feet above the waste tank bottom |
| Spare Inlet Line from Tank 15/16 Valve Box | 3-inch inner pipe, 4-inch outer jacket | Penetrates the waste tank northeast wall and is approximately 25.8 feet above the waste tank bottom |
| Ventilation Duct from Riser IP-154 to Riser 1 | 10 inches at Riser 1 and 7.75 inches at IP-154; duct is 19 feet long from riser to riser | The duct extends to the top of the waste tank and 4 feet below the tank riser |
| Transfer Line to Tk 15/16 Valve Box and HDB-2 Nozzle 12 | 3-inch inner pipe, 4-inch outer jacket | 1 foot above tank top and connects to the Riser 2a transfer pump |
| Inhibited Water (IW) Line | 4-inch pipe above tank top with no jacket, 6-inch jacket inside tank top | Penetrates Risers 4 and 7 and is approximately 12 feet above the waste tank bottom |
| Medium (150#) Steam Line | 2-inch pipe | Penetrates Riser 5 and extends approximately 10 feet into the waste tank |

[HTF-SKM-2014-00029]

## 7.2 Structures and Equipment Involved with RFS

Modifications to the top of Tank 16H will be made to accommodate tank grouting and riser capping activities. Risers or other waste tank penetrations extending above the grade level will not require capping if the grout level in the riser or penetration also extends above the grade level. In those risers or waste tank penetrations where bringing the grout level above the grade level is not achievable, a grout cap shall be placed greater than, or equal to, the height of the void. After external motors, piping, electrical, and instrumentation commodities have been removed from the riser, individual risers may be capped with bulk-fill grout, 5,000 psi concrete, or other suitable material. Each waste tank riser will be filled with grout from the top. [SRR-LWE-2014-00013] After all waste tanks and ancillary structures in the HTF have been removed from service, decisions on removal of external structures such as structural steel trusses, mechanical and electrical piping/conduit, instrumentation and power cables/wiring, raceways, motors, and any other remaining equipment on the waste tank top footprint will be addressed in conjunction with the final RCRA/CERCLA closure of the HTF OU.

Additional details on the isolation from service of the waste tank mechanical, electrical, equipment, and piping systems are presented in the Tank 16H Isolation Strategy. [M-CTP-H-00001] The isolation strategy will continue to be updated, as necessary, with new information made available from field walkdowns and tank inspections.

Several pieces of equipment used to support Tank 16H waste removal efforts and heel removal efforts will be entombed in place as part of the RFS process. Equipment in the Tank 16H primary and annulus planned to be entombed in the grout is included in Tables 7.2-1 and 7.2-2, respectively. As new information is made available from field walkdowns and tank inspections, any necessary changes will be documented. As the waste tank is filled, the equipment internal space will be filled to the extent practicable with grout to minimize void space. [SRR-LWE-2014-00013]

**Table 7.2-1: Equipment to Remain in Tank 16H Primary**

| Equipment | Grout Plan | Location(s) |
|---|---|---|
| Transfer pump and thermowell | Grout fill pump and thermowell | Suspended from Riser 2a |
| Two Robotic Sampling Crawlers | Entomb crawlers | One below Riser 3, one below Riser 6 |
| Six spray wash chambers | Grout portion of spray chamber located inside the riser; the area in between the top of the riser and the 4-inch high grating of the spray chamber will be covered with a grout plate | Spray chambers are on Risers 2, 2a, 3, 4a, 6, and 8; extend above the top of the riser and are secured to 4 inch high structural steel grating |
| Three dip tubes, 4-inch flex duct, reel tape, and High Liquid Level Conductivity Probe (HLLCP) | Grout fill HLLCP and piping, and dip tubes; entomb flex duct and reel tape | 3-foot 6-inch riser contains a reel tape, HLLCP, dip tubes that extend to the bottom of the waste tank, and flex duct welded to riser plug with an open end 5 feet 8 inches into the waste tank |
| Two rotary spray jet assemblies with installed IW Line | Grout rotary spray jet and abandoned IW line in place | Extends approximately 15 feet into the waste tank from the top of Risers 4 and 7 |
| 150# Steam Line, thermowells, three (3) 1-inch pipes | Grout fill steam line, 1-inch piping, and thermowell | In Riser 5 the steam line and 1-inch piping extends 10 inches below the riser; the thermowell extends to the tank bottom |
| Demister and electrically isolated heating and ventilation (H&V) system | Grout through H&V riser and entomb demister | Demister rests inside H&V riser and extends to tank top |

[SRR-LWE-2014-00013]

**Table 7.2-2: Equipment to Remain in Tank 16H Annulus**

| Equipment | Grout Plan | Location(s) |
|---|---|---|
| Thermowell | Grout interior space | Suspended from IP-39 to the bottom of the annulus |
| Level detection bubbler (isolated) | Grout interior space | Extends to the bottom of the annulus from IP-42 |
| Transfer jet | Detach from support bolt and allow to rest on annulus floor; entomb transfer jet | IP-65 |
| 1-inch Tygon tubing | Due to its condition, tubing assumed to collapse during grouting | Suspended from IP-154 and extends to annulus floor |
| 1-inch pipe | Grout interior space | Suspended from IP-259 port plug |

[SRR-LWE-2014-00013]

## 7.3 Stabilization Strategy

### 7.3.1 Waste Tank Grouting Selection

In May 2002, DOE issued an Environmental Impact Statement (EIS) on waste tank cleaning and stabilization alternatives. [DOE-EIS-0303] The DOE studied five alternatives:

- Empty, clean, and fill with grout
- Empty, clean, and fill waste tank with sand
- Empty, clean, and fill waste tank with saltstone
- Clean and remove waste tanks
- No action

The EIS concluded the Fill-with-Grout option was preferred. The DOE also issued a Record of Decision selecting the Fill-with-Grout alternative for SRS waste tank closure. [DOE-EIS-0303]

Evaluations described in the EIS showed the Fill-with-Grout alternative to be the best approach to minimize human health risks and safety risks associated with closure of the waste tanks. [DOE-EIS-0303] This alternative offers several advantages over the other alternatives evaluated such as:

- Provides greater long-term stability of the waste tanks and their stabilized contaminants than the sand-fill approach;
- Provides for retaining radionuclides within the waste tanks by using reducing agents in the grout in a fashion that the sand-fill would not;
- Avoids the technical complexities and additional worker radiation exposure that the fill-with-saltstone approach would entail;
- Produces smaller impacts due to radiological contaminant transport than the sand- and saltstone-fill alternatives;
- Avoids the excessive personnel radiation exposure, and provides greater occupational safety impact than would be associated with the clean-and-remove alternative. [DOE-EIS-0303]

Cementitious materials are often used to stabilize radioactive wastes. Grout has been one of the most commonly used materials for solidifying and stabilizing radioactive wastes, and the technology is at a mature stage of development. [ISBN: 0-309-59313-1] The purpose of this stabilization is to maintain waste tank structure and minimize water infiltration over an extended period of time, thereby impeding the release of stabilized contaminants into the environment. The grout fill that will be used has reducing properties (i.e., low redox or $E_h$) which minimize the mobility of the chemicals after closure. All grout formulas are alkaline because grout is a cement-based material that naturally has a high pH. This alkalinity is compatible with the carbon steel waste tank construction materials. Grout has a high compressive strength and low permeability, which enhances its ability to limit the migration of contaminants after closure. The grout formulas are also designed to promote flowability, thereby enabling a near level placement within the waste tank. [SRNL-STI-2011-00551, SRR-CWDA-2010-00128]

Grout is primarily a mixture of cement and water proportioned to produce a pourable consistency. Studies have focused on improving grout production and batching, grout flow, measurement of the effective diffusion coefficients in reducing fill grout, and measurement of hydraulic properties. [WSRC-STI-2007-00369, WSRC-STI-2007-00641]

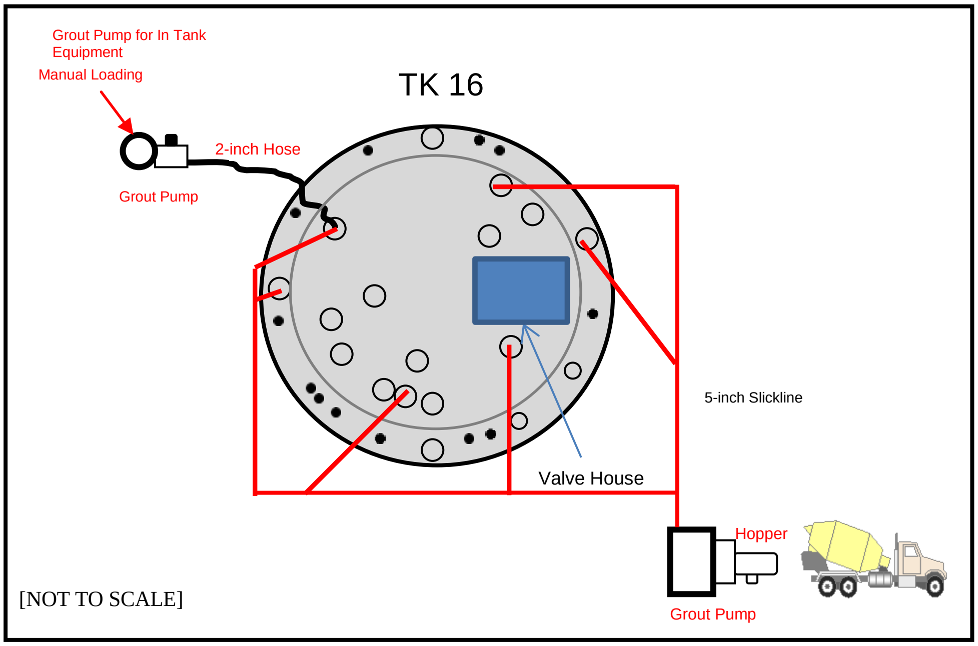
Filling a cleaned waste tank with grout prevents the walls and ceiling from possible collapse thereby providing long-term stability. The grout fill also helps to reduce water intrusion into the waste tank over time. Reducing the amount of water entering a closed waste tank retards the migration of residual materials from the waste tank to the environment. Testing has demonstrated that the chemical and physical characteristics of the grout formula used at SRS retards the movement of chemical and radiological constituents. [WSRC-TR-97-0102]

### 7.3.2 Waste Tank Grouting Plan

Grout will be supplied by an off-site vendor. The vendor will deliver the grout to HTF using unmodified concrete mixer trucks. The grout will be off-loaded to a hopper. Pumps will push the grout through commercial slicklines to the primary tank and annulus grouting risers. The slicklines will be configured to support the filling of one primary or annulus riser at a time. The primary tank and the annulus will be filled with grout in a sequence that will be protective of the wall structure. [SRR-LWE-2014-00013]

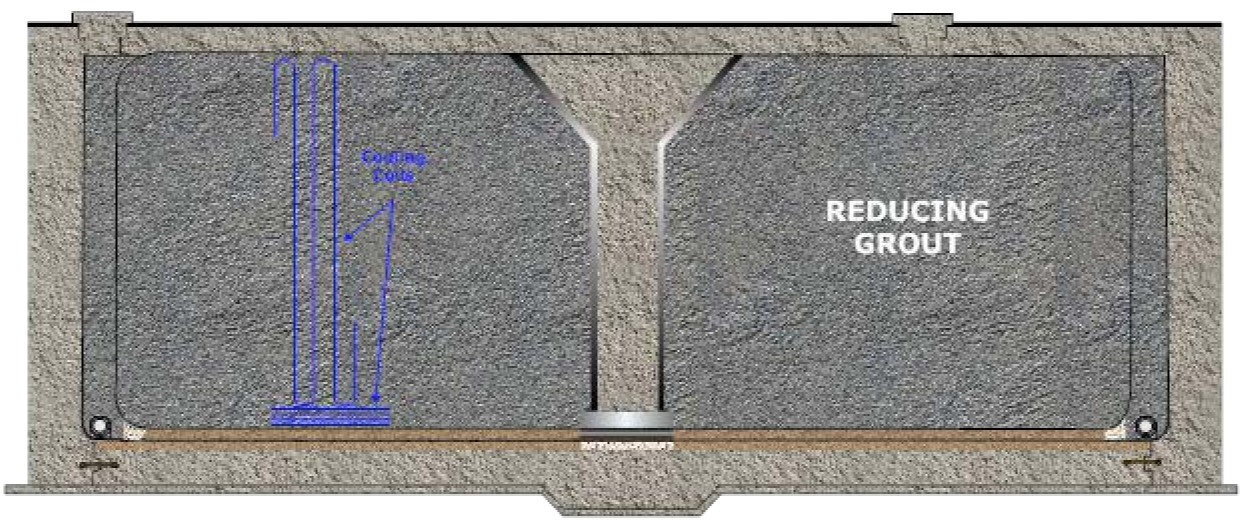
Reducing grout will be used to fill the entire Tank 16H primary and annulus tank volume, with the possible exception of the annulus ventilation duct, which may require an alternative grout mixture with more flowability (Section 7.3.3). The reducing grout will flow and cover the remaining residual material. The ability of the grout to flow and cover the remaining residual material was successfully demonstrated during the grouting of Tanks 5F and 6F. However, internal waste tank obstructions and interferences in Tank 16H may increase the risk of uneven grout distribution. To reduce this risk, the plan is to introduce bulk fill grout into the primary tank at multiple risers. If additional pour locations are required to cover the remaining residual materials, additional access points will be identified and installed to address the exact area requiring special effort. The location and number of risers used during grouting will be dependent on actual field conditions experienced. Figure 7.3-1 shows a typical grout equipment layout. [SRR-LWE-2014-00013] Figure 7.3-2 illustrates the typical grouted configuration for a Type II tank. [SRR-CWDA-2010-00128]

**Figure 7.3-1: Tank 16H Typical Grout Equipment Layout**




Note: Slickline routing shown is for illustration only. The slickline will be configured to support filling of one primary tank riser or annulus riser at a time using fittings and diversion valves. Actual slickline routing will be per field instruction. [SRR-LWE-2014-00013]

**Figure 7.3-2: Typical Grout Configuration for Type II Tanks**




[SRR-CWDA-2010-00128]

Tank grout typically consists of two major states, cured and fresh. [WSRC-STI-2007-00369] The major properties of cured grout include: high compressive strength, low effective diffusion coefficient, low hydraulic conductivity, low porosity, and high dry bulk density. The fresh grout properties include: high flow, low bleed water generation, set time, low air content, and high wet unit weight (density). Slump-flow is used as an acceptance criterion for grout delivered to the HTF and air content will be measured for information. Quality control requirements of the grout production are included as part of the grout procurement specification. [C-SPP-F-00055]

Independent testing determined that certain formulas of grout provide a superior protection for any stabilized contaminant that might remain in the waste tank. [WSRC-STI-2007-00369] The reducing grout properties associated with the Tank 16H grout are taken from the specification in *Tanks 18 and 19-F Structural Flowable Grout Fill Material Evaluation and Recommendations* (SRNL-STI-2011-00551) which are based on testing of the grout formula for waste tank fill. The HTF PA (Table 3.2-9 and Table 4.2-28) outlines the key mechanical and chemical properties used in PA modeling. A grout formula that meets the key specifications will reduce water intrusion, retard migration of residual contaminants, and inhibit a hypothetical future MOP from drilling into the waste tank.

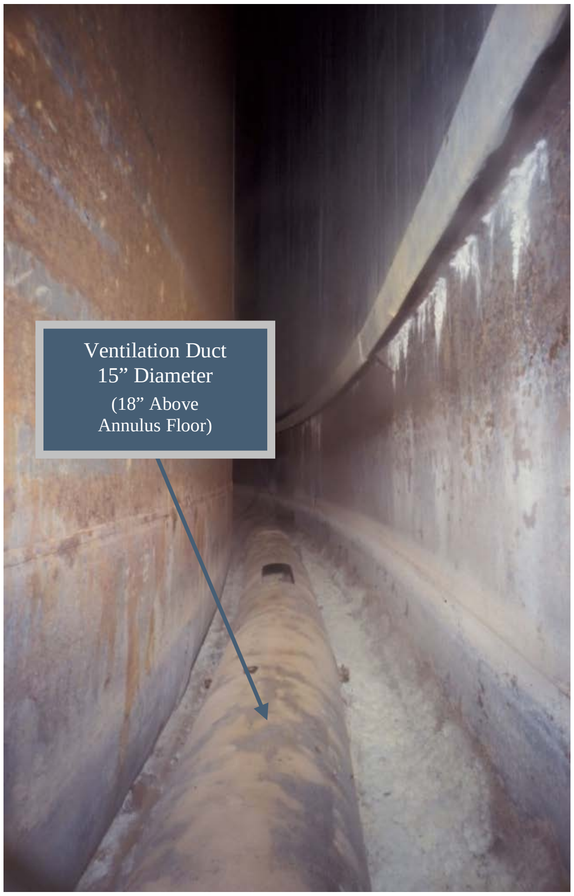
The waste tank risers will be modified as needed to permit grout placement into the waste tank. Video cameras will be used during the grout pouring process to monitor for anomalies and potential void space formations. Each waste tank riser will be filled with grout from the top. Provisions will be made to provide delivery points into the waste tank to manage air displacement, to address bleed water build-up, and to handle any waste tank top overflow. The waste tank will be ventilated until after grouting is complete. Since the commencement of waste tank grouting requires approval of this CM, the final grouted tank configuration will be reported in the Final Configuration Report for Tank 16H. [SRR-LWE-2014-00013]

### 7.3.3 Annulus Grouting

Grout will be introduced into the annulus, between the outside radius of the annulus ventilation duct and the annulus steel pan. Because the ductwork has numerous exhaust vent openings, initial filling of the duct system through the ventilation system inlet and exhaust risers is not required.

The lower portion of the ventilation duct will fill through the exhaust vent opening during bulk fill. In parallel with filling of the annulus, the vertical section of the annulus ventilation inlet duct may be filled all the way back to grade level with bulk fill grout. In a similar fashion, the annulus ventilation exhaust duct will be filled to grade level. To maintain integrity of the primary tank wall structure, grout will be poured alternately into the primary tank and the annulus to meet structural integrity requirements. The annulus risers will be filled to the level of the riser opening planes. Figure 7.3-3 shows the annulus and ventilation duct in Tank 16H. [SRR-LWE-2014-00013]

**Figure 7.3-3: View of Tank 16H Annulus and Ventilation Duct (IP-35, September 2005)**




### 7.3.4 Cooling Coil Grouting

The current plan is to flush all intact cooling coils prior to the introduction of grout. The flush water will remove chromate cooling water from the coils and will ensure a uniformly wetted path exists for the grout to follow. The chromate water flushed from intact cooling coils may be collected and returned to an active waste tank, or waste collection tote. Grout will be placed into the primary tank prior to any cooling coil grouting. The initial grout layer will support the vertical cooling coils and help prevent failure of the vertical coils during grouting.

Coils that have been severed will be grouted from each end to the extent practicable. There may be sections of coils with breaks not connected to the coil inlets and/or outlets that cannot be internally filled. Coils that are no longer intact (e.g., failed with a guillotine break) will only be filled passively as the bulk grout is added to the tank. [SRR-LWE-2014-00013]

# 8.0 MAINTENANCE AND MONITORING PLANS

The FFA establishes requirements for the prevention and mitigation of releases or threats of releases at or from the HTF, and any needed remediation of soils and groundwater when all HTF waste tanks have been removed from service. Because not all waste tank systems will be removed from service at the same time, there will be an interim period where some systems remain operational, while others are removed from service. [WSRC-OS-94-42]

Following stabilization, Tank 16H will become subject to the maintenance and monitoring requirements of an IROD/RCRA Permit Modification. The tank will then be removed from the Construction Permit #17,424-IW. In the interim period following RFS until application of the IROD/RCRA Permit Modification and any subsequent needed final FFA corrective/remedial actions, Tank 16H will be subject to the following maintenance and monitoring requirements.

- Historically, groundwater monitoring has been performed in accordance with the current SRS programs that have been conducted inside and around HTF since the 1970s, as requested by SCDHEC in support of Construction Permit #17,424-IW (DHEC_01-25-1993). The *H-Area Tank Farm Groundwater Monitoring Plan and Sampling and Analysis Plan* (SRNS-RP-2012-00146) provides the requirements for groundwater monitoring. The analysis of groundwater samples is performed by a laboratory certified for applicable parameters in accordance with SCDHEC Regulation 61-81, *State Environmental Laboratory Certification Program*. Results have been and will continue to be reported annually to SCDHEC and EPA.
- Annual visual inspections of the area surrounding Tank 16H will be conducted and maintenance actions will be performed, as appropriate. The grout is the primary barrier to contaminant release. The grout, where visible, will be inspected for significant cracking. The stormwater system will be maintained to ensure that any possible water infiltration through grout is minimized. Inspections will commence within one year of grout stabilization and will be performed annually. Deficiencies will be corrected as soon as practical and will be documented by procedure. Within 30 days of detection, DOE will notify SCDHEC of any significant cracking of the grout or degradation of the stormwater system and will establish a schedule to complete necessary maintenance activities. Inspection records will be maintained until all tanks have been removed from service and the HTF OU is closed.
- Access controls for on-site workers will be provided via the Site Use Program, Site Clearance Program, work control, worker training, worker briefing of health and safety requirements and identification signs located at the waste unit boundaries.
- EPA and SCDHEC will be notified in advance of changes in land use in accordance with the *Savannah River Site Land Use Plan*. [SRNS-RP-2013-00162]
- Access controls against trespassers will be provided as consistent with the 2000 RCRA Part B Permit Renewal Application, Volume I, Section F.1, which describes the security procedures and equipment, 24-hour surveillance system, artificial or natural barriers, control entry systems, and warning signs in place at the SRS boundary. [WSRC-IM-98-30]

# 9.0 CONCLUSION

Bulk waste and heel removal activities performed in Tank 16H were successful in removing over 99% of the total waste from the tank primary and annulus. The Tank 16H bulk waste and heel removal campaign results are summarized in Table 9.0-1.

**Table 9.0-1: Tank 16H Primary Tank and Annulus Waste Removal Details**

| | Primary Tank | Annulus | Total |
|---|---|---|---|
| Total Starting Volume (gallons)[a] | 1,060,000 | 25,700 | 1,085,700 |
| Total Solids Removed (gallons) | 76,670 | 4,090 | 80,760 |
| Total Solids Remaining (gallons) | 330 | 1,910 | 2,240 |
| **Percent of Total Waste Volume Removed (%)** | **>99.9** | **92.6** | **99.8** |

[a] Starting volumes are based on historical high waste volumes in the waste tank.

Based on the information presented in this CM, DOE has determined that further waste removal efforts are not technically practicable from an engineering perspective for Tank 16H. This determination is based on the approach followed and defined in the HTF GCP.

- Visual Observation in the Tank Primary – For the Tank 16H primary tank, the determination to cease waste removal activities was primarily based on visual observation. Visual inspections inside the primary tank were performed using remotely operated cameras suspended from waste tank risers and on-board cameras mounted on robotic crawlers used during sampling. These visual observations showed there was a significant reduction in residual material volume as a result of the waste removal efforts. Figure 9.0-1 shows the Tank 16H primary after the completion of waste removal efforts. As described in Section 3.1, extensive waste removal efforts were performed in the tank primary and left only a small amount of remaining residual material.

**Figure 9.0-1: View of the Tank 16H Primary Tank After Waste Removal**

- Analysis of Deploying an Additional Annulus Waste Removal Technology – Visual observation and measurements taken during sampling in the Tank 16H annulus showed residual material thickness ranging from 2 inches to 8 inches (Section 4.0). Figure 9.0-2 shows a view of the Tank 16H annulus during sampling activities. An analysis of deploying another removal technology was performed and demonstrated that the benefits of additional annulus removal did not outweigh the associated risks (Sections 3.2.2 and 6.0). [U-ESR-H-00107] The recommendation is based on the following two points:
    - The dose to implement additional annulus waste removal far exceeds the marginal waste/risk reduction realized if annulus waste removal activities continue. Furthermore, the potential safety risks of executing any removal (e.g., airborne release of aerosolized waste, high pressure line hazards) are greater than the long term risks of leaving the residual material in place.
    - The cost to benefit ratio appears unjustified. A detailed cost-benefit analysis substantiates the conclusion that a rough order of magnitude estimate of $7M for deployment of water dissolution and sluicing to reduce the peak TEDE by approximately 0.1 mrem/year is not prudent.

**Figure 9.0-2: View of the Tank 16H Annulus during Sampling at IP-35**

- Human Health and Environment Impacts – Tank 16H has been characterized to determine actual inventories for the residual materials. Updating the fate and transport model with the actual inventories projects no impact to human health and the environment (Section 5.0). The Tank 16H SA described in Section 5.0, provides reasonable assurance that groundwater concentrations derived from residual contamination in the waste tanks and ancillary structures will meet the HTF GCP performance objectives for the initial 1,000-year DOE compliance period after HTF closure and provides even greater assurance that human health and the environment will continue to be protected after the HTF waste tank systems have been stabilized and removed from service. [SRR-CWDA-2014-00106]
- Isolation Strategy – The isolation strategy demonstrates that Tank 16H will be isolated from the remainder of the HTF WTS and the HTF support systems, precluding them from any future waste processing activities (Section 7.1).
- Stabilization – DOE has evaluated stabilization alternatives in the EIS (DOE-EIS-0303) and has determined that the "Fill with Grout" alternative is the best approach to minimize human health and safety risks associated with the waste tanks RFS (Section 7.3).
- Maintenance and Monitoring – DOE will monitor groundwater, conduct annual surface visual inspections, and control access to the HTF during the interim period between Tank 16H RFS until final closure of the HTF OU (Section 8.0).

DOE has determined that all HTF GCP requirements have been met to proceed with removing Tank 16H from service and is ready to stabilize the waste tank with grout. Approval of this CM by SCDHEC signifies State acceptance of the proposed DOE closure activities for Tank 16H and State concurrence that waste removal activities for Tank 16H can cease. In accordance with the FFA, EPA will provide concurrence that waste removal activities may cease. Following stabilization, DOE will submit to SCDHEC a Final Configuration Report for Tank 16H with certification that the RFS activities have been performed in accordance with the HTF GCP and this CM.

Based on this approach, DOE has determined that residual material has been removed from Tank 16H to the extent technically practicable from an engineering perspective and is ready to proceed to isolation and stabilization activities summarized in Section 7.0. Based on the information provided in this CM and supporting documents, it may be concluded that (1) there is reasonable assurance that, at the time of final FFA corrective/remedial actions, groundwater concentrations derived from residual contamination in the waste tanks and ancillary structures will be less than the South Carolina state drinking water standards and (2) further residual removal is not technically practicable from an engineering perspective.

# 10.0 REFERENCES

**Note:** References identified as (Copyright) were used in the development of this document, but are protected by copyright laws. No part of the publication may be reproduced in any form or by any means, including photocopying or electronic transmittal in any form by any means, without permission in writing from the copyright owner.

10 CFR 61, *Licensing Requirements for Land Disposal of Radioactive Waste*, http://www.nrc.gov/reading-rm/doc-collections/cfr/part061/, U.S. Nuclear Regulatory Commission, Washington, DC, December 22, 2011.

40 CFR 261_App VIII, *Identification and Listing of Hazardous Waste*, Office of the Federal Register, National Archives and Records Administration, Washington, DC, March 24, 2011.

CBU-PIT-2005-00228, Hamm, B.A., *Savannah River Site High-Level Waste Tank Farm Closure, Radionuclide Screening Process (First-Level), Development and Application*, Savannah River Site, Aiken, SC, Rev. 0, November 7, 2006.

C-SPP-F-00055, *Furnishing and Delivering of Tank Closure Grout*, Savannah River Site, Aiken, SC, Rev. 3, December 3, 2012.

DHEC_01-25-1993, *Construction Permit #17,424-IW, SRS F/H-Area, Aiken and Barnwell County*, South Carolina Department of Health and Environmental Control, Columbia, SC, January 25, 1993.

DHEC_04-11-2013, *DHEC's Concurrence to Preliminary Cease Waste Removal and Proceed to the Sample and Analysis Phase of the Tank Closure Process for Tank 16H*, South Carolina Department of Health and Environmental Control, Columbia, SC, April 11, 2013

DHEC_11-23-2010, *Request to Include Tank 241-916H Dated October 14, 2010 Construction Permit Nos. 17,424-IW F and H Area High Level Waste Tank Farms Savannah River Site Aiken County*, South Carolina Department of Health and Environmental Control, Columbia, SC, November 23, 2010.

DOE G 413.3-4A, *Technology Readiness Assessment Guide*, U.S. Department of Energy, Washington DC, September 15, 2011.

DOE M 435.1-1, Chg. 1, *Radioactive Waste Management Manual*, U.S. Department of Energy, Washington DC, June 19, 2001.

DOE O 458.1, Chg. 3, *Radiation Protection of the Public and the Environment*, U.S. Department of Energy, Washington DC, January 15, 2013.

DOE/SRS-WD-2014-001, *Basis for Section 3116 Determination for Closure of H-Tank Farm at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 0, December 3, 2014.

DOE-EIS-0303, *High-Level Waste Tank Closure Final Environmental Impact Statement*, Savannah River Site, Aiken, SC, Rev. 0, May 2002.

DP-1023, Costas, L.P., et al., *Stress Corrosion Cracking of Carbon Steel in Simulated Waste Solutions*, Savannah River Site, Aiken, SC, June 1966.

DP-1358, Poe, W.L., *Leakage from Waste Tank 16, Amount, Fate, and Impact*, Savannah River Site, Aiken, SC, November 1974.

DP-1468, Bradley, R.F., et al., *A Low-Pressure Hydraulic Technique for Slurrying Radioactive Sludges in Waste Tanks*, Savannah River Site, Aiken, SC, November 1977.

DP-1471, Bradley, R.F., *Chemical Dissolving of Sludge from a High Level Waste Tank at the Savannah River Plant*, Savannah River Site, Aiken, SC, November 30, 1977.

DPSP 79-17-12, West, W.L., *Tank 16 Demonstration Single-Pump Test Results*, Savannah River Site, Aiken, SC, April 26, 1979.

DPSP-79-17-17, Comly, C., *Tank 16 Demonstration Multipump Test Results*, Savannah River Site, Aiken, SC, June 29, 1979.

DPSP-80-17-21, Snell, E.B., *Second Tank 16 Annulus Cleaning Test Process and Equipment Description*, Savannah River Site, Aiken, SC, October 8, 1980.

DPSP-80-17-23, West, W.L., *Tank 16 Demonstration Water Wash and Chemical Cleaning Results*, Savannah River Site, Aiken, SC, December 16, 1980.

DPSPU 77-11-17, *History of Waste Tank 16 1959 through 1974*, Savannah River Site, Aiken, SC, July 1977.

DPSPU-77-272-135, Gordon, D.E., *Removal of Waste Salt from Annulus of Tank 16*, Savannah River Site, Aiken, SC, May 16, 1977.

DPST-79-538, Fowler, J.R., *Simulation of Acid Cleaning of Tank 16 with Reduced Amount of Oxalic Acid*, Savannah River Site, Aiken, SC, February 4, 1980.

DPST-80-377, Kiser, D.L., *Tank 16H Annulus Cleaning*, Savannah River Site, Aiken, SC, May 7, 1980.

DPSTD-241-TK-16H, Hill, A.J., Jr. and Parsons, F.A., *Technical Data Summary, Removal of Sludge and Chemical Cleaning of Tank 16H*, Savannah River Site, Aiken, SC, February 15, 1977.

EPA_04-10-2013, Pope, R.H., *EPA's Concurrence to Preliminary Cease Waste Removal and Proceed to the Sample and Analysis Phase of the Tank Closure Process for Tank 16H*, U.S. Environmental Protection Agency, April 10, 2013.

EPA_MCL_11-2012, *Regulating Public Water Systems and Contaminants Under the Safe Drinking Water Act*, http://water.epa.gov/lawsregs/rulesregs/regulatingcontaminants/basicinformation.cfm, U.S. Environmental Protection Agency.

EPA_RSL Tbl_11-2011, Superseded, *Regional Screening Level (RSL) Summary Table November 2011*, U.S. Environmental Protection Agency, February 2012.

HLW-STE-98-0218, Hess, H.M., *Sludge Removal Summary Interoffice Memorandum*, Savannah River Site, Aiken, SC, August 4, 1998.

HTF-SKM-2014-00029, Voegtlen, R.O., Walters, C.D., *Tank 16 Riser Diagram*, Savannah River Site, Aiken, SC, Rev. A, September 25, 2014.

IOM-7914, Morris, O.M., *Tank 16 Annulus Cleaning*, Savannah River Site, Aiken, SC, July 6, 1977.

IOM-20506, Comly, C., *Tank 16 Annulus Salt Analyses Minutes of Meeting at Savannah River Laboratory on April 27, 1978*, Savannah River Site, Aiken, SC, Rev. 0, May 1, 1978.

ISBN: 0-309-59313-1, Copyright, *The State of Development of Waste Forms for Mixed Wastes: U.S. Department of Energy's Office of Environmental Management, Committee on Mixed Wastes*, http://download.nap.edu/catalog.php?record_id=9459, National Research Council, Commission on Geosciences, Environment and Resources, 1999.

LWO-CES-2007-00012, *Tank 16 Annulus Cleaning Demonstration Project Record of Critical Decision 1 (CD-1) Conceptual Design*, Savannah River Site, Aiken, SC, Rev. 0, March 28, 2007.

LWO-LWE-2007-00085, *Evaluation of Tank 16 Annulus Inspections 3/5/07 - 3/29/07*, Savannah River Site, Aiken, SC, May 22, 2007.

M-CLC-H-03244, Voegtlen, R.O., *Determination of Potential Quantities of Chromate Cooling Water, Chromate, and Chromium Addition to Tank 16 Due to Coil Grouting*, Savannah River Site, Aiken, SC, Rev. 0, March 28, 2007.

M-CTP-H-00001, Frazier, S.L., *Tank 16H Isolation Strategy*, Savannah River Site, Aiken, SC, Rev. 0, March 25, 2013.

MSDS-43759, *Material Safety Data Sheet, Oxalic Acid*, Sigma-Aldrich, St. Louis, MO, December 29, 2008.

NCRP-160 (Copyright), *Ionizing Radiation Exposure of the Population of the United States (2009)*, National Council on Radiation Protection and Measurements, Bethesda, MD, March 2009.

N-ESR-G-00001, Superseded, *High Level Waste Emergency Response Data and Waste Tank Data*, Savannah River Site, Aiken, SC, Rev. 470, April 21, 2009.

SCDHEC R.61-58, *State Primary Drinking Water Regulation*, http://www.scdhec.gov/Agency/RegulationsAndUpdates/LawsAndRegulations/Water/, South Carolina, Department Of Health and Environmental Control, Columbia, SC, August 28, 2009.

SCDHEC R.61-67, *Standards for Wastewater Facility Construction*, http://www.scdhec.gov/Agency/RegulationsAndUpdates/LawsAndRegulations/Water/, South Carolina Department of Health and Environmental Control, Columbia, SC, May 2002.

SCDHEC R.61-81, *State Environmental Laboratory Certification Program*, http://www.scdhec.gov/Agency/RegulationsAndUpdates/LawsAndRegulations/, South Carolina Department of Health and Environmental Control, Columbia, SC, January 1981.

SCDHEC R.61-82, *Proper Closeout of Wastewater Treatment Facilities*, http://www.scdhec.gov/Agency/RegulationsAndUpdates/LawsAndRegulations/Water/, South Carolina Department of Health and Environmental Control, Columbia, SC, April 11, 1980.

SRNL-STI-2011-00323, Shine, E.P., *Technical Review of the Method of Constructing Composite Samples with Uncertain Volumetric Proportions*, Savannah River Site, Aiken, SC, Rev. 0, May 2011.

SRNL-STI-2011-00551, Superseded, Langton, C.A., Stefanko, D.B., *Tanks 18 and 19-F Structural Flowable Grout Fill Material Evaluation and Recommendations*, Savannah River Site, Aiken, SC, Rev. 0, September 2011.

SRNL-STI-2012-00178, Hay, M.S., et al., *Characterization of Tank 16H Annulus Samples*, Savannah River Site, Aiken, SC, Rev. 0, April 2012.

SRNL-STI-2012-00309, Hay, M.S., Reboul, S.H., *Characterization of Tank 16H Annulus Samples Part II: Leaching Results,* Savannah River Site, Aiken, SC, Rev. 0, June 2012.

SRNL-STI-2013-00100, Shine, E.P., *Analysis of Sampling Plan Options for Tank 16H from the Perspective of Statistical Uncertainty*, Savannah River Site, Aiken, SC, Rev. 0, February 2013.

SRNL-STI-2014-00321, Superseded, Oji, L.N., et al., *Tank 16H Residual Sample Analysis Report*, Savannah River Site, Aiken, SC. Rev. 1, October 2014.

SRNS-RP-2012-00146, *H-Area Tank Farm Groundwater Monitoring Plan and Sampling and Analysis Plan*, Savannah River Site, Aiken, SC. Rev. 1, July 2012.

SRNS-RP-2013-00162, *Savannah River Site Land Use Plan*, Savannah River Site, Aiken, SC, May 2013.

SRR-CES-2010-00067, Allen, P.M., *Construction Permit No.: 17,424-IW: F and H-Area High-Level Radioactive Waste Tank Farms - Request to Include Tank 241-916H*, Savannah River Site, Aiken, SC, October 14, 2010.

SRR-CWDA-2009-00045, *F-Tank Farm Waste Tank Closure Inventory for Use in Performance Assessment Modeling*, Savannah River Site, Aiken, SC, Rev. 2, October 2012.

SRR-CWDA-2010-00023, Superceded, *H-Area Tank Farm Closure Inventory for Use in Performance Assessment Modeling*, Savannah River Site, Aiken, SC, Rev. 3, May 10, 2012.

SRR-CWDA-2010-00023, *H-Area Tank Farm Closure Inventory for Use in Performance Assessment Modeling*, Savannah River Site, Aiken, SC, Rev. 4, November 11, 2014.

SRR-CWDA-2010-00128, *Performance Assessment for the H-Area Tank Farm at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 1, November 2012.

SRR-CWDA-2011-00022, *Industrial Wastewater General Closure Plan for H-Area Waste Tank Systems,* Savannah River Site, Aiken, SC, Rev. 0, May 2012.

SRR-CWDA-2011-00050, *Liquid Waste Tank Residuals Sampling and Analysis Program Plan*, Savannah River Site, Aiken, SC, Rev. 2, July 2013.

SRR-CWDA-2011-00106, *Qualification and Management of $K_d$ Data for Use in C&WDA Performance Assessments*, Savannah River Site, Aiken, SC, Rev. 0, June 15, 2011.

SRR-CWDA-2011-00117, *Liquid Waste Tank Residuals Sampling-Quality Assurance Program Plan*, Savannah River Site, Aiken, SC, Rev. 1, July 2013.

SRR-CWDA-2012-00027, *Tank 5 Inventory Determination*, Savannah River Site, Aiken, SC, Rev. 1, August 2012.

SRR-CWDA-2012-00156, *Tank 16 Radionuclide and Chemical Screening for Residual Inventory Determination*, Savannah River Site, Aiken, SC, Rev. 0, February 2013.

SRR-CWDA-2012-00179, Pavletich, J.P., Wiggins, A.W., *Documentation of Materials Provided for Use in the Statistical Evaluation of Sampling Options for Tank 16*, Savannah River Site, Aiken, SC, Rev. 0, December 18, 2012.

SRR-CWDA-2013-00018, *Tank 16 Sample Location Determination Report*, Savannah River Site, Aiken, SC, Rev. 1, July 2014.

SRR-CWDA-2013-00035, Pavletich, J.P., Wiggins, A.W., *Tank 16 Residuals Sampling Option Recommendation*, Savannah River Site, Aiken, SC, Rev. 0, February 26, 2013.

SRR-CWDA-2013-00041, *Proposal to Cease Waste Removal Activities in Tank 16 and Enter Sampling and Analysis Phase*, Savannah River Site, Aiken, SC, Rev. 1, April 1, 2013.

SRR-CWDA-2013-00058, *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 1, July 31, 2014.

SRR-CWDA-2014-00017, *Dimensions of Type I and II Waste Storage Tanks*, Savannah River Site, Aiken, SC, Rev. 0, January 27, 2014.

SRR-CWDA-2014-00071, *Tank 16 Inventory Determination*, Savannah River Site, Aiken, SC, Rev. 0, October 23, 2014.

SRR-CWDA-2014-00090, *Tank 16 Final Characterization Data Quality Assessment*, Savannah River Site, Aiken, SC, Rev. 1, October 23, 2014.

SRR-CWDA-2014-00106, *Tank 16 Special Analysis for the Performance Assessment for the H-Area Tank Farm at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 1, February 2015.

SRR-LWE-2010-00240, Clark, J.L., *Tank Mapping Methodology*, Savannah River Site, Aiken, SC, Rev. 1, November 28, 2012.

SRR-LWE-2011-00156, Clark, J.L., *Tank 12 Slurry Pump Run Strategy to Support In-tank Low Temperature Aluminum Dissolution and Waste Removal*, Savannah River Site, Aiken, South Carolina, Rev. 5, August 18, 2011.

SRR-LWE-2011-00201, Pasala, N.R., *Information on the Radiological and Chemical Characterization of the Savannah River Site Tank Waste as of July 5, 2011*, Savannah River Site, Aiken, South Carolina, Rev. 0, September 26, 2011.

SRR-LWE-2012-00039, Clark, D.J., *Estimation of Waste Material in the Tank 16 Annulus Following Sampling in November 2011*, Savannah River Site, Aiken, South Carolina, Rev. 0, February 28, 2012.

SRR-LWE-2012-00224, Bhatt, P.N., *Tank 16 Primary Tank Preliminary Mapping*, Savannah River Site, Aiken, SC, Rev. 0, January 10, 2013.

SRR-LWE-2013-00010, Clark, J.L., *Tank 16 Annulus Waste Volume Determination*, Savannah River Site, Aiken, SC, Rev. 0, January 15, 2013.

SRR-LWE-2013-00027, Walters, C.D., *Tank 16 Sample Location Verification Document*, Savannah River Site, Aiken, SC, Rev. 2, December 17, 2014.

SRR-LWE-2013-00057, *Tank 16 Sampling and Analysis Plan*, Savannah River Site, Aiken, SC, Rev. 2, July 2014.

SRR-LWE-2014-00013, Walters, C.D., *Tank 16H Grout Strategy*, Savannah River Site, Aiken, SC, Rev. 1, January 7, 2015.

SRR-LWE-2014-00017, Walters, C.D., *Tank 16 Internal Equipment Evaluation*, Savannah River Site, Aiken, SC, Rev. 0, March 13, 2015.

SRR-LWE-2014-00055, Arthur, G., *Annual SCDHEC Technology Briefing*, Savannah River Site, Aiken, SC, Rev. 0, April 23, 2014.

SRR-LWE-2014-00151, Clark, J., *Tank 16H Annulus Sampling Photographs*, Savannah River Site, Aiken, SC, Rev. 0, October 13, 2014.

SRR-LWP-2012-00068, Bhatt, P.N., *Tank 16 Annulus Cleaning Demonstration*, Savannah River Site, Aiken, SC, Rev. 1, January 8, 2013.

SRR-RPE-2013-00003, Ferguson, W.L., *Tank 16 Annulus Cleaning Dose Estimate*, Savannah River Site, Aiken, SC, Rev. 0, February 25, 2013.

SRR-WRC-2012-0018, *Tank 16 Annulus Waste Removal Recommendation*, Savannah River Site, Aiken, SC, Rev. 1, May 29, 2012.

U-ESR-H-00107, Clark, D.J., *Tank 16H: Preliminary Evaluation of Cessation of Annulus Waste Removal Activities*, Savannah River Site, Aiken, SC, Rev. 0, March 7, 2013.

U-ESR-H-00113, Clark, J.L., *Tank 16 Final Residual Solids Determination and Uncertainty Estimate*, Savannah River Site, Aiken, SC, Rev. 1, November 2013.

W162688, *200 Area, Waste Storage Tanks - 241 H, Pan for 85' -0" Diam - Plate Details Steel*, Savannah River Site, Aiken, SC, Rev. 14, August 2, 1955.

W163593, *200 Area Building 241-H Vertical Cooling Coils for 85'-0" Dia. Waste Storage Tank*, Savannah River Site, Aiken, SC, Rev. 4, January 3, 1956.

W163658, *200 Area Building 241H Bottom Cooling Coils for 85'-0" Dia. Waste Storage Tank*, Savannah River Site, Aiken, SC, Rev. 2, March 29, 1955.

WDPD-13-40, Hennessey, B.T., *Request for Concurrence to Proceed to Sample and Analysis Phase of the Tank Closure Process for Tank 16H (CERCLIS Number: 89)*, Savannah River Site, Aiken, SC, April 4, 2013.

WSRC-IM-98-30, *2000 Renewal Application for a RCRA Part B Permit*, Vol. I, Part 1, Section F.1, Savannah River Site, Aiken, SC, Rev. 1, January 2002.

WSRC-OS-94-42, *Federal Facility Agreement for the Savannah River Site*, Savannah River Site, Aiken, SC, August 16, 1993.

WSRC-SA-2002-00007, *Concentration, Storage, and Transfer Facilities*, Savannah River Site, Aiken, SC, Rev. 15, September 2013.

WSRC-STI-2007-00369, *Hydraulic and Physical Properties of Tank Grouts and Base Mat Surrogate Concrete for FTF Closure*, Savannah River Site, Aiken, SC, Rev. 0, October 29, 2007.

WSRC-STI-2007-00641, Langton, C.A., et al., *Grout Formulations and Properties for Tank Farm Closure*, Rev. 0, November 12, 2007.

WSRC-TR-97-0102, Caldwell, T.B., *Tank Closure Reducing Grout*, Savannah River Site, Aiken, SC, Rev. 0, April 1997.

# APPENDIX A: WASTE TANK SYSTEM TRACKING

Future closure of the waste tanks and ancillary structures will be conducted in such a way that structures will be included in CMs when determined that it is practical to remove the structures from service simultaneously with the waste tanks and there is no longer a need for the ancillary structures to manage waste in tanks that are still in service. The ancillary structures to be closed as part of the HTF are listed in Table A-1. As CMs are developed and approved, Table A-1 will be updated to include the document number and date of RFS for each of the ancillary structures listed in Permit #17,424-IW (DHEC_01-25-1993) to ensure that all waste tanks and ancillary structures have been addressed.

**Table A-1: HTF Waste Systems Tracking**

| Waste Tank System | CM Document Number | Date of RFS |
|---|---|---|
| Tank 9 | | |
| Tank 10 | | |
| Tank 11 | | |
| Tank 12 | | |
| Tank 13 | | |
| Tank 14 | | |
| Tank 15 | | |
| Tank 16 | SRR-CWDA-2013-00091 | |
| Tank 21 | | |
| Tank 22 | | |
| Tank 23 | | |
| Tank 24 | | |
| Tank 29 | | |
| Tank 30 | | |
| Tank 31 | | |
| Tank 32 | | |
| Tank 35 | | |
| Tank 36 | | |
| Tank 37 | | |
| Tank 38 | | |
| Tank 39 | | |
| Tank 40 | | |
| Tank 41 | | |
| Tank 42 | | |
| Tank 43 | | |
| Tank 48 | | |
| Tank 49 | | |
| Tank 50 | | |
| Tank 51 | | |

**Table A-1: HTF Waste Systems Tracking (Continued)**

| Waste Tank System | CM Document Number | Date of RFS |
|---|---|---|
| 242-H Evaporator Pot | | |
| Mercury Collection Tank | | |
| Cesium Removal Column Pump Tank | | |
| Overheads Tank, North | | |
| Overheads Tank, South | | |
| 242-16H Evaporator Pot | | |
| Mercury Collection Tank | | |
| Cesium Removal Column Pump Tank | | |
| Overheads Tank, North | | |
| Overheads Tank, South | | |
| 242-25H Evaporator Pot | | |
| Mercury Collection Tank | | |
| Cesium Removal Column Pump Tank | | |
| Overheads Tank, North | | |
| Overheads Tank, South | | |
| HPP-1 | | |
| HPP-2 and HPT-2 | | |
| HPP-3 and HPT-3 | | |
| HPP-4 and HPT-4 | | |
| HPP-5 and HPT-5 | | |
| HPP-6 and HPT-6 | | |
| HPP-7 and HPT-7 | | |
| HPP-8 and HPT-8 | | |
| HPP-9 and HPT-9 | | |
| HPP-10 and HPT-10 | | |
| Concentrate Transfer System (242-3H) | | |
| Concentrate Transfer System (242-18H) | | |
| HDB-1 | | |
| HDB-2 | | |
| HDB-3 | | |
| HDB-4 | | |
| HDB-5 | | |
| HDB-6 | | |
| HDB-7 | | |
| HDB-8 | | |
| H-Area Catch Tank | | |