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Revision 0

DOCUMENTATION OF REMOVAL OF HIGHLY RADIOACTIVE RADIONUCLIDES IN WASTE TANK 16

H-TANK FARM SAVANNAH RIVER SITE

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EXECUTIVE SUMMARY

The discussions presented in this report demonstrate the successful deployment of a mix of technologies to remove over 99% of the waste from Tank 16 in the Savannah River Site (SRS) H-Tank Farm (HTF), and remove greater than 99% of the highly radioactive radionuclide (HRR) inventory. This report demonstrates the following:

- Visual inspections of the waste tank primary and annulus indicated that there was a significant reduction in residual material volume resulting from waste removal efforts.
- The extent of technology has been reached for the cleaning technology deployed in the Tank 16 primary from 1972 to 1980 (i.e., bulk waste removal with multiple Slurry Pumps [SLPs] and heel removal with Bulk Oxalic Acid [BOA]). No alternate practical technology has been identified that has reached a level of maturity for deployment to remove significant additional HRRs.
- The extent of technology has been reached for the cleaning technology deployed in the Tank 16 annulus from 1972 to 1977 (i.e., mixing and dissolution using steam mixing jets). No alternate practical technology has been identified that has reached a level of maturity for deployment to remove significant additional HRRs. Continued heel removal efforts in Tank 16 would impact other risk reduction activities associated with removing sludge from other waste tanks, including Type I and Type II tanks, in preparation for closure and stabilization of the removed sludge at Defense Waste Processing Facility (DWPF).
- A cost-benefit analysis for deploying another cleaning technology in the primary and annulus was performed, and it demonstrated that it was not practical to continue with active waste removal activities in Tank 16. The analysis criteria for additional HRR removal from Tank 16 included technology capabilities, worker dose, schedule impacts, a quantified cost summary and a risk and benefit analysis. The amount of residual material in the primary tank is considered so small that its removal would result in negligible risk reduction, while incurring a high cost. It was determined that the cost of additional cleaning of the primary tank would significantly outweigh the negligible risk reduction benefit. One representative alternative for removing additional HRRs from the Tank 16 annulus, dissolution and sluicing, was used for comparison purposes. However, after evaluating and comparing the benefits and the costs, it was determined that removing additional HRRs from the Tank 16 annulus would not produce a net social benefit, that is, it would not be sensible or useful in light of the overall benefit to human health, safety and the environment, for the following reasons:
    - Worker occupational dose would be incurred during any additional HRR removal with only minimal reduction in the dose to a hypothetical future inhabitant of the waste tank farm after HTF closure.
    - Spending greater than $7 million to deploy an alternative technology would result in only minimal dose reduction to a hypothetical future inhabitant of the waste tank farm.
    - The estimated risk reduction per dollar spent to a hypothetical future inhabitant of the waste tank farm is extremely low, therefore the benefit per dollar spent would be lower than other United States Department of Energy (DOE) remediation projects.

- Other factors that reinforce that removing additional HRRs from the Tank 16 annulus would not produce a net social benefit include:
  - Delaying Tank 16 closure to remove additional HRRs from the annulus using a technology such as dissolution and sluicing, or to take advantage of possible advances in waste removal technologies, would have a significant adverse impact on the site's Liquid Waste Program.
  - The estimated occupational dose and financial cost utilized throughout the cost-benefit analysis are conservatively low even if additional HRR removal from the annulus had been performed prior to waste tank isolation and grouting preparations. Taking into consideration the current field conditions of Tank 16, these values represent extremely conservative assumptions for the occupational dose and financial costs that would be associated with performing additional HRR removal at this time.
  - At the time of Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) closure if the as low as reasonably achievable (ALARA) analysis performed were to indicate the need for additional dose reduction after HTF closure, the closure cap could be redesigned to take advantage of advancements in cap design to reduce infiltration of surface water or additional barriers such as subsurface barrier walls could be installed to mitigate contaminant movement. This would extend the timing and reduce the magnitude of the peak dose resulting from the residual radioactivity in HTF.
- Due to inaccessibility for waste removal from the sand layers and the limited inventory assigned to the sand layers, it was determined that the cost of attempting waste removal in the sand pads would significantly outweigh the negligible risk reduction benefit.

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LIST OF ACRONYMS

95%UCL	Upper 95% Confidence Limit
ALARA	As Low As Reasonably Achievable
BOA	Bulk Oxalic Acid
BWRE	Bulk Waste Removal Efforts
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ci	Curie(s)
CSR	Chemical Sludge Removal
DOE	United States Department of Energy
DWPF	Defense Waste Processing Facility
EDE	Effective Dose Equivalent
EPA	United States Environmental Protection Agency
FFA	Federal Facility Agreement
FTF	F-Tank Farm
HM	H-Modified
HRR	Highly Radioactive Radionuclide
HTF	H-Tank Farm
IP	Inspection Port
ISCORS	Interagency Steering Committee on Radiation Standards
LWTRSAPP	Liquid Waste Tank Residuals Sampling and Analysis Program Plan
LWTRS-QAPP	Liquid Waste Tank Residuals Sampling - Quality Assurance Program Plan
MDC	Minimum Detectable Concentration
MOP	Member of the Public
MSR	Mechanical Sludge Removal
NDAA	Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005
NRC	United States Nuclear Regulatory Commission
OA	Oxalic Acid
PA	Performance Assessment
SCDHEC	South Carolina Department of Health and Environmental Control
SLP	Slurry Pump
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TEDE	Total Effective Dose Equivalent
wt%	weight percent

1.0 PURPOSE

This document provides an overview of closure activities for Tank 16 from the completion of bulk waste removal efforts (BWRE) through heel removal, sampling, analysis and inventory determination. Additionally, this document provides a cost-benefit analysis for removing additional HRRs from Tank 16 considering factors such as financial cost, worker dose, regulatory milestones and technology limitations. This document will support DOE's Tier 2 Closure Authorization decision to close Tank 16.

2.0 BACKGROUND

Section 3116(a) of the *Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005* (NDAA) (hereinafter referred to as NDAA Section 3116) provides that certain waste resulting from reprocessing is not high-level waste if the Secretary of Energy, in consultation with the United States Nuclear Regulatory Commission (NRC), determines, among other things, that the waste has had HRRs removed to the maximum extent practical. [NDAA_3116] The *Basis for Section 3116 Determination for Closure of H-Tank Farm at the Savannah River Site* (hereinafter referred to as HTF 3116 Basis Document) identifies the HRRs and describes DOE's approach for determining that HRRs have been removed to the maximum extent practical. [DOE/SRS-WD-2014-001] The HTF HRRs and the approach used to remove HRRs are summarized below.

2.1 H-Tank Farm Highly Radioactive Radionuclides

Based on consultation with the NRC, DOE views HRRs to be those radionuclides that, using a risk-informed approach, contribute most significantly to radiological risk to workers, the public and the environment. For HTF, the HTF 3116 Basis Document identified the HRRs shown in Table 2.1-1. [DOE/SRS-WD-2014-001]

Table 2.1-1: HTF Highly Radioactive Radionuclides

Radionuclide	Radionuclide Half-Life (years)	Potential Long-Term Radiological Hazards	Potential Short-Term Radiological Hazards
Sr-90	2.89E+01		X
Tc-99	2.11E+05	X	
I-129	1.57E+07	X	
Cs-137	3.00E+01		X
U-233	1.59E+05	X	
U-234	2.46E+05	X	
U-235	7.04E+08	X	
Np-237	2.14E+06	X	
Pu-238	8.77E+01	X	
Pu-239	2.41E+04	X	
Pu-240	6.56E+03	X	
Am-241	4.32E+02	X	
Am-243	7.37E+03	X	

[DOE/SRS-WD-2014-001]

The fission products for Cs-137 and Sr-90 and their secular equilibrium daughter products, Ba-137m and Y-90, are by far the predominant source of radioactivity in HTF waste, accounting for approximately 96% of current radioactivity. [DOE/SRS-WD-2014-001]

2.2 Approach to Removal of Highly Radioactive Radionuclides

Removal of HRRs begins with the removal of solids and liquid from a waste tank or ancillary structure in a bulk waste removal phase. Following BWRE, heel removal is performed using an appropriate mix of technologies accounting for the physical configuration of the waste tank and the chemical characteristics of the waste.

Throughout the process, DOE continually evaluates the ongoing effectiveness of the technology being implemented and optimizes the existing technologies. In addition, DOE evaluates the usefulness and practicality of additional technology deployment once the existing technology has reached the point of diminished effectiveness for HRR removal. DOE's approach consists of the following phases: initial technology selection, technology implementation, technology execution, technology effectiveness evaluation and additional technology evaluation. [DOE/SRS-WD-2011-001]

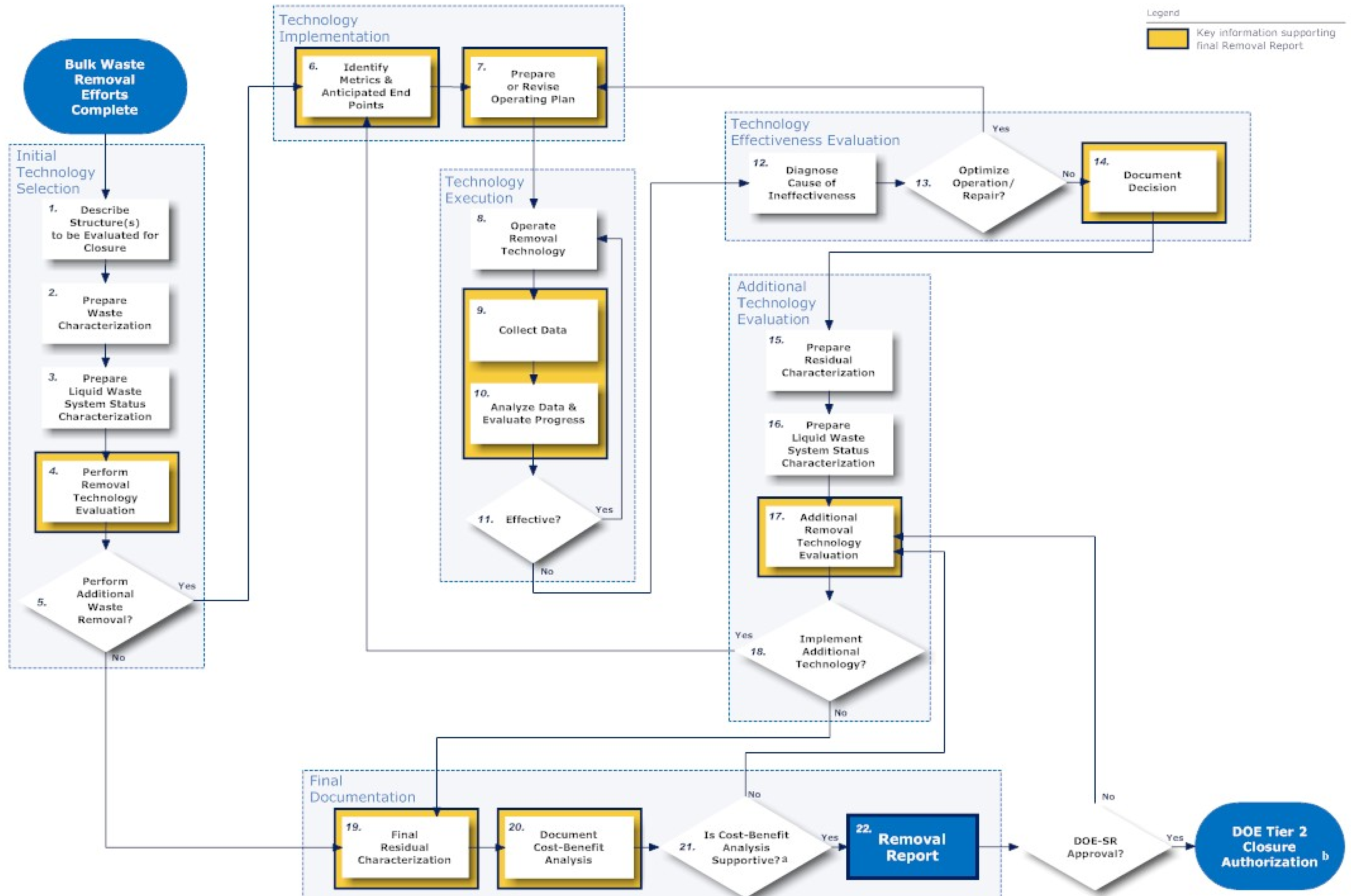
The cleaning process employed is thorough and the process is reviewed and documented during cleaning. DOE uses measures such as visual (remote) observation of remaining waste tank residuals against landmarks in the waste tanks (or ancillary structures), transfer line radiation readings, sampling and analysis, radiation monitoring and equipment operating parameters to evaluate efficiency and effectiveness of cleaning operations. Moreover, removal activities on a given waste tank or ancillary structure will not be considered complete until it is clearly demonstrated and documented, for each individual waste tank or ancillary structure, that further deployment of the technology is no longer useful or sensible, and that other proven technologies have been evaluated and would not be practical. These documented considerations will take into account a variety of factors including such things as:

- conditions in the specific waste tank or ancillary structure
- status of the HTF and the overall Liquid Waste System (e.g., available waste tank space)
- available proven technologies
- potential benefits from long-term risk reduction from continued HRR removal
- increased radiation exposure to site workers or the public due to removal activities
- increased risk associated with impacts to other DOE missions involving risk-reducing activities
- direct monetary expenditures
- effectiveness of available technologies

Typically, the cost-benefit analysis will be relatively simple and will focus on the financial costs for implementation of new technologies versus the decrease in the potential future doses resulting from the additional removal of residuals. [NUREG-1854]

The approach is outlined in Figure 2.2-1. [DOE/SRS-WD-2014-001]

Figure 2.2-1: Approach



[a] In this context, DOE is assessing the practicability of additional radionuclide removal with emphasis on HRRs.

[b] Per the HTF Industrial Wastewater General Closure Plan (SRR-CWDA-2011-00022), DOE will authorize removal from service actions through approval of the DOE Tier 2 Closure Authorization only after DOE, SCDHEC and EPA have reached mutual agreement that waste removal activities can cease.

2.3 Report Structure

This report is structured to address each of the key phases in the approach above for Tank 16. The report discusses:

- The operational history of Tank 16
- The selection, operational performance and effectiveness of the cleaning technology used in the Tank 16 primary tank and annulus during each phase of the waste removal campaigns
- The rationale for suspending use of each cleaning technology
- The effectiveness of removing the overall waste volume and of the specific HRRs from the Tank 16 primary tank and annulus at the completion of waste removal operations
- The estimated costs, potential benefits and potential impacts associated with the development and deployment of additional cleaning technologies. In addition to the direct monetary expenditures, the cost-benefit analysis includes other factors such as long-term risk reduction to the public, downstream impacts to the Liquid Waste System and impacts to worker radiation exposure.

3.0 TANK 16 DESIGN AND CONSTRUCTION

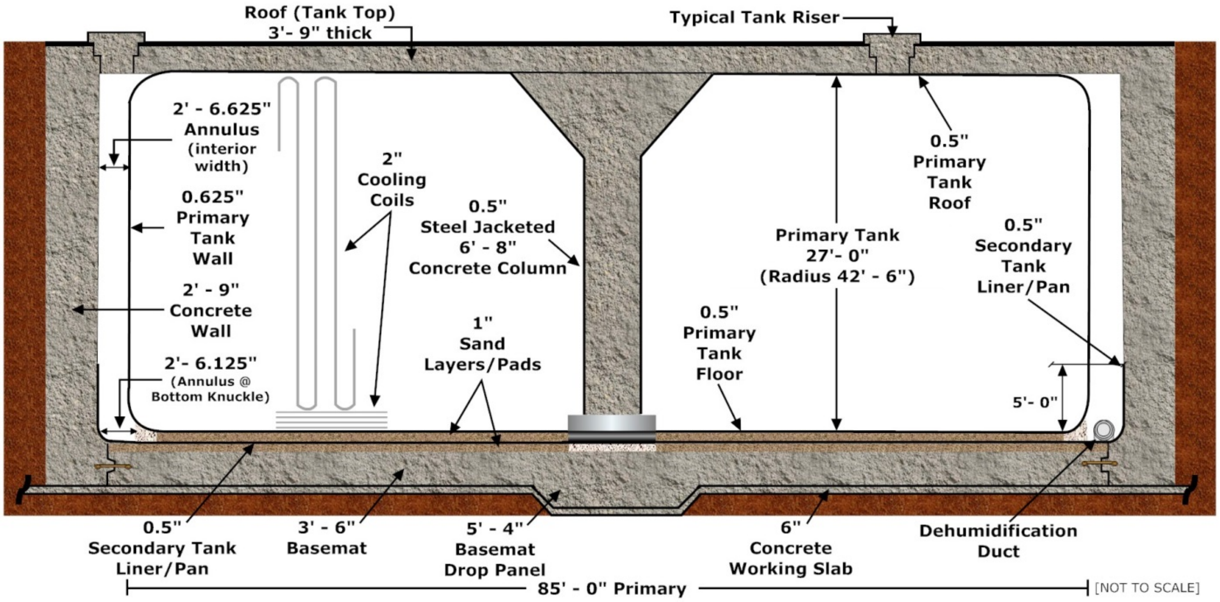
3.1 Type II Tank Design

Tank 16 is one of the four Type II tanks (Tanks 13 through 16) in HTF that were constructed between 1955 and 1956. The characteristics of typical Type II tanks are shown in Figure 3.1-1. A 95-foot-8.5-inch outer diameter concrete vault surrounds the Type II primary tank 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 16 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. 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 their distal end. Eight 14-inch long by 6-inch wide openings are equally spaced along the top of each ductwork section. [DP-1358]

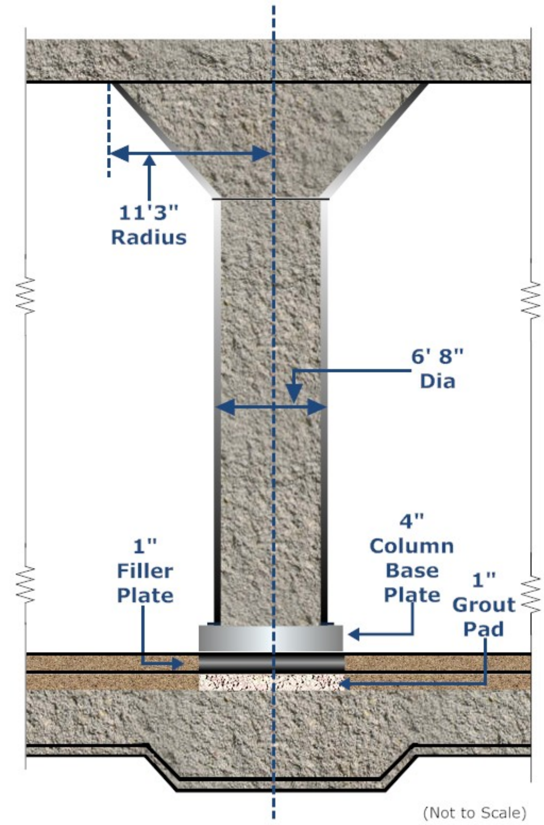
Figure 3.1-1: Typical Type II Waste Tank Cross Section



The working slab for the four 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 3.1-2). 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 3.1-2: 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 (see 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 3.1-3 shows the Tank 16 cooling coils and center support column.

Figure 3.1-3: Tank 16 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 3.1-4, 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 limits 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 16 primary tank into the annulus pan, thirteen additional annulus riser openings, or inspection ports (IPs), were added later to permit 100% annulus inspections. The location of the IPs are shown in Figure 3.1-5.

Additional details for the Type II tanks are provided in Section 3.0 of the *Performance Assessment (PA) for the H-Area Tank Farm at the Savannah River Site* (hereinafter referred to as HTF PA). [SRR-CWDA-2010-00128]

Figure 3.1-4: Type II Waste Tank Access Risers for Waste Removal Equipment Diagram

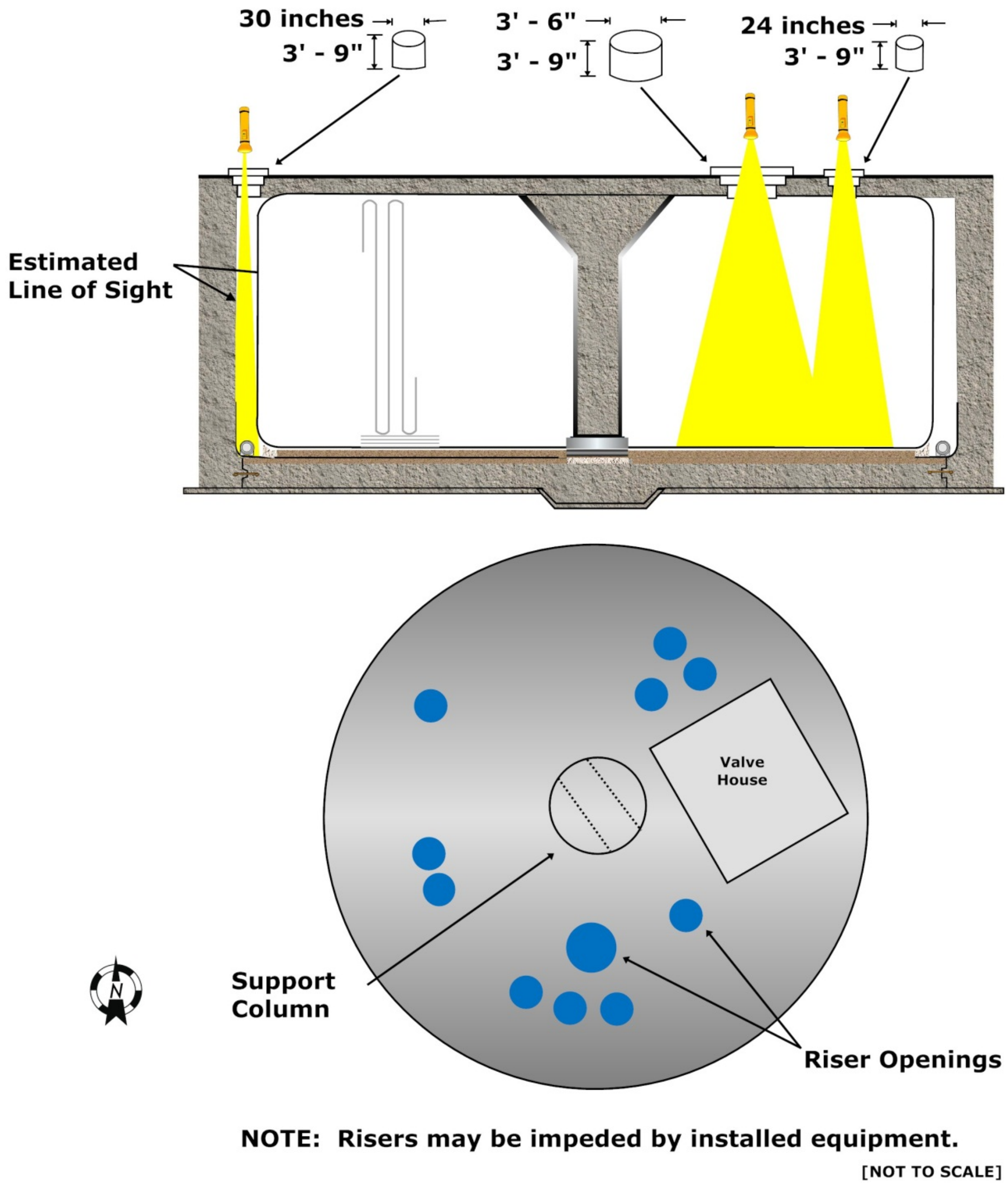
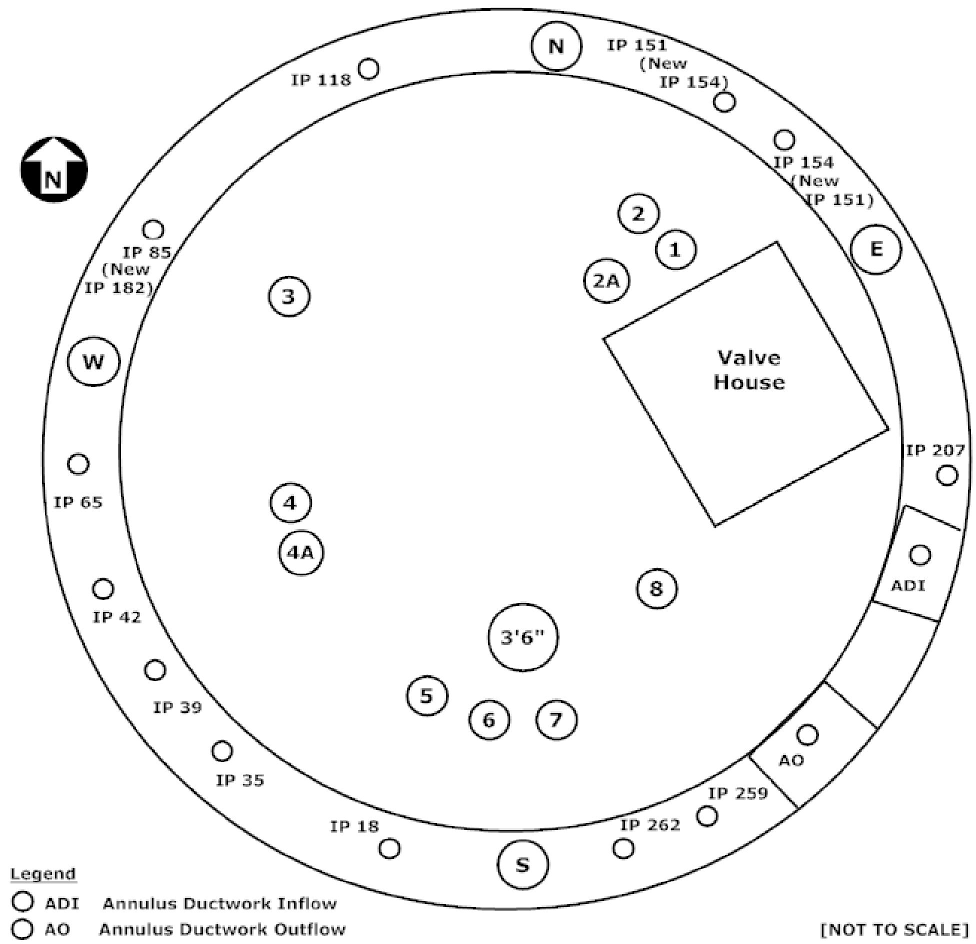


Figure 3.1-5: Tank 16 Primary and Annulus Riser and Inspection Port Configuration



3.2 Waste Tank Operational Service History

This section summarizes information on the waste types received and processed through Tank 16. It is not intended to be a detailed accounting of all waste transfers to and from the waste tank throughout its operational history. Details on the waste removal operations conducted in Tank 16 are provided in Section 4.0.

3.2.1 Waste Tank Operational Service Summary

Tank 16 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 16 for waste receipts. The bases for the decision to continue using Tank 16 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 waste tank.

2. The amount of storage capacity in H Area was limited to unfilled volumes in Tanks 14, 15 and 16. At this time, additional waste storage capacity was needed to support H-Canyon operations.
3. Experience with other previously leaking waste tanks (i.e., 9, 10 and 14) 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 16 were resumed after the November 1959 evaluation. [DP-1358]

In May 1960, Tank 16 reached its highest historical fill level (primary tank level of 303 inches equal to 1,060,000 gallons[1]). 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 a waste transfer to Tank 14 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 14. 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 15. 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 liquid level in the primary tank 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 (see Figure 3.1-5 for IP locations). 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 vertical welds on

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

the primary tank. Sandblasting the carbon steel wall 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 16 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, Tank 16 began to receive waste again in 1968. At the time, the use of Tank 16 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 16 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 waste tanks that had been concentrated by an evaporator system. By June 1968, Tank 16 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 16 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 16 for additional waste receipts had ceased and supernate removal to remove liquid from the primary tank was initiated.

In December 1978, after bulk liquid removal, the Tank 16 primary contained approximately 77,000 gallons of sludge solids. Bulk solids removal was initiated using a mechanical method with SLPs. After completion of mechanical sludge removal (MSR), the residual material had been reduced to a heel of approximately 5,250 gallons of sludge solids plus remaining liquid slurry medium. [DPSP-79-17-17] Chemical cleaning was initiated with oxalic acid (OA) which further reduced the residual heel to approximately 3,680 gallons of sludge solids and residual liquid. [DPSP-80-17-23] Following chemical cleaning a final MSR method was used to reduce the residual heel in the Tank 16 primary to an estimated 330 gallons. [U-ESR-H-00113]

In early 1977, an estimated 6,000 gallons of waste salt cake (i.e., crust and sludge) and sand remained in the annulus. [DPSPU-77-272-135] Annulus cleaning operations using steam mixing jets removed some of the salt cake from the annulus in 1977. [IOM-7914] During Tank 16 annulus characterization sampling in 2013, the annulus waste volume was determined to be 1,910 gallons. [U-ESR-H-00113]

The details of waste removal operations are described in Section 4.0 of this document.

4.0 WASTE REMOVAL

This section describes the processes used to remove waste and associated HRRs from Tank 16. Section 4.1 provides a summary of waste removal from the Tank 16 primary that included four phases:

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

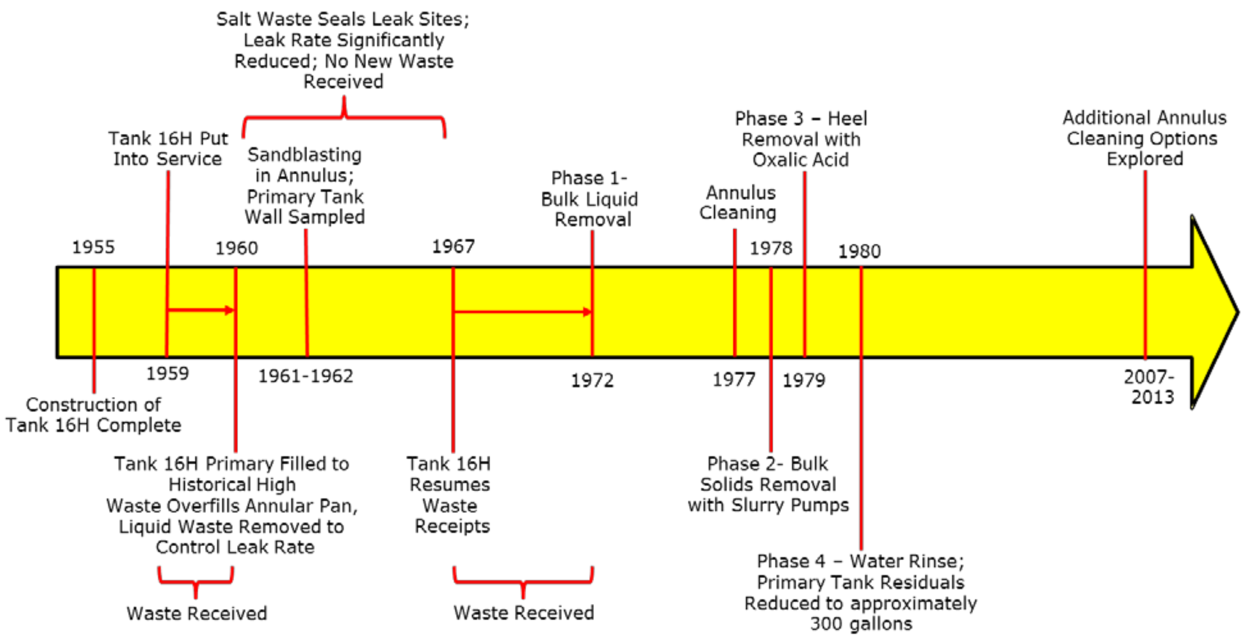
Section 4.2 provides a summary of waste removal from the Tank 16 annulus.

The information provided in this section summarizes, and supplements, information provided in *Industrial Wastewater Closure Module for the Liquid Waste Tank 16H H-Area Tank Farm Savannah River Site* (SRR-CWDA-2013-00091).

4.1 Tank 16 Primary Waste Removal History

Figure 4.1-1 shows the Tank 16 historical timeline that includes waste removal activities.

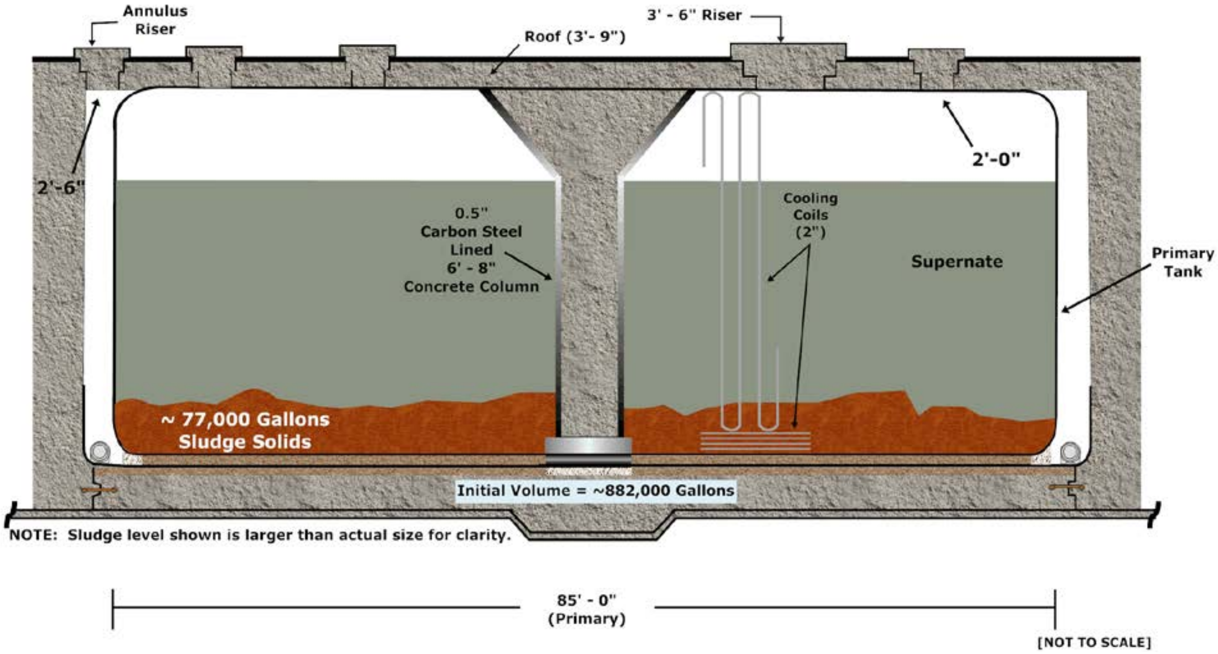
Figure 4.1-1: Tank 16 Historical Timeline



[Not to Scale]

Figure 4.1-2 shows the Tank 16 primary tank condition prior to the March 1972 start of waste removal efforts. Tank 16 contents included a historical high of approximately 1,060,000 gallons of waste during operations in May 1960. [SRR-CWDA-2011-00126] Approximately 77,000 gallons of this waste was in a wet solids form called sludge (mainly comprised of insoluble metal hydroxide solids) with their associated interstitial liquid. [DPSP 79-17-12, DPSP-79-17-17] The remainder was free-standing liquid (supernate). The source of the waste in Tank 16 was mainly from its service as a waste receipt tank for H-Canyon waste as described in Section 4.2.1.

Figure 4.1-2: Tank 16 Primary Tank Condition in March 1972 Prior to Liquid Waste Removal Efforts



4.1.1 Phase 1: Tank 16 Bulk Liquid Waste Removal Efforts

During this phase of waste removal, as a result of a series of transfers out of Tank 16 in March 1972, the free-standing liquid (liquid above the sludge) was removed from the primary tank. During this phase, approximately 768,000 gallons of liquid was transferred from Tank 16 to Tank 14 leaving approximately 114,000 gallons of sludge and solids with associated interstitial liquid. The liquid was allowed to evaporate, leaving a residual heel volume of 77,000 gallons. [DPSP 79-17-12, DPSP-79-17-17]

4.1.2 Phase 2: Tank 16 Bulk Solids Waste Removal Efforts with Slurry Pumps

In 1977, a new waste tank cleaning technology was developed by Savannah River National Laboratory (SRNL). This new technology utilized a low-pressure sludge-slurrying technique using existing supernate, thus minimizing the need for water addition and high-pressure systems associated with previously used water jet sludge removal systems. 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] The MSR efforts with SLPs consisted of multiple campaigns focused on the removal of bulk waste and were not expected to preferentially separate any hazardous or radiological constituents. From December 1978 to November 1979, five different MSR campaigns were carried out in Tank 16. For the first two campaigns in Tank 16, a single SLP was installed in Riser 2 to demonstrate the effectiveness of an SLP. The first campaign used water as the slurry media and the second campaign used supernate. Supernate was used in the second demonstration because it had a higher specific gravity, and it was a beneficial reuse in terms of overall waste tank farm waste tank space. Following the completion of the first two campaigns, an

additional SLP was installed in Riser 4A and Riser 8 to increase the cumulative percentage of sludge removed during MSR Campaigns 3 and 4. The SLP in Riser 8 was relocated to Riser 6 for MSR Campaign 5 to allow installation of a rotary spray in Riser 8 for Phase 3 chemical sludge removal (CSR) campaigns. For Campaigns 3, 4 and 5, a specific SLP run strategy was developed depending on the location of the remaining material at that time. At the conclusion of each campaign, an inspection of the primary tank residuals was performed to approximate the volume and location of the material remaining. The MSR campaigns reduced the sludge volume from approximately 77,000 gallons to approximately 5,250 gallons. This is an overall sludge reduction of approximately 93%. Over the course of the five MSR campaigns, approximately 142,000 gallons of supernate was pumped into Tank 16. Also, approximately 134,600 gallons of water were added to Tank 16, which generates new waste volume added to the Liquid Waste System. The SLPs were operated for approximately 1,150 total hours during the MSR campaigns.[2] The Waste Removal Details for the Phase 2 Tank 16 MSR campaigns are summarized in Table 4.1-1. [DPSP-79-17-17, DPSP-80-17-23]

Table 4.1-1: Waste Removal Details for the Phase 2 Tank 16 MSR Campaigns

MSR Campaign	**1**	**2**	**3**	**4**	**5**
Dates of Run	12/78	1/79	1/79	2/79	11/79
Slurry Pump Locations	Riser 2	Riser 2	Risers 2, 4A, 8	Risers 2, 4A, 8	Risers 2, 4A, 6
Operating Time, hours					
Pump 2	86	208	168	76	72
Pump 4A	NA	NA	94	76	56
Pump 6	NA	NA	NA	NA	72
Pump 8	NA	NA	169	76	NA
Flush Water Added, gallons	8,000	27	172	297	0
Bearing Water Added, gallons	9,000	12,800	49,300	29,300	25,700
Supernate Added, gallons	0	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	ND
Cumulative Solids Removed, %	15	35	83	98	ND

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. No pump installed in riser.
ND Not Determined
[DPSP-79-17-17, DPSP-80-17-23]

As stated in *Tank 16 Demonstration Water Wash and Chemical Cleaning Results*, it was determined to conclude waste removal with multiple SLPs and move into the OA cleaning phase, since wide-angle photographs showed that no significant sludge remained. [DPSP-80-

[2] The SLPs were operated in either "oscillating" or "indexing" mode. In oscillating mode, the pumps continually rotate during the pump operating period and the direction of spray is continually changing. In indexing mode, the pump indexing angle is fixed and therefore the direction of the spray is fixed.

17-23] The final sludge-slurry volume estimate of approximately 5,250 gallons was ALARA based on the diminished effectiveness of the last MSR campaign. Hence, MSR campaigns were ceased.

Many steps were taken during BWRE to optimize the effectiveness of the SLPs during the MSR campaigns. Based on lessons learned from the single SLP operations in Riser 2 (Campaigns 1 and 2), it was determined that three SLPs would provide sufficient sludge mixing throughout the primary tank. To optimize sludge removal in Tank 16 during MSR, additional SLPs were inserted into Risers 4A and 8 for Campaigns 3 and 4. The SLP was relocated from Riser 8 to Riser 6 for Campaign 5. Initial operations of the three SLPs effectively reduced the sludge volume, but a mound remained under Riser 3. When three SLPs in oscillation mode would not remove the mound, indexing runs directed the pump discharges at the Riser 3 mound to effectively remove it. At the start of Campaign 3, the SLPs were run at 1,700 rpm (versus a maximum of 1,800 rpm) because of high motor amperage. However, as the viscosity of the slurry decreased with more mixing, the pump speed was increased to 1,800 rpm to maximize effectiveness. MSR Campaign 4 successfully removed sludge, but MSR Campaign 5 showed minimal waste removal indicating the technology had removed as much sludge as practical, given the limited mixing zones and cooling coil and center column obstructions. The SLP runs had been optimized to the extent practical and a chemical cleaning technology using OA was used to further reduce the sludge volume in Tank 16.

A detailed chronology of the MSR campaigns can be found in Section 3.1.2 of *Industrial Wastewater Closure Module for the Liquid Waste Tank 16H H-Area Tank Farm Savannah River Site*. [SRR-CWDA-2013-00091]

4.1.3 Phase 3: Tank 16 Heel Removal Efforts Using Oxalic Acid

In 1977 when SRS was first confronted with the problem of removing residual sludge (heel) from waste tanks, SRNL carried out a series of tests designed to find the best reagent for this purpose. It was necessary to select a reagent that would minimize corrosion of the carbon steel waste tanks and any of its associated equipment while dissolving the residual sludge. This test concluded that OA (Decon 4518) would be the best reagent for heel removal. [DP-1471] 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.

Unlike the MSR campaigns, the 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 weight percent (wt%) OA at an acid-to-sludge ratio of greater than 20:1 would be effective at removing the solids from the Tank 16 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 16 following completion of MSR campaigns.

From November 1979 to March 1980, four CSR campaigns, including two water washes in Campaign 1, were carried out in Tank 16. To perform the CSR campaigns, 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. The rotary spray jet in Riser 8 was replaced with a SLP prior to the Phase 4 water rinse campaign. The four CSR campaigns reduced the estimated residual heel volume in Tank 16 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. This is a total reduction of approximately 30%. The total sludge reduction is difficult to determine due to the metal oxalates formation. The CSR campaigns combined lasted for four months. The SLPs were operated for approximately 100 to 140 hours in the first CSR campaign, approximately 39 to 48 hours in the second CSR campaign, approximately 46 hours in the third CSR campaign and were operated for approximately 48 hours in the final CSR campaign. The overall effectiveness and hours of SLP operation during CSR campaigns are shown in Table 4.1-2.

Table 4.1-2: Tank 16 CSR Campaigns Comparison

Campaign	**1**	**2**	**3**	**4**
Dates of Run	11-12/79	2/80	2/80	3/80
Slurry Pump Locations	Risers 2, 4A, 6	Risers 2, 4A, 6	Risers 2, 4A, 6	Risers 2, 4A, 6
Operating Time, hours				
Slurry Pump 2	140	48	46	48
Slurry Pump 4A	121	48	46	48
Slurry Pump 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]

A total of 72,970 gallons of 4 wt% OA (heated to 90°C) and 352,300 gallons of combined bearing and spray water were processed through the primary tank during the CSR campaigns.

The spray water was also heated to 90°C to optimize dissolution of salt deposits in the primary tank.

The increase in heel volume between CSR Campaigns 3 and 4 may have been due to uncertainty in the volume estimation and/or oxalate precipitation. [DPSP-80-17-23] Based upon formation of new solids, it was determined that additional OA cleaning would not be effective. Therefore, it was determined to enter a water rinse phase to mix and remove the remaining solids.

A detailed chronology of the CSR campaigns can be found in Section 3.1.3 of *Industrial Wastewater Closure Module for the Liquid Waste Tank 16 H-Area Tank Farm Savannah River Site*. [SRR-CWDA-2013-00091]

4.1.4 Phase 4: Tank 16 Heel Removal Efforts Using a Water Rinse

In August 1980, 56,000 gallons of 90°C heated water were sprayed through the four rotary sprayers in Tank 16. The SLPs were turned on and the pump in Riser 8 was indexed toward a mound that was observed after CSR Campaign 4. After four days of mixing, a sludge-slurry of 195,000 gallons was transferred to Tank 15. 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]

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 16 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]

Table 4.1-3 shows the waste removal details of the Tank 16 Phase 4 water rinse campaign.

Table 4.1-3: Waste Removal Details for the Tank 16 Phase 4: Water Rinse Campaign

Dates of Run	8/80
Slurry Pump Locations	Risers 2, 4A, 8
Operating Time, hours	
Pump 2	106
Pump 4A	128
Pump 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.

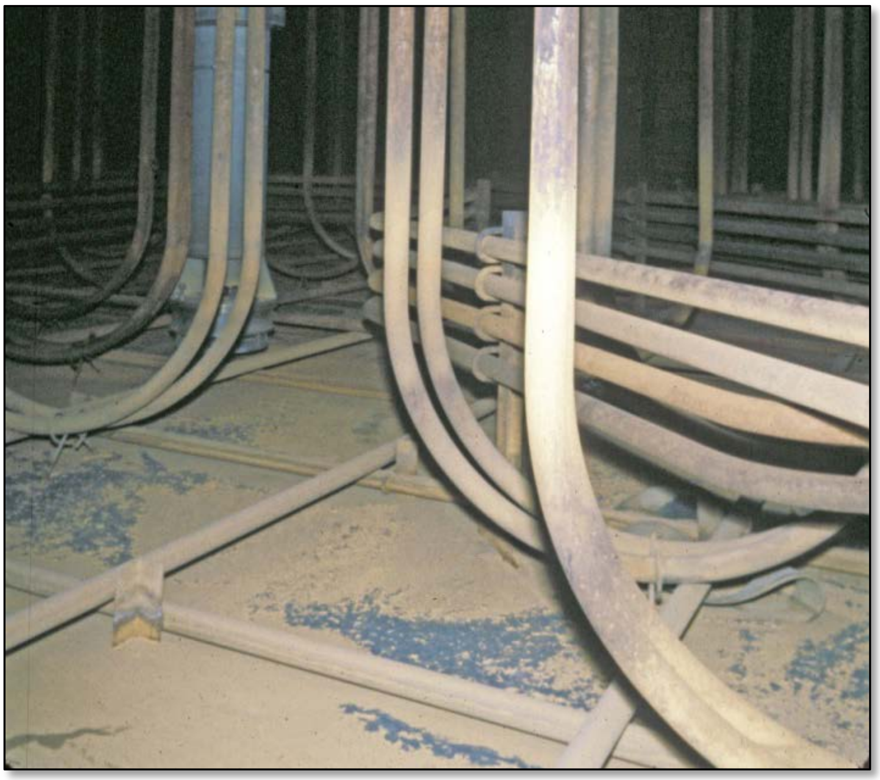
[DPSP-80-17-23, U-ESR-H-00113]

At the completion of the Phase 4 water rinse campaign, a total of 112,000 gallons of spray water and 72,500 gallons of bearing water had been added.

Figure 4.1-3 shows a Tank 16 photograph of the primary tank floor after the water rinse. This figure shows that there were only very small solids accumulations present in the primary tank.

A detailed chronology of the water rinse campaign can be found in Section 3.1.4 of *Industrial Wastewater Closure Module for the Liquid Waste Tank 16H H-Area Tank Farm Savannah River Site*. [SRR-CWDA-2013-00091]

Figure 4.1-3: Tank 16 after the Phase 4 Water Rinse Campaign



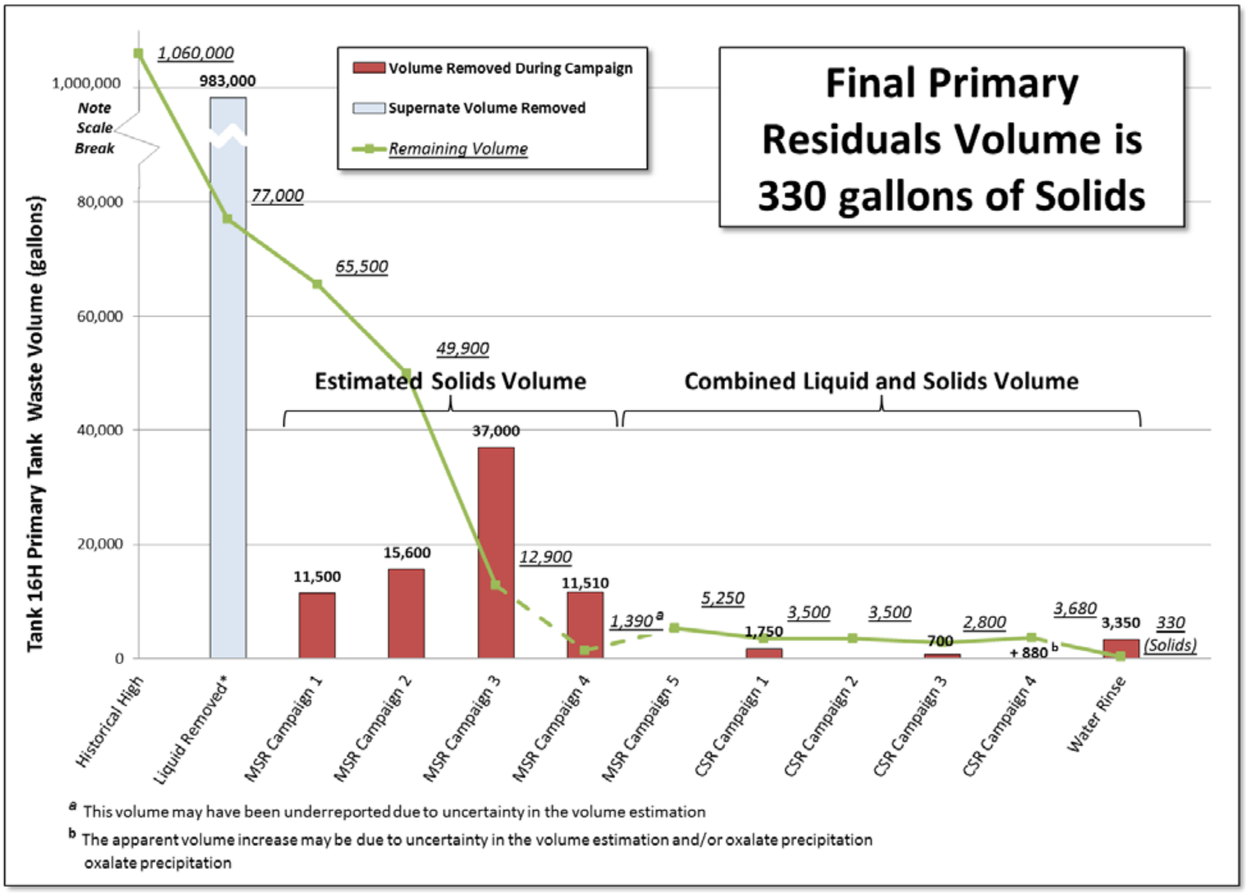
4.1.5 Tank 16 Primary Waste Removal Efforts Summary

During waste removal activities in the Tank 16 primary, the total volume was reduced from 1,060,000 gallons to an estimated 330 gallons, a reduction of approximately 99.9%. The total solids removed during these phases was approximately 76,670 gallons (77,000 gallons to 330 gallons), a reduction of 99.6%. A summary of the overall waste removal phases and their effectiveness can be seen in Table 4.1-4. A summary of the estimated liquid and solids removal during each of the individual waste removal campaigns is shown in Figure 4.1-4.

Table 4.1-4: Tank 16 Primary Waste Removal Activities Results Summary

Inventory	Tank 16 Primary Waste	
	Approximate Gallons	Cumulative % Removed
Inventory Prior to Phase 1 Campaign (Historical High)	1,060,000	0
Inventory Prior to Phase 2 Campaigns (MSR)	77,000	92.7
Inventory Prior to Phase 3 Campaigns (CSR)	5,250	99.5
Inventory Prior to Phase 4 Campaign (Water Rinse)	3,680	99.7
Final Residual Inventory	330	99.9

Figure 4.1-4: Summary of Tank 16 Primary Tank Waste Removal by Campaign



During operational and waste removal life cycle of Tank 16, approximately 141,900 gallons of supernate were processed through Tank 16. Also, approximately 347,400 gallons of flush/spray water, 324,000 gallons of bearing water and 73,000 gallons of OA were added to the primary tank during the cleaning phases. These liquid additions impact the liquid waste system as new waste streams are created through waste removal which must eventually be

processed. The overall strategy for Tank 16 liquid addition was to maximize the use of Tank 21 and 22 supernate to limit the new waste created in the HTF. Tank 21 and 22 supernate was added to the primary tank as a slurry medium with a relatively high specific gravity that kept the solids suspended longer. The SLPs were run for a total of approximately 2,300 hours. Table 4.1-5 shows a breakdown of the liquids used during the cleaning process. Table 4.1-6 shows a summary table for Tank 16 waste removal activities. [DPSP-79-17-17, DPSP-80-17-23]

Table 4.1-5: Breakdown of Charged Liquids and Other Parameters During Tank 16 Primary Mechanical and Chemical Cleaning

Tank 16 Campaigns	Flush/Spray Water Added (gal)	Supernate Added (gal)	OA Added (gal)	Bearing Water Added (gal)	Estimated Sludge Remaining (gal)
MSR 1	8,000	0	0	9,000	65,500
MSR 2	27	29,500	0	12,800	49,900
MSR 3	172	16,200	0	49,300	12,900
MSR 4	297	38,000	0	29,300	1,390 [a]
MSR 5	0	58,200	0	25,700	5,250 [b]
CSR 1	133,000	0	0	55,000	3,500 [b]
CSR 2	41,600	0	12,600	22,900	3,500 [b c]
CSR 3	46,500	0	9,870	27,200	2,800 [b]
CSR 4	5,800	0	50,500	20,300	3,680 [b]
Water Rinse	112,000	0	0	72,500	330 [d]
Total→	**347,396**	**141,900**	**72,970**	**324,000**	

[a] This volume may have been underreported due to uncertainty in the volume estimates.
[b] This heel volume includes sludge solids plus remaining liquid slurry medium.
[c] 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.
[d] The original 1,000 gallon estimate made in 1980 was revised during the final volume determination in 2013.
[DPSP-79-17-17, DPSP-80-17-23, U-ESR-H-00113]

Table 4.1-6: Tank 16 Primary Waste Removal Efforts Summary Table

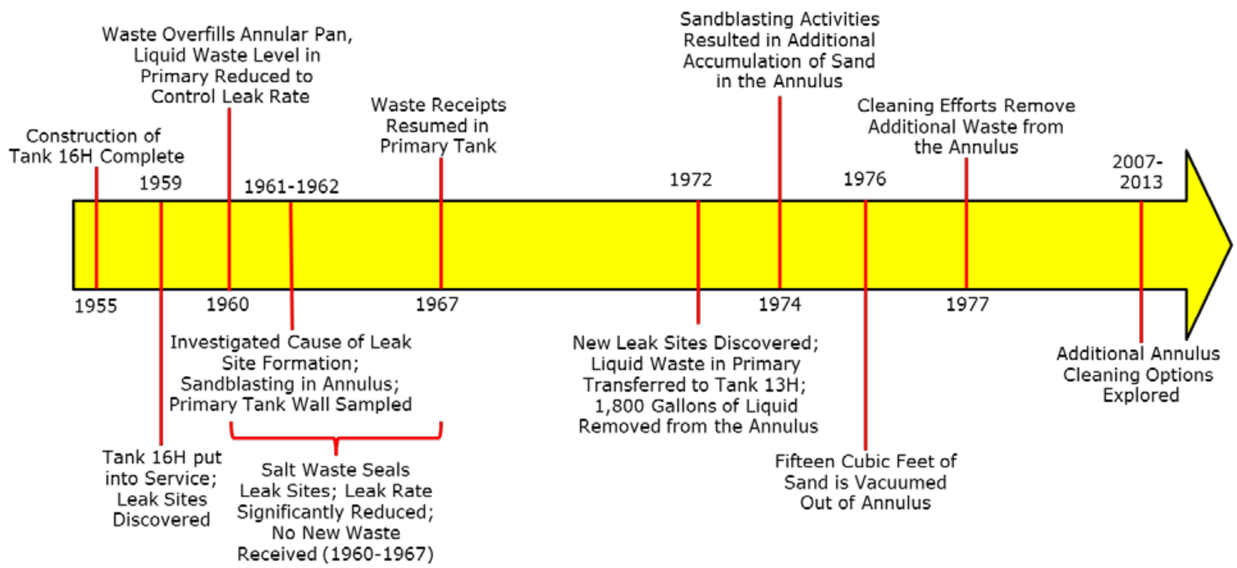
Total Starting Volume (gal)	1,060,000
Total SLP Run Time (hr)	2,297
Total Liquid Introduced into the Primary Tank (gal)	886,266
Total New Waste Created (gal)	744,000
Total Solids Removed (gal)	76,670
Ratio of New Waste Created-to-Total Solids Removed	10:1
Total Residual Solids Remaining (gal)	330
Percent of Total Volume Removed (%)	99.9

4.2 Tank 16 Annulus Waste Removal History

The information provided in this section summarizes, and supplements, information provided in Section 3.2 of the *Industrial Wastewater Closure Module for the Liquid Waste Tank 16H H-Area Tank Farm Savannah River Site*, SRR-CWDA-2013-00091.

Figure 4.2-1 provides a historical timeline that includes Tank 16 Annulus waste removal activities.

Figure 4.2-1: Tank 16 Annulus Historical Timeline



[Not to Scale]

As discussed in Section 3.2.1, Tank 16 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. In September 1960, the annulus pan overflowed and an estimated “tens of gallons” escaped the concrete encasement entered the surrounding soil. [DP-1358] Between September and October 1960, waste continued to leak from the primary tank into the annulus and was subsequently transferred out to Tank 14. Leakage to the annulus stopped when the liquid level in the primary tank was lowered below the middle horizontal primary 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, primary tank wall sampling and dye-penetrant testing. [U-ESR-H-00107]

Tank 16 was returned to limited service in October 1967, but in January and February 1972, inspection of the annulus revealed new leak sites and enlarged salt deposits on the primary tank wall and annulus floor. By March 1972, the use of the Tank 16 for additional waste receipts had ceased. 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 14. [DPSPU 77-11-17]

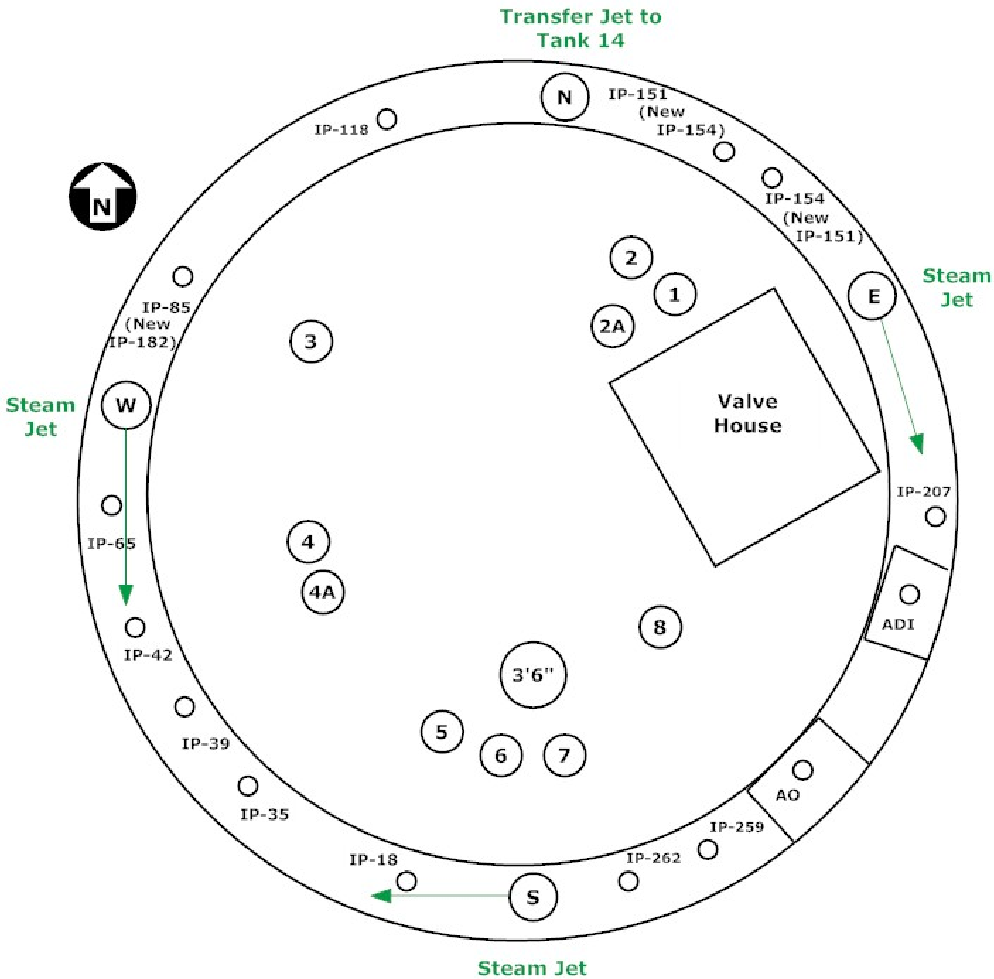
In September 1972, 800 gallons of liquid were jetted out of the annulus. In October 1973, another attempt was made to remove liquid with a dewatering jet. However, no appreciable waste was removed. [DPSPU 77-11-17]

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 14. [DPSPU-77-272-135] The waste removal efforts began in May 1977, when 14,000 gallons of low heat waste supernate from Tank 22 were transferred to the Tank 16 primary tank as ballast to prevent the primary tank bottom from bowing when water was added to the annulus. Steam mixing jets (25 gpm) 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 16 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 gpm, 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 4.2-2 shows the placement of the jets in the Tank 16 annulus and the circulation direction for each.

Figure 4.2-2: Steam Jet Configuration for Tank 16 Annulus Cleaning



After three transfers of approximately 4,800 gallons of salt solution to Tank 14 via the transfer jet 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 16 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. Initial specific gravity of the solution being transferred out of the Tank 16 annulus was 1.39. Annulus waste removal was stopped when the specific gravity of the solution decreased to less than 1.01, indicating minimal waste material was going into solution. Additional removal of this mostly insoluble material using the existing method would be difficult. In July 1977, further annulus cleaning activities were suspended due to diminished effectiveness and to avoid delaying the Tank 16 primary tank sludge removal demonstration (i.e., *Phase 2: Tank 16 Bulk Solids Waste Removal Efforts with Slurry Pumps* as described in Section 4.1.2). [IOM-20506]

In March 2007, the Tank 16 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 6.2.1.1, 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 16 annulus characterization sampling in 2013, a total of 11 new samples were collected from inside and outside the ductwork and the waste depth was 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]

4.2.1 Tank 16 Annulus Waste Removal Efforts Summary

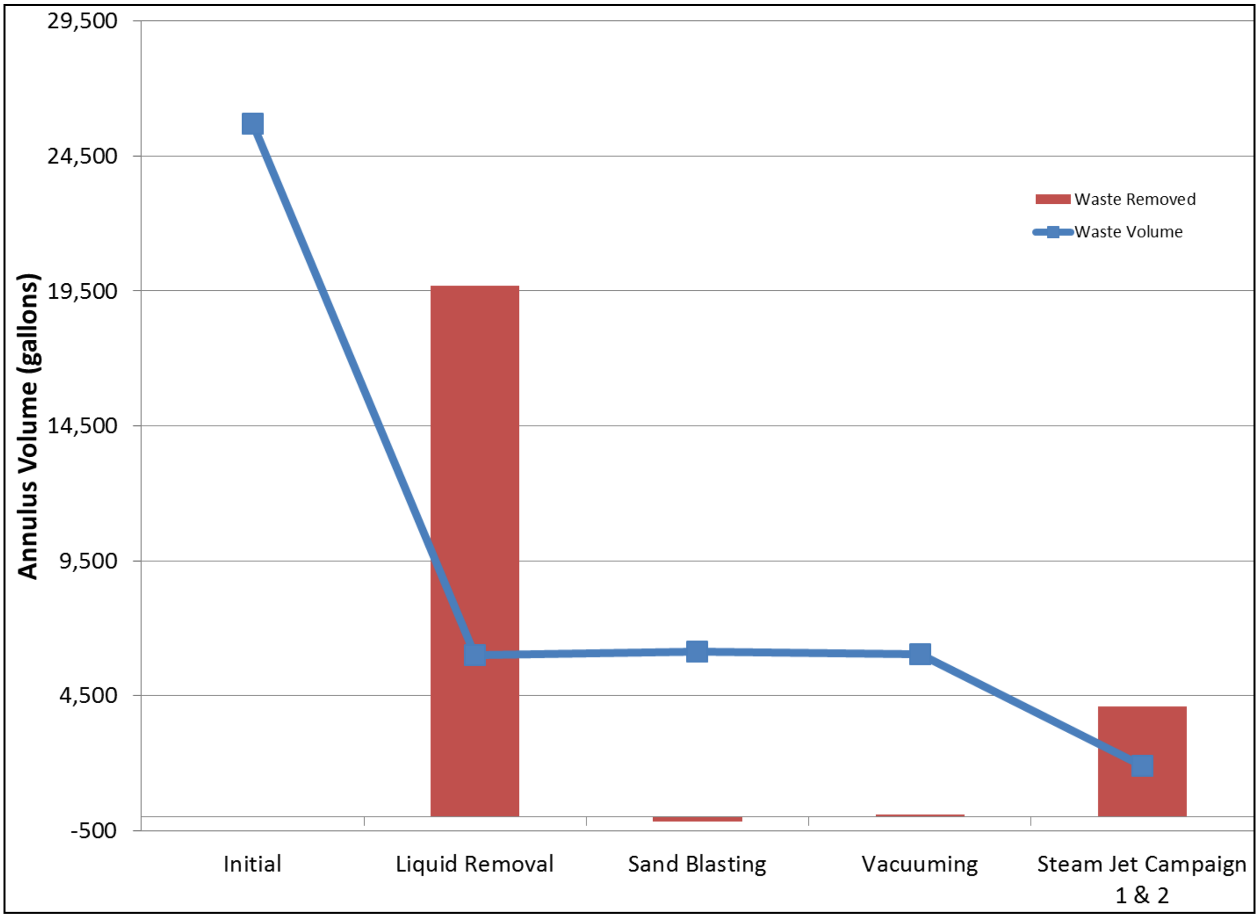
During waste removal activities in the Tank 16 annulus, the total volume was reduced from approximately 25,700 gallons to an estimated 1,910 gallons, a reduction of approximately 92.6%. A summary of the overall annulus waste removal phases and their effectiveness can be seen in Table 4.2-1. A summary of the estimated waste volume removal during each of the individual waste removal campaigns is shown in Figure 4.2-3.

Table 4.2-1: Tank 16 Annulus Waste Removal Activities Results Summary

Date	Activity	Net Change (gallons)	Estimated Waste Volume (gallons)	Cumulative % Removed
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	0
September 1960 to 1977	Numerous transfers made to Tank 14. 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. [DPSPU-77-272-135]	- -	6,000	- -
May 1977	Annulus cleaning with steam jets.	-1,400	4,600	79.0
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 Outside duct = 1,500 **Final Total = 1,910**	92.6

- - Not Applicable

Figure 4.2-3: Remaining Tank 16 Annulus Waste Estimation Following Cleaning Campaigns



During the Tank 16 annulus waste removal using steam jets campaign in 1977, approximately 48,000 gallons of water were added. This included approximately 3,000 gallons of condensate from steam and approximately 600 gallons of water used to install and unplug steam jets. These liquid additions impact the Liquid Waste System as new waste streams are created through waste removal which must eventually be processed. Prior to annulus waste removal with steam jets, 14,000 gallons of low heat waste supernate from Tank 22 were transferred to the Tank 16 primary tank as ballast to prevent the primary tank bottom from bowing when water was added to the annulus. Tank 22 supernate was used to limit the new waste created in HTF. The steam jets were run for a total of approximately 1,230 hours. [IOM-7914] Table 4.2-2 shows a summary table for Tank 16 waste removal activities.

Table 4.2-2: Tank 16 Annulus Waste Removal Efforts Summary Table

Total Starting Volume (gal)	25,700
Total Steam Jet Run Time (hrs)	1,232
Total Liquid Introduced into the Annulus (gal)	48,350
Total New Waste Created (gal)	48,350
Total Estimated Waste Removed (gal)	23,800
Ratio of New Waste Created-to-Total Solids Removed	2:1
Total Estimated Solids Remaining (gal)	1,900
Percent of Total Volume Removed (%)	92.6

4.3 Basis to Proceed with Sampling and Analysis Activities in Tank 16

Heel removal operations using the MSR, CSR and Water Rinse methods were completed on the Tank 16 primary as described in Sections 4.1.2, 4.1.3 and 4.1.4. Tank 16 annulus waste removal was completed using steam jets as described in Section 4.2. The MSR, CSR and Water Rinse equipment were determined to have cleaned the primary tank to the range of their capability and were no longer effective at removing additional waste. Therefore, their operation was suspended. The steam jets were determined to have cleaned the annulus to the range of their capability and were no longer effective at removing additional waste. The following factors, described in the subsections below, were used in making a determination to suspend operations:

- Visual observation of the primary tank floor indicating no significant accumulations of residual solids
- Additional Technology Evaluation results
- Performance assessment indicating the long-term risk associated with annulus salt/sand compounds are low
- Potential risk to today's workers and environment would not result in significant risk to future generations [SRR-CWDA-2013-00041]

4.3.1 Visual Observations

Visual inspections of the tank primary, utilizing remotely operated cameras, indicated that there was a significant reduction in residual material volume resulting from the waste removal efforts operations. Mounds of residual material that had existed prior to heel removal were eliminated leaving a minimal dusting of solids across the primary tank floor. Based on preliminary mapping, the Tank 16 primary had approximately 300 gallons. [U-ESR-H-00113] This amount of residual material on the primary tank floor was considered so small that its removal would result in negligible risk reduction. It was determined that the cost of additional cleaning of the primary tank would significantly outweigh the negligible risk reduction benefit.

The remaining sodium aluminosilicate mineral in the Tank 16 annulus 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 steam jets

would be difficult. In July 1977, further annulus cleaning activities were suspended to avoid delaying the Tank 16 primary tank sludge removal demonstration. [IOM-20506]

In 2011 as part of an annulus cleaning evaluation, 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 was estimated to be 3,300 gallons in February 2012. [SRR-LWE-2012-00039] This was the Tank 16 annulus residual material estimated volume used in the evaluation to cease waste removal activities in Tank 16 in March 2013. The final annulus waste volume was determined to be 1,910 gallons in November 2013. [U-ESR-H-00113]

4.3.2 Additional Technology Evaluation Results

4.3.2.1 Dry Removal Technology

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 each was provided a request for proposal. Three vendors provided proposals to perform additional waste removal from the Tank 16 annulus. A mechanical cleaning system using robotic technology was chosen as the best value. 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 system would vacuum dry material out of the annulus and dehumidification duct to a process system skid that included 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 system was completed in 2007, but the project was suspended at that time due to funding constraints. When the project was reestablished in 2010, development and deployment costs were estimated to be $7 to $10 million, and the new schedule for implementation was greater than three years. It was determined that the dry removal technology would be more difficult to implement, cost more to execute and take longer than originally planned. Therefore, additional alternatives (i.e., chemical cleaning with OA and water/steam based technologies) were evaluated. [SRR-WRC-2012-0018, U-ESR-H-00107]

4.3.2.2 Oxalic Acid Technology

In 2012, SRNL OA leaching tests on Tank 16 annulus material showed that approximately 34 to 45% of solids 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. [U-ESR-H-00107]

4.3.2.3 Water Sluicing Technology

The proposed strategy for water 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 break up material and expose more surface area. The soluble fraction would be dissolved through vigorous mixing, and larger pieces of insoluble material would have to be broken down to a smaller particle size for mobilization and transport. A

final soak and rinse would potentially be performed at the end of cleaning. 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.

An assessment indicated that water sluicing would remove 53% to 67% of the material from the annulus. [SRR-WRC-2012-0018] 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. There was only a moderate ability to move material within the spray zone and limited movement of solids to the transfer pump suction. 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 become aerosolized and airborne during annulus cleaning operations utilizing this removal technology. This presented a significant challenge to control contamination and worker protection. Administrative and engineering safety significant/safety class controls 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 sluicing to attempt further cleaning in the Tank 16 annulus. [SRR-LWP-2012-00068]

4.3.2.4 Additional Removal Considerations

Based on evaluations that included laboratory testing on actual Tank 16 material as well as full scale mock up testing, it was determined that significant removal of key radionuclides from the annulus is unlikely. A significant amount of the material is natrodavyne, and this mineral has low solubility. The material is difficult to break up and move to the transfer pump suction. Furthermore, there are challenging nuclear hazards such as waste aerosolization associated with mobilizing the material.

A qualitative assessment indicates that the long-term risk to future generations and the environment is low because of the relatively low concentrations of long-lived actinides in the salt/sand compounds present in the Tank 16 annulus. The potential risk to workers to install and operate additional waste removal systems in the annulus would not result in significant long-term risk reduction.

4.3.3 Agreement to Proceed with Sampling and Analysis

In accordance with 9.b of Appendix L in the *Federal Facility Agreement* (FFA) *for the Savannah River Site* (and subsequent modifications), DOE, South Carolina Department of Health and Environmental Control (SCDHEC) and the United States Environmental Protection Agency (EPA) must reach agreement that waste removal from the waste tanks may be suspended. Following waste removal campaigns in the tank primary using the mechanical, chemical and water rinse technologies and waste removal campaigns in the

annulus using steam jet technology, DOE briefed officials of SCDHEC and EPA on March 12, 2013 on the results of cleaning Tank 16. [WSRC-OS-94-42, SRR-CWDA-2013-00041]

The briefing demonstrated that:

- The mechanical cleaning, chemical cleaning and water rinse technologies have been effective in the Tank 16 primary such that there is only a very small volume of residual solids remaining. Waste removal activities reached the extent of these technologies to remove significant additional waste.
- Steam jet technology has been effective in the Tank 16 annulus and it is unlikely that significant removal of additional key radionuclides is possible.
- Over 99% of the waste and the associated hazardous constituents and radionuclides in the primary tank has been removed.
- A qualitative assessment of additional options indicates that additional waste removal efforts are not practicable.
- A qualitative assessment indicates that 10 Code of Federal Regulations (CFR) 61, Subpart C performance objectives (see Section 6.1.1.1) would be met.

Following the briefing DOE requested concurrence to proceed to the sample and analysis phase of the waste tank closure process in Tank 16. [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 16 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_04-16-2013]
>
> 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]

5.0 FINAL RESIDUAL CHARACTERIZATION

After receipt of letters from EPA and SCDHEC agreeing with DOE to suspend waste removal, DOE characterized the residual material in Tank 16 to obtain the inventory of chemical and radiological constituents, including HRRs.

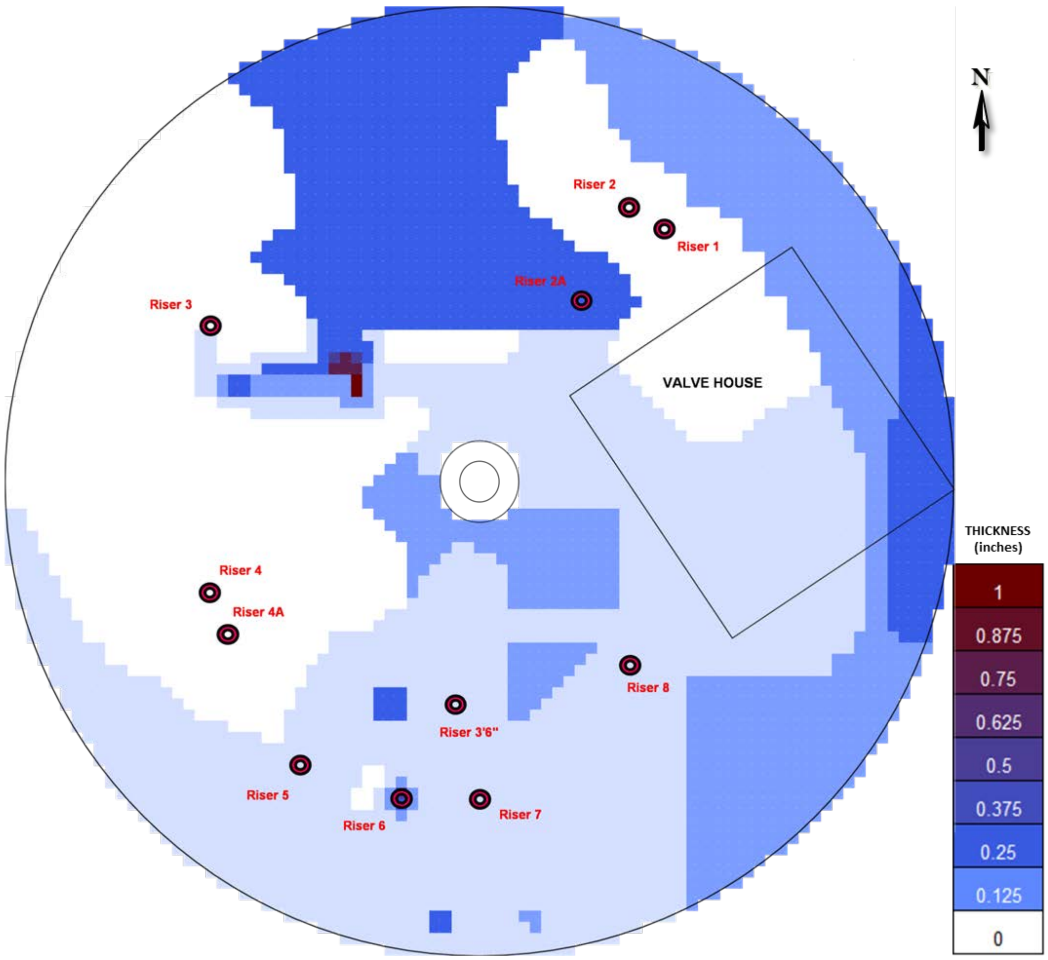
The characterization approach was consistent with those developed and presented in the *Liquid Waste Tank Residuals Sampling and Analysis Program Plan* (LWTRSAPP) and the *Liquid Waste Tank Residuals Sampling – Quality Assurance Program Plan* (LWTRS-QAPP). [SRR-CWDA-2011-00050, SRR-CWDA-2011-00117] A data quality assessment of the Tank 16 sample analytical data was performed to establish that the characterization data quality was acceptable for use in the Tank 16 inventory determination. [SRR-CWDA-2014-00090] A description of the methodology and determination of the Tank 16 residual inventory is provided in the *Tank 16 Inventory Determination*. [SRR-CWDA-2014-00071]

5.1 Residual Waste Characterization

5.1.1 Residual Volume Determination

In January 2011, photographs were taken of the interior of Tank 16 at various locations and elevations inside the primary tank. Additionally, video was taken from a camera mounted on the crawlers used for sampling residual material on the floor. The pictures and video were evaluated by a mapping team to determine the height of any residual material in the primary tank. Known dimensions of waste tank design features aided in determining residual material height. The depths of the regions of residual material were determined and plotted onto a gridded map of the primary tank floor. Figure 5.1-1 shows a map of the residual material in the Tank 16 primary. Based on final mapping estimates, Tank 16 has 330 gallons in the primary. [U-ESR-H-00113]

Figure 5.1-1: Tank 16 Residual Material Configuration

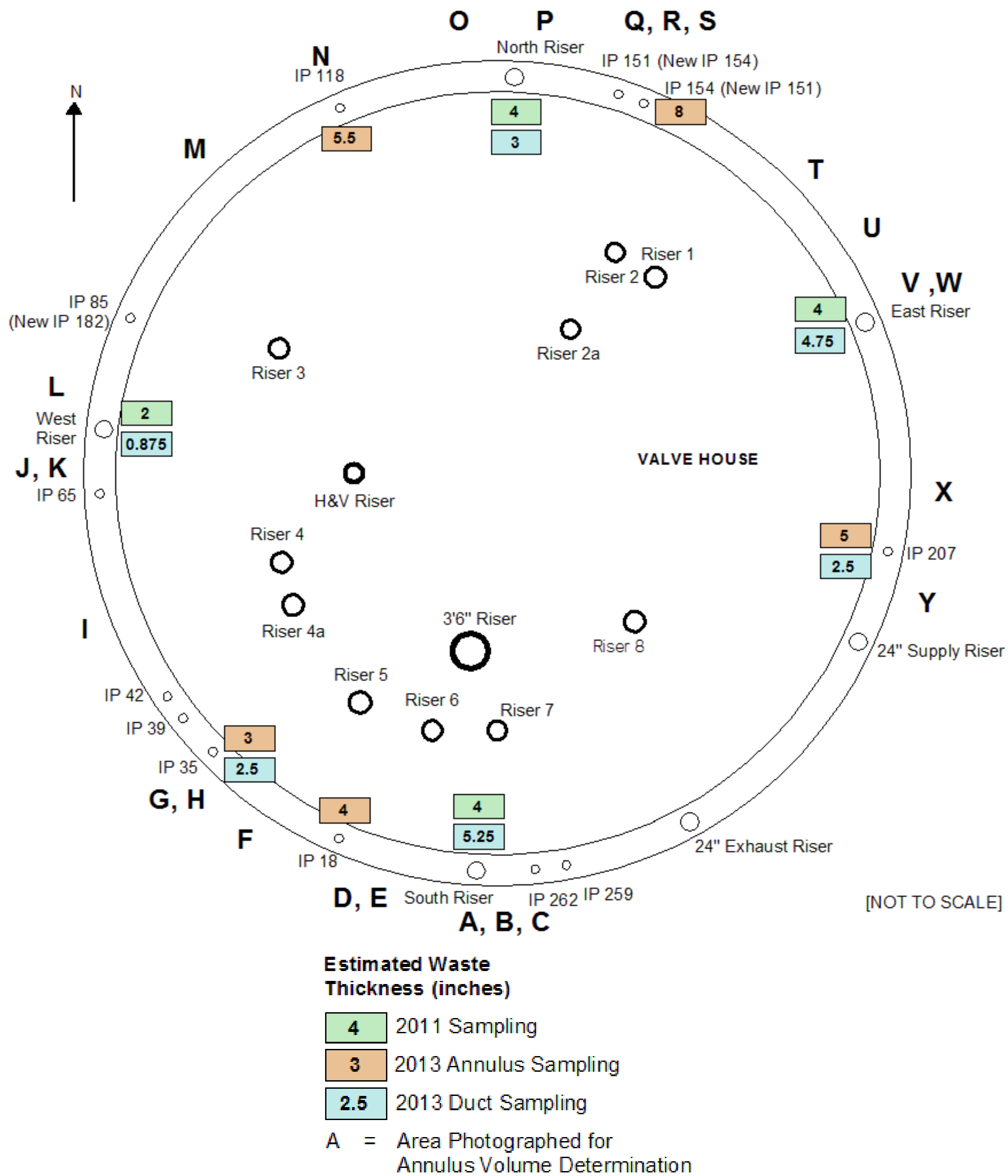


[U-ESR-H-00113]

Similar to the Tank 16 primary, the Tank 16 annulus was mapped using photographs and video taken from multiple annulus risers and inspection ports. The pictures and video were evaluated by a mapping team to determine the height of residual material in the waste tank annulus. Known dimensions of waste tank design features aided in determining residual material height. Sampling efforts in 2013 of the annulus floor and in the dehumidification duct also helped determine residual material height. The height of the solids were measured with a sample tool during sampling activities. 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. The colored boxes on Figure 5.1-2 contain the waste thickness measurements recorded during annulus sampling in 2011 and 1213, while the letters around the waste tank perimeter indicate areas photographed during 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 5.1-2: Tank 16 Annulus Camera and Sampling Locations with Residual Material Depth Measurements



[U-ESR-H-00113]

Since the Tank 16 cleaning history is similar to Tank 5, results from a previous Tank 5 cooling coil sample analysis were evaluated to assess any inventory associated with the Tank 16 interior metal surfaces that had been in contact with waste. The cooling coil and wall surface inventories calculated for Tank 5 using the analytical results were generally determined to be less than 1% of the floor residuals inventory and would have little impact on the overall waste tank inventory. [SRR-CWDA-2012-00027] Additionally, video footage of the Tank 16 interior does not show an appreciable amount of residual material remaining on the interior support column, cooling coils and primary tank wall surface. Therefore, any associated inventory on the Tank 16 internal surfaces is also expected to be insignificant compared to the overall waste tank inventory. Therefore, a separate Tank 16 interior surface inventory was not determined. [SRR-CWDA-2014-00071]

Various pieces of equipment used during the operational and the waste removal processes will remain in Tank 16. 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. The total internal hold-up volume is estimated at 26 gallons for equipment in the primary tank and six gallons for equipment in the annulus. [SRR-LWE-2014-00017]

Tank 16 has sand layers between the primary tank liner and the secondary liner (annulus pan), and between the secondary liner and the basemat. In 1960, 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. The secondary sand layer is conservatively estimated to contain 2% of the residuals volume of the primary sand layer. This yields a volume of 26 gallons in the secondary sand layer. [SRR-CWDA-2010-00023]

Additional details regarding residual volume determination can be found in Section 4.1 of *Industrial Wastewater Closure Module for the Liquid Waste Tank 16H H-Area Tank Farm Savannah River Site*. [SRR-CWDA-2013-00091]

5.1.2 Residual Waste Sampling

5.1.2.1 Representative Characterization

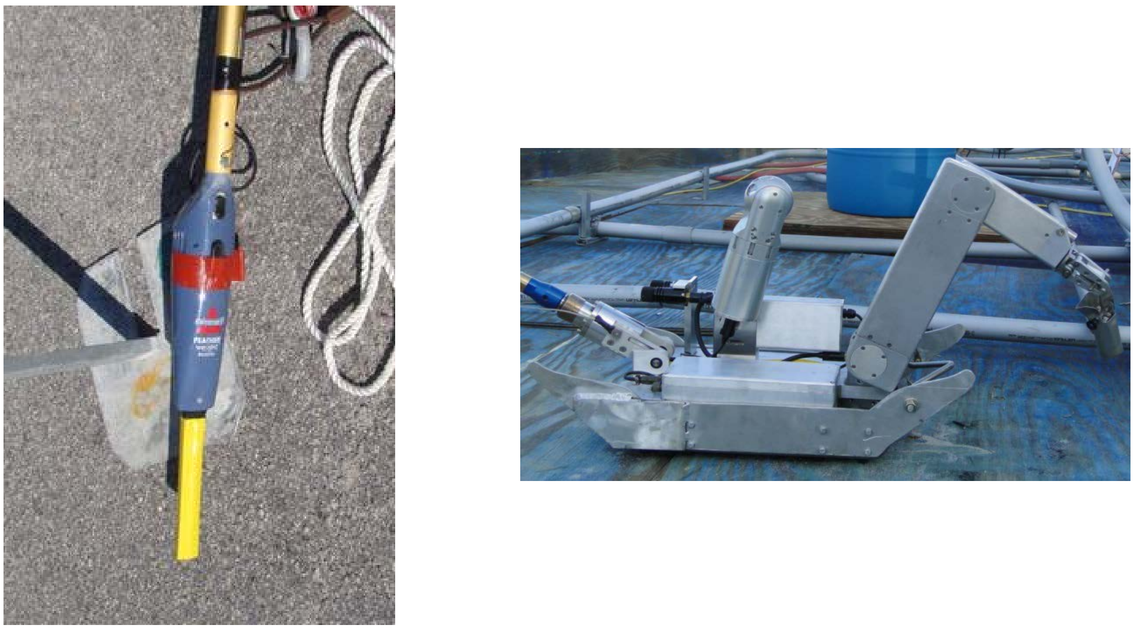
Because the primary tank contained only an estimated 330 gallons of residual material, discrete sample collection and analysis was performed. The Tank 16 annulus sampling was performed using stratified random sampling with volume proportional compositing to produce composite samples for analysis. The objective is to represent and characterize the residual material for the entire waste tank.

The sampling approach is consistent with the sampling and analysis approach documented in the LWTRSAPP. [SRR-CWDA-2011-00050] The LWTRSAPP was developed and subsequently approved by SCDHEC.

5.1.2.2 Sampling Technique

The sampling plan for the Tank 16 primary was divided into two parts: pole-mounted vacuum sampling and crawler-mounted vacuum sampling. Pole sampling is performed by manually lowering the vacuum sampler into the solids accumulation and was intended to retrieve a representative sample of the residual solids under Riser 8. Crawler sampling used a robotic crawler to place the vacuum sampler on the primary tank floor under Risers 3 and 6. Figure 5.1-3 shows an example of the pole-mounted vacuum sampler and crawler utilized to samples from the Tank 16 primary floor.

Figure 5.1-3: Pole-Mounted Vacuum Sampler and Crawler



Because the residual material on the annulus floor and in the annulus ductwork 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 5.1-4).

Figure 5.1-4: Auger Tool used to Disaggregate Material Prior to Sample Collection

For sampling residuals inside the annulus 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 pole-mounted vacuum. Figure 5.1-5 shows the hole cutter test results on a ductwork mockup.

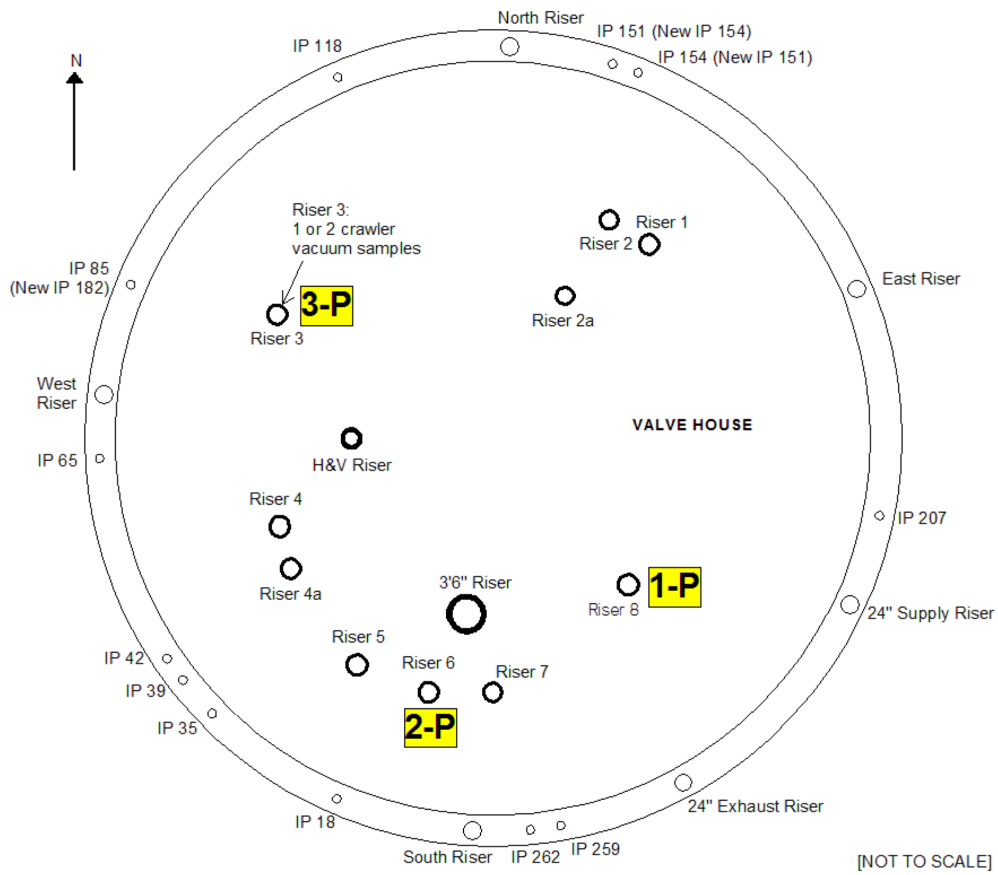
Figure 5.1-5: Annulus Duct Hole Cutter Mockup

5.1.2.3 Tank 16 Primary Residual Waste Sampling

The Tank 16 primary sample plan was developed based on the preliminary volume estimate and distribution of the material. As previously noted, the primary tank contained only 330 gallons of residual material, so discrete sample collection and analysis was planned and implemented. This plan sited samples based on the location of sufficient solids for collection and, separation into different areas of the waste tank, and sample tool access.

Samples from the areas under Risers 3, 6 and 8 were successfully collected and were analyzed discreetly. The results were ultimately used for calculating the primary tank average residual material floor concentrations. The sampling plan is provided in the *Tank 16 Sampling and Analysis Plan*. [SRR-LWE-2013-00057] Figure 5.1-6 illustrates the final Tank 16 primary floor sample locations.

Figure 5.1-6: Final Tank 16 Primary Floor Sample Locations



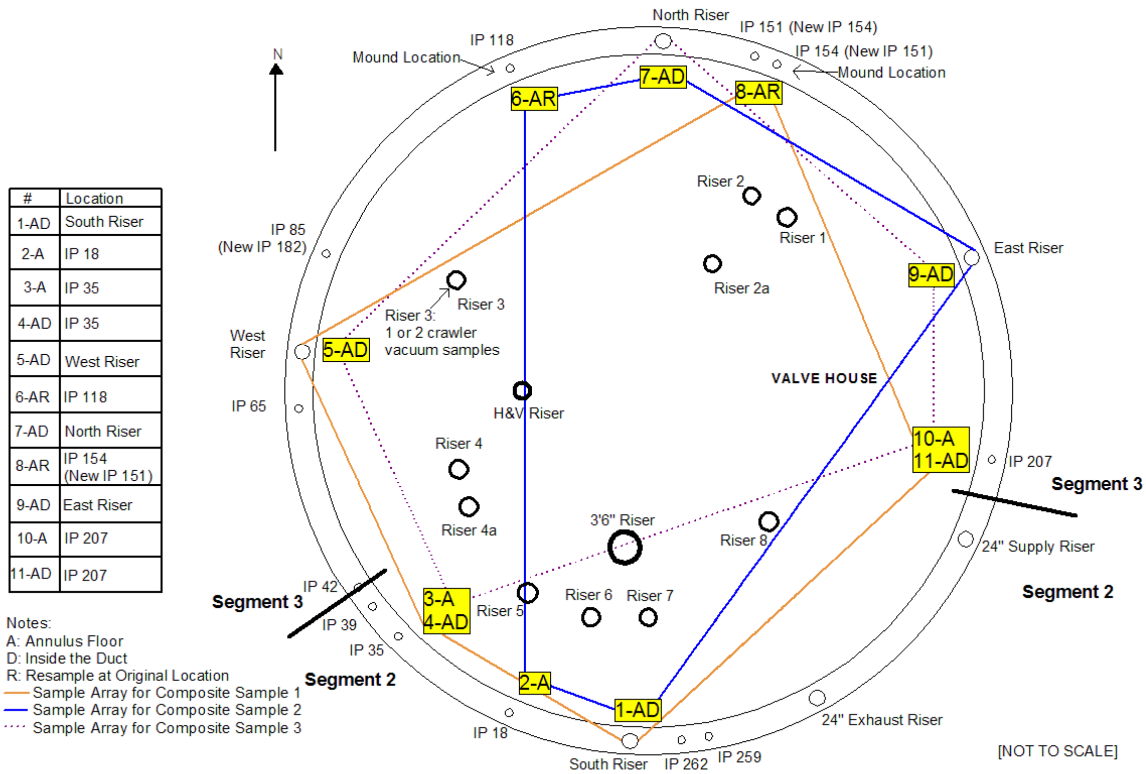
5.1.2.4 Tank 16 Annulus Residual Waste Sampling

The Tank 16 sample plan for the annulus residual material was developed based on the preliminary volume estimate and distribution of the material. This plan sited samples based on the location of the final recognized accumulations. The residual material was divided into three general material segments. 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.

Samples were planned for collection from these areas to be composited into three samples. Three sampling arrays were designed to representatively sample the areas. Five samples per array were to be collected for each composite sample, totaling 15 discrete samples. Excess material remaining from the analysis of four annulus process samples collected in 2011 was available and 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 sampling plan is provided in the *Tank 16 Sampling and Analysis Plan*. [SRR-LWE-2013-00057]

The final annulus sample locations and identifications are shown in Figure 5.1-7. 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.

Figure 5.1-7: Final Tank 16 Annulus Sample Locations



5.1.3 Characterization of Waste Tank Residual Materials

5.1.3.1 Sample Analyses

The discrete primary tank samples and composite annulus samples analyzed by SRNL were to characterize the constituents listed in Table 5.1-1.

Table 5.1-1: Radiological Analyte List for Tank 16 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	

Radionuclide screening resulted in 39 constituents for analysis. The starting point for the radionuclide screening for Tank 16 was the 54 radionuclide analytes identified in the HTF PA. [SRR-CWDA-2010-00128] These were the same radionuclides analyzed in the Tank 5, 18 and 19 samples with the following exceptions: three radionuclides were added; Cf-251, Th-232, Ra-228, and three radionuclides were deleted; Nb-93m, Sb-126, 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 F-Tank Farm (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 5, 6, 18 and 19 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 was aimed at eliminating those radionuclides that resulted in a peak dose estimate of less than 1.0E-02 mrem/year in the HTF PA model. [SRR-CWDA-2012-00156] Therefore, it would have taken significant effort to analyze for these radionuclides with no expected impact on the results. 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*. [SRR-CWDA-2012-00156]

Details of the analyses and results can be found in *Tank 16H Residual Sample Analysis Report*. [SRNL-STI-2014-00321]

5.1.3.2 Establishing Inventories Based on Results

A statistical study of the sampling results was performed and for those constituents with measured concentration values it provided the mean, standard deviation and upper 95% confidence limit (95%UCL) of the mean for the concentration values. For those constituents where the concentration was non-detectable or less than the TDL, the lowest and highest minimum detectable concentrations (MDCs) were used to bound the concentration values for the constituent. The statistical study refers to these constituents as having concentrations less than their MDC. For those constituents with a mixture of detected and non-detected concentrations, the constituents were treated as either those with measured values or those with non-detectable values. The inventories were determined by multiplying the residuals volume by the concentration (for each constituent). Composite residual material samples were created and analyzed to determine the concentrations. 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 95%UCL of the mean for each of

the factors (i.e., concentration and density) was used. For constituents that were not detected, the lowest MDC was used. [SRR-CWDA-2014-00071]

5.1.3.3 Quantification of Residual Contaminants

The methodology used to develop the inventory determines and evaluates each of the inventories from discrete elements of the waste tank. The discrete elements to be determined are listed below.

- Primary tank floor
- Waste tank annulus
- Primary and secondary sand layers
- Cooling coils and primary tank wall (waste tank internal surfaces)
- 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)

Using the 95% UCL values, the inventories for each of the separate elements was determined and then summed to determine the total residual inventory for Tank 16. Because the waste tank internal surfaces inventory was considered negligible, it was not included in the overall Tank 16 residual inventory. The estimate of the chromium from the grouting of the cooling coils in Tank 16 is 6.52 kg. [M-CLC-H-03244] The 6.52 kg of chromium from the residual material hold-up in the cooling coils is added to the primary tank floor inventory for the final Tank 16 inventory. A more in-depth description of the methodology and determination of the Tank 16 residual inventory are provided in the *Tank 16 Inventory Determination* for all of the analytes. [SRR-CWDA-2014-00071]

5.2 Removal of Highly Radioactive Radionuclides

5.2.1 Highly Radioactive Radionuclides Present Prior to Waste Removal

To quantitatively address how effective the waste removal techniques have been at removing HRRs, the percentages of removal are determined by comparing the inventory of the curies of radioactivity that was present prior to waste removal and the residual inventory based on the final residual characterization described in Section 5.1. For Tank 16, the original inventory was determined as of 1972. This was the year that waste removal was initiated as shown on Figure 4.1-1. [SRR-CWDA-2015-00019]

The waste material in Tank 16 prior to waste removal (March 1972) is made up of the supernate and sludge within the primary tank as well as the waste material in the Tank 16 annulus. Based on Tank 16's operating history, waste material is also known to have overflowed from the annulus and is therefore assumed to be in the Tank 16 primary and secondary sand pads. The historical information and sample data that is used to determine inventory vary between the Tank 16 supernate, sludge, annulus, and sand pads. Therefore, different methods are used to determine the inventory for each of these areas. [SRR-CWDA-2015-00019]

The supernate inventory for Tank 16 prior to waste removal is calculated using the radionuclide concentrations provided in the waste characterization data from *Characterization of Radionuclides in HLW Sludge Based on Isotopic Distributions in Irradiated Assemblies* (WSRC-TR-94-0562). This document provides the radionuclide

content of the H-Modified (HM) waste that was transferred to Tank 16 and gives the radionuclide concentrations in Ci/gal of the soluble material (i.e., supernate) in the HM high heat waste. The supernate concentrations were used along with supernate volume prior to waste removal (768,000 gallons per *Proposal to Cease Waste Removal Activities in Tank 16 and Enter Sampling and Analysis Phase*, SRR-CWDA-2013-00041) to determine the supernate inventory for each HRR prior to waste removal. [SRR-CWDA-2015-00019] It should be noted that the highest operating volume in Tank 16 was approximately 1,060,000 gallons in May 1960. [SRR-CWDA-2011-00126]

The sludge inventory for Tank 16 prior to waste removal is determined using the Waste Characterization System 1.5 and associated Sludge 1.5 computer programs. These programs are updated periodically to reflect changes in the HTF waste composition based on waste tank sample results, solids measurements, and pre-transfer and post-transfer data. Sludge 1.5 has a record of all sludge transfers into Tank 16 and the radionuclide inventory for each transfer. Using a built in decay capability in Sludge 1.5, the radionuclide inventory of the sludge in Tank 16 was decayed to March 1, 1972. The summation of the decayed radionuclide inventory from all the sludge transfers to Tank 16 gives the total sludge inventory for Tank 16 prior to waste removal. [SRR-CWDA-2015-00019]

The waste in the Tank 16 annulus was recently characterized and is found in *Tank 16 Inventory Determination* (SRR-CWDA-2014-00071). It is assumed that the characterization of the annulus residual material is applicable to the annulus material prior to waste removal. The residual inventory for each HRR is multiplied by the ratio of the annulus waste material volume prior to waste removal (6,000 gallons per *Proposal to Cease Waste Removal Activities in Tank 16 and Enter Sampling and Analysis Phase*, SRR-CWDA-2013-00041) to the annulus residual material volume (1,910 gallons per *Tank 16 Inventory Determination*, SRR-CWDA-2014-00071) to provide the annulus inventory prior to waste removal. [SRR-CWDA-2015-00019]

The residual inventory for the Tank 16 primary and secondary sand pads was determined and is found in *Tank 16 Inventory Determination* (SRR-CWDA-2014-00071). The primary and secondary sand pad inventory prior to waste removal is not expected to differ from the residual material since waste removal from the sand pads was not possible. Therefore the primary and secondary sand pad HRR inventories prior to waste removal have been set equal to the primary and secondary sand pad residual inventories found in *Tank 16 Inventory Determination* (SRR-CWDA-2014-00071). [SRR-CWDA-2015-00019]

5.2.2 Percent of Radioactive Radionuclides Removed

The percentages of HRRs removed for individual radionuclides in Tank 16 are shown in Table 5.2-1.

Table 5.2-1: Percentage of HRRs Removed from Tank 16

Radionuclides	Tank 16 HRR Inventory Prior to Waste Removal (1972) (Ci)	Tank 16 HRR Residual Inventory (2014) (Ci)	% Removed
Sr-90	4.02E+06	4.23E+04	98.9%
Tc-99	1.40E+03	4.95E+00	99.6%
I-129	2.15E+00	1.47E-02	99.3%
Cs-137	9.22E+06	9.68E+03	99.9%
U-233	1.26E-01	3.83E-02	69.7%
U-234	2.32E+00	3.26E-02	98.6%
U-235	4.07E-02	3.06E-04	99.2%
Np-237	4.46E+00	3.58E-02	99.2%
Pu-238	3.64E+04	6.48E+01	99.8%
Pu-239	9.28E+02	8.18E+00	99.1%
Pu-240	5.08E+02	3.72E+00	99.3%
Am-241	4.14E+03	1.46E+01	99.6%
Am-243	6.77E+00	1.37E-02	99.8%
Total	**1.33E+07**	**5.21E+04**	**99.6%**

[SRR-CWDA-2015-00019]

Of the 5.21E+04 curies of radioactivity remaining in Tank 16, Cs-137 and Sr-90, two HRRs with half-lives of approximately 30 years, make up approximately 99% of the curies. Based on the results shown in Table 5.2-1, greater than 99% of the HRRs have been removed from Tank 16. [SRR-CWDA-2015-00019]

6.0 ASSESSMENT OF THE IMPACT OF DEPLOYING ADDITIONAL REMOVAL TECHNOLOGY

The purpose of this analysis is to compare the cost and benefits of removing additional HRRs from Tank 16 to determine whether there would be a net social benefit from this endeavor; that is, whether the benefits would outweigh the costs. This analysis considers whether the costs, such as monetary costs, delays in higher risk reducing activities, or occupational exposure of site workers to hazardous or potentially hazardous materials, including radioactive materials, outweigh the potential benefits associated with further HRR removal. This cost-benefit analysis considered a broad range of costs including resultant schedule impacts on other on-going cleaning activities and waste disposition activities, as well as the current state of waste removal capabilities and technologies. These costs are evaluated against the benefits of additional HRR removal from Tank 16 relative to the potential averted dose to a member of the public (MOP) and inadvertent intruder. Also discussed are the potential benefits identified in NRC guidance and the benefits of reducing the amount of radioactive waste disposed of onsite.

Due to the small amount of waste remaining in the primary tank, no assessment of the impact of deploying additional removal technology to remove additional waste from the primary tank was performed. The amount of residual material in the primary tank is considered so small that its removal would result in negligible risk reduction, while incurring a high cost. Additionally, no assessment of the impact of deploying additional removal technology in the sand layers was performed due to inaccessibility for waste removal and the limited assigned inventory.

The subsequent sub-sections provide the following information:

Section 6.1, Impact of Waste Tank Residuals, provides a description of the predicted impact on a MOP from the closed HTF, including impact of Tank 16 residuals.

Section 6.2, Evaluation of Technologies for Additional Removal of Highly Radioactive Radionuclides, summarizes the waste removal processes that have been considered for additional HRR removal from the Tank 16 annulus.

Section 6.3, Benefits of Additional Removal of Highly Radioactive Radionuclides, identifies the benefits that would be produced by removing additional HRRs from the Tank 16 annulus, focusing on averted dose to a MOP and provides perspective to these benefits.

Section 6.4, Cost of Additional Removal of Highly Radioactive Radionuclides, describes the costs that would be associated with use of the additional waste removal processes that have been considered.

Section 6.5, Discussion of Costs and Benefits, discusses key matters related to evaluation of costs and benefits and describes DOE’s decision criteria.

Section 6.6, Evaluation of Criteria and Cost-Benefit Conclusions, describes the conclusions from the analysis and summarizes the basis for these conclusions.

6.1 Impact of Waste Tank Residuals

6.1.1 Predicted Impacts of the Waste Tank Residuals

The predicted performance of the closed HTF in protecting a hypothetical MOP or inadvertent intruder who may inhabit the area in the future – in particular, the contribution of

Tank 16 residuals to the predicted radiological dose to this individual – is an important element in the cost-benefit analysis. This section therefore provides brief summaries of the analyses performed and discusses the results of these analyses pertaining to protection of the hypothetical MOP or inadvertent intruder.

6.1.1.1 Performance Objectives

The requirements of 10 CFR 61, Subpart C and DOE Manual 435.1-1 allow a maximum annual dose to a MOP following waste tank farm closure of 25 mrem/yr from residual radioactivity in the facility. DOE Manual 435.1-1 and DOE Order 458.1 require that such doses be ALARA, as does 10 CFR 61.41, *Protection of the General Population for Releases of Radioactivity*, which states that "Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable." In addition, the requirements of 10 CFR 61.42, *Protection of Inadvertent Intruders*, and DOE Manual 435.1-1 allow a maximum dose to an inadvertent intruder following waste tank farm closure of 500 mrem/yr from residual radioactivity in the facility. DOE Manual 435.1-1 also establishes a 100 mrem/yr chronic dose limit for evaluating impacts to an inadvertent intruder.

To evaluate impacts, the HTF 3116 Basis Document provides model results up to 100,000 years after facility closure. This approach envelopes both the 1,000-year period after closure, as described in DOE Manual 435.1-1 for performance assessments for DOE low-level waste disposal facilities, as well as the 10,000-year period suggested in NUREG-1854.

6.1.1.2 H-Tank Farm Performance Assessment

DOE uses performance assessments to provide reasonable assurance that low-level waste disposal or closure of facilities will meet the required performance objectives for the protection of the public and the environment. A performance assessment for a facility such as HTF involves detailed analyses of potential radiation doses to those who may be affected in future years to ensure that when the facility is closed it will meet its performance objectives. Special analyses are performed to evaluate the significance of new information or new analytical methods to the results and associated conclusions of a performance assessment. As waste tanks and ancillary structures are cleaned at the HTF, the final residual inventories will be used to update the HTF fate and transport modeling performed as part the HTF PA. [SRR-CWDA-2010-00128] This allows for evaluation of the difference between the projected and final waste tank inventories to determine if the results of the HTF PA and the conclusions reached based on the HTF PA information remain valid. The *Tank 16 Special Analysis for the Performance Assessment for the H-Tank Farm at the Savannah River Site*, SRR-CWDA-2014-00106, (hereinafter referred to as: Tank 16 Special Analysis) evaluates the impact of all the waste tanks and ancillary structures utilizing the final residuals that remain in Tank 16 (using final residual characterization data discussed in Section 5.0).

6.1.1.2.1 H-Tank Farm Models

A conceptual model describes all of the relevant properties of the closed facility. The estimated radionuclide inventory at the time of closure is a key element in the conceptual model, as are properties that control radionuclide migration such as material solubility and distribution coefficients.

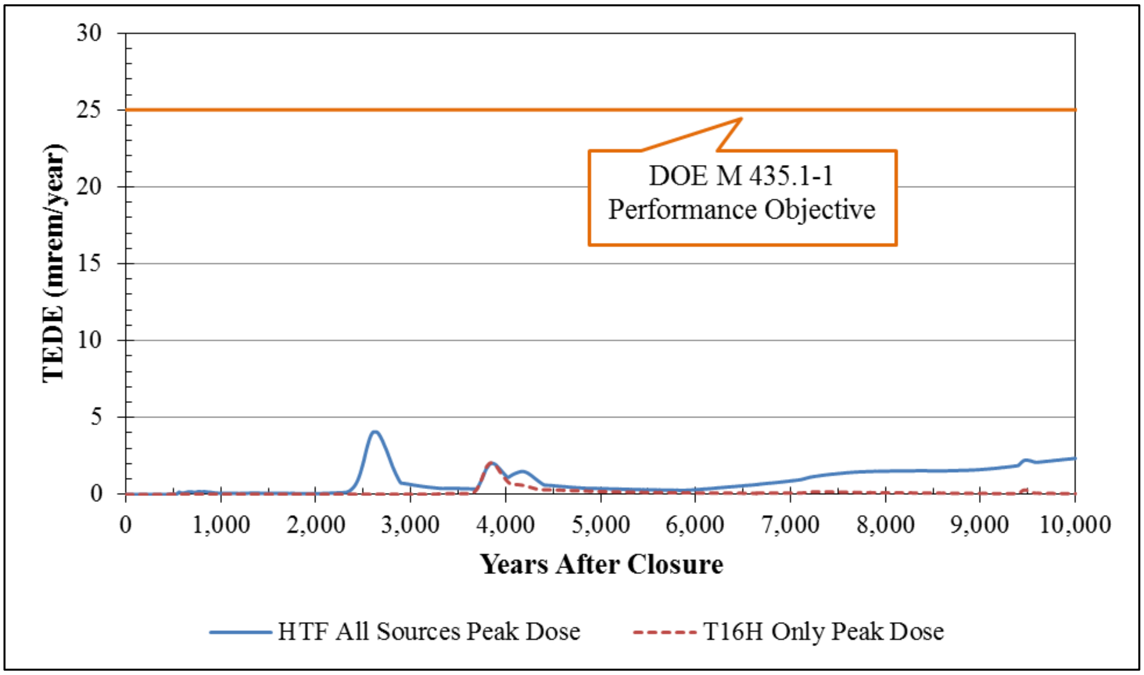
Mathematical models are used with the conceptual model to calculate potential doses under different scenarios. The HTF PA makes use of HELP, PORFLOW, GoldSim and CAP88-PC. These computer codes are described in the HTF PA. [SRR-CWDA-2010-00128]

Because of the complexities in groundwater flow, for modeling purposes within the HTF PA, the HTF is divided into six sectors labeled A through F. The highest predicted groundwater radionuclide concentration 100 meters hydraulically downgradient from the HTF boundary, regardless of the specific sector, is conservatively used in predicting the maximum dose to a MOP. [SRR-CWDA-2010-00128]

6.1.1.2.2 H-Tank Farm Key Performance Assessment Results

The HTF PA modeling was used to determine an all-pathways dose to a MOP for comparison with the performance objectives. The Base Case[3] analysis projected the peak all-pathways dose to a MOP to be less than the 25 mrem/yr performance objective during the 10,000-year period following HTF closure. The results of the Tank 16 Special Analysis, which utilized the actual Tank 16 residual inventories, also projected the peak all-pathways Base Case dose to a MOP to be less than 25 mrem/yr. The Tank 16 Special Analysis provides the updated results using projected HTF waste tank inventories. As shown in Figure 6.1-1, the maximum peak annual all-pathways total effective dose equivalent (TEDE) to a MOP during the initial 10,000 years following HTF closure using the updated inventories is approximately 4 mrem/yr and occurs at year 2,610.

Figure 6.1-1: MOP Peak All-Pathways TEDE Within 10,000 Years



[SRR-CWDA-2013-00091]
Note: The horizontal orange line at 25 mrem/yr is provided for illustration only.

[3] The Base Case represents the waste tank system configuration modeling case within the HTF PA that represents the best estimate of expected conditions for the HTF closure system based on available information at the time the HTF PA was developed.

The peak all-pathways dose projection includes the groundwater pathways and air pathways associated with all HTF waste tanks and associated ancillary structures, with the groundwater pathway being the most significant contributor. The air pathways contribution was insignificant in comparison to the groundwater pathway contribution. The peak groundwater Base Case pathway dose in 10,000 years is primarily associated with I-129 (99%). The Ra-226 results from the decay of Pu-238 and U-234. [SRR-CWDA-2014-00106]

Tank 12 is the primary contributor to the Base Case all-pathways peak dose to the MOP at 100-meters within 10,000 years. The dose is associated with I-129, with all other radionuclides contributing less than 1% at the year of peak dose (year 2,610). The individual contributors to peak groundwater pathway dose in 10,000 years are changed from the HTF PA. The peak dose is dominated by I-129 because the Tank 12 I-129 inventory was increased from the assigned HTF PA inventory. [SRR-CWDA-2014-00106]

The Tank 16 Special Analysis projects the maximum peak annual dose to a HTF inadvertent intruder to be approximately 46 mrem/yr at year 10,000 following HTF closure from a chronic scenario (i.e., drilling through a transfer line and using groundwater maximum concentrations at one meter from the HTF). [SRR-CWDA-2014-00106]

6.1.1.2.3 Tank 16 Contribution to Peak Dose

As previously discussed, the Tank 16 Special Analysis projects a maximum all-pathways TEDE within the performance period, resulting from all HTF waste tanks and ancillary structures, of approximately 4 mrem/yr at approximately 2,610 years after closure. Tank 16 is a negligible contributor to the 100-meter peak all-pathways annual TEDE within 10,000 years (less than 0.1 mrem/yr at year 2,610). The modeling assumes that neither the carbon-steel primary tank liner or five-foot high annulus pan are present for Tank 16 to retard contaminant transport. Although Sector A provides the highest doses when considering all of the sources within the HTF, Tank 16 provides greater impacts on Sector C. Tank 16 is the dominant contributor to a 2.1 mrem/yr peak (TEDE) at year 3,850, primarily due to I-129. This 2.1 mrem/yr peak (TEDE) at year 3,850 is the highest peak associated with Tank 16 within 100,000 years after HTF closure. [SRR-CWDA-2014-00106]

6.1.1.3 H-Tank Farm Performance Assessment Conclusions

The Tank 16 Special Analysis results continue to provide reasonable assurance that compliance is maintained with the specific requirements, among others, of 10 CFR 61, Subpart C, as referenced in NDAA Section 3116 and DOE Manual 435.1-1. The additional sensitivity and uncertainty analyses performed using lessons learned regarding waste release modeling and distribution coefficients provide further confidence. The results presented in the HTF PA reflecting the Tank 16 projected operational closure inventory is not significantly impacted by new information regarding the final residual inventories that remain in Tank 16. [SRR-CWDA-2010-00128]

6.2 Evaluation of Technologies for Removal of Additional Highly Radioactive Radionuclides

This section discusses technologies that could potentially be deployed to remove additional waste and HRRs from the Tank 16 annulus and the viability of those technologies accounting for current conditions.

As described in Section 4.1, waste removal was performed in the Tank 16 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. This amount of residual material on the primary tank floor was considered so small that its removal would result in negligible risk reduction. It was determined that the cost of additional cleaning of the primary tank would significantly outweigh the negligible risk reduction benefit.

As described in Section 5.1.1, 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. 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, it was determined that the cost of attempting waste removal in the sand pads would significantly outweigh the negligible risk reduction benefit.

6.2.1 Analysis of Potential Cleaning Technologies

DOE has developed a robust process to assess the technical readiness of new technologies as described in DOE Guide 413.3-4A, *Technology Readiness Assessment Guide*. The process evaluates technology maturity using the Technology Readiness Level scale that was pioneered by the National Aeronautics and Space Administration in the 1980's. It is through this process that 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 *Industrial Wastewater General Closure Plan for H-Area Waste Tank Systems,* SRR-CWDA-2011-00022, 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]

There are three categories of cleaning technologies that could be deployed for additional annulus cleaning in Tank 16. These include mechanical removal, water dissolution and sluicing, and chemical cleaning with OA. The following subsections describe the available technologies and their viability for removing additional material from the Tank 16 annulus.

6.2.1.1 Mechanical Cleaning Technologies

As described in Section 4.2, in early 1977 steam mixing jets (25 gallons per minute) were installed in the Tank 16 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 due to diminished effectiveness and to avoid delaying the Tank 16 primary tank sludge removal demonstration. No additional waste removal has been performed in the Tank 16 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 16 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 $16.6 million) 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]

No new mechanical cleaning technologies have been identified or are technically mature enough for deployment in the Type II tanks such as Tank 16. [SRR-LWE-2014-00055] In addition, the final sampling and analysis of Tank 16 residuals did not reveal any new information that brings into question the viability associated with additional mechanical cleaning campaigns discussed above.

6.2.1.2 Water Dissolution and Sluicing

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 16 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 waste 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 $7 million 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. [SRR-WRC-2012-0018] As discussed in detail in Section 4.3.2, 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 become 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 16 annulus. [SRR-LWP-2012-00068]

No new water dissolution and sluicing technologies have been identified or are technically mature enough for deployment in the Type II tanks such as Tank 16. [SRR-LWE-2014-00055] In addition, the final sampling and analysis of Tank 16 residuals did not reveal any new information that brings into question the viability associated with additional water dissolution and cleaning campaigns discussed above.

6.2.1.3 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 16 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. As noted

in Section 4.3.2, 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 $7 million).

The use of OA to remove additional waste from the Tank 16 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]

6.2.2 Highly Radioactive Radionuclide Removal Effectiveness

Table 6.2-1 shows the total residual inventory of HRRs in Tank the 16 annulus. The cooling coil and wall inventory was determined to be negligible. The floor inventory, which includes the equipment holdup, was determined to be insignificant and therefore not evaluated for removal. The material associated with the sand pads was determined to be inaccessible for removal. Additional discussion on residual inventories is provided in Section 4.1.2 through 4.1.3 of *Industrial Wastewater Closure Module for the Liquid Waste Tank 16 H-Area Tank Farm Savannah River Site*. [SRR-CWDA-2013-00091] Therefore, it is reasonable to evaluate removal of additional HRRs from the annulus in the following subsections. As discussed in Section 6.3.4, the predicted dose reduction resulting from additional HRR removal in the Tank 16 annulus is highly dependent on the specific radionuclide being removed.

Table 6.2-1: Highly Radioactive Radionuclide Inventory in the Tank 16 Annulus

Radionuclides	Tank 16 Annulus Inventory (Ci)
Sr-90	1.6E+04
Tc-99	1.9E+00
I-129	7.9E-03
Cs-137	5.7E+03
U-233	<1.1E-02
U-234	1.2E-02
U-235	1.8E-04
Np-237	2.0E-02
Pu-238	3.5E+01
Pu-239	4.7E+00
Pu-240	2.1E+00
Am-241	7.7E+00
Am-243	<8.0E-03
Total	**2.18E+04**

[SRR-CWDA-2014-00071]

Without performing additional studies with actual field tests, the effectiveness of any future technology for additional HRR removal from the Tank 16 annulus cannot be accurately predicted. Removal of all of the HRRs from the Tank 16 annulus is considered unrealistic.

6.2.3 Selection of Technology for Potential Removal of Additional Highly Radioactive Radionuclides

No new technology has been identified that has reached a level of maturity for deployment for removal of significant additional HRR concentrations from the Tank 16 annulus. The financial costs associated with deployment of additional annulus material removal activities for removal of additional HRRs was estimated to be about $7 million for the lowest cost technology of water dissolution and sluicing. The vendor-proposed mechanical cleaning technology costs over $16.6 million, 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 estimated removal efficiencies for these technologies could not be provided in a manner that would allow for differentiating between the effectiveness of the technologies. Therefore, a representative technology for additional waste removal – water dissolution and sluicing – was selected for use in analyzing the costs and benefits of additional HRR removal. The financial costs associated with deployment of additional annulus material removal activities for removal of additional HRRs was estimated to be about $7 million. [U-ESR-H-00107] Without performing additional studies with actual field tests, the effectiveness of an additional cleaning campaign, or campaigns, on HRR removal from the Tank 16 annulus cannot be predicted. Therefore, in order to assess the costs and benefits of additional HRR removal, it was assumed that use of this technology

would remove 75% of the remaining HRRs from the Tank 16 annulus and would cost $7 million.

6.3 Benefits of Additional Removal of Highly Radioactive Radionuclides

This section describes the benefits of removing additional HRRs from the Tank 16 annulus. It evaluates the dose impact and potential benefits of additional HRR removal from the Tank 16 annulus. Finally, there is discussion on the value of averted dose and potential benefits of reducing the amount of radioactive waste disposed of onsite.

6.3.1 Consideration of Potential Benefits

6.3.1.1 Potential Impact on Dose

The Tank 16 Special Analysis projected that the maximum dose to a hypothetical future MOP from all sources within the closed HTF during the performance period would be approximately 4 mrem/yr TEDE approximately 2,610 years following HTF closure. As previously discussed, because of the complexities in groundwater flow, for modeling purposes, the HTF is divided into six sectors labeled A through F. The highest predicted groundwater radionuclide concentration, 100 meters hydraulically down gradient from the HTF boundary, regardless of the specific sector, is used in predicting the maximum dose to a MOP. [SRR-CWDA-2010-00128] Although Sector A provides the highest doses when considering all of the sources within the HTF (i.e., the approximately 4.1 mrem/yr peak TEDE is associated with Sector A), the Tank 16 annulus provide greater impacts on Sector C based on the projected groundwater flow paths emanating from the location of those waste tanks. Therefore, to evaluate the maximum potential impact of just the Tank 16 annulus residual inventories this discussion focuses on the Sector C dose results.

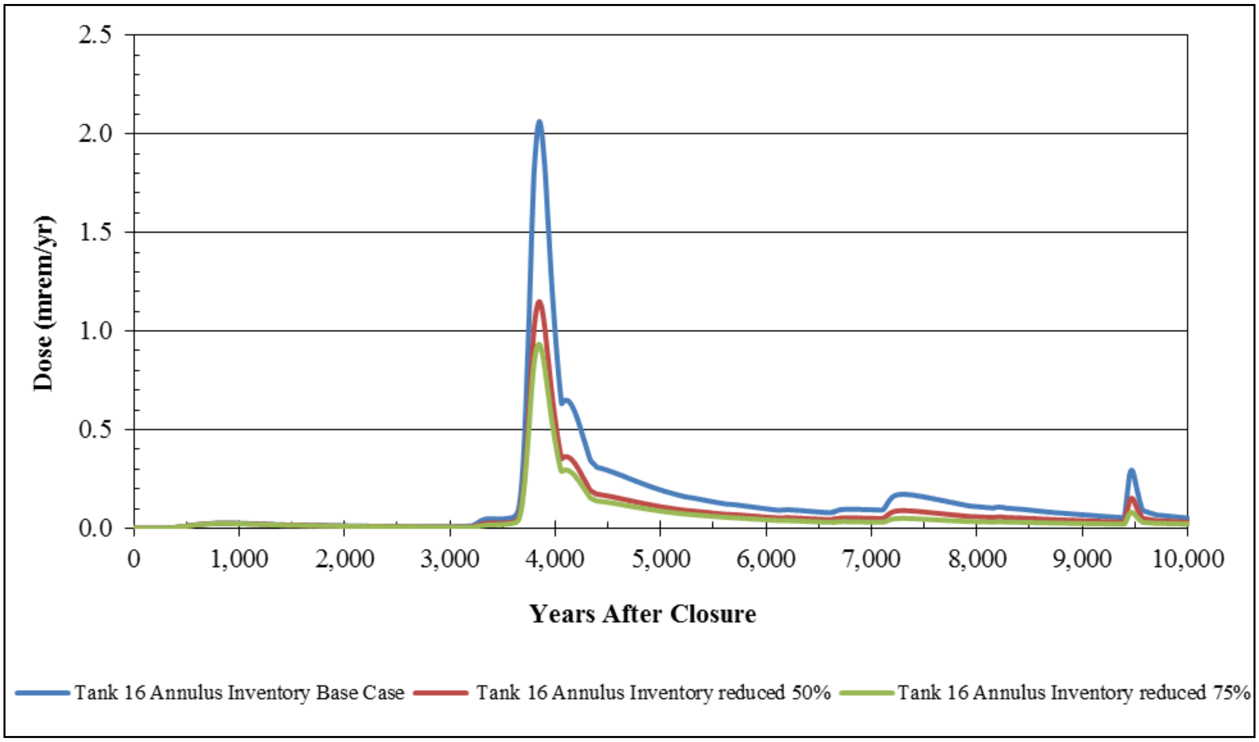
Tank 16 is modeled as "degraded" (i.e., no liners, primary or five-foot annulus pan, or residual liner materials, such as iron oxides, are assumed to be present to mitigate contaminant transport in the PA modeling for these waste tanks). The modeling assumption that no carbon-steel primary tank liner 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 Tank 16, the liner is not assumed to exist, or otherwise retard flow in the integrated conceptual model.

The potential averted dose associated with additional HRR removal from the Tank 16 annulus can be inferred from Figure 6.3-1. This figure shows the results of modeling performed as part of the Tank 16 Special Analysis. [SRR-CWDA-2014-00106] The figure shows that the Tank 16 100-meter all-pathways peak TEDE is 2.1 mrem/yr at year 3,850 due to I-129. There are no other TEDE peaks due to Tank 16 above 0.5 mrem/yr in 100,000 years. If one-half of the annulus volume were removed, the Tank 16 100-meter all-pathways peak dose would still be 1.1 mrem/yr due to I-129. If 75% of the annulus inventory were removed, the Tank 16 100-meter all-pathways peak dose would be approximately 0.9 mrem/yr (an averted TEDE of 1.2 mrem/yr or 60 millirem over 50 years). This 0.9 TEDE is attributed to the remaining HRR inventory in the annulus, primary and sand pads. It is impractical to consider removal of 100% of the Tank 16 inventory due to the difficulty of removing all waste from the annulus and the primary and the tremendous effort to gain

access for waste removal from the sand pads. A cost benefit analysis associated with 100% HRR removal from Tank 16 is implicitly unnecessary based on the low dose benefit from removal, the significant additional worker exposure associated with removal and tremendous cost that additional cleaning would entail.

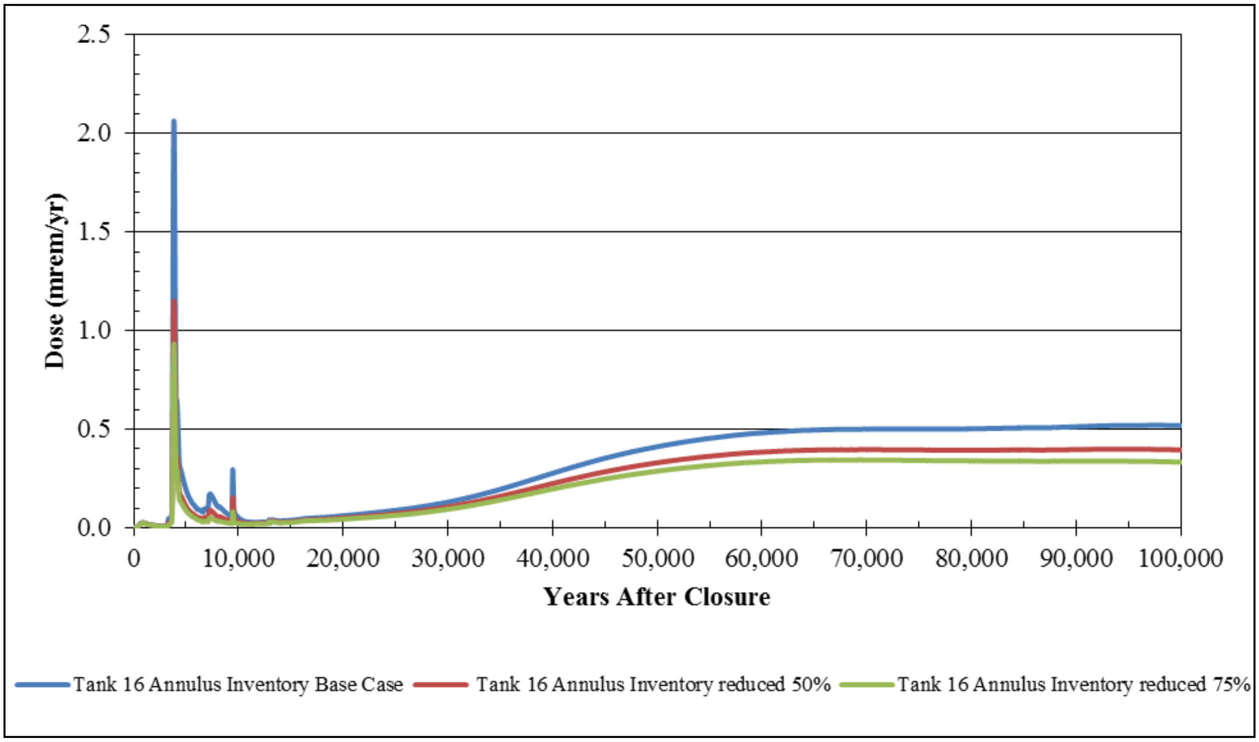
Results are shown for the 100-meter MOP, peak all-pathways TEDE in 10,000 years and 100,000 years with the current Tank 16 inventory and with 50% and 75% of the inventory in Figures 6.3-1 and 6.3-2.

Figure 6.3-1: Sector C 100-Meter MOP Peak All-Pathways TEDE within 10,000 Years with Tank 16 Contribution Only – Variable Tank 16 Annulus Inventory



[SRR-CWDA-2014-00106]

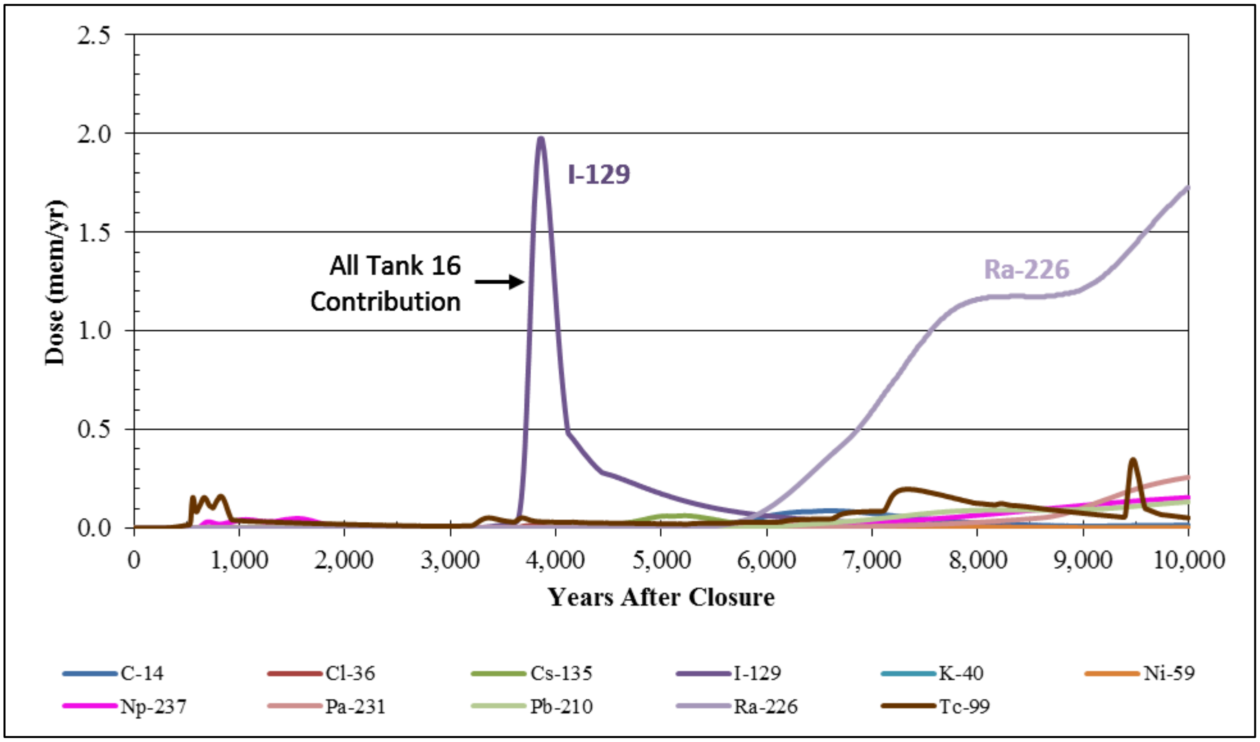
Figure 6.3-2: Sector C 100-Meter MOP Peak All-Pathways TEDE within 100,000 Years with Tank 16 Contribution Only – Variable Tank 16 Annulus Inventory



[SRR-CWDA-2014-00106]

Figure 6.3-3 shows the HTF individual radionuclide contributions to the Sector C 100-meter groundwater pathway effective dose equivalent (EDE) and the Tank 16 I-129 groundwater pathway peak EDE.

Figure 6.3-3: Individual Radionuclide Contributors from All Waste Tanks to the Sector C 100-Meter Groundwater Pathway EDE, 10,000 Years



[SRR-CWDA-2014-00106]

6.3.1.2 Consideration of NRC Guidance on Cost-Benefit Analyses

NRC guidance in NUREG-1854 identifies potential benefits associated with performing additional radionuclide removal beyond removal performed to meet the applicable performance objectives. Table 6.3-1 lists the potential benefits provided in NUREG-1854 and shows how the benefits apply to the Tank 16 annulus.

Table 6.3-1: Benefits of Additional Highly Radioactive Radionuclide Removal

Potential Benefits (NUREG-1854)	**Tank 16**
Averted long-term dose to members of the public, including potential inadvertent intruders	An estimated maximum reduction in the predicted all-pathways dose to a MOP from removing 75% of the HRRs from the annulus is 1.2 mrem/yr. This savings of 1.2 mrem/yr would amount to a predicted 50-year averted dose of 60 mrem. There would be no reduction in radiation doses to a potential inadvertent intruder because regional drilling practices do not provide for encountering hard subsurface rocks, making installation of a water well that encountered residual waste in the grouted waste tank unrealistic.
Reduction in radiological dose to workers because of increased waste stabilization, decreased numbers of waste transfers in tank farms, or other similar considerations	There would be no worker radiation dose reduction, but rather an increase to current worker dose as discussed in Section 6.2.1.
Decrease in costs of other entities, such as risks reduction in costs incurred by public water supply utilities to meet the requirements of the Safe Drinking Water Act	Modeling determined radionuclide concentrations at the seeplines down gradient from HTF and at the 100-meter boundary for both 1,000 years and 10,000 years after HTF closure. These modeling results demonstrate reasonable assurance that the respective peak doses remain below the state drinking water standards during the 1,000-year DOE compliance period following closure of HTF. Additionally, no constituents modeled are above the state drinking water standards at the seeplines within the 10,000-year period following HTF closure. The modeled peak groundwater concentration at 100 meters associated with the Tank 16 I-129 inventory is 13 pCi/L (which equates to an approximate 4.2 mrem/yr modeled beta-gamma EDE and would therefore exceed the 4 mrem/yr beta-gamma dose requirement of the state drinking water standard) at year 3,850 following HTF closure. 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). These modeling results are anticipated to be conservative and not anticipated because of continue DOE proprietorship over the site, groundwater use restrictions and the more likely groundwater exposure at the seeplines where the modeled beta-gamma EDE is below the state drinking water standard. Accordingly, there would be negligible cost benefit to the public water supply during this period from removing additional HRR inventory from Tank 16. [SRR-CWDA-2013-00091]

Table 6.3-1: Benefits of Additional Highly Radioactive Radionuclide Removal

Potential Benefits (NUREG-1854)	Tank 16
Reduction of impact on natural resources, such as groundwater aquifers	Modeling determined radionuclide concentrations at the seeplines down gradient from HTF and at the 100-meter boundary for both 1,000 years and 10,000 years after HTF closure. These modeling results demonstrate reasonable assurance that the respective peak doses remain below the state drinking water standards during the 1,000-year DOE compliance period following closure of HTF. Additionally, no constituents modeled are above the state drinking water standards at the seeplines within the 10,000-year period following HTF closure. The modeled peak groundwater concentration at 100 meters associated with the Tank 16 I-129 inventory is 13 pCi/L (which equates to an approximate 4.2 mrem/yr modeled beta-gamma EDE and would therefore exceed the 4 mrem/yr beta-gamma dose requirement of the state drinking water standard) at year 3,850 following HTF closure. 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). These modeling results are anticipated to be conservative and not anticipated because of continue DOE proprietorship over the site, groundwater use restrictions and the more likely groundwater exposure at the seeplines where the modeled beta-gamma EDE is below the state drinking water standard. Accordingly, there would be negligible reduction of impacts on natural resources, such as groundwater aquifers, during this period from removing the radionuclide inventory in Tank 16. [SRR-CWDA-2013-00091]
Improvement of esthetics, changes in land use and reduction in monitoring costs	This benefit does not apply. (NRC indicates in NUREG-1854 that it is not expected to be applicable in most cases.)

As shown in Table 6.3-1 there would be no substantial benefit to the public, workers or the environment to removing additional HRRs from the Tank 16 annulus.

6.3.1.3 ALARA Considerations

DOE defines ALARA in DOE Order 458.1 as follows:

> *"An approach to radiation protection to manage and control releases of radioactive material to the environment, and exposure to the work force and to members of the public so that the levels are as low as is reasonably achievable, taking into account societal, environmental, technical, economic, and public policy considerations. As used in this Order, ALARA is not a specific release or dose limit but a process which has the goal of optimizing control and management of releases of radioactive material to the environment and doses so that they are as far below the applicable limits of the Order as reasonably achievable."*

DOE's definition of ALARA in 10 CFR 835, *Occupational Radiation Protection*, is similar but adds the provision that exposure includes "both individual and collective".

The DOE definitions of ALARA are similar to the NRC definition. ALARA is a universally recognized fundamental principle of radiation protection. As can be seen from the definition, it is comparable with the second criterion of Section 3116(a) of the NDAA, although somewhat broader in scope.

Given this comparability, it is useful to consider whether additional HRR removal from the Tank 16 annulus would be consistent with the ALARA principle. Appendix N to NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance, Characterization, Survey, and Determination of Radiological Criteria*, provides guidance on ALARA analyses for decommissioning plans, including quantitative cost-benefit analyses.

Appendix N describes five different possible benefits of achieving a decommissioning goal below the dose limit: (1) collective dose averted, (2) regulatory cost avoided, (3) changes in land values, (4) esthetics and (5) reduction in public opposition.

The first possible benefit differs from the approach used in NUREG-1854, which focuses on averting dose to an individual who inhabits the area of the closure facility sometime in the future. Regarding collective dose averted, Appendix N states that "In the simplest form of the analysis, the only benefit from a reduction in the level of residual radioactivity is the monetary value of the collective averted dose to future occupants of the site." Formula N-1 of NUREG-1757, Volume 2, shows how the benefits of the averted dose can be calculated:

$$B_{AD} = \$2{,}000 \text{ x } PW(AD_{collective})$$

Where B_{AD}	=	benefit from an averted dose for a remediation action, in current U.S. dollars
\$2,000	=	value in dollars of a person-rem averted (from NUREG/BR-0058)
$PW(AD_{collective})$	=	present worth of a future collective averted dose

Appendix N states that:

> *"An acceptable value for a collective dose is $2,000 per person-rem averted, discounted for a dose averted in the future. See Section 4.3.3 of "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," NUREG/BR-0058, Revision 2, November 1995. For doses averted within the first 100 years, a discount rate of 7% should be used. For doses averted beyond 100 years, a 3% discount rate should be used."*

This process does not directly apply to the Tank 16 annulus case because it is based on collective dose averted rather than individual dose averted. However, it is noteworthy that NRC uses the $2,000 per person-rem averted dose value with discounting for future dose reductions even though these would be involuntary doses without benefits, rather than voluntary occupational doses that would result in benefits.

The other four potential benefits – regulatory costs avoided[4], changes in land values, esthetics and reduction in public opposition – would not be significant factors in the case of the Tank 16 annulus.

6.3.1.4 Potential Benefits From Reducing Radioactive Waste Disposed of Onsite

If additional waste were to be removed from the Tank 16 annulus, it would be pretreated like other tank waste, with the sludge/solids waste likely vitrified for eventual disposal in an offsite geologic repository for high-level waste and the salt waste fraction destined for treatment and the decontaminated salt solution ultimately disposed of as low-level waste in the Saltstone Disposal Facility. The Tank 16 annulus residuals that would be removed in connection with additional HRR removal, assuming 75% removal, would be expected to be vitrified in approximately 8 high-level waste canisters. [SRR-LWP-2015-00004] This process would therefore reduce radioactive waste disposed of onsite by a small amount – approximately 1,425 gallons (190 cubic feet) – which can be viewed as another benefit of additional waste retrieval. The estimated 190 cubic feet is negligible by comparison with the volume of low-level waste disposed of onsite in Fiscal Year 2014, which was 5,118 cubic meters (approximately 180,740 cubic feet), being approximately 0.1% of that amount. [SRNL-STI-2013-00718, SRNL-STI-2014-00582] The benefit would obviously be relatively small because of the relatively small waste volume.

6.3.2 Consideration of Potential Benefits Late Dose

6.3.2.1 Potential Impact on Late Dose

The Tank 16 inventory contributes less than 0.5 mrem/yr (TEDE) during the late dose period of 10,000 through 100,000 years after HTF closure. As previously noted, the Tank 16 peak dose occurs at 3,850 years after HTF closure. Additional removal of HRRs from Tank 16 would therefore have insignificant benefit during the late dose period.

6.3.2.2 Averted Long-Term Dose

As previously discussed, the main benefit associated with removal of additional HRRs would be the reduction in predicted dose to a future hypothetical MOP. Assuming 75% of remaining waste is removed from the Tank 16 annulus, the 50-year averted dose associated with doses beyond the 10,000-year period would be 9.5 millirem (0.19 mrem/yr x 50 years).

6.3.3 Consideration of Uncertainties

There are uncertainties in many aspects of this cost-benefit analysis. Regarding the identified benefits, there are some uncertainties in the estimated dose reduction. The Tank 16 Special Analysis describes these uncertainties and concludes that the uncertainty in the timing and magnitude of the high dose peaks associated with I-129 are not sufficient for this dose peak to impact performance within 1,000 years after HTF closure. In the Base Case the Tank 16 annulus residuals do not impact the HTF peak dose to a hypothetical future MOP due to the waste tank liner failing at the time of closure. Uncertainty in the timing of the waste tank liner failures could potentially result in an increase to the projected doses if the waste tank liner in Tank 16 were to fail later than currently assumed. Although the Tank 16 Special

[4] Regulatory costs avoided in this context pertain to differences between restricted and unrestricted license termination for NRC-licensed sites. [NUREG-1757, Volume 2]

Analysis did not specifically model a case with later liner failure, projected doses which currently occur within 10,000 years after HTF closure provide insight to the magnitude of the doses that could be expected in the case of later liner failure. Due to the impacts of other barriers (e.g., closure cap, waste tank roof, waste tank grout, waste tank basemat), determining the impact to dose, in the case of later liner failure, is not as simple as shifting the projected dose peaks later in time. If later liner failure did result in an later release of contaminants into the groundwater, it is expected that the magnitude of the dose peaks would be lower than the peaks which currently occur within 10,000 years. The reason it is expected that the magnitude of the doses would be lower is that release of the contaminants would likely occur over a longer period of time while other barriers are less degraded (e.g., closure cap, basemat, grout), resulting in the quantity of contaminates released at any given point in time being lower than what currently is modeled in the Base Case and Composite Sensitivity Study. Therefore, it is reasonable to assume that the magnitude of the peak dose projected to occur within 10,000 years would bound the peak dose that may occur later in the case of later liner failure. For Tank 16, as discussed in Section 6.3.4, this dose would be 2.1 mrem/yr (TEDE).

There is uncertainty in the percentage of the HRRs that could be removed from the waste tank by use of any technology evaluated. Removal of less than the 75% of the HRRs in the annulus would reduce the potential benefit of estimated dose averted. Removal of more than 75% of the HRRs in the annulus would only provide minimal additional benefit. Removal of greater than 75% of Tank 16 HRRs results in minimal dose reduction.

Uncertainties are also present in the cost for implementing the process of HRR removal. However, the $7 million is considered very conservative relative to the actual costs that would be required to implement additional HRR removal.

Given such uncertainties, DOE concluded that a case with assumed removal of 75% of the Tank 16 annulus inventory coupled with 14 person-rem worker exposure and an assumed $7 million cost of implementation and potential averted dose of 1.2 mrem/yr would take the overall uncertainties into account for this cost-benefit analysis.

6.3.4 Value of the Averted Dose

Ionizing radiation is an established carcinogen. The “value” of averted radiation dose is associated with improved health of the exposed person or persons, in particular, a reduced risk of developing cancer.

6.3.4.1 Estimating Risk From Exposure to Ionizing Radiation

All radiological risk factors are based on observed and documented health effects to actual people who have received extremely high acute doses (more than 10,000 millirem) of radiation, such as the Japanese atomic bomb survivors. Radiological risks at low doses (less than 10,000 millirem) are theoretical and are estimated by extrapolating the observed health effects at high doses to the low-dose region by using a linear, no-threshold model. However, cancer and other health effects have not been observed consistently at low radiation doses because the health risks either do not exist or are so low that they are undetectable by current scientific methods. [SRNS-STI-2014-00006]

The potential lifetime risk of an exposed individual developing a fatal or nonfatal cancer because of his or her radiation dose (TEDE) can be estimated using guidance issued by the Interagency Steering Committee on Radiation Standards (ISCORS).[5] [ML112720579] As an example, using the peak dose during the initial 10,000 years from Tank 16 in the Tank 16 Special Analysis, the increased risk to an individual receiving an additional dose of 2.1 mrem/yr (a total of 105 millirem over 50 years) developing cancer would be estimated as 8.4E-05, that is, about one chance in 12,000 using this guidance.

6.3.4.2 Perspective on the Estimated Amount of Averted Dose

Various comparisons can be used to provide perspective on dose saving from additional HRR removal.

6.3.4.2.1 General Comparisons

Comparisons such as the following have often been used to help put very low radiation doses in perspective:

- DOE specifies an occupational dose limit for general employees of 5 rem/yr (5,000 mrem/yr) in 10 CFR 835, *Occupational Radiation Protection*.
- DOE specifies an allowable dose to a MOP of 100 mrem/yr in DOE Order 458.1, *Radiation Protection of the Public and the Environment*.
- The average person in the United States receives 620 mrem/yr from naturally occurring background radiation and medical procedures as described in NCRP-160, *Ionizing Radiation Exposure of the Population of the United States*.
- The average person living in Denver, Colorado receives greater than 1,000 mrem/yr from naturally occurring background radiation alone. [NRC_01-01-2011]

6.3.4.2.2 Comparison to Variations in Ambient Radiation Levels Around SRS

The average person living in the Central Savannah River Area receives an annual radiation dose of approximately 620 mrem/yr. The major sources of this dose are natural background radiation (311 mrem/yr) and medical exposure (300 mrem/yr). [NCRP-160]

The site measures ambient gamma radiation levels onsite and offsite as part of its environmental monitoring program. These levels are measured using thermoluminescent dosimeters that are read quarterly with the readings compiled in annual totals. Table 6.3-2 shows annual totals measured at several offsite locations in 2011. [SRNS-STI-2014-00006]

[5] The guidance in ISCORS Report 2002-2 – *A Method for Estimating Radiation Risk from Total Effective Dose Equivalent (TEDE)* – is used because the estimated doses are expressed in terms of TEDE. DOE recommends that agencies use a conversion factor of 8E-04 from ISCORS Report 2002-2 per rem for morbidity (total cancer incidence) in qualitative or semi-quantitative estimates of risk from radiation exposure to members of the general public. [ML112720579]

Table 6.3-2: Variations in Ambient Radiation Levels Measured Around SRS

Location	Annual Total (mR)[a]	Difference from Average (mR)[b]
Jackson, SC	97	-10
Barnwell, SC	103	-4
Beech Island, SC	122	+15
Girard, GA	118	+11
Williston, SC	124	+17
Martin, SC	100	-7
McBean, GA	94	-13
New Ellenton, SC	113	+6
Windsor, SC	93	-14

[a] From SRNS-STI-2014-00006, Data Table 5-6, rounded to whole numbers.
[b] Average from SRNS-STI-2014-00006, Data Table 5-6, for nine offsite population centers.

Table 6.3-2 shows variation in the measured ambient gamma radiation levels from terrestrial and cosmic sources, which are two components of natural background radiation. Such variation is common and is primarily due to differences in radioactivity in the soil or construction materials at the different locations. These measured levels are lower than the total radiation exposure to individuals near SRS because medical and other sources are not included.

The estimated dose to the hypothetical maximally exposed offsite individual from site operations is reported in the annual SRS Environmental Report. This estimate for calendar year 2013 was 0.19 millirem from the air, standard liquid and irrigation pathways. [SRNS-STI-2014-00006]

As can be seen from the table, the difference between levels at the town of Windsor and the town of Williston is 31 mR/yr. Because of this difference in natural background radiation levels, the potential increased risk to an individual moving from a home in Windsor to a home in Williston would be around 15 times greater than the potential reduced risk associated with averting approximately 2.1 mrem/yr maximum dose by removing all of the residual HRRs from Tank 16.

6.3.4.2.3 Monetary Value of Averted Dose

Cost-benefit analyses normally assign monetary values to radiation doses for comparison purposes, such as $2,000 per person-rem as specified in NUREG/BR-0058, *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission*. NRC originally developed a conversion factor of $1,000 per person-rem for use in comparing the costs and benefits of averted population dose – that is, collective dose in person-rem – from nuclear power plant emissions and later changed the value to $2,000 per person-rem in NUREG-1530,

Reassessment of NRC's Dollar Per Person-Rem Conversion Factor. However, this conversion factor is not directly applicable to NDAA Section 3116 waste determinations because (1) it applies to collective dose, not dose to an individual and (2) because it is generally applied to voluntary occupational doses, where the predicted dose to a single MOP in NDAA Section 3116 waste determination analyses is involuntary.[6]

Nonetheless, from a radiation protection standpoint, application of the $2,000 per person-rem value to exposure to a single individual would not be unreasonable at very low doses such as 1 mrem/yr. There would be no difference in the total increased risk of developing cancer – the main theoretical insult to the body from relatively low doses of radiation – whether the dose was received by one person or two or more persons. However, this would not be the case for very high doses where other health effects could occur in a solely exposed individual.

While such considerations could not readily be used to establish a specific dollar value for involuntary exposure to an individual, it would be reasonable to conclude that expenditure of large sums to save a dose of a few millirem to an involuntarily exposed individual would not be sensible.

In the case of Tank 16, the total predicted 50-year averted TEDE was determined to be 60 millirem with removal of 75% of the Tank 16 annulus inventory. Therefore, use of the $7 million estimate for additional removal of HRRs would result in a $117 million per rem estimated unit cost of dose reduction.

6.4 Cost of Additional Removal of Highly Radioactive Radionuclides

This section identifies both the direct and indirect costs to remove additional HRRs from Tank 16 using the representative technology.

6.4.1 Summary of Additional Costs

This analysis is consistent with NRC guidance in NUREG-1854 in evaluation of additional costs. NRC guidance in Table 2-1 of NUREG-1854 identifies potential costs associated with performing additional radionuclide removal beyond removal performed to meet the applicable performance objective. Table 6.4-1 lists the potential costs provided in NUREG-1854 and shows how they apply to additional HRR removal from Tank 16.

[6] However, as discussed in Section 6.3.1.3, NRC does use the $2,000 per person-rem value, with discounting, in Appendix N to NUREG-1757, Volume 2, even though the predicted dose received by future occupants of the remediated site would be involuntary and without benefit.

Table 6.4-1: Costs of Additional Highly Radioactive Radionuclide Removal

Potential Costs (NUREG-1854)	Tank 16 Case
Radiological dose to workers due to additional radionuclide removal activities	The collective additional dose to workers for the representative technology is estimated to be 14 rem.[7] However, this dose would be much higher without engineered controls and other provisions to minimize worker dose consistent with DOE ALARA requirements. The monetary value of 14 rem would be $28,000 using the conversion of $2,000 per person-rem commonly used in such cases, without consideration of the additional costs necessary to minimize worker exposure. These costs are addressed below.
Financial cost of additional radionuclide removal	This cost is very conservatively estimated to be, at a minimum, approximately $7 million. This represents the total cost estimate for personnel to perform demolition and removal work, annulus cleaning using water dissolution and sluicing and post annulus cleaning sampling.[8]
Additional transportation risks	No transportation risks are expected.
Chemical and physical effects of removal activities on downstream waste processing or storage systems	No chemical effects are expected. However, the additional HRR removal process would generate an estimated 150,000 gallons of new radioactive waste, which would have to be processed and treated for disposal as discussed previously.
Additional impacts on DOE's mission or schedule	Devoting effort to removing additional HRRs from the Tank 16 annulus would impact the HTF closure effort by tying up common infrastructure and taking up limited waste tank space and would impact the Liquid Waste Program in other ways by diverting funding away from higher risk reduction activities. See discussion in Section 6.2.
Doses to the public due to additional removal activities	Not expected to be significant.
Environmental disruption due to additional removal activities	Not expected to be significant.
Non-radiological workplace accidents due to additional removal activities	This cost, which would be relatively small, was not quantified in the interest of conservatism.

[7] This represents the estimated dose if additional removal had been carried out prior to waste tank isolation and grouting preparations. Since that time, DOE has done considerable work in preparing Tank 16 for closure (e.g., removal of equipment, isolation of lines, preparation of risers for grout addition). Therefore, performance of additional cleaning campaigns in the Tank 16 annulus at this time would likely result in considerably more worker dose than previously estimated.

[8] This represents the estimated cost if additional removal had been carried out prior to waste tank isolation and grouting preparations. Since that time, DOE has done considerable work in preparing Tank 16 for closure (e.g., removal of equipment, isolation of lines, preparation of risers for grout addition). Therefore, performance of additional cleaning campaigns in the Tank 16 annulus at this time would cost considerably more than previously estimated.

As can be seen in Table 6.4-1, the direct and indirect costs of additional radionuclide removal using the representative technology is conservatively estimated to be approximately $7 million. As noted previously the unit cost of averted dose to the future MOP during the initial 10,000 years after HTF closure is $117 million per rem.

For the period after 10,000 years out to 100,000 years, the total predicted 50-year averted TEDE was determined to be only 7.5 millirem. Therefore, use of the $7 million estimate for additional removal of HRRs would result in a $900 million per rem estimated unit cost of dose reduction.

This analysis also considered NRC regulatory guidance in Appendix N of NUREG-1757, Volume 2 (see Section 6.3.1.3). Table N-1 in Appendix N describes six different possible costs of achieving a decommissioning goal below the dose limit: (1) remediation costs, (2) additional occupational/public dose, (3) occupational non-radiological risks, (4) transportation direct costs and implied risks, (5) environmental impacts and (6) loss of economic use of the site/facility. These possible costs are generally equivalent to those listed in NUREG-1854 and reproduced above in Table 6.4-1, with remediation costs being equivalent to the cost of additional HRR removal.

6.5 Discussion of Costs and Benefits

This section discusses matters important to determining whether the benefits of removal of additional HRRs would outweigh the costs and describes the decision criteria that DOE originally established for use as guidance in *Cost-Benefit Analysis for Removal of Additional Highly Radioactive Radionuclides from Tank 18.* [SRR-CWDA-2012-00026] As described in the HTF 3116 Basis Document, DOE will follow the same approach for all cost-benefit analyses associated with the HTF waste tanks. [DOE/SRS-WD-2014-001]

6.5.1 Net Social Benefit

Cost-benefit analyses typically involve estimating the equivalent monetary value of the benefits and the costs of alternatives or of a particular undertaking such as a new project and comparing these monetary values to support a decision as to the best alternative or whether the particular undertaking would be worthwhile. Being worthwhile means that the benefits outweigh the costs; that is, there would be net social benefit in undertaking the endeavor.

NUREG/BR-0184 refers to cost-benefit analyses as value-impact analyses. It states that:

> *"…a value-impact analysis is a balancing of the benefits (values) and costs (impacts) associated with a proposed action or decision. Values and impacts should be evaluated in monetary terms when feasible, resorting to qualitative terms where conversion to monetary equivalents cannot be done."*

Section 6.3 describes the benefits (values) of additional HRR removal from Tank 16 and Section 6.4 describes the associated costs (impacts). Both the benefits and the costs have been quantified to the extent practical, but it was not practical, nor necessary for this evaluation to establish the equivalent money value of the primary benefit – the estimated averted dose to a future MOP from the closed waste tank farm – or the benefit of a small reduction in radioactive waste to be disposed of onsite.

It is important to place these benefits in perspective to provide a qualitative measure of their importance. This can be done for an estimated averted dose by (1) identifying the calculated increased risk of the exposed individual developing cancer, (2) by comparing the estimated averted dose to dose limits for occupational and public exposure and (3) by comparing the estimated dose reduction to the 620 mrem/yr that the average American received in 2006 from naturally occurring background radiation and medical procedures. As previously described, because there would be minimal averted dose associated with additional HRR removal from Tank 16 during the initial 10,000 years after HTF closure, there would be minimal net benefit relative to averted dose.

6.5.2 Additional Perspective on Occupational Dose

As shown in Table 6.4-1, the assumed increased radiation dose to workers of approximately 14 rem is valued at approximately $28,000 using NRC guidance in NUREG/BR-0058. The estimated worker dose will likely result from smaller doses to many people involved with the work, it is not practical to determine exactly how many people will be involved. Regardless, the assumed 14 rem dose associated with additional HRR removal would be at the benefit of 1.2 mrem/yr dose avoidance to a hypothetical future inhabitant of the waste tank farm area during the initial 10,000 years after HTF closure. As noted in Table 6.4-1, the 14 rem estimated dose represents if additional removal had been carried out prior to waste tank isolation and grouting preparations. Since that time, DOE has done considerable work in preparing Tank 16 for closure (e.g., removal of equipment, isolation of lines, preparation of risers for grout addition). Therefore, performance of additional cleaning campaigns in Tank 16 at this time would likely result in considerably more worker dose than previously estimated.

In addition, as discussed in Section 6.3.1.4 removal of additional material from Tank 16 would result in the generation of additional DWPF canisters. The processing, storing, shipping and disposal of the canisters would also add to the occupational dose associated with additional HRR removal.

6.5.3 Additional Perspective on Financial Costs

The $7 million utilized for the purposes of this evaluation reflects the costs associated with demolition and removal work, annulus cleaning using water dissolution and sluicing, and post annulus cleaning sampling. The full financial costs of performing water dissolution and sluicing campaigns was not formally estimated, but it would have increased the costs to even greater than $7 million. It is important to recognize that additional monetary costs would be incurred. For example, procedure revisions, engineering reviews, flow sheet preparation, readiness reviews and additional operational support would be necessary. As noted in Table 6.4-1, $7 million represents the estimated cost if additional removal had been carried out prior to waste tank isolation and grouting preparations. Since that time, DOE has done considerable work in preparing Tank 16 for closure (e.g., removal of equipment, isolation of lines and preparation of risers for grout addition). Therefore, performance of additional cleaning campaigns in Tank 16 at this time would require considerably more than the $7 million utilized throughout this cost-benefit analysis.

As discussed in Section 6.3.1.4, additional HRR removal from Tank 16 would result in the production of additional DWPF canisters. The $7 million being used in this evaluation does

not factor in the cost of producing, storing and transporting additional DWPF canisters. Consideration of these factors makes it clear that the $7 million being utilized in this evaluation is a very conservative value.

6.5.4 Unit Cost of Risk Reduction

The estimated cost of risk reduction for removing additional HRRs can be compared to the estimated cost of risk reduction for other DOE remediation efforts following cost-benefit assessment guidance in *The Decommissioning Handbook.* [ASME 2004] Table 6.5-1 compares such risk reduction costs.

Table 6.5-1 compares the risk reduction versus cost for DOE remediation efforts associated with Tank 16 HRR removal, Idaho National Laboratory and West Valley Demonstration Project. It can be seen that Tank 16 HRR removal has the lowest risk reduction per cost (7.0E-12) compared to the remediation efforts at the other DOE facilities. This value is based on the following:

- TEDE reduction over 50 years from removal of an additional 75% of the HRRs from the Tank 16 annulus: 60 mrem (1.2mrem x 50 years)
- Risk reduction in terms of excess cancers per rem from radiation exposure to a MOP: 8E-04 x 0.06 rem = 4.8E-05
- Risk reduction per cost to remove 75% of the HRRs from the Tank 16 annulus: 4.8E-05 (risk reduction) / $7.0E+6 (cost) = approximately 7.0E-12.

Table 6.5-1: Risk Reduction Cost Comparisons

Project	TEDE Reduction (mrem over 50 years)	Risk Reduction Factor[a]	Estimated Dollar Cost	Risk Reduction/ Cost
Tank 16 additional 75% HRR removal from the annulus	60	4.8E-05	7.0E+06	7.0E-12
Idaho National Laboratory Technical Area North-607 (Hot Shop Area containing approximately 77 curies in 2006) [DOE/ID-11302]	NA	3.3E-03[b]	3.4E+07[c]	8.0E-10
Idaho National Laboratory TRA Hot Cells (Building with three hot cells containing 1,800 curies in 2009) [DOE/ID-11397]	NA	2.0E-01[d]	6.3E+06[e]	3.0E-08
Idaho National Laboratory Engineering Test Reactor Complex. This complex contained 59,000 curies in 2006 with >99% in the reactor vessel. Alternative 3 removed the vessel and Alternative 2 grouted it in place. [DOE/ID-11272]	NA	3.3E-04[f]	2.0E+06[c]	2.0E-10
West Valley Demonstration Project, Phase 1 of the decommissioning. Phase 1 activities include complete removal of the Process Building and Vitrification Facility. [DOE-WVDP-2009, DOE/EIS-0226]	101,000[g]	8.08E-02	1.2E+09[h]	7.0E-11

NA = not available

[a] For total increased cancer risk over 50 years using 8E-04 excess cancers per rem TEDE as recommended by the Interagency Steering Committee on Radiation Standards. [ML112720579]

[b] Based on a 2.0E-03 for 30 years extrapolated to 50 years.

[c] In 2006 dollars.

[d] Based the total risk to a future resident over 30 years of 1.21E-01 extrapolated to 50 years.

[e] In 2009 dollars.

[f] Based the total risk to a future resident over 30 years of 2.0E-04 extrapolated to 50 years.

[g] From Table H-48 of the Final Environmental Impact Statement. [DOE/EIS-0226] This estimate is for the peak annual dose to a future MOP (a resident farmer) exposed to contamination from use of groundwater from a hypothetical well sunk into the area of the Vitrification Facility under the no-action alternative. Phase 1 of the decommissioning will completely remove the Vitrification Facility so the annual dose afterwards would be negligible compared to the no-action peak annual dose. This estimated dose was not extended over 50 years in the interest of conservatism (that would have made the unit risk reduction cost 50 times higher).

[h] From Table 4-55 of the Final Environmental Impact Statement. [DOE/EIS-0226] This estimated cost applies to all of the Phase 1 decommissioning activities. The unit cost of dose reduction would have been higher if the estimated cost for removal of just the Vitrification Facility had been used.

6.5.5 Additional Discussion on ALARA

The definition of ALARA in DOE Order 458.1 requires that societal, environmental, technical, economic and public policy considerations be taken into account in ALARA analyses, with the goal of optimizing control and management of releases of radioactive material to the environment and the resulting doses so that they are as far below the applicable limits of the Order as reasonably achievable. The NRC cost-benefit analysis guidance in NUREG-1854 is generally consistent with DOE Order 458.1 requirements for ALARA analyses, although NUREG-1854 does not mention public policy considerations. The NRC ALARA analysis guidance in NUREG-1757, Volume 2 is likewise generally consistent with the DOE requirements. Consequently, following the NRC guidance in this cost-benefit analysis is comparable to performing an ALARA analysis as required by DOE.

ALARA analyses are discussed in the HTF PA as required by DOE Manual 435.1-1. Section 5.8 of the HTF PA notes that a final ALARA analysis will be completed to support CERCLA closure of HTF, which will include the final design considerations for the closure cap, the final cover for the area. If this final ALARA analysis were to indicate the need for additional dose reduction, measures could be taken such as installation of engineered barriers to extend the timing and/or reduce the magnitude of peak dose from the residual radioactivity in HTF. DOE has evaluated potential options that could be utilized if deemed necessary in the future. [SRNL-STI-2012-00079]

6.5.6 Schedule Considerations

Another potential cost identified in Table 6.4-1 is associated with delaying Tank 16 closure to remove additional HRRs. Tank 16 is a Type II tank that does not meet current requirements for secondary containment and is required to be operationally closed per the FFA. Tank 16 and two other waste tanks are to be closed by October 27, 2015.

While DOE does not consider schedule adherence to be an overriding factor in waste tank operational closure, it is important to both DOE and to the State of South Carolina as the primary stakeholder. DOE therefore would not propose further delaying Tank 16 operational closure unless it can be shown that there would be significant benefit in doing so.

6.5.7 Decision Criteria

Because the benefits of additional HRR removal from Tank 16 cannot be expressed in terms of monetary value, the following risk-informed criteria are being used as guidance in reaching a decision on this matter. These criteria, which were developed for use as guidance in *Cost-Benefit Analysis for Removal of Additional Highly Radioactive Radionuclides from Tank 18* are intended to help make the decision-making process as quantitative as practical. [SRR-CWDA-2012-00026]

6.5.7.1 Four Decision Criteria

The criteria are as follows:

(1) For the benefits to exceed the related costs, the estimated worker occupational dose to remove additional HRRs should not exceed the predicted 50-year averted dose to a MOP by a significant amount.

(2) For the benefits to exceed the related costs, the unit monetary cost of dose reduction should not exceed the $2,000 per person-rem value that NRC assigns to averted collective dose by a significant amount.

(3) For the benefits to exceed the related costs, the unit risk reduction cost (the estimated risk reduction in terms of the increased probability of the MOP developing cancer divided by the estimated cost of HRR reduction) should be significantly greater than the unit risk reduction cost for other representative DOE remediation projects.

(4) Operational closure of Tank 16 should not be delayed in the absence of significant benefit.

If the first three criteria are met, then the benefits would clearly outweigh the costs. If none of the first three criteria are met and the unit risk reduction cost, Criterion (3), is significantly lower than other representative DOE remediation projects, then the costs would clearly outweigh the benefits. If only one or two were to be met, or the unit risk reduction cost, Criterion (3), is comparable to other representative DOE remediation projects, then the fourth criterion would be taken into consideration.

6.5.7.2 Basis for the Criteria

These criteria are based on consideration of NRC guidance and DOE ALARA requirements and information presented in previous sections of this analysis.

6.5.7.2.1 Criterion (1)

The dose to a MOP following waste tank farm closure would be involuntary and without benefits. Occupational dose to remove additional HRRs from Tank 16 would be voluntary and expected to yield benefits as discussed in Section 6.3. However, these differences would not justify the occupational dose substantially exceeding the MOP dose. It would be neither reasonable nor sensible to remove additional HRRs from Tank 16 if the worker dose to accomplish this substantially exceeded the predicted averted dose to a hypothetical MOP during the initial 10,000 years after facility closure.

DOE has used the term *a significant amount* in the criterion to allow risk-informed judgment to be used in determining whether this criterion is met because of the lack of an accepted monetary value for averted dose in waste determinations.

6.5.7.2.2 Criterion (2)

In NUREG-1854, NRC states regarding waste determinations that:

> *"Most notably, it is unclear whether it is appropriate to apply specific cost-benefit metrics discussed in the general guidance to DOE waste determinations. It appears to be more appropriate to compare the costs and benefits of additional radionuclide removal to the costs and benefits of other similar DOE risk-reduction activities (see Examples 1-4). In particular, <u>the $2,000 per person-rem conversion factor</u> that NRC uses in some contexts (e.g., regulatory analyses, ALARA analyses for license termination) <u>may not be a useful metric to apply to waste determination reviews</u>, because the metric is based on collective dose and it is designed to be applied with economic discounting. The long performance period relevant to waste determinations hinders the use of any metric based on collective dose because it is unrealistic to attempt to predict what the population near a disposal site will be for thousands of years after site closure. In addition, NRC staff previously has recommended that the monetary value associated with averted future doses not be discounted in analyses relevant to 10 CFR Part 61."* [emphasis added]

DOE agrees with NRC that the $2,000 per person-rem conversion factor should not be applied directly in this case. Rather than attempting to establish a specific monetary value for averted dose to a MOP for waste determinations, DOE elected to use the term *a significant amount* as in the first criterion to allow the use of risk-informed judgment in determining whether the criterion is met.

6.5.7.2.3 Criterion (3)

The statement in NUREG-1854 quoted above states that, "It appears to be more appropriate to compare the costs and benefits of additional radionuclide removal to the costs and benefits of other similar DOE risk-reduction activities (see Examples 1-4)." The examples in provided in NUREG-1854 generally apply to the final stages of waste removal from underground reprocessing waste tanks. However, DOE has found such efforts to be costly and often yield only minimal benefits in terms of averted dose to a MOP. Given this experience, DOE considers it better to compare unit costs with other types of DOE remediation projects of comparable scope.

As discussed previously, DOE defined the unit cost of risk reduction as the increased probability of the MOP developing cancer divided by the estimated project cost, as suggested in *The Decommissioning Handbook*. [ASME 2004]

6.5.7.2.4 Criterion (4)

This criterion takes into account the potential penalties that could be imposed on DOE for missing the waste tank closure deadline both monetary costs as well as loss of credibility. The costs associated with impacts to other aspects of the Liquid Waste Program, including other risk-reduction activities such as DWPF sludge batch preparation and salt processing are also considered. In addition, the significance of potential benefits are evaluated, such as the magnitude of potential averted dose as compared to average doses received from naturally occurring background radiation and medical procedures.

6.5.7.2.5 Reduction in the Amount of Onsite Waste Disposal

DOE considered including a criterion related to the benefit from the estimated reduction in onsite radioactive waste disposal. However, a reduction of approximately 190 cubic feet is so small compared to the amount of low-level waste routinely disposed of onsite that it would be negligible.

6.6 Evaluation of Criteria and Cost-Benefit Conclusions

This section evaluates the impacts during the 10,000-year performance period against the established criteria and describes DOE conclusions in regards to the costs and benefits of additional HRR removal from Tank 16.

DOE has determined that the costs of removing additional HRRs from Tank 16 would outweigh the benefits; that is, removing HRRs would do more harm than good and would not be practical for the following reasons:

(1) The estimated worker occupational dose of 14 rem to remove additional HRRs would be realized with a 60 millirem 50-year dose savings to a hypothetical future inhabitant of the waste tank farm. Therefore, the estimated worker dose is approximately 230 times the 50-year averted TEDE to the MOP, that is, 230 workers could receive an average dose of 60 millirem during the waste removal work and associated activities. DOE considers this difference to be significant, thus the first decision criteria is not met.

(2) The unit cost of dose reduction would be $117 million per rem based on a 60 millirem 50-year averted TEDE costing $7 million, approximately 58,600 times higher than the $2,000 per person-rem value that NRC assigns to averted collective dose. [NUREG/BR-0058] Thus, the second decision criteria is not met.

(3) The unit risk reduction cost during the initial 10,000-years after closure, shown in Table 6.5-1, is lower than for other typical DOE remediation projects, that is, the risk reduction per unit cost is less, thus the third decision criteria is not met.

Because none of these decision criteria are met and the unit risk reduction cost, Criterion (3), is lower than other representative DOE remediation projects, the costs clearly outweigh the benefits.

Other factors that reinforce this judgment include:

- Delaying Tank 16 closure to remove additional HRRs using a technology such as water dissolution and sluicing, or to take advantage of possible advances in other waste removal technologies, would have a significant adverse impact on the site's Liquid Waste Program.
- The estimated values for occupational dose and financial cost utilized throughout the cost-benefit analysis represent conservative values even if additional HRR removal had been performed prior to waste tank isolation and grouting preparations. Taking into consideration the current field conditions of Tank 16, these values represent extremely conservative assumptions for occupational dose and financial costs that would be associated with performing additional HRR removal at this time.

- The 2.1 mrem/yr peak TEDE to a MOP from Tank 16 is only 9% of the 25 mrem/yr performance objective.
- The estimated averted dose to a future MOP from Tank 16 is less than 1% of the 620 mrem/yr the average person in the United States receives from naturally occurring radiation and medical procedures.
- Additional monetary expenditures required to remove additional HRRs would likely be at the expense of other risk-reduction activities.
- At the time of CERCLA closure if the ALARA analysis performed were to indicate the need for additional dose reduction during the performance period, the closure cap could be redesigned to take advantage of advancements in cap design to reduce infiltration of surface water or additional barriers such as subsurface barrier walls could be installed to mitigate contaminant movement. This would extend the timing and reduce the magnitude of the peak dose resulting from the residual radioactivity in HTF.

7.0 CONCLUSION

Bulk waste and heel removal activities undertaken in Tank 16 were successful in removing over 99% of the waste inventory, which resulted in a removal of greater than 99% of the HRRs. The percentages of HRRs removed for individual radionuclides is shown in Table 7.0-1.

Table 7.0-1: Percentage of HRRs Removed from Tank 16

Radionuclides	Tank 16 HRR Inventory Prior to Waste Removal (1972) (Ci)	Tank 16 HRR Residual Inventory (2014) (Ci)	% Removed
Sr-90	4.02E+06	4.23E+04	98.9%
Tc-99	1.40E+03	4.95E+00	99.6%
I-129	2.15E+00	1.47E-02	99.3%
Cs-137	9.22E+06	9.68E+03	99.9%
U-233	1.26E-01	3.83E-02	69.7%
U-234	2.32E+00	3.26E-02	98.6%
U-235	4.07E-02	3.06E-04	99.2%
Np-237	4.46E+00	3.58E-02	99.2%
Pu-238	3.64E+04	6.48E+01	99.8%
Pu-239	9.28E+02	8.18E+00	99.1%
Pu-240	5.08E+02	3.72E+00	99.3%
Am-241	4.14E+03	1.46E+01	99.6%
Am-243	6.77E+00	1.37E-02	99.8%
Total	**1.33E+07**	**5.21E+04**	**99.6%**

[SRR-CWDA-2015-00019]

The information discussed within this document demonstrates the following for Tank 16.

- Visual inspections of the waste tank indicated that there was a significant reduction in residual material volume in the primary tank resulting from the waste removal operations. Figure 7.0-1 shows Tank 16, after the completion of waste removal operations (Section 4.0).

Figure 7.0-1: Tank 16 After Completion of Waste Removal Operations

- The extent of technology has been reached for the cleaning technology recently deployed in Tank 16 (i.e., MSR, CSR and water rinse).
- No new practical technology has been identified that has reached a level of maturity for deployment to remove significant additional HRRs from Tank 16.
- Continued operation for further cleaning of either Tank 16 would impact other risk reduction activities associated with removing sludge from other waste tanks, including other Type II and Type I tanks, in preparation for closure and stabilization of the removed sludge at DWPF.
- A cost-benefit analysis for deploying another cleaning technology was performed and it demonstrated that it was not practical to continue with active waste removal activities in Tank 16. The analysis included such things as technology capabilities, worker dose, schedule impacts, a quantified cost summary and a risk and benefit analysis. One representative alternative for removing additional HRRs – water dissolution and sluicing – was used for comparison purposes. After evaluating and comparing the benefits and the costs, it was determined that removing additional HRRs from Tank 16 would not produce a net social benefit – that is, it would not be sensible or useful in light of the overall benefit to human health, safety and the environment – for the following reasons:

  (1) Worker occupational dose would be incurred during any additional HRR removal with minimal dose reduction to a hypothetical future inhabitant of the waste tank farm after HTF closure.

  (2) Spending greater than $7 million would result in minimal dose reduction to a hypothetical future inhabitant of the waste tank farm.

  (3) The estimated risk reduction per dollar spent to a hypothetical future inhabitant of the waste tank farm is essentially very low (e.g. 7.0E-12) and the benefit per dollar spent would be lower than other DOE remediation projects.

  These three conclusions are appropriate when considering the initial 10,000-year time period following closure of HTF and assuming removal of 75% of the radionuclide inventory, including HRRs, from the Tank 16 annulus. Other factors that reinforce that removing additional HRRs from Tank 16 would not produce a net social benefit include:

  - Delaying Tank 16 closure to remove additional HRRs from the annulus using a technology such as water dissolution and sluicing, or to take advantage of

possible advances in waste removal technologies, would have a significant adverse impact on the site's Liquid Waste Program.

- The estimated occupational dose and financial cost utilized throughout the cost-benefit analysis are conservatively low even if additional HRR removal had been performed prior to waste tank isolation and grout preparations. Taking into consideration the current field conditions of Tank 16, these values represent extremely conservative assumptions for occupational dose and financial costs that would be associated with performing additional HRR removal at this time.
- At the time of CERCLA closure if the ALARA analysis performed were to indicate a need for additional dose reduction during the performance period, the closure cap could be redesigned to take advantage of advancements in cap design to reduce infiltration of surface water or additional barriers such as subsurface barrier walls could be installed to mitigate contaminant movement. This would extend the timing and reduce the magnitude of the peak dose resulting from the residual radioactivity in HTF.

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