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Revision 1

COST-BENEFIT ANALYSIS FOR REMOVAL OF ADDITIONAL HIGHLY RADIOACTIVE RADIONUCLIDES FROM TANK 18

F-AREA TANK FARM SAVANNAH RIVER SITE

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Prepared by: Savannah River Remediation LLC
Closure and Waste Disposal Authority
Aiken, SC 29808

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APPROVAL PAGE

Concurrence By: [signature] 3/7/12

W. L. Isom, Team Lead
Tank 18 Residual Material Removal Options
Systems Engineering Evaluation
Savannah River Remediation LLC

Date

Approved By: [signature] 3/7/12

D. C. Wood, Manager
Waste Removal and Tank Closure
Savannah River Remediation LLC

Date

Approved By: [signature] 3/7/12

K. A. Hauer, Manager
Closure and Waste Disposal Authority
Savannah River Remediation LLC

Date

REVISION SUMMARY

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LIST OF ACRONYMS AND ABBREVIATIONS

ADMP	Advanced Design Mixer pump
ALARA	As Low As Reasonably Achievable
ARP	Actinide Removal Process
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHA	Consolidated Hazards Analysis
CHAP	Consolidated Hazards Analysis Process
CSEE	Confined Sluicing End Effector
CTS	Concentrate Transfer System
D&R	Disassembly and Removal
DOE	U.S. Department of Energy
DSA	Documented Safety Analysis
DWPF	Defense Waste Processing Facility
EMTEG	Environmental Management Technical Expert Group
EPA	U.S Environmental Protection Agency
FDB	F-Tank Farm Diversion Box
FFA	Federal Facility Agreement
gpm	gallons per minute
H&V	Heating and Ventilation
HEPA	High Efficiency Particulate Air
HLW	High-Level Waste
hp	horsepower
HRR	Highly Radioactive Radionuclide
ISCORS	Interagency Steering Committee on Radiation Standards
LDUA	Light Duty Utility Arm
MAR	Material at Risk
MARS	Mobile Arm Retrieval System
MARS-S	Mobile Arm Retrieval Sluicing System
MARS-V	Mobile Arm Retrieval Vacuum System
MCU	Modular Caustic Side Solvent Extraction Unit
MLDUA	Modified Light Duty Arm
MOP	Member of the Public
mrem	millirem
NEPA	National Environmental Policy Act

NDAA	Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005
NRC	U.S. Nuclear Regulatory Commission
NTB	Non-Technical Baseline
pH	Measure of acidity or alkalinity of a solution
PNNL	Pacific Northwest National Lab
PODD	Performance Objective Demonstration Document
psi	pounds per square inch
Pu	Plutonium
PUREX	Plutonium Uranium Extraction
RCRA	Resource Conservation and Recovery Act
SCDHEC	South Carolina Department of Health and Environmental Control
SCIX	Small Column Ion Exchange
SEE	Systems Engineering Evaluation
SME	Subject Matter Expert
SMP	Submersible Mixer Pump
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions, LLC
SRR	Savannah River Remediation LLC
SRS	Savannah River Site
STP	Standard Transfer Pump
SWPF	Salt Waste Processing Facility
TEDE	Total Effective Dose Equivalent
TER	Technical Evaluation Report
TFA	Tanks Focus Area
TMR	TMR Associates, LLC
TNX	Training and Experimental Test Facility
WRPS	Washington River Protection Solutions

EXECUTIVE SUMMARY

The purpose of this analysis is to compare the cost and benefits of removing additional highly radioactive radionuclides (HRRs) from Tank 18 in F-Tank Farm at the Savannah River Site (SRS) to determine whether there would be net social benefit from this endeavor, that is, whether the benefits would outweigh the costs. This analysis is also intended to inform the Secretary of Energy in regards to a potential determination by the Secretary as to whether HRRs have been removed from this tank to the maximum extent practical prior to its closure, as required by the second criterion of Section 3116(a) of the *Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005*, which is commonly referred to as the NDAA.

Scope of the Analysis

This analysis incorporates information from and supplements the 2011 report, *Documentation of Removal of Highly Radioactive Radionuclides in Waste Tanks 18 and 19*. That report described a previous analysis evaluating the costs and benefits of additional HRR removal from Tanks 18 and 19.

The 2011 report was considered by the U.S. Nuclear Regulatory Commission (NRC) in its consultative role related to F-Tank Farm closure pursuant to Section 3116 of the NDAA. NRC recommended in its Technical Evaluation Report that the Department (1) more fully evaluate the **practicality of additional radionuclide removal** from Tank 18 and (2) explore options for delaying operational closure (i.e., grouting) of this tank to provide additional time for alternative technologies to be developed that could result in greater removal of HRRs **if additional HRR removal is deemed to be practical**. Regarding Tank 19, the NRC Technical Evaluation Report explains that, "Although the information provided for Tank 19 under Criterion 2 [NDAA Section 3116(a)] is similar to that provided for Tank 18, given the lower inventory and risk associated with Tank 19, NRC staff thinks that final closure of Tank 19 can proceed as planned."

This analysis also addresses related matters, including whether operational closure of Tank 18 should be delayed until a technology that could more effectively remove additional HRRs becomes available.

Waste Removal from Tank 18

Tanks 18 and 19 and other underground waste tanks in F-Tank Farm are being closed in accordance with U.S. Department of Energy (DOE) requirements, the site Federal Facility Agreement, and Section 3116 of the NDAA. The Federal Facility Agreement established that, among other things, the SRS waste tanks that do not meet secondary containment standards – in F-Tank Farm these are the older style Type I and Type IV waste tanks – must be removed from service according to the Federal Facility Agreement schedule. Tank 18 is a Type IV tank that lacks secondary containment, although it does not have a history of leakage. In accordance with the Federal Facility Agreement, it is required to be operationally closed by December 31, 2012.

Waste was removed from Tank 18 in four phases, with the last phase making use of a robotic retrieval system called the Sand Mantis (also referred to as simply the "Mantis" in some documentation). Over 99 percent of the original waste and approximately 99 percent of the HRRs were removed from the tank.

Technologies for Additional HRR Removal and Potential Benefits

In support of this analysis, a Systems Engineering Evaluation (SEE) was performed for Tank 18 to identify the most promising technologies for removal of residual material that would potentially result in a reduction in the inventory of HRRs. A SEE is a process SRS adopted from the National Aeronautics and Space Administration in 1998. It is a formal process used to select an alternative from two or more options that have been determined to be feasible to meet specific functions, selected criteria, and requirements. The results of the SEE are included as an Appendix to this cost-benefit analysis. Over 50 potential technologies for additional HRR removal were identified and screened and four of these technologies were evaluated in detail. One representative alternative for removing HRRs – an improved design Sand Mantis – was used in this cost-benefit analysis for comparison purposes.

Various potential benefits from use of this removal method were considered. The primary benefit was determined to be a reduction in the predicted peak all-pathways total effective dose equivalent[1] from the closed F-Tank Farm to a hypothetical future member of the public. Without performing additional studies with actual field tests, the effectiveness of any future technology at removing additional HRRs from either the floor or walls of Tank 18 cannot adequately be predicted. To bound the potential benefits for the purposes of this analysis, the benefits of removing all of the residual HRRs from Tank 18 were evaluated. Based on an assumption of removing all of the HRRs from Tank 18, the maximum reduction in the predicted all-pathways dose would be approximately three millirem per year during the period of peak dose within 10,000 years after tank farm closure. This savings would amount to a predicted **50-year** averted dose of approximately 150 millirem.

Removal of all of the HRRs from Tank 18, which would include removal of those associated with corrosion products on the tank wall as well as those on the tank floor, is not considered to be realistic. Nonetheless, it is being assumed for this analysis for conservatism. The predicted dose reduction resulting from additional Tank 18 HRR removal is highly dependent on the specific HRRs being removed.

The monetary value of the 150 millirem averted dose could not be specifically established because the typical $2,000 per person-rem (or $2 per person-millirem) saved conversion factor for collective dose recommended by the NRC does not directly apply to the individual dose savings. However, the risk to an individual associated with an additional three millirem per year dose is known to be small.

Related F-Tank Farm Performance Analyses

A performance period of 10,000 years was used in assessing compliance with the performance objectives for the F-Tank Farm system related to future hypothetical members of the public and inadvertent intruders in evaluation of compliance with Criterion 3 in Section 3116 of the NDAA[2]. The potential benefits discussed above are relative to the initial 10,000 years after closure.

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[1] The term *dose*, when used in regard to specific values, means total effective dose equivalent throughout this report.

[2] Criterion 3 reads as follows:

However, to gain a better understanding of the closed F-Tank Farm system performance, DOE also performed analyses extending to 100,000 years after closure, well beyond the 1,000-year period required by DOE Order 435.1, *Radioactive Waste Management* (and its associated Manual) for assessing compliance with performance objectives. Despite the large uncertainty associated with such longer-term predictions, DOE considered the potential benefits from reducing the higher doses predicted by the extended analyses with respect to removing HRRs to the maximum extent practical.

Potential Costs

Various potential costs of implementing the representative removal method were considered, including additional estimated worker dose of approximately 3.2 person-rem (3,200 person-millirem). The total cost was estimated to be approximately $38 million in 2012 dollars. This $38 million value represents the least costly of the four technologies evaluated in detail. Removing additional HRRs using this process would take approximately five years and would have an adverse impact on the F-Tank Farm closure effort by tying up common infrastructure and taking up part of the limited available tank space, thereby detracting from other site risk reduction efforts and effectively delaying completion the site Liquid Waste program by about one month.

Additional delay of Tank 18 operational closure would also be a concern to DOE. The December 31, 2012 closure requirement already represents an extension to the original operational closure deadline for Tanks 18 and 19 that allowed DOE to perform additional waste removal utilizing the Sand Mantis. Further delay of Tank 18 operational closure beyond December 31, 2012 would require additional negotiations with the State regulator, which, if unsuccessful, could subject DOE to substantial Federal civil enforcement and penalties if the operational closure deadline were to be missed in the absence of an agreed-upon schedule change. The $38 million estimate mentioned previously does not include any potential penalties resulting from a delay.

As noted previously, one representative technology was used in this analysis for comparison purposes. However, over 90 percent of the monetary costs (i.e., $35 million of the $38 million) and system impacts associated with delaying Tank 18 operational closure and performing additional HRR removal are not dependent on the specific technology selected, but rather on activities such as preparing the tank for re-entry, installation of transfer lines, operational support, procedure development, sampling, laboratory analyses, continued maintenance and

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"(3) (A) does not exceed concentration limits for Class C low-level waste as set out in Section 61.55 of title 10, Code of Federal Regulations, and will be disposed of—

(i) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations; and

(ii) pursuant to a State-approved closure plan or State-issued permit, authority for the approval or issuance of which is conferred on the State outside of this section; or

(B) exceeds concentration limits for Class C low-level waste as set out in section 61.55 of title 10, Code of Federal Regulations, but will be disposed of –

(i) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations;

(ii) pursuant to a State-approved closure plan or State-issued permit, authority for which is conferred on the State outside of this section; and

(iii) pursuant to plans developed by the Secretary in consultation with the Commission."

monitoring of the tank, preparation of closure documentation, and impacts to the Liquid Waste Program, not considering potential penalties associated with missing the operational closure deadline.

Conclusions

After establishing criteria to use as guidance in decision-making and comparing the benefits and the costs, DOE determined that removing additional HRRs from Tank 18 would not produce 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) The estimated worker occupational dose to remove additional HRRs would be approximately 20 times greater than the predicted averted dose a hypothetical future member of the public would receive over a period of 50 years, a significant difference.

(2) The $253 million per rem estimated unit cost of dose reduction is 126,000 times higher than the $2,000 per person-rem value that NRC assigns to averted collective dose, a significant difference.

(3) The estimated risk reduction per dollar spent is lower than the risk reduction per dollar on typical DOE remediation projects, that is, the risk reduction per unit cost is less.

These conclusions apply to the reference case that conservatively assumes removal of 100 percent of the radionuclide inventory from Tank 18. DOE also evaluated two other cases: (1) a bounding case with 100 percent inventory removal considering monetary estimate uncertainties and (2) a case considering the predicted 500 millirem per year dose peak 40,000 years after facility closure as described in the F-Tank Farm Performance Assessment. DOE concluded that the costs would outweigh the benefits in these cases also.

These results demonstrate that deploying another cleaning technology to remove additional HRRs from Tank 18 would not be practical. Therefore, there would be no advantage in delaying operational closure of the tank to await potential development of a better removal technology.

1.0 INTRODUCTION

1.1 Purpose

The purpose of this analysis is to compare the cost and benefits of removing additional HRRs from Tank 18 in F-Tank Farm at SRS to determine whether there would be net social benefit from this endeavor, that is, whether the benefits would outweigh the costs. This analysis was performed in consideration of a recommendation by NRC under its NDAA Section 3116 consultation role to more fully evaluate the practicality of additional HRR removal from Tank 18 and explore options for delaying operation closure (i.e., grouting of the tank) if additional HRR removal is deemed to be practical. [ML112371715]

This analysis is also intended to inform the Secretary of Energy in regards to a potential determination by the Secretary as to whether HRRs have been removed from this tank to the maximum extent practical prior to its closure as required by the second criterion of Section 3116(a) of the NDAA. This criterion reads as follows: "(2) has had highly radioactive radionuclides removed to the maximum extent practical." The HRRs identified for F-Tank Farm are listed below. [DOE/SRS-WD-2010-001] For information, the half-life in years associated with each HRR is also provided in parentheses:

- Sr-90 (2.89E+01)
- Tc-99 (2.11E+05)
- I-129 (1.57E+07)
- Cs-137 (3.00E+01)
- U-234 (2.46E+05)
- Np-237 (2.14E+06)
- Pu-238 (8.77E+01)
- Pu-239 (2.41E+04)
- Pu-240 (6.56E+03)
- Am-241 (4.32E+02)

1.2 Scope and Technical Basis

This analysis incorporates information from and supplements the 2011 report, *Documentation of Removal of Highly Radioactive Radionuclides in Waste Tanks 18 and 19*. [SRR-CWDA-2011-00091] It applies only to Tank 18, which is an underground waste storage tank with a nominal operating capacity of 1,300,000 gallons. In support of this analysis, a comprehensive review of potential methods for removing additional waste and HRRs from Tank 18 was performed as documented in the SEE report included as Appendix A of this report.

Fifty-four potential technologies for additional HRR removal were identified and screened. Four of these were evaluated in detail and one representative alternative was used for comparison purposes. Because it was not practical to determine monetary equivalents for the benefits from additional HRR removal, DOE established decision criteria related to the relationship between averted dose and worker dose, the unit cost of the averted dose, the relative value of a reduction in radioactive waste disposed of onsite, and schedule conformance. However, DOE did not consider schedule conformance to be an overriding concern even though Tank 18 operational closure is required to complete by December 31, 2012 as a regulatory milestone in the legally enforceable *SRS Federal Facility Agreement of 1993*, as amended. [WSRC-OS-94-42]

Without performing additional studies with actual field tests, the effectiveness of any future technology for additional HRR removal from either the floor or walls of Tank 18 cannot accurately be predicted. Consequently, DOE conservatively assumed in the reference case that all residual HRRs would be removed from Tank 18 even though removal of all HRRs, including those on the tank wall, is unrealistic.

The predicted dose reduction resulting from additional Tank 18 HRR removal is highly dependent on the specific HRRs being removed. For perspective, DOE also evaluated a bounding case with removal of 100 percent of the Tank 18 HRR inventory considering uncertainties in the technology direct cost estimates. DOE also considered the potential benefits associated with reducing the higher doses predicted by the extended 100,000 years after closure analyses by removing additional HRRs.

Guidance considered in this analysis included NRC guidance in (1) Section 3.4 (Cost-Benefit Analysis) of NUREG-1854, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations*, (2) Appendix N (ALARA Analyses) to NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance Characterization, Survey, and Determination of Radiological Criteria*, and (3) NUREG/BR-0184, *Regulatory Analysis Technical Evaluation Handbook*. Also considered were DOE requirements for the as low as reasonably achievable (ALARA) process in DOE Order 458.1, *Radiation Protection of the Public and the Environment*, which pertain to management, storage, and disposal of radioactive waste. Guidance on discounting methods issued by the Office of Management and Budget was considered but the estimated costs were expressed in 2012 dollars for conservatism.

1.3 Background

F-Tank Farm contains 22 underground waste tanks, two of which were operationally closed in 1997.

1.3.1 F-Tank Farm Closure Process

This tank farm is being closed in accordance with the requirements of DOE Order 435.1, *Radioactive Waste Management*, and the associated DOE Manual 435.1-1, *Radioactive Waste Management Manual* using a process consistent with the *SRS Federal Facility Agreement* of 1993, as amended [WSRC-OS-94-42], and with the following laws:

- The *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA);
- The *National Environmental Policy Act* (NEPA);
- The *Resource Conservation and Recovery Act* (RCRA);
- The *Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005* (hereinafter referred to as the NDAA); and
- The *South Carolina Pollution Prevention Act.*

Required closure documents pertinent to this analysis include:

- A Performance Assessment for F-Tank Farm prepared in accordance with DOE Manual 435.1-1 to demonstrate, among other things, that the performance objectives of 10 CFR 61, Subpart C, which are comparable to the DOE performance objectives for low-level waste disposal in DOE Manual 435.1-1, will be met [SRS-REG-2007-00002];

- A Special Analysis for Tank 18 and Tank 19 prepared in accordance with DOE Manual 435.1-1 that takes into account the residual radionuclide inventory for Tank 18 and Tank 19 developed after final characterization of those tanks [SRR-CWDA-2010-000124]; and
- A determination that the stabilized (i.e., grouted) tank residuals are not high-level waste, which may be made by the Secretary of Energy in consultation with NRC pursuant to Section 3116 of the NDAA.

After all of the tanks in the tank farm have been filled with grout and operationally closed, the tank system will be removed from the Wastewater Permit issued by the South Carolina Department of Health and Environmental Control (SCDHEC). Final closure of the operable unit that includes F-Tank Farm will eventually be accomplished under the provisions of RCRA and CERCLA, which will include installation of a permanent cover.

1.3.2 Tank 18 Design and History

Tank 18 is an old-style Type IV underground waste storage tank, one of four of this type in F-Tank Farm. This design does not have an annulus or a secondary steel liner that would provide secondary containment, however Tank 18 does not have a history of leakage. Type IV tanks lack internal cooling coils. [SRR-CWDA-2011-00091]

Construction of Tank 18 was completed in 1958 and the tank entered service in 1959 as a waste receipt tank for the F-Canyon Separations Facility. It remained in service until 1986 when waste removal began. [SRR-CWDA-2011-00091]

Waste was initially removed from Tank 18 in three phases:

- Bulk waste removal efforts were accomplished in 1986 to remove the supernate (concentrated liquid waste), which left approximately 550,000 gallons of sludge which contained some freestanding and interstitial liquid.
- Bulk sludge waste removal was accomplished in 1986 and 1987, which left a tank heel of approximately 37,000 gallons of sludge; and
- Initial heel removal was accomplished in 2002 and 2003 using an advanced design mixer pump, the best available technology based on a comprehensive SEE developed in 2001, which left more than 4,300 gallons of solids in the tank. The tank walls were washed by spraying them with water during this time. [SRR-CWDA-2011-00091]

At the conclusion of this effort, DOE moved forward with plans to close Tanks 18 and 19, which included preparation of a Draft 3116 Basis Document for these tanks and an associated Performance Objectives Demonstration Document, which was similar in scope to a performance assessment. These documents were submitted to NRC for consultation review in 2005. [DOE-WD-2005-002, CBU-PIT-2005-00106]

In 2006, however, information on a new tank cleaning technology was provided at a tank cleaning technical exchange workshop sponsored by SRS. This technology was a robotic ultra-high-pressure eductor retrieval system developed by TMR Associates, LLC (TMR) of Lakewood Colorado. Given its potential for removal of additional waste from Tanks 18 and 19, DOE elected to halt closure preparations for these tanks and to attempt to remove additional waste from them using this new technology. DOE informed NRC of this plan and in December, 2007 formally requested NRC to halt its review of the Draft 3116 Basis Document for Tank 18 and Tank 19. [ML080090405]

The site spent the next four years (1) developing, procuring, and testing this new mechanical heel removal device, which became known as the Sand Mantis; (2) using it to remove additional waste from the two tanks; (3) characterizing the residual waste; (4) developing a new Performance Assessment; and (5) preparing a new F-Tank Farm 3116 Basis Document. This effort to remove additional waste became Phase 4 of the Tank 18 waste removal program. [SRR-CWDA-2011-00091]

After operating in Tank 18 for a total of 415 hours the Sand Mantis reached the limits of its effectiveness. The device had been able to reach all parts of the tank floor[3] and visual inspections made following Sand Mantis operations indicated a significant reduction in residual waste on the floor. Dose rates measured on the waste transfer line in the final stages of tank cleaning confirmed the reduced effectiveness near the end of Sand Mantis operations. [SRR-CWDA-2011-00091]

DOE in the fall of 2009 proposed that waste removal be discontinued and DOE, SCDHEC, and the U.S. Environmental Protection Agency (EPA) Region IV concurred with proceeding to the sample and analysis phase. The Tank 18 residuals were then characterized. The overall reduction in HRRs in Tank 18 was approximately 99 percent, from an initial estimate of approximately 1,200,000 curies to approximately 17,000 curies as of 2010. [SRR-CWDA-2011-00091]

As the Sand Mantis cleaning effort proceeded, DOE developed a new Draft F-Tank Farm 3116 Basis Document and a new F-Tank Farm Performance Assessment, focusing on the entire tank farm, rather than just Tanks 18 and 19. DOE worked closely with NRC, SCDHEC, and EPA Region IV staffs in development of the Performance Assessment to obtain early input from these organizations in a collaborative effort to help ensure that the approach being taken would be satisfactory to them. [SRR-CWDA-2011-00054]

In addition, the Federal Facility Agreement tank closure schedule had to be renegotiated with SCDHEC using the dispute resolution process to move the Tank 18 closure date from February 28, 2007 to the current milestone date of December 31, 2012. [WSRC-OS-94-42]

1.3.3 Predicted Performance of the Closed Tank Farm

The F-Tank Farm Performance Assessment predicted a maximum all-pathways dose to a member of the public, utilizing projected inventories for Tank 18 and 19, of 2.5 millirem per year at approximately 10,000 years after F-Tank Farm closure, an order of magnitude below the 25 millirem per year performance objective. [SRS-REG-2007-0002]

A Special Analysis developed using the actual inventories in Tank 18 and Tank 19 from final characterization [SRR-CWDA-2010-000124] predicted a maximum all-pathways dose to a

[3] During removal activities using the Sand Mantis in Tank 18, the Sand Mantis was able to reach all portions of the waste tank, therefore travel was not limited as noted by NRC in its Technical Evaluation Report. Page 74 of the Technical Evaluation Report states that "Mantis travel limitations may also have hampered efforts to remove large quantities of material remaining in the western portion of the tank, although the NRC staff was unable to confirm this with DOE prior to finalization of this TER." [ML112371715]

member of the public of 3.4 millirem per year, again at approximately 10,000 years after tank farm closure for the 10,000-year performance period. In response to NRC request for additional information discussed below, DOE provided a predecisional draft version, Revision 0a, of the Special Analysis to the NRC. The final version of the Special Analysis included sensitivity studies varying plutonium solubility values, distribution coefficient values and other parameters. The final version of the Special Analysis also included additional discussion regarding dose peaks predicted in the modeling to occur beyond the 10,000-year performance period.

1.3.4 Consultation With NRC

DOE consulted with NRC on the Draft F-Tank Farm 3116 Basis Document in accordance with Section 3116 of the NDAA. NRC submitted a request for additional information to DOE in connection with its review in December 2010. [ML1032001240, ML103190402] DOE provided its response to this request in June 2011. [SRR-CWDA-2011-00054]

In October 2011, NRC issued its Technical Evaluation Report for the Draft F-Tank Farm 3116 Basis Document and the F-Tank Farm Performance Assessment. [ML112371715] The transmittal letter contained the following language pertaining to closure of Tank 18: [ML112371169]

> "One of the NRC staff's recommendations under Criterion 2 is of particular note. Considering additional information provided by DOE in its RAI responses, Tank 18 now appears to be the single largest risk driver for the FTF facility and is scheduled for closure per the Federal Facility Agreement by December 2012. Given its risk significance, the NRC staff thinks that DOE should more fully evaluate the practicality of additional radionuclide removal from Tank 18 and explore options for delaying final closure (i.e., grouting) of Tank 18 for the reasons listed below. It is important to note that the risk associated with a short delay in the grouting of Tank 18 on the order of a few years is not expected to be significant given ongoing operation and maintenance of the FTF and the fact that a large portion of the residual liquid waste has been removed; however, a decision to delay the grouting of Tank 18 should consider any associated short term risks.
>
> 1. Insufficient information was provided to the NRC staff related to the costs and benefits of additional radionuclide removal and other factors influencing the decision regarding the practicality of additional HRR removal from Tank 18. The NRC staff recommends that DOE provide additional information or perform additional analyses to support the Criterion 2 demonstration for Tank 18.
>
> 2. Significant technical uncertainties exist with respect to DOE's ability to meet the performance objectives in 10 CFR Part 61, Subpart C, that the NRC staff thinks can be addressed in the near-term (e.g., solubility studies). Permanent closure activities such as grouting of the waste tank may make it more difficult for DOE to evaluate or reduce the risks associated with this waste tank in the future, if risk reduction is deemed necessary pending results of future research. Additionally, the results of the near term studies could reduce the extent to which other

uncertainties will need to be addressed to support Criterion 3 of the NDAA for tank farm closure.

3. A delay in Tank 18 closure could provide additional time for alternative technologies to be developed (e.g., the improved Sand Mantis design that is anticipated to be used on the H Tank Farm Type IV tanks), that could result in greater removal of HRRs from Tank 18, if additional HRR removal is deemed practical."

The Technical Evaluation Report provided additional details. Regarding Tank 19, the Technical Evaluation Report explains that, "Although the information provided for Tank 19 under Criterion 2 [NDAA Section 3116(a)] is similar to that provided for Tank 18, given the lower inventory and risk associated with Tank 19, NRC staff thinks that final closure of Tank 19 can proceed as planned." [ML112371715]

This cost-benefit analysis and its associated SEE was prepared to further inform operational closure decisions associated with Tank 18. This document directly addresses items 1 and 3, above, that were noted in the NRC Technical Evaluation Report. Item 2 is being addressed through separate documentation.

1.3.5 Other Preparations for Tank 18 Closure

Other preparations for tank closure included development of the *Industrial Wastewater General Closure Plan for F-Area Waste Tank Systems*. [LWO-RIP-2009-00009] This plan supports removal from service of the entire tank farm under the State Industrial Wastewater Construction Permit [DHEC_01-25-1993], which describes the protocols by which DOE plans to close the tank farm systems.

The site also prepared the *Industrial Wastewater Closure Module for the Liquid Waste Tanks 18 and 19 at the F-Area Waste Tank Farm, Savannah River Site*. [SRR-CWDA-2010-00003] This plan was prepared in accordance with the General Closure Plan to support removal from service of the two tanks.

1.4 Organization of this Report

The subsequent sections of this report provide the following information:

Section 2, Tank 18 and Its Residuals, provides a more detailed description of Tank 18 and its residuals, including the estimated HRR inventory and more information on the predicted impact on a member of the public from the closed F-Tank Farm.

Section 3, Highly Radioactive Radionuclide Removal Processes Used, briefly describes the waste removal processes that have been used and the results.

Section 4, Other Waste Removal Processes Evaluated, summarizes the additional waste removal processes that have been considered.

Section 5, Benefits of Additional Highly Radioactive Radionuclide Removal, identifies the benefits that would be produced by use of the representative process for removing additional HRRs, focusing on averted dose to a member of the public and provides information to help place these benefits into perspective.

Section 6, Cost of Additional Highly Radioactive Radionuclide Removal, describes the costs that would be associated with use of the additional waste removal processes that have been considered.

Section 7, Discussion of Costs and Benefits, discusses key matters related to evaluation of costs and benefits and describes DOE's decision criteria.

Section 8, Conclusions, describes the conclusions from the analysis and summarizes the basis for these conclusions.

Section 9, References, lists those references cited in the text.

Appendix A, Tank 18 Residual Material Removal Options Systems Engineering Evaluation, documents the SEE performed in support of this cost-benefit analysis.

2.0 TANK 18 AND ITS RESIDUALS

The section briefly describes the affected environment for Tank 18, provides a brief description of the tank, summarizes its operational history, describes its characterization after use of the Sand Mantis in Phase 4 of the tank cleaning program, and discusses the predicted impacts of the tank residuals on a hypothetical future member of the public. This information is intended to help place into context the later discussions about cost and benefits of additional HRR removal.

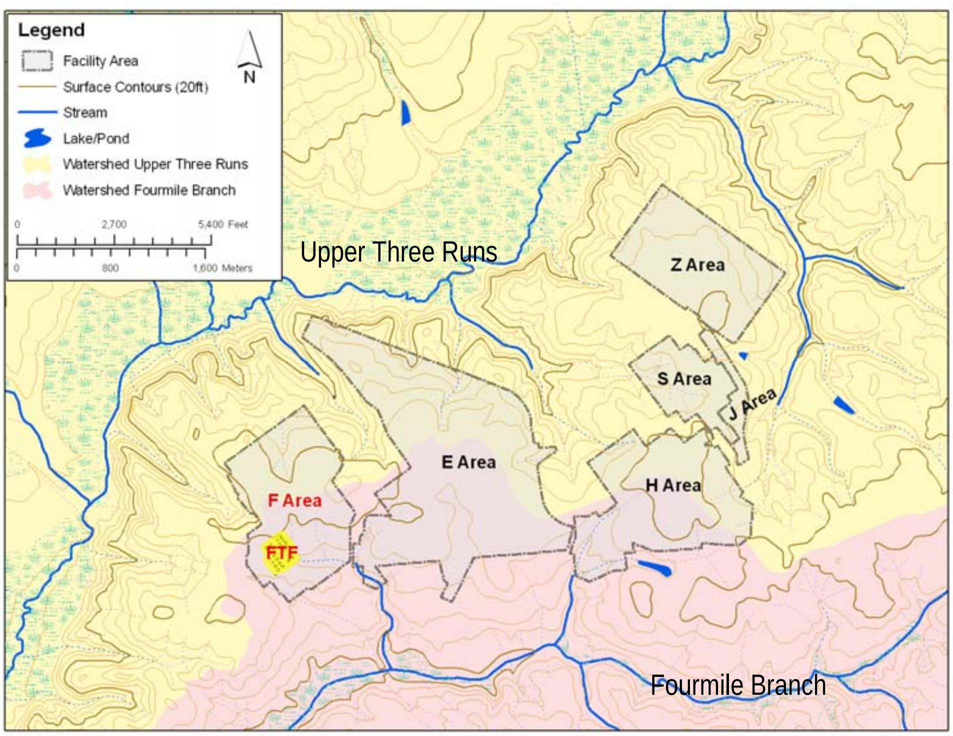
2.1 Affected Environment

An important factor in analyses related to Tank 18 and F-Tank Farm is the affected environment. The following information in Sections 2.1.1 through 2.1.7 was taken from the F-Tank Farm Performance Assessment which provides additional details. [SRS-REG-2007-00002]

2.1.1 Location

SRS is located in south-central South Carolina, approximately 100 miles from the Atlantic coast. The major physical feature at SRS is a 20-mile stretch of the Savannah River that serves as the southwestern boundary of the site and the South Carolina-Georgia border. SRS occupies a roughly circular area of approximately 310 square miles and contains production, service, and research and development areas. The developed areas occupy less than 10 percent of the SRS area, while the remainder of the site is undeveloped forest or wetlands. Figure 2-1 shows F-Tank Farm within the General Separations Area, which is located in the central portion of the site.

Figure 2-1: Location of F-Tank Farm in the General Separations Area

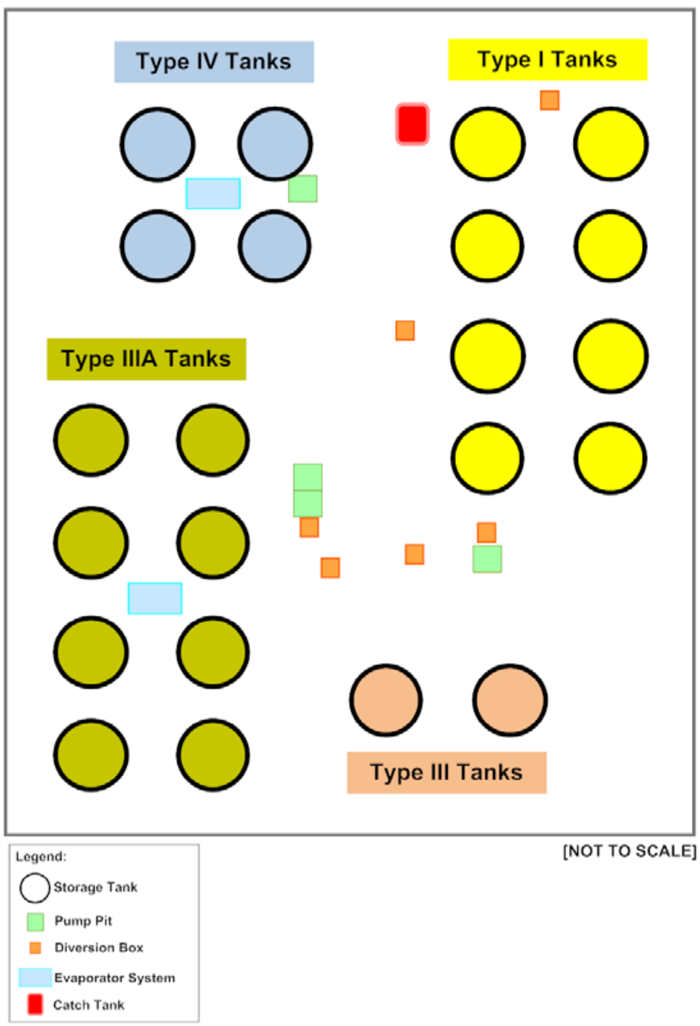


Regarding the other facilities shown in the figure, F-Area contains F-Tank Farm and the F-Canyon Separations Facility, the source of most of the waste that was managed in Tank 18. E-

Area contains low-level radioactive waste disposal facilities. H-Area contains the H-Canyon Separations Facility and H-Tank Farm. S-Area contains the Defense Waste Process Facility where high-level waste is vitrified and storage buildings for the vitrified waste canisters. The Saltstone Production Facility and the Saltstone Disposal Facility are located in Z-Area. J-Area is the future home of the Salt Waste Processing Facility that is currently under construction.

F-Area occupies 364 acres. F-Tank Farm is an active waste storage facility containing 22 underground carbon steel waste tanks that store, or once stored, liquid radioactive waste generated primarily from the F-Canyon PUREX process. Figure 2-2 shows the layout of F-Tank Farm.

Figure 2-2: Layout of F-Tank Farm



Land within a five-mile radius of F-Tank Farm is entirely within SRS boundaries and is currently used either for industrial purposes or as forested land. Current land use within the entire General Separations Area is classified as heavy nuclear industrial.

2.1.2 Climate

The SRS region has a humid subtropical climate characterized by relatively short, mild winters and long, warm, and humid summers. Summer-like conditions typically last from May through September.

Winds in summer are light and cold fronts generally remain well north of the area. Daily high temperatures during the summer months exceed 90°F on more than half of all days on average. Scattered afternoon and evening thunderstorms are common. Based on SRS monitoring data, the average rainfall in F-Area is approximately 49 inches per year.

In the winter months, conditions frequently alternate between warm, moist, subtropical air from the Gulf of Mexico region and cool, dry polar air. Less than one-third of winter days have minimum temperatures below freezing on average, and days with temperatures below 20°F are infrequent. The average temperature during the 1968 to 2005 period was approximately 64°F. Measurable snowfall occurs an average of about once every two years.

2.1.3 Ecology

SRS supports abundant terrestrial and semi-aquatic wildlife, as well as a number of species considered threatened or endangered. Since the early 1950s, the site has changed from 67 percent forest and 33 percent agriculture to 94 percent forest, with the remainder in aquatic habitats and developed areas.

SRS supports 44 species of amphibians, 60 species of reptiles, 255 species of birds, and 55 species of mammals. Large mammals include white-tail deer and feral hogs. Several fish species – none of which are endangered – can be found in the two streams that flow north and south of the General Separations Area, which are known as Upper Three Runs and Fourmile Branch, respectively, as shown in Figure 2-1.

2.1.4 Geology, Seismology, and Volcanology

SRS is on the Atlantic Coastal Plain, Physiographic Province approximately 25 miles southeast of the fall line that separates the relatively unconsolidated Coastal Plain sediments. Beneath the Coastal Plain sedimentary sequence are two geologic terranes: (1) the Dunbarton basin, a Triassic-Jurassic Rift basin, filled with lithified terrigenous and lacustrine sediments; and (2) a crystalline terrane of metamorphosed sedimentary and igneous rock that may range in age from Precambrian to late Paleozoic from the crystalline igneous and metamorphic rocks of possibly late Precambrian to late Paleozoic age in the Piedmont Province.

Early to middle Mesozoic (Triassic to Jurassic) rocks occur in isolated fault-bounded valleys either exposed within the crystalline belts or buried beneath the Coastal Plain sediments. The Coastal Plain sediments were derived from erosion of the crystalline rocks during late Mesozoic (Cretaceous) in stream and river valleys and are represented locally by gravel deposits adjacent to present-day streams and by sediments filling upland depressions (sinks and Carolina Bays). The Cretaceous and younger sediments are not significantly indurated. The total thickness of the sediment package at SRS varies between approximately 700 feet at the northwest boundary and 1,200 feet at the southeast boundary.

The vadose zone is comprised of the middle to late Miocene-age "Upland Unit," that extends over much of SRS. The term "Upland Unit" is an informal name used to describe sediments at higher elevations located in the Upper Coastal Plain in southwestern South Carolina. This area has also been referred to as the Aiken Plateau. The occurrence of cross-bedded, poorly sorted sands with clay lenses in the Aiken Plateau indicates fluvial deposition (high-energy channel deposits to channel-fill deposits) with occasional transitional marine influence. This depositional environment results in wide differences in lithology and presents a very complex system of transmissive and confining beds or zones. The lower surface of the Upland Unit is very irregular due to erosion of the underlying formations.

The seismic history of the southeastern U.S. spans a period of nearly three centuries, and is dominated by the Charleston earthquake of August 31, 1886 (estimated magnitude of 7.0). The historical database for the region is essentially composed of two data sets extending back to as early as 1698. The first set is comprised of pre-network, mostly qualitative data (1698-1974), and the second set covers the relatively recent period of instrumentally recorded or post-network seismicity, 1974 through April 2009.

The most recent seismic event located within a 50 mile radius of SRS occurred on March 27, 2009, with a magnitude of 2.6. No damage to SRS was recorded. There have, however, been four earthquakes with epicenter locations within SRS. They occurred on June 9, 1985 (magnitude of 2.6); August 5, 1988 (magnitude of 2.0); May 17, 1997 (magnitude of 2.3), and October 8, 2001 (magnitude of 2.6). No strong motion accelerometers were triggered as a result of these earthquakes.

SRS is not located within a region of active plate tectonics characterized by volcanism,

2.1.5 Hydrogeology

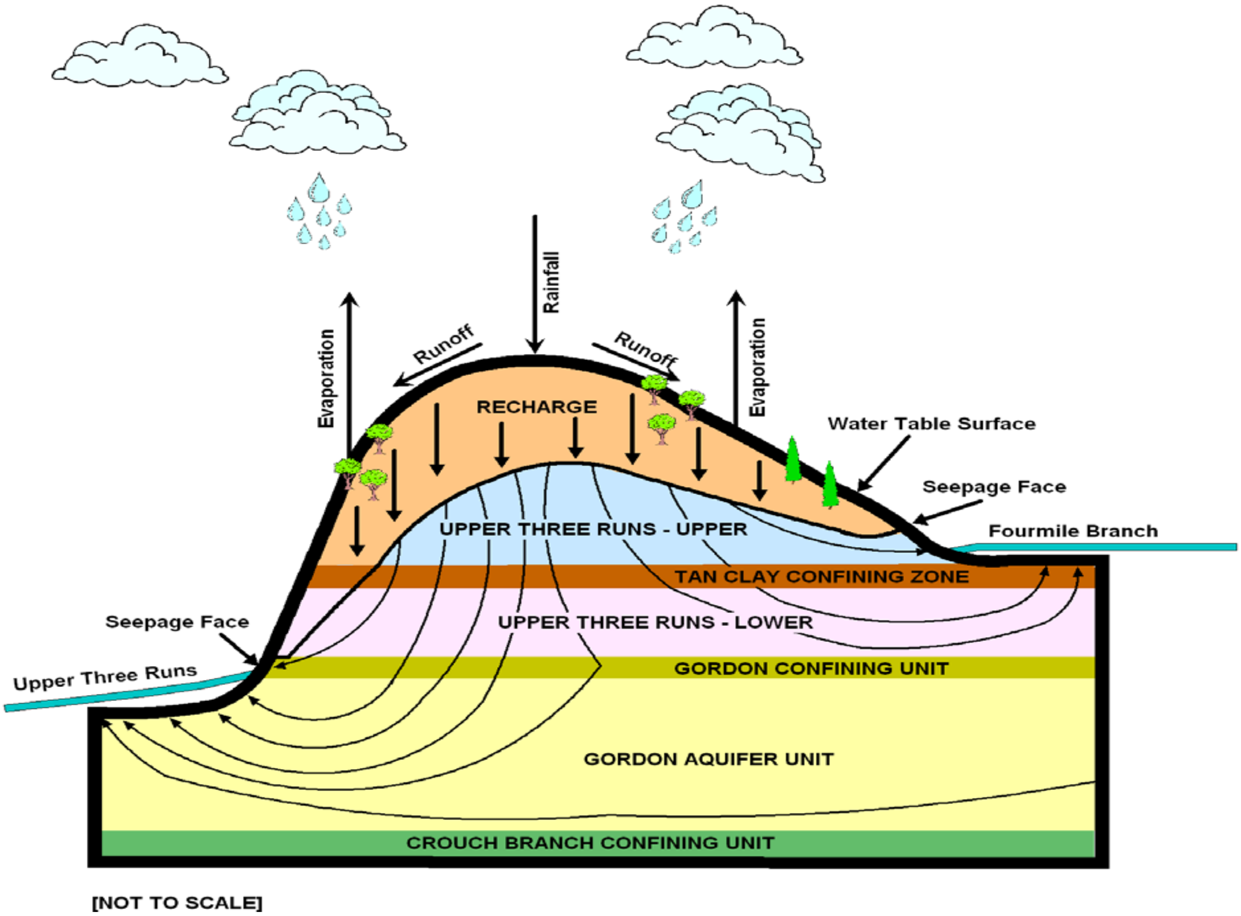
The aquifers of primary interest for F-Tank Farm modeling are the Upper Three Runs and Gordon Aquifers. Potential contamination from F-Tank Farm is not expected to enter the deeper Crouch Branch Aquifer because an upward gradient exists between the Crouch Branch and Gordon Aquifers near Upper Three Runs. Figure 2-3 is a cross-sectional schematic representation of groundwater flow patterns in the Upper Three Runs and Gordon Aquifers along a north-south cross-section running through the center of F-Tank Farm, shown with significant vertical exaggeration.

F-Tank Farm is located over a groundwater divide between Upper Three Runs and Fourmile Branch. Owing to this condition, contaminants are expected to eventually discharge to both streams, depending on the location of individual sources within the tank farm. This flow pattern complicates groundwater modeling. The streams themselves eventually drain to the Savannah River.

2.1.6 Geochemistry

The migration of radionuclides in the subsurface environment is dependent on physical and chemical properties of cementitious materials, soils, and groundwater. Many studies and analyses have been conducted, producing a large body of data on distribution coefficients (i.e., K_d values).

Figure 2-3: Conceptual Diagram of Groundwater Flow Beneath the General Separations Area



2.1.7 Natural Resources

Natural resources at SRS are managed under the *Natural Resources Management Plan*. [NRMP-2005] SRS monitors non-radioactive liquid discharges to surface waters through the National Pollutant Discharge Elimination System permit program, as mandated by the Clean Water Act. SRS has permits in place for discharges to the waters of the United States and South Carolina. These permits establish the specific sites to be monitored, parameters to be tested, and the monitoring frequency, as well as analytical, reporting, and collection methods.

SRS streams and the Savannah River are classified by SCDHEC as "freshwaters," which are defined as surface water suitable for (1) primary and secondary contact recreation and as a drinking water source after treatment in accordance with SCDHEC requirements, (2) fishing and survival and propagation of a balanced indigenous aquatic community of fauna and flora, and (3) industrial and agricultural uses.

SRS domestic water is supplied by 17 separate systems, all of which utilize groundwater sources.

2.1.8 Natural and Background Radiation

All human beings are exposed to ionizing radiation. The average person living in the Central Savannah River Area or elsewhere in the United States receives an annual radiation dose of approximately 620 millirem per year. The major sources of this dose are natural background radiation (311 millirem per year) and medical exposure (300 millirem per year). [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 2-1 shows annual totals measured at several offsite locations in 2010. [SRNS-STI-2011-00059]

Table 2-1: Variations in Ambient Radiation Levels Measured Around SRS

Location	Miles From SRS Boundary	Annual Total (mR)(1)	Difference from Average (mR)(2)
Aiken, SC Airport	25	64	-38
Barnwell, SC	7.5	95	-7
Beech Island, SC	13	116	+14
Williston, SC	9	110	+8

NOTES: (1) From SRNS-STI-2011-00059, Data Table 5-6, rounded to whole numbers.
(2) Average from SRNS-STI-2011-00059, Data Table 5-6, for nine offsite locations.

Table 2-1 shows considerable 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 at the different locations.

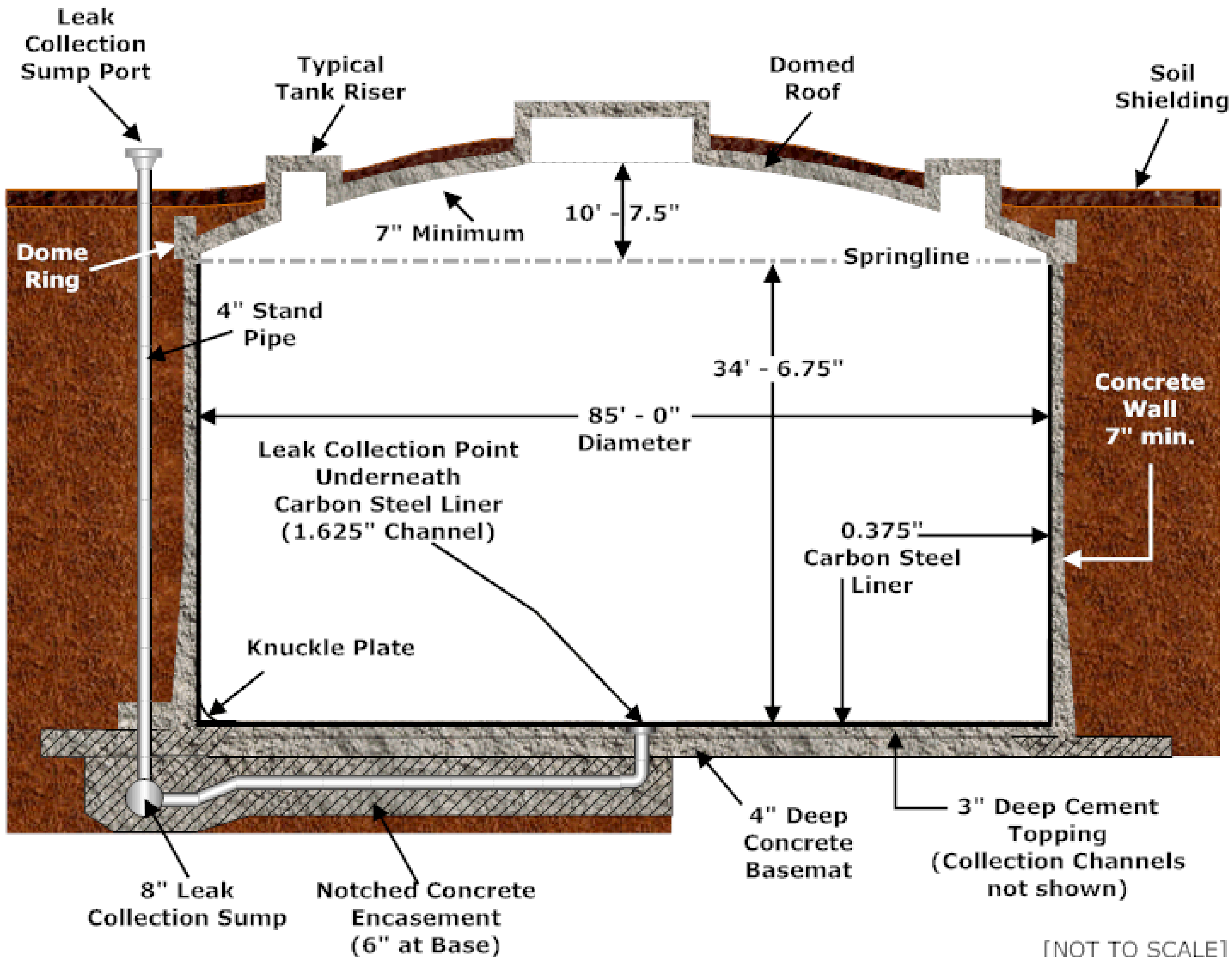
The estimated dose to the hypothetical maximally exposed offsite individual from site operations is reported in the annual SRS Environmental Report. This estimate for calendar year 2010 was 0.11 millirem from the air and liquid pathways. [SRNS-STI-2011-00059]

2.2 Type IV Waste Tank Design

Tank 18 is one of four Type IV waste tanks (Tanks 17 through 20) in F-Tank Farm. Figure 2-4 shows the characteristics of a typical Type IV waste tank. The F-Tank Farm Type IV waste tanks were constructed in the late 1950s to receive low-heat waste only and did not require cooling coils

The basemat shown in the figure is comprised of a four-inch thick reinforced concrete slab covered with a three-inch thick, wire-mesh reinforced cement layer. Drainage channels used for leak detection below the carbon steel tank liners were formed in the three-inch thick cement topping layer and drain to a collection point, that in turn empties to a collection chamber (sump) below the waste tank footing at the edge of the waste tank wall. A leak detection probe can be placed in the chamber through the leak collection sump port shown in the upper left of the figure.

Figure 2-4: Typical Type IV Waste Tank Cross Section



Type IV waste tanks have no secondary containment. The tank primary container is an 85-foot diameter by 34-foot, 6.75-inch high open-topped tank with walls and floor made of 0.375-inch thick carbon steel plates and reinforced on the interior with three, four-inch by four-inch, L-shaped carbon steel bands, known as stiffener bands. The bands and waste tank liner are anchored to the enclosing concrete vault wall. These tanks have sidewall penetrations near the top for three-inch diameter stainless steel inlet and outlet transfer lines, and four-inch diameter stainless steel transfer lines. [SRS-REG-2007-00002]

As shown in Figure 2-4, the Type IV primary containers are completely enclosed in concrete vaults. The tank roof is a self-supporting, hemispherical dome made of seven to 10-inch thick concrete. The dome has an internal curvature radius of 90 feet, four inches and a maximum rise of 10 feet, 7.5 inches above the springline. The concrete roof is not lined with carbon steel on the inside as seen in the figure. Figure 2-5 shows the F-Tank Farm Type IV tanks under construction.

Figure 2-5: Type IV Tanks Under Construction

The nominal capacity of 1,300,000 gallons for the Type IV tanks equates to 3,540 gallons per inch (depth) of stored material. The carbon steel tank floor is essentially flat with no sump, significant low points, or slope.

The concrete vault for Type IV waste tanks was built around the primary liner using a material called shotcrete, which is concrete sprayed on the surface. The core wall was constructed of 0.75- to 1.5-inch thick layers of shotcrete.

Since there is no annulus in these tanks, a three-layer backfilling system was used to surround the sidewalls of the concrete vault. The backfill consisted of a vermiculite fill layer, a special manually compacted fill of soil, and a test controlled compacted fill of soil. The vermiculite fill provides a cushion layer for expansion of the primary tank with temperature variations of the waste tank and waste tank contents.

As originally designed and constructed, the dome of Tank 18 had seven access risers. The six original perimeter risers are two feet in diameter (opening to waste tank interior), approximately five feet long and approximately 37 feet from the bottom of the riser to the waste tank bottom.

The single center riser is approximately eight feet in diameter (opening to the tank interior), approximately five feet long, and 45 feet from the bottom of the riser to the bottom of the waste tank. The riser design configuration provides limited access to the waste tank interior. [SRS-REG-2007-00002]

2.3 Tank 18 Operational History

Tank 18 was constructed in 1958 and entered service in 1959 as an F-Canyon waste receipt tank. This waste tank remained active and operational until 1986 when waste removal activities were initiated. The largest volume of waste stored in Tank 18 was approximately 1,300,000 gallons.

Between 1959 and 1977, Tank 18 received low-heat waste directly from F Canyon. Tank 18 also supported the 242-F evaporator operations, as both a receiver of concentrated supernate and overheads and as a feed tank for the evaporator. From 1962 to 1981, Tank 18 received concentrated supernate and, from 1966 to early 1983, overheads from the 242-F evaporator. From 1960 through 1976, Tank 18 was used as a feed tank for the 242-F evaporator.

In 1973, Tank 18 also received approximately 12,000 gallons of waste from H-Tank Farm evaporator overheads and, in 1974, approximately 719,000 gallons of high-heat waste from H-Tank Farm. In 1980 and 1981, Tank 18 received salt and/or sludge removal waste from waste removal activities associated with Tanks 17, 19, and 20. Throughout this period, Tank 18 served as a hub for Tanks 17 through 20 activities. During this operation, some of the zeolite resins from Tank 19 were transferred to, and settled in, Tank 18. [SRR-CWDA-2011-00091]

Tank 18 has no known leak sites. Waste removal from this tank is discussed in Section 3.

2.4 Tank 18 Residual Characterization

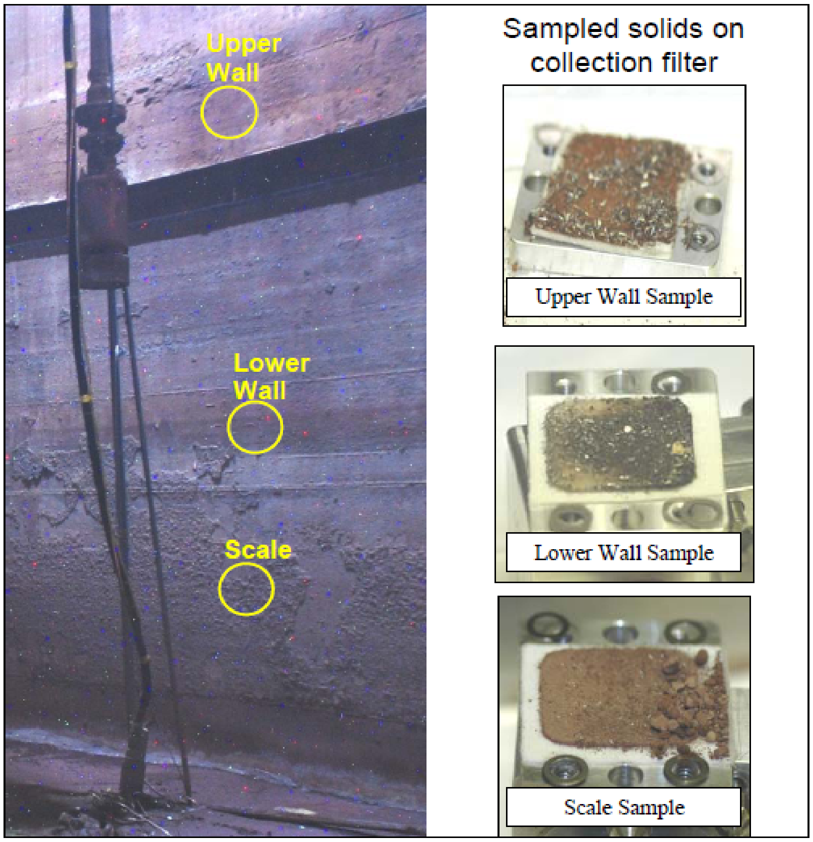
The residual material in Tank 18 was characterized at the conclusion of Phase 4 waste removal. This subsection summarizes the approach to the characterization of Tank 18 and provides the key results. This summary is based on the *Tank 18 Residual Characterization Report*, which should be referred to for additional detail. [SRR-CWDA-2010-00117] Section 6.1 of the report on documentation of removal of HRRs from Tanks 18 and 19 also explains the characterization approach and can be referred to for additional information on the characterization of Tank 18. [SRR-CWDA-2011-00091]

Tank 18 was characterized after completion of the Phase 4 waste removal campaign. [SRR-CWDA-2010-00117] The characterization process consisted of (1) sampling and analysis to determine the concentration of radionuclides on the tank floor and tank wall, (2) mapping and volume estimation to determine the amount of residual material on the tank floor and wall, and (3) characterizing this residual material based on the concentration of radionuclides and the quantity of material.

The best estimate for the volume of material of the tank floor was 3,900 gallons. Eight samples of material were collected from the tank floor, two which were archived instead of immediately analyzed. Three samples from the tank wall were collected and analyzed. Visual inspection of the tank wall using high quality digital cameras in connection with the characterization had revealed the presence of scale on portions of the lower wall, which was estimated to be 0.1875 inches thick, in addition to the expected corrosion film. Two samples of the corrosion film were collected at locations about 17 feet above the tank floor and one sample of the scale was also collected. Figure 2-6 shows the sample locations.

Figure 2-6: Tank 18 Wall Sampling Locations

(Figure 3.2.1 of SRR-CWDA-2010-00117)



The volume of scale on the tank wall was estimated by study of high resolution photos and use of landmarks, which produced a best estimate of 110 gallons. The measured radionuclide concentrations in the scale were found to be comparable to those measured in waste samples from the tank floor. The activity in the corrosion film was estimated by expressing the measured radionuclide concentrations in the samples on a surface area basis and multiplying these concentrations by the total surface area of the tank wall.

Table 2-2 shows the results of the characterization for HRRs. The inventories for the tank floor and tank wall are shown separately to support later discussions about the estimated reduction in predicted dose to the hypothetical member of the public from the closed tank farm from additional HRR removal.

Table 2-2: Tank 18 Residual Highly Radioactive Radionuclide Inventory as of 2020

[SRR-CWDA-2012-00038]

Radionuclide	Floor		Wall		Total Inventory(1) (Curies)
	Inventory (Curies)	Percentage of Total (%) $\left[\frac{\textit{HRR Floor Inventory}}{\textit{HRR Floor Inventory}}\right]$	Inventory (Curies)	Percentage of Total (%) $\left[\frac{\textit{HRR Floor Inventory}}{\textit{HRR Floor Inventory}}\right]$	
Am-241	9.4E+01	58	6.9E+01	42	1.6E+02
Cs-137	4.7E+03	51	4.5E+03	49	9.2E+03
I-129	2.0E-04	76	6.3E-05	24	2.6E-04
Np-237	1.1E-01	58	7.8E-02	42	1.9E-01
Pu-238	6.9E+01	5	1.2E+03	95	1.3E+03
Pu-239	2.0E+02	71	8.5E+01	29	2.9E+02
Pu-240	4.5E+01	68	2.1E+01	32	6.7E+01
Sr-90	7.4E+02	30	1.8E+03	70	2.5E+03
Tc-99	7.0E-01	77	2.1E-01	23	9.1E-01
U-234	2.2E-01	70	9.3E-02	30	3.1E-01

NOTES: (1) Due to rounding, total inventories shown may differ slightly from those contained in the *Tank 18 Residual Characterization Report*. [SRR-CWDA-2010-00117]

Of particular significance is the high percentage of Pu-238 on the tank wall because this radionuclide is especially important to performance of the closed tank farm, as discussed below.

To help ensure accuracy in the inventory, a statistical analysis was performed to ensure the adequacy of the floor sampling plan. Uncertainty analyses were also performed for the floor waste volume, the floor analytical data, and the wall analytical data. Evaluation of the data showed that the concentration of Pu-238 measured in corrosion film samples from the tank wall was much higher than the concentration in the floor samples, which was unexpected. The measured Pu-238 concentrations in these wall samples were used in compiling the inventory, even though this approach is considered to be very conservative.

2.5 Predicted Impacts of the Tank Residuals

The predicted performance of the closed tank farm in protecting a hypothetical member of the public who may inhabit the area in the future – in particular, the contribution of Tank 18 residuals to the predicted dose to this individual – is an important element in the cost-benefit analysis. This section therefore provides brief summaries of the F-Tank Farm Performance Assessment and the Special Analysis for Tanks 18 and 19 and discusses the results of these analyses pertaining to protection of the hypothetical member of the public. [SRS-REG-2007-00002, SRR-CWDA-2010-00124]

2.5.1 Performance Objective

The requirements of 10 CFR 61, Subpart C and DOE Manual 435.1-1 provide for a maximum dose to a member of the public following tank farm closure of 25 millirem per year 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."

2.5.2 F-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 F-Tank Farm 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. These analyses make use of two types of models.

F-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.

One or more mathematical models are used with the conceptual model to calculate potential doses under different scenarios. The F-Tank Farm Performance Assessment makes use of HELP, PORFLOW, GoldSim, and CAP88-PC. These computer codes are described in the Performance Assessment. [SRS-REG-2007-00002]

Because of the complexities in groundwater flow, for modeling purposes, the F-Tank Farm is divided into five sectors labeled A through E and, among other things, the highest predicted groundwater radionuclide concentration 100 meters hydraulically downgradient from the F-Tank Farm boundary, regardless of the specific sector, is used in predicting the dose to a member of the public. [SRS-REG-2007-00002]

F-Tank Farm Key Performance Assessment Results

The F-Tank Farm Performance Assessment modeling was used to determine an all-pathways dose to a member of the public for comparison with the performance objectives. The Base Case analysis projected the peak all-pathways dose to a member of the public to be less than the 25 millirem per year performance objective during the 10,000-year performance period[4], as shown in Figure 2-7. The peak all-pathways dose projection includes the groundwater pathways and air pathways associated with all F-Tank Farm tanks and associated ancillary structures with the groundwater pathway being the most significant contributor. The groundwater pathway contributed 2.3 millirem of the estimated peak dose; the radionuclides most important to the groundwater pathway results were U-233, U-234, and Np-237. [SRS-REG-2007-00002]

Tank 18 is the primary contributor to the Base Case all-pathways peak dose because of several factors unique to the F-Tank Farm Type IV tanks in general and Tank 18 in particular. For example, the Type IV tank design differs from the other tanks in that Type IV tanks do not have a secondary containment and have a relatively thin basemat (see Figure 2-4). The FTF Type IV tanks are also closer to the water table than the other F-Tank Farm tanks. Of the four F-Tank Farm Type IV tanks, Tank 18 is the primary dose contributor based on the specific Tank 18 inventory at closure (a function of its unique waste receipt history resulting in a significant accumulation of insoluble sludge solids prior to waste removal activities), which differs from the other Type IV tanks.

The F-Tank Farm Performance Assessment used a performance period of 10,000 years after facility closure, that is, the maximum estimated doses during that period were compared to the performance objectives. This period is 10 times longer than the 1,000-year compliance period required by required by DOE Manual 435.1-1 for low-level waste disposal facilities. This longer performance period provides added assurance that the performance objectives will be met and is consistent with NRC guidance in NUREG-1854. [SRS-REG-2007-00002]

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[4]A performance period of 10,000 years was used in assessing compliance with the performance objectives for the F-Tank Farm system related to future hypothetical members of the public and inadvertent intruders in evaluation of compliance with Criterion 3 in Section 3116 of the NDAA. Criterion 3 reads as follows:

"(3) (A) does not exceed concentration limits for Class C low-level waste as set out in Section 61.55 of title 10, Code of Federal Regulations, and will be disposed of—

(i) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations; and

(ii) pursuant to a State-approved closure plan or State-issued permit, authority for the approval or issuance of which is conferred on the State outside of this section; or

(B) exceeds concentration limits for Class C low-level waste as set out in section 61.55 of title 10, Code of Federal Regulations, but will be disposed of –

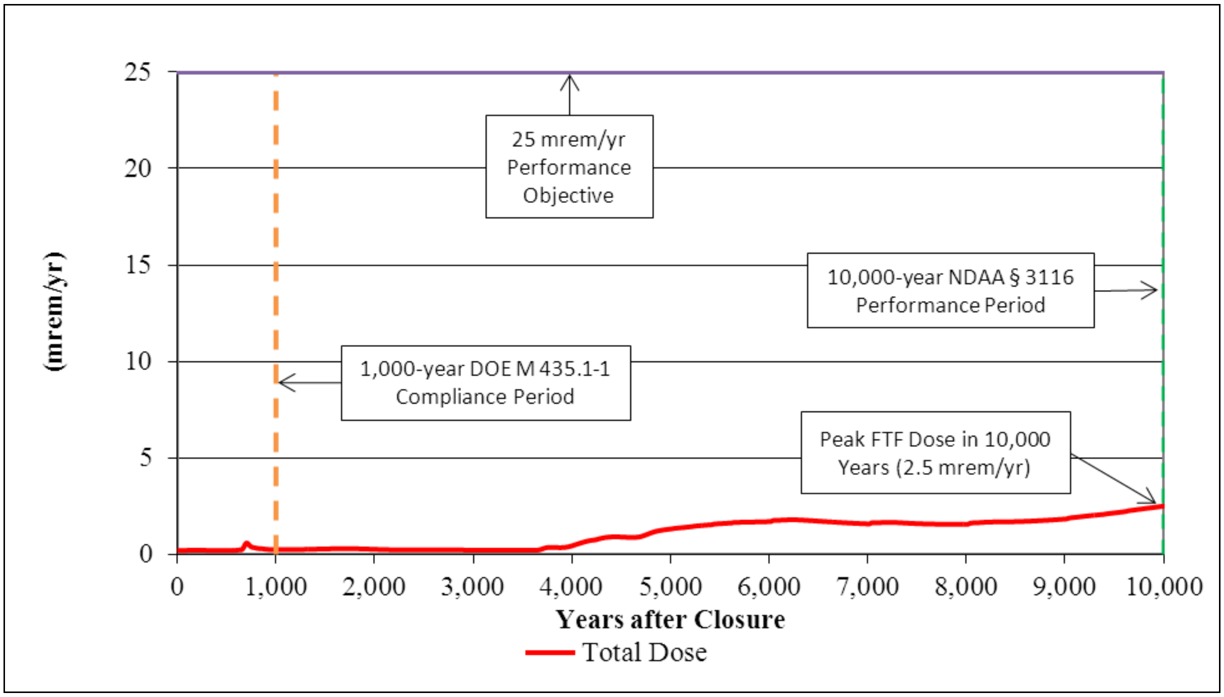
(i) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations;

(ii) pursuant to a State-approved closure plan or State-issued permit, authority for which is conferred on the State outside of this section; and

(iii) pursuant to plans developed by the Secretary in consultation with the Commission."

Figure 2-7: Member of the Public Peak All-Pathways Dose Over the Performance Period

F-Tank Farm Performance Assessment [SRS-REG-2007-00002]



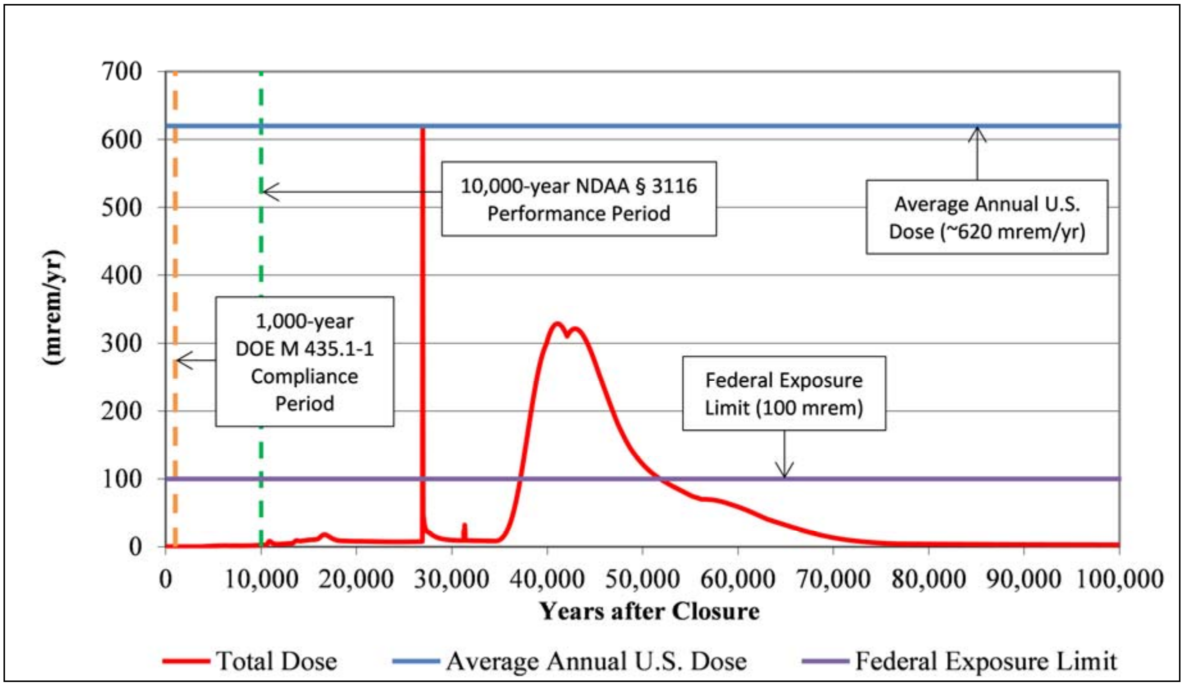
Additional Results

The F-Tank Farm Performance Assessment also included the results of model runs for extended periods. These model runs are used to identify dose peaks beyond the end of the performance period so they can be considered in DOE's evaluation of the results to support risk-informed decisions on the performance of the closed facility.

For additional information, Figure 2-8 displays the peak all-pathways dose 100,000 years after closure, an additional 90,000 years beyond the performance period and 100 times the DOE compliance period. [SRS-REG-2007-00002]

Figure 2-8: Member of the Public Peak All-Pathways Dose Over 100,000 Years

F-Tank Farm Performance Assessment [SRS-REG-2007-00002]



The peak dose of approximately 600 millirem at approximately 30,000 years is associated with the original conservative estimate for Tc-99 inventory in the F-Tank Farm Type I tanks. As discussed in the DOE response to NRC request for additional information, preliminary analysis of sampling results from the first two Type I tanks that have undergone waste removal suggests residual inventories of Tc-99 to be significantly less than the estimated value used in the F-Tank Farm Performance Assessment. [SRR-CWDA-2011-00054] Based on this information, DOE believes this peak to be artificially amplified by one to two orders of magnitude. The next most significant peak which occurs at approximately year 40,000 is associated with Pu-239, and is mainly associated with Tank 18 inventory.

NRC in its Technical Evaluation Report expressed concern about the timing of this predicted dose peak: [NRC-TER-2011]

> "The peak dose associated with Pu from Tank 18 could be mitigated through: (i) additional waste characterization that might suggest greater solubility control of Pu than assumed in the PA; (ii) additional experimentation or modeling that would support more favorable assumptions regarding natural attenuation of Pu; or (iii) through additional inventory reduction of Tank 18 (effectiveness dependent on degree of solubility control). However, considering the fact that unacceptably high peak doses could occur within the 10,000 year period of compliance with only a factor of 3 or 4 faster time to collective failure of a combination of barriers for Tc or Pu, respectively, and considering the large uncertainty associated with predictions of long-term performance of engineered barriers,

NRC staff are not convinced that the high peak doses currently presented in DOE's PA (or lower peak doses of unknown magnitude that might be associated with a more realistic model) could not be realized within a 10,000 year compliance period."

This matter is discussed further in Section 2.5.3 below.

2.5.3 Special Analysis Results

The Special Analysis made use of the residual radionuclide inventories for Tank 18 and Tank 19 prepared using analytical data from samples collected after use of the Sand Mantis. [SRR-CWDA-2010-00124] This inventory totaled approximately 32,000 curies in 2010 with the HRR estimates shown in Table 2-2. As noted previously, DOE provided a predecisional draft version, Revision 0a, of the Special Analysis to the NRC in response to NRC request for additional information. The final version of the Special Analysis added sensitivity studies varying plutonium solubility values, distribution coefficient values and other parameters, along with additional discussion regarding high dose peaks predicted to occur beyond the 10,000-year performance period.

The Special Analysis predicts a maximum all-pathways dose within the performance period of 3.4 millirem per year at approximately 10,000 years after closure. The groundwater pathway contributes 3.2 millirem of this estimate; the radionuclides most important to the groundwater pathway results were Ra-226, U-234, Pa-231, and Np-237, with Ra-226 producing 62 percent of the maximum dose. The Ra-226 results from the decay of Pu-238 and U-234. The Tank 18 inventory contributed approximately 91 percent of the maximum groundwater dose. [SRR-CWDA-2010-00124, Table 6-3-9] The reason for the results differing from the Performance Assessment was use of the radionuclide inventory from the final residual characterization.

Utilizing the actual residual inventories at closure for Tanks 18 and 19 did not significantly impact the peak groundwater pathway doses. The peak groundwater pathway dose in 20,000 years went down slightly (from 18 to 17 millirem per year), while the peak groundwater pathway dose in 10,000 years went up from 2.3 to 3.2 millirem per year. [SRR-CWDA-2010-00124]

The Special Analysis also includes sensitivity analyses to assess the potential impacts out to 100,000 years, an additional 90,000 years past the end of the performance period. The analysis evaluated the possibility that a dose peak of approximately 500 millirem at 40,000 years after tank farm closure – which is primarily from Pu-239 in Tank 18 as predicted in the Performance Assessment – could occur much earlier during the performance period.

The results showed that, while there is uncertainty around the peak dose associated with the residual Pu-239 in Tank 18, there is reasonable assurance that the Pu-239 peak dose could not move forward into the 10,000-year performance period. [SRR-CWDA-2010-00124]

3.0 HIGHLY RADIOACTIVE RADIONUCLIDE REMOVAL PROCESSES USED

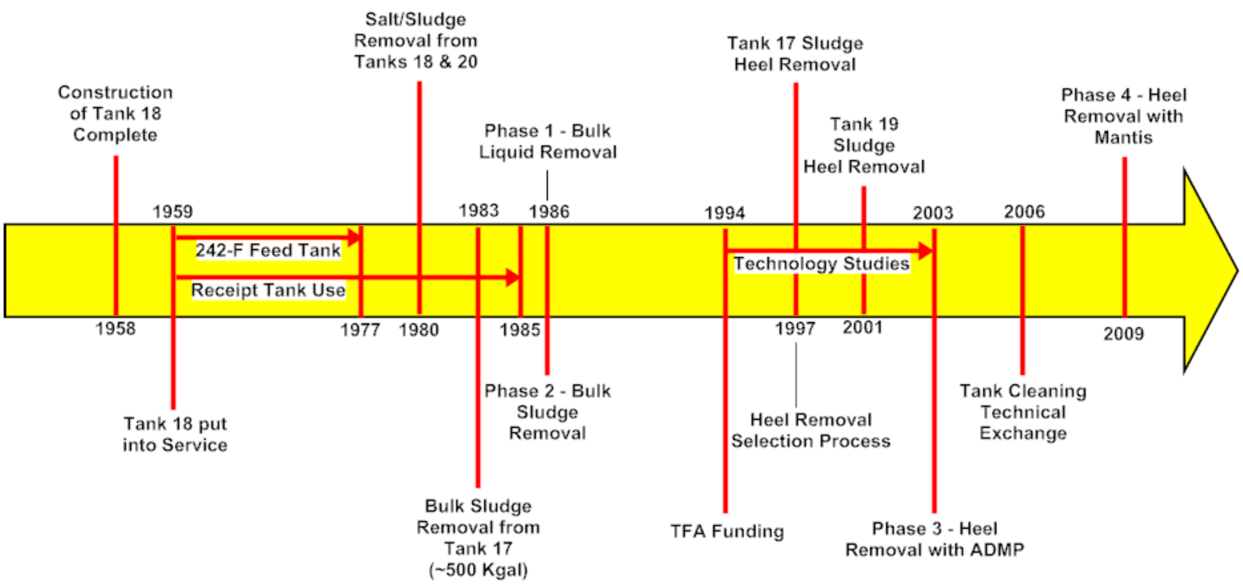
This section briefly describes the processes used to remove waste and HRRs from Tank 18. It provides brief summaries of the phases of waste removal, with these phases defined as indicated in Section 1.3 as:

- Phase 1: bulk liquid waste removal,
- Phase 2: bulk sludge waste removal,
- Phase 3: heel removal with the Advanced Design Mixer Pump, and
- Phase 4: heel removal with the Sand Mantis

The information in this section is taken from the 2011 report, *Documentation of Removal of Highly Radioactive Radionuclides in Waste Tanks 18 and 19* and that report should be referred to for additional information, including references for the information discussed below. [SRR-CWDA-2011-00091]

Figure 3-1 shows the Tank 18 historical timeline, including the waste removal activities.

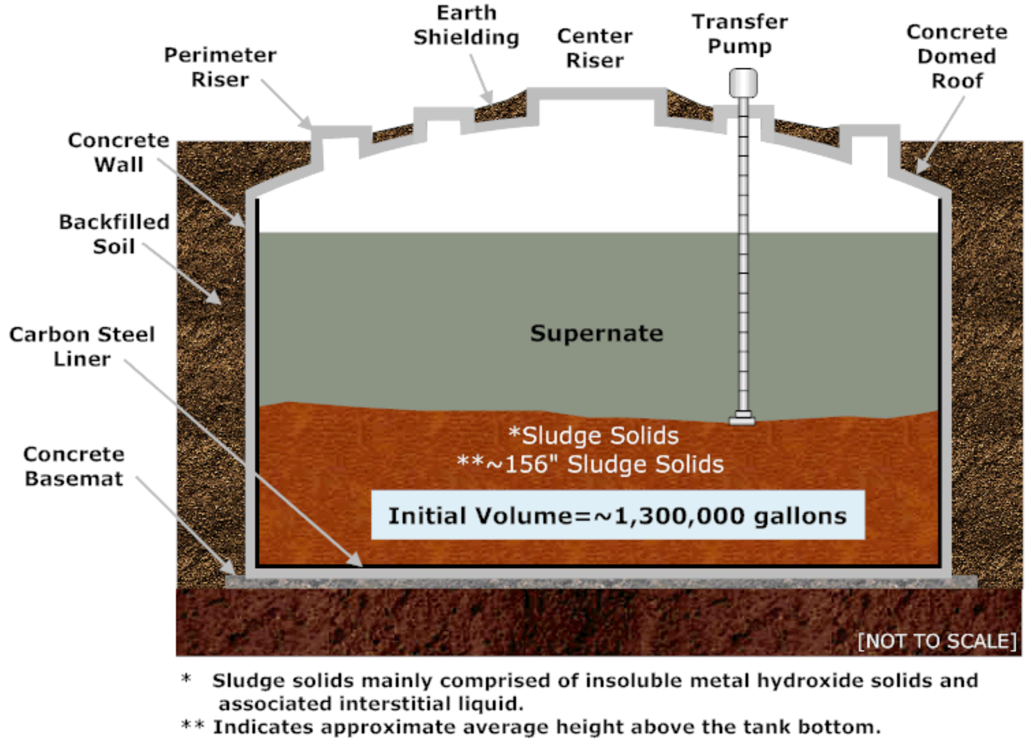
Figure 3-1: Tank 18 Historical Timeline



3.1 Phase 1, Bulk Liquid Waste Removal

Prior to beginning the waste removal campaign, the Tank 18 waste level routinely approached the tank nominal capacity of approximately 1,300,000 gallons of total waste and this value was used as the baseline volume at the beginning of the waste removal campaign. At the time waste removal activities commenced, approximately 550,000 gallons of this waste were in a wet solids form called sludge – which is mainly comprised of insoluble metal hydroxide solids with their associated interstitial liquid – and the remainder was freestanding liquid (supernate). Figure 3-2 shows this condition.

Figure 3-2: Tank 18 Initial Condition Prior to Waste Removal (January 1986)



During this phase, the concentrated liquid wastes, including both freestanding liquid (the liquid above the sludge) and some interstitial liquid (liquid in the sludge), were removed in early 1986. Approximately 850,000 gallons were removed to provide sufficient space for water additions to support bulk sludge removal. After the liquid waste was removed, an estimated volume of approximately 550,000 gallons of sludge remained[5], which contained both freestanding and interstitial liquid. This volume appears as the lower shaded volume in Figure 3-2.

3.2 Phase 2, Bulk Sludge Waste Removal

Long-shaft standard mixer pumps were the baseline mixer technology for bulk waste removal efforts. Inhibited water or salt solution was added to the waste tank and the standard mixer pumps exerted a sweeping liquid jet action on the sludge to promote its mixing and allow the particles to be suspended for transferring.

From July 1986 to August 1987, seventeen different sludge slurry transfers combined into four campaigns were accomplished. Bulk sludge waste removal operations were stopped in Tank 18 because the sludge solids removal rate decreased and waste tank storage space was not available for receipt of additional sludge slurry transfers from water additions that would have been required for additional campaigns. The spent zeolite resin was not present in Tank 18 during this time because the Tank 19 material had not yet been transferred into Tank 18.

[5] Some historical documentation (e.g., daily operational surveillance reports) cites the estimated sludge volume to be approximately 600,000 gallons; however, for conservatism in calculating removal efficiencies, 550,000 gallons is used.

During the bulk sludge removal phase, approximately 500,000 gallons of sludge solids were slurried and removed, with the final sludge slurry transfer completed in August 1987.

3.3 Phase 3, Heel Removal With the Advance Design Mixer Pump

Using photographs taken in May 1988, it was estimated that approximately 37,000 gallons of solids remained in Tank 18 at the conclusion of the bulk sludge waste removal campaign. An additional 12,500 gallons of insoluble solids were later transferred into Tank 18 from the heel removal operations from Tank 17 and Tank 19, including approximately 2,500 gallons of spent zeolite resin from Tank 19.

A detailed technology selection process culminated in selection of the Advanced Design Mixer Pump as the preferred technology for heel removal. Extensive testing demonstrated its effectiveness.

The Advance Design Mixer Pump was installed in the tank center riser in September 2002. The heel removal strategy consisted of adding well water, mixing with the Advance Design Mixer Pump, and transferring the sludge slurry to Tank 7.

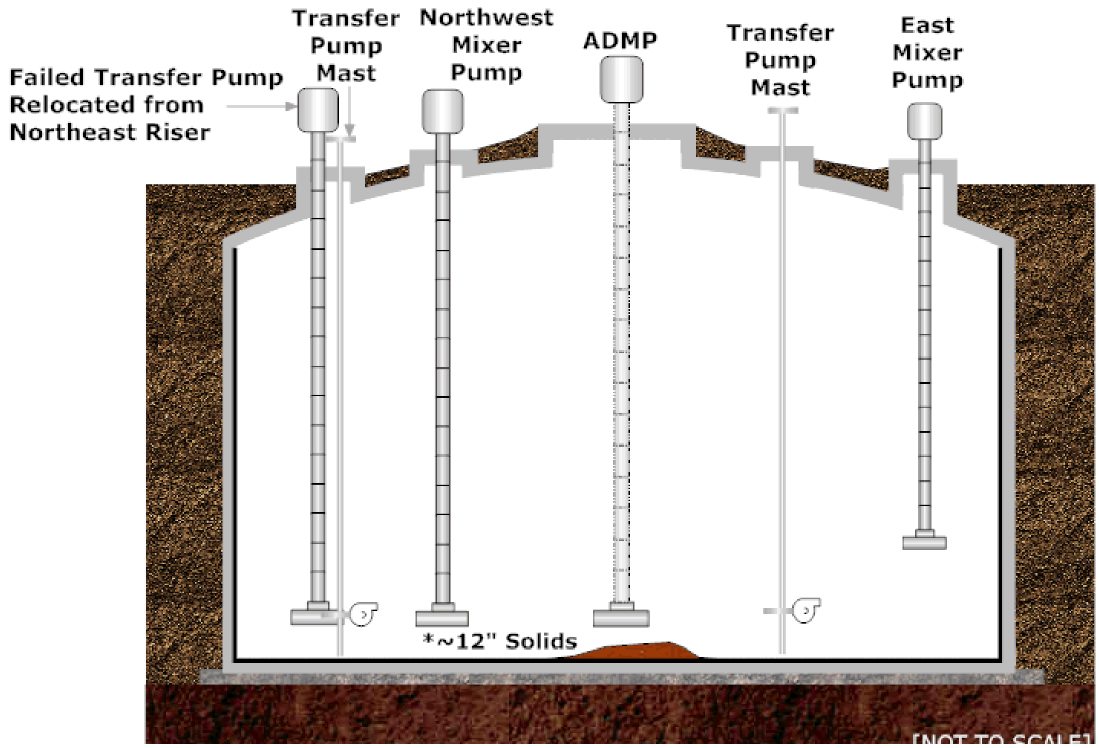
During the latter part of these operations, the wall of Tank 18 was washed with water from nozzles in the east and west ports of the center riser using a spray nozzle with pan-and-tilt capability and an operating capacity of 65 gallon per minute (gpm) at 175 pounds per square inch (psi). The tank wall surfaces were washed from top to bottom, focusing on areas with deposits, including the stiffener bands. Approximately 2,800 gallons of water were used in this process. Afterwards, using the video technology in service at the time, no visible quantities of waste could be seen on the wall, with an estimated 14 gallons of waste left on the lower stiffener band in the southwest part of the tank. [CBU-LTS-2003-00115]

The Phase 3 heel removal campaign reduced the wet solids volume in Tank 18 from approximately 49,500 gallons to a then estimated 4,300 gallons. Later Phase 4 heel removal efforts and the associated final volume determination indicated that estimate was low. Figure 3-3 illustrates the condition of Tank 18 following Phase 3 heel removal.

3.4 Phase 4, Heel Removal with the Sand Mantis

As noted previously, after completion of Phase 3, a Performance Objective Demonstration Document for Tanks 18 and 19 had been prepared along with a Draft Tank 18 and 19 3116 Basis Document and these documents had been provided to NRC for review. [CBU-PIT-2005-00106, DOE-WD-2005-002] However, in 2006 DOE elected to halt closure preparations for Tanks 18 and 19 and try to remove additional waste and highly radioactivity radionuclides from these tanks using a newly identified tank cleaning technology.

Figure 3-3: Tank 18 Following Phase 3 – Heel Removal with Advanced Design Mixer Pump (July 2003)



3.4.1 Obtaining and Testing the Sand Mantis

In March 2006, a tank cleaning technical exchange involving waste tank cleaning experts from across the DOE Complex and from commercial industry took place in Atlanta, Georgia. Among the tank cleaning methods discussed were two new technologies:

- An in-tank crawler/robotic arm utilizing air vacuuming as a motive force for waste heel removal and
- An in-tank crawler/robotic arm utilizing pressurized water eduction for waste heel removal.

Contract Award and Initial Testing

DOE recognized that these were potentially optimal technologies uniquely applicable for removal of additional waste from Tanks 18 and 19 and moved forward with soliciting proposals. DOE awarded a three-part subcontract to TMR for the company’s mechanical waste removal system, which consisted of a robotic crawler called a Mantis.

After review of the test results from the proof of concept testing and the full-scale demonstration, DOE concluded that TMR had successfully met the requirements to proceed to actual heel removal in Tanks 18 and 19.

Features of the New Technology

The TMR mechanical waste removal system consisted of a remotely controlled in-tank Mantis, an umbilical hose containing hydraulic supply lines and the high-pressure water hoses, an in-tank waste retrieval hose, ultra-high-pressure water skids, a hydraulic pump skid, a minimum 150-kilowatt diesel generator, above ground hose-in-hose transfer lines, a waste mixing chamber, and the necessary support structures. Figure 3-4 shows the final design. The device was designed for a service life of 250 hours of operation.

Figure 3-4: Final Sand Mantis Design

The Sand Mantis was remotely operated within the waste tank by an outside operator. It had a high-pressure (4,500 psi) hydro-lance at the front that was used to break up waste mounds and an eductor (17,500 psi) used to aspirate waste from the floor of the waste tank. Operation of the Sand Mantis was monitored using in-tank lighting, cameras and video surveillance equipment.

The TMR design had an independent aboveground transfer line routed from Tanks 18 and 19 to the waste receipt tank, Tank 7. The hose-in-hose design provided full secondary containment and radiation shielding was installed around the line.

3.4.2 Tank 18 Heel Removal With the Sand Mantis

A new riser was installed in Tank 18 for installation of the mechanical cleaning equipment. DOE authorized initiating Tank 18 waste heel removal on January 29, 2009. The waste transfer operations started the next day.

On February 8, 2009 the rear wheel, which is used to tilt the front of the crawler downward, failed. The heel removal operations were continued without forward-downward spray or the ability to tilt the crawler until February 12, 2009. Operations were suspended to repair the tilt wheel, which was replaced with a shoe assembly fabricated from a five-inch length of steel tubing, which increased the length of the control arm to mimic the leverage provided by the original tilt wheel. This change provided the ability to tilt the forward end of the Sand Mantis down to the remaining waste solids.

The forward-downward spray system was pressurized on March 7, 2009 and the forward spray nozzles were utilized in an effort to optimize the ratio of water added to solids removed from the waste tank.

At the conclusion of operations on March 13, 2009, the Sand Mantis was operated in predetermined areas to measure the effectiveness of further operations. The effectiveness measurement used consisted of monitoring the radiation detector readings during operations in ten locations in the waste tank. The radiation readings inside of the temporary shielding were recorded during the cleaning operation for each area to understand the cleaning effectiveness.

This survey process confirmed that the Sand Mantis had reached its limits for effective removal of solid waste materials. At completion of these effectiveness operational runs, the total Sand Mantis operating time, including testing, was approximately 459 hours. During its operation, several repairs were made to the Sand Mantis and to its support system to extend the operational life to maximize additional heel removal. By the end of the operational life, the Sand Mantis blade (a rubber squeegee device) had become worn and degraded, making additional waste removal very inefficient because of a high water-to-waste ratio.

3.4.3 Tank Conditions After Completion of Phase 4 Cleaning

Table 3-1 shows the percentages of waste removed from Tank 18 in the four phases of waste removal. Figure 3-6 shows the overall reduction in Tank 18 waste volume from beginning to end.

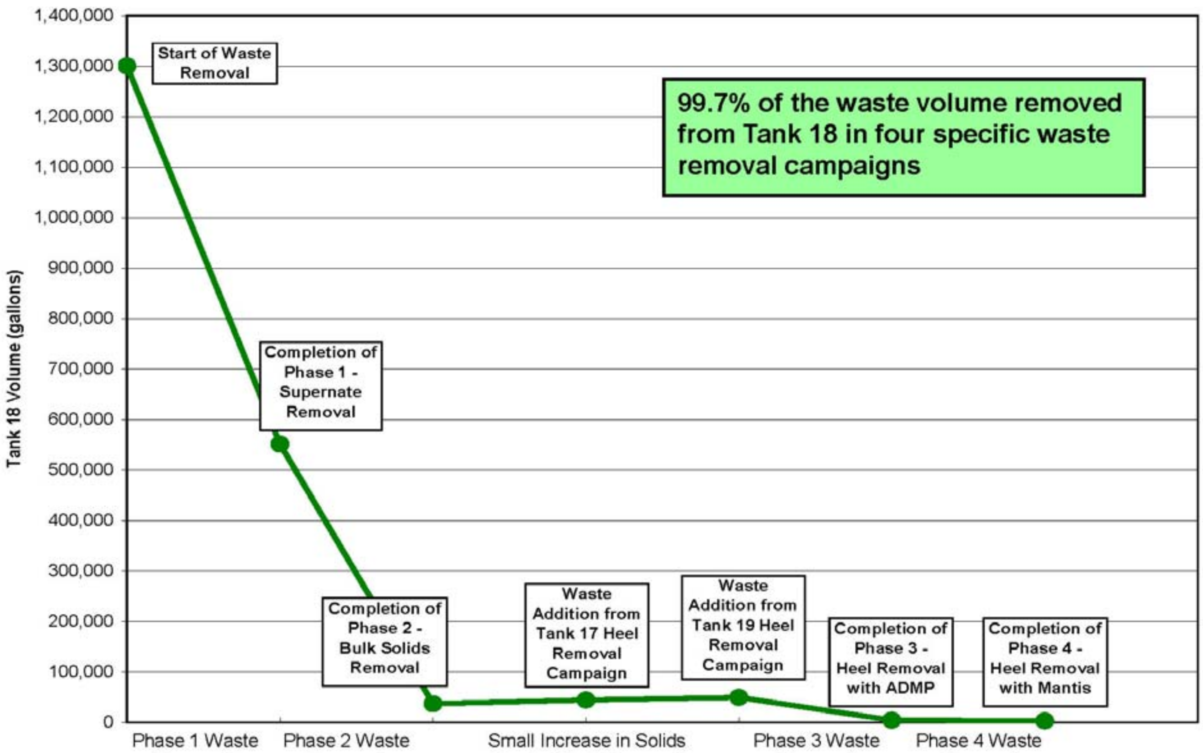
Table 3-1: Summary of Results of Waste Removal Activities in Tank 18

Inventory	Tank 18 Waste	
	Approximate Gallons	**Cumulative % Removed**
Inventory Prior to Waste Removal	1,300,000	0
Inventory at Completion of Phase 1 Campaign	550,000	57.7
Inventory at Completion of Phase 2 Campaign	37,000	97.2
Inventory at Completion of Phase 3 Campaign	4,300(1)	99.7
Inventory at Completion of Phase 4 Campaign	4,000	99.7

NOTE: (1) The inventory following Phase 3 was underestimated, as noted previously.

As shown in Table 3-1, approximately 4,000 gallons of the starting waste volume of 1,300,000 gallons in Tank 18 remain inside the waste tank. DOE removed approximately 99.7 percent of the waste volume from Tank 18 in the four waste removal phases as shown in Table 3-1 and Figure 3-5.

Figure 3-5: Tank 18 Waste Volume Reduction By the Four Waste Removal Campaigns



3.4.4 Basis for Ceasing Mechanical Cleaning Using the Sand Mantis

By March 13, 2009, the existing Sand Mantis equipment had cleaned Tank 18 to the extent of its capability and was no longer effective at removing additional waste, so DOE suspended its operation.

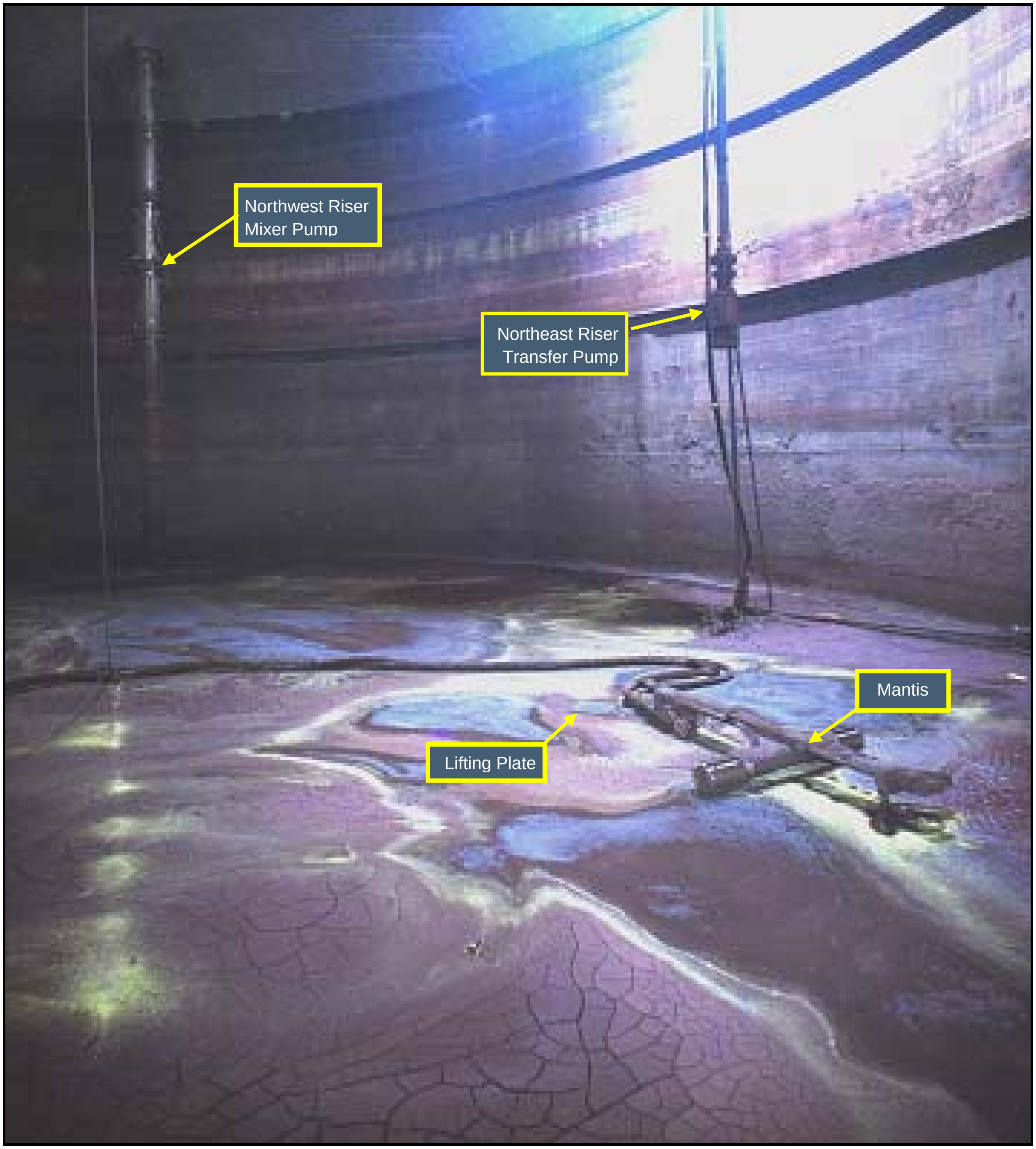
Agreement to Proceed with Sampling and Analysis

In accordance with the F-Tank Farm General Closure Plan [LWO-RIP-2009-00009], DOE briefed EPA officials on September 24, 2009 and SCDHEC officials on October 1, 2009 on the results of the Sand Mantis cleaning of Tanks 18 and 19. [SRR-CWDA-2009-00030] DOE followed up the presentation with a formal request for concurrence to proceed with the sample and analysis phase for Tanks 18 and 19 and the two regulators concurred.

Visual Observations

Visual inspections of the tanks indicated that there was a significant reduction in residual material volume resulting from the Sand Mantis operations. Mounds of residual material that had existed prior to heel removal using the Sand Mantis were no longer present. Volume estimated showed that Tank 18 had 4,000 gallons of residual solids (3,900 gallons on the floor and approximately 100 gallons on the wall). Figures 3-6 shows final tank conditions.

**Figure 3-6: Tank 18 after Completion of Mantis Operations (July 2009)
(View from New Mechanical Cleaning Riser Looking North)**



Diminished Transfer Line Radiation Level Trends and Confirmatory Operation

As noted previously, a radiation monitoring system had been installed on the inside and outside of the transfer line shielding from Tanks 18 to assess the solid waste transfer process and measure the effectiveness of Sand Mantis operations. The measure of effectiveness consisted of evaluating radiation levels monitored during the cleaning of the ten locations in the tank selected to ensure that the data were representative of the entire tank bottom. The results of this confirmatory monitoring demonstrated that the Tank 18 Sand Mantis had reached diminished effectiveness for removal of solid waste materials.

3.4.5 Sand Mantis Equipment Degradation

Several repairs had to be made to the Sand Mantis and its supporting equipment for both Tanks 18 and 19 to extend operational life and to maximize additional heel removal. For example, after approximately four days of operation the rear wheel of the Sand Mantis utilized in Tank 19 failed. Preparations to replace the wheel to ensure that repairs could be efficiently made while minimizing worker radiation exposure took three months.

Based on the lessons learned from the experience with the Sand Mantis in Tank 19, the Tank 18 Sand Mantis was redesigned before being deployed to strengthen the wheel assembly. Even with this redesign, the wheel assembly on the Tank 18 Sand Mantis failed after nine days of operation as mentioned previously an innovative in-tank repair was made by increasing the length of the control arm to mimic the leverage provided with the original wheel on the tilt-arm assembly. As a result of these efforts, the Sand Mantis was operated for almost twice its design life in Tank 18.

Even with equipment repairs to extend operational life, the existing Sand Mantis equipment eventually reached the point where it was no longer effective in removing additional waste at the low residual levels remaining in Tank 18. After extended operations, the forward blades eventually wore to the point that they were no longer effectively corralling the waste in front of the suction head of the Sand Mantis, severely affecting the waste removal efficiency. In addition, after Tank 18 Sand Mantis repair completion and during further operations, it was determined that the full capability of the tilt-arm assembly to reach the 0.5-inch level in the tank was not being realized, further reducing the effectiveness of the Tank 18 Sand Mantis at low residual waste levels.

3.4.6 Impacts on Tank Space and the Liquid Waste System

The impact of waste removal system operation on tank space and the Liquid Waste System as a whole is an important consideration in evaluating the cost and benefits of further HRR removal.

Through experience gained during Sand Mantis operations it became evident that solids removal effectiveness could be optimized by operating the Sand Mantis such that the mounds were used as a “backstop” to help corral the waste thus increasing the solids content in the discharge stream to Tank 7. During Sand Mantis operations in the tank, it was determined that the hoses attached to the Sand Mantis could actually be used to help corral the waste into mounds as well. By the end of Sand Mantis operations, the remaining material in Tanks 18 and 19 was no longer contained in mounds or able to be corralled into mounds, but was spread in a thin layer on the bottom of the tank. As a result, the water efficiency – that is, the gallons of waste removed per gallon water used – during continued Sand Mantis operations was steadily decreasing.

Impacts of Secondary Waste Generation

Water used for operation of the Sand Mantis was being added at nearly a constant rate regardless of the amount of waste being removed. The increased water-to-waste ratio issue was compounded by the deterioration of the forward blades on the Sand Mantis and the degradation of the eductor system. The experiences in Tank 18 and Tank 19 form the primary basis for many of the cost estimates discussed in Section 6 of this cost-benefit analysis.

At the start of Sand Mantis operations, it was estimated that a combined total of approximately 150,000 gallons of waste, consisting of existing tank solids and water added for removal, would be generated in completing solids removal from both Tanks 18 and 19. However, Sand Mantis operations actually generated approximately 250,000 gallons of waste – 110,000 gallons from Tank 18 and 140,000 gallons from Tank 19. The increase in waste generated compared to the amounts planned resulted from decreased heel removal efficiency and Sand Mantis operations taking much longer than originally planned.

The greatest impact of this increased waste generation was that available space in Tank 7 (the receipt tank for Sand Mantis removal operations for both Tank 18 and 19) was being depleted by the additional waste being created by extended Sand Mantis operations. Tank 7, a Type I tank, was being used as the receipt tank for waste generated by Sand Mantis operations because of its proximity to Tanks 18 and 19 and because there was insufficient tank operating space existing in the F-Tank Farm Type III/IIIA tanks to receive the expected waste generated from Sand Mantis operations. At the completion of Sand Mantis operations on April 23, 2009, there was less than 25,000 gallons of receipt space remaining in Tank 7. Based on its operational history, it was expected that continued operation of a Sand Mantis would add approximately 8,000 gallons per day of new waste to the tank farm system. Therefore, existing Tank 7 receipt space when Sand Mantis operations were suspended would have only supported an additional three to four days of additional Sand Mantis operations.

Impacts of Evaporator Use on Cleaning Other tanks

In addition, when Tanks 18 and 19 Sand Mantis operations were suspended and continued heel removal was being evaluated, Sludge Batch 6 was in the process of being prepared for feed to the Defense Waste Processing Facility. Sludge Batch 6 preparation involved removing bulk sludge from Tanks 4 and 7 in F-Tank Farm and Tank 12 in H-Tank Farm (Type I tanks) into Tank 51, a Type III/IIIA tank used for sludge batch preparation, thereby significantly reducing the risk associated with the sludge stored in these Type I tanks. The subsequent Sludge Batch 6 washing operation in Tank 51 required both tank farm evaporators to process the additional washwater (over one million gallons) generated by washing the sludge to meet Defense Waste Processing Facility feed specifications. At that time, additional load on the evaporators resulting from waste generated from additional Tanks 18 and 19 cleaning would have delayed the preparation of Sludge Batch 6, potentially causing a feed break and subsequent shut down of the Defense Waste Processing Facility. It would have also had the effect of delaying sludge removal efforts for the preparation of Sludge Batch 7, which removed additional sludge from Tank 4 and also includes sludge in Tank 7 that originated from Tanks 5 and 6 (Type I tanks) heel removal.

Impacts on Waste Vitrification

In addition to supporting Tanks 18 and 19 cleaning, Tank 7 was also the hub tank supporting tank cleaning initiatives in Tanks 5 and 6 and bulk sludge removal initiatives for Tank 4. That is, most, if not all, of the transfers associated with these activities also go into Tank 7 before being moved on to their final tank destination. Due to the unique transfer line configuration in F-Tank Farm, this overall integration of waste transfers and equipment usage is a closely monitored process to maximize efficient use of all resources associated with risk reduction activities in the tank farm. For example, additional cleaning efforts in Tanks 18 and 19 would have continued to occupy Tank 7, thereby precluding a planned transfer from Tank 7 to Tank 51 needed to maintain the Sludge Batch 6 schedule. In addition, it would have delayed chemical cleaning in Tank 5 resulting in a subsequent delay in Tank 6 heel removal because these two tanks utilize some of the same equipment to perform heel removal.

From an overall Liquid Waste System risk perspective, it is important to ensure that continuation of sludge feed to the Defense Waste Processing Facility is maintained. Without qualified sludge feed, the vitrification facility would have to shut down and stop vitrifying sludge waste into canisters for storage. This factor must be taken into consideration when priority decisions are made involving conflicting uses of a key Liquid Waste System facility such as Tank 7, which is integral to supporting both sludge waste removal and needed to maintain feed to the Defense Waste Processing Facility and heel removal activities supporting removal from service of other waste tanks.

4.0 OTHER WASTE REMOVAL PROCESSES EVALUATED

This section discusses the 2012 SEE performed to identify and evaluate potential methods for removing additional waste and HRRs from Tank 18. Readers should refer to Appendix A for details.

4.1 The 2012 Systems Engineering Evaluation

This subsection briefly summarizes the approach to the 2012 SEE and the general conclusions, and then summarizes the results of evaluation of the four methods that were evaluated in detail.

4.1.1 Approach

The SEE was performed for Tank 18 to identify the most promising technologies for removal of residual material that would potentially result in a reduction in the inventory of HRRs remaining in the tank after closure. A SEE is a process the Savannah River Site adopted from the National Aeronautics and Space Administration in 1998. It is a formal process used to select an alternative from two or more options that have been determined to be feasible to meet specific functions, selected criteria and requirements.

The 2012 SEE was performed by a team of seven experienced senior engineers and scientists from Savannah River Remediation, Savannah River National Laboratory, and Washington River Protection Solutions at the Hanford site, augmented by other subject matter experts. This team performed an independent review of proven, new, and emerging waste retrieval technologies, including those identified in a 2003 SEE [G-ESR-G-00051], by the collective experience of the team, and by Internet searches.

The team identified and screened 54 different technologies using formal screening criteria. The 30 that passed were rated on complexity, effectiveness, maturity, impact (such as secondary waste generated), and time required for implementation.

4.1.2 Overall Conclusions

The team did not identify any new or emerging tank cleaning technologies that had not been previously considered by the site, and identified no other new developments that appeared to be on the horizon. However, it determined that the tools necessary to implement various cleaning technologies have become more mature in recent years, that more vendors can supply these tools, and that four technologies merited further study.

Due to the current level of technical maturity of these technologies, without performing additional studies with actual field tests, the effectiveness of any of the technologies for additional HRR removal from either the floor or walls of Tank 18 could not be accurately predicted by the team. Therefore, the team made relative comparisons between technologies when evaluating potential effectiveness.

The four types of technologies meriting further consideration were:

- Robotic crawlers such as the Sand Mantis, with liquid mobilization and vacuuming;
- An articulating arm with multiple degrees of freedom, with liquid mobilization and vacuuming;
- A feed and bleed process involving mixing and recirculation using pumps; and

- Acid cleaning with robotic support, that is, direct acid cleaning controlled by robotics.

Details of each the technologies listed above can be found in Appendix A. Table 4-1 summarizes key attributes of the four types of technologies that merited further consideration.

Table 4-1: Key Attributes of Technologies Evaluated in Detail

Implementation Estimates For Highest Ranked Technology of Each Type(1)	**Robotic crawlers such as the Sand Mantis, with liquid mobilization and vacuuming**	**Articulating arm, with liquid mobilization and vacuuming**	**Feed and bleed process with mixing and recirculation with pumps**	**Direct acid cleaning with robotic support**
Development and Testing Time (years)	2	2-3	2-3	2-4
Field Implementation Time (years)(2)	1	1	1	1
Sample Analysis and Closure Documentation Time (years)(3)	2	2	2	2
Direct Cost (millions of $)(4)	13	14	25	15
Total Cost (millions of $)(5)	38	40	70	60
Occupational Dose required (person-rem)	3.2	2.8	5.4	3.2
Secondary Waste (thousands of gallons)	200-300(6)	200-300	400-600	300-400

NOTES: (1) The highest ranked technologies of each type were:

- Robotic crawlers similar to the Sand Mantis, with liquid mobilization and vacuuming: modified Sand Mantis.
- Articulating arm, with liquid mobilization and vacuuming: SA Technology Power Remote Manipulator.
- Feed and bleed: process using a recirculation line similar to the system used on Tank 6.
- Acid cleaning with robotic support: acid addition and transfer using robotics

(2) Includes collecting but not analyzing characterization samples.

(3) Includes laboratory sample analyses; preparation of the characterization report; revising documentation such as the Special Analysis, the revision and approval process for the Closure Module, etc.

(4) Including (1) development; (2) testing; (3) field implementation; and (3) additional tank characterization, including sample analyses. The $13 million direct cost estimate was higher than the $8 million estimate in SRR-CWDA-2010-00091 because, unlike the $8 million estimate, the $13million estimate includes (1) approximately $3.5 million for contingency and risk escalation, (2) costs for restoration of systems that have been isolated from the tank farm, (3) additional modeling to support the special analysis, and (4) rework of the F-Tank Farm 3116 Basis Document and the regulatory documents.

(5) Direct costs plus (1) $1 million per year for tank maintenance during the resulting operational closure delay and (2) $20 million per month for resulting impacts on the liquid waste management program.

(6) This estimate is higher than actual 110,000 gallons produced during Phase 4 due to the lower depths of waste (0.125 to 2.5 inches) requiring a higher ratio of water added to waste removed. This difference is consistent with the report SRR-CWDA-2011-00091 which notes that "an upgraded Mantis, if deployed, would have significantly diminished removal efficiency as related to the quantity of waste removed versus the amount of water required to remove residual waste (i.e. gallons of waste removed per gallons of new waste created in the receipt tank).

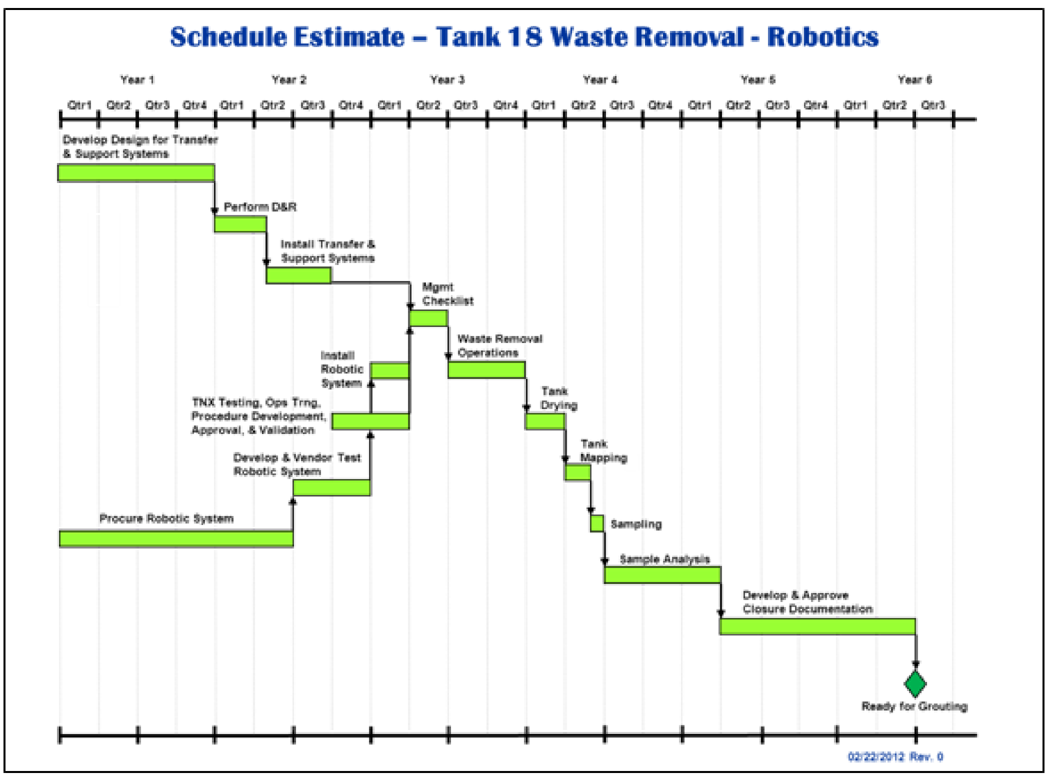
4.2 Robotics, With Liquid Mobilization and Vacuuming

The modified Sand Mantis technology would have the least development time and the lowest direct and total implementation costs. Use of the Sand Mantis has been described in detail in Section 3.4. Potential modifications to support removal of additional waste on the floor of Tank 18 would involve redesign of several components:

- Redesign of the rubber squeegee device at the suction head is needed because the squeegee experienced severe wear due to the amount of scraping on the tank floor. The ½ inch high lifting plates on the floor were thought to have contributed to the wear.
- The sapphire-lined jet nozzles and vacuum system in the suction head experienced wear causing a reduction in suction force. A more robust, hardened vacuum system is needed to extend the life and maintain suction force.
- The drive mechanism of the Sand Mantis degraded during operations. The Sand Mantis was able to reach all portions of the tank, however degradation of the drive mechanism did make reaching far areas of the tank floor more difficult. A more durable motive force system is needed.
- A redesigned suction intake is needed because the Tanks 18 and 19 mantis design had difficulty lifting solids with depths less than ½ inch. The strainer component that prevented larger debris from entering the suction was thought to have contributed to the difficulty in lifting solids < one inch.

Figure 4-1 shows the conceptual schedule.

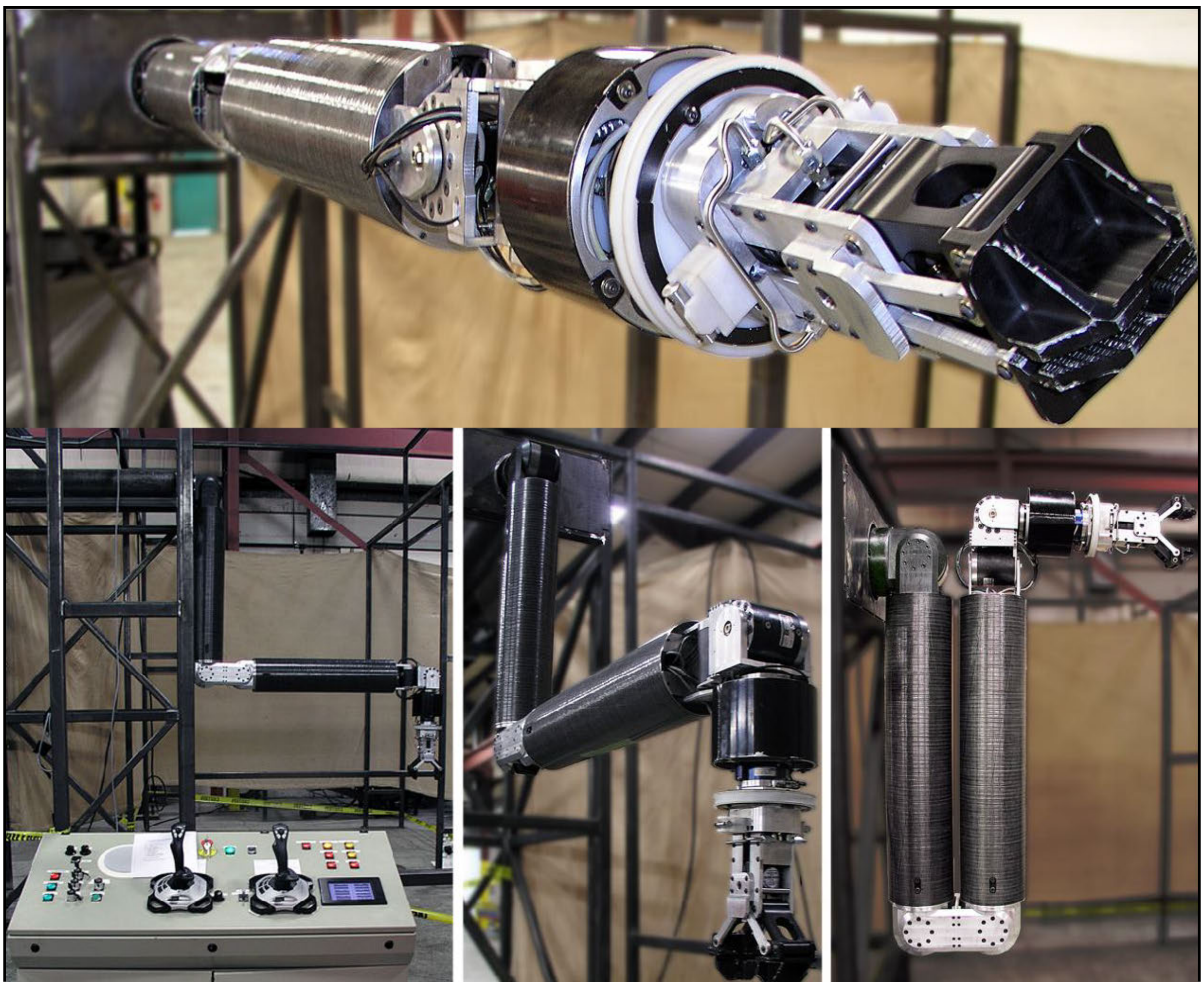
Figure 4-1: Conceptual Schedule for Implementing the Modified Sand Mantis Method



This technology would make use of the S.A. Technology Power Remote Manipulator or an equivalent remote manipulator to position a liquid mobilization-vacuum system on the tank floor, which would be used to remove additional waste and HRRs.

Figure 4-2 shows the S.A. Technology Power Remote Manipulator. This device makes use of a carbon fiber arm with three degrees of motion operated by a combination of electric and hydraulic drives. The handling capacity ranges from 112 to 168 pounds depending on orientation. It can be used with a wide range of attachments, such as grippers, dry media blasting, and hydrolasing heads. This remote manipulator could be deployed inside Tank 18 without major structural alterations to the tank. However, the current design could not reach all parts of the tank so design changes and testing would be necessary.

Figure 4-2. S.A. Technology Power Remote Manipulator



The S.A Technologies Power Remote Manipulator has not been used for work inside a DOE underground waste tank. However, a unit was designed, built, tested, and delivered in six months to the Dounreay Site Restoration project in the United Kingdom, according to the manufacturer.

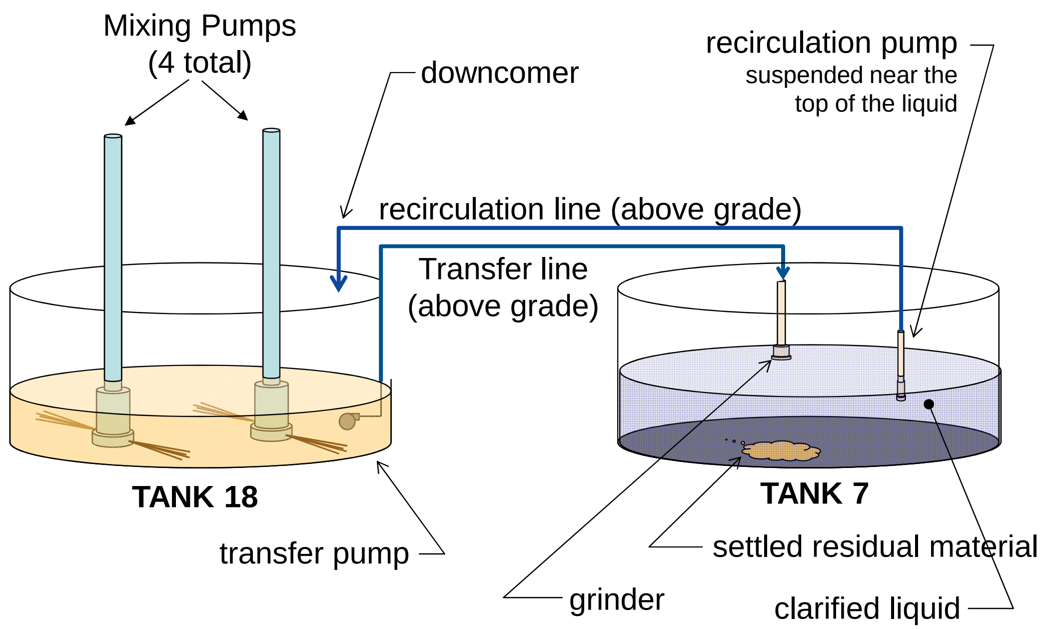
[http://www.satechnology.com/pdf/PRM%20PDF%20Information%20Packet.pdf] The results from use of the device are expected to become available in late 2012.

The equipment to be procured would include the manipulator, with spares, and a 400-foot waste transfer hose. As shown in Table 4-1, the direct cost would be approximately $14 million and the total overall cost would be approximately $40 million. The conceptual schedule would be similar to the schedule shown in Figure 4-1 and is estimated to span more than five years.

4.3 Feed and Bleed, With Mixing and Recirculation Using Pumps

The team considered this to be the most mature and well understood of the four technologies evaluated in detail. This process involves continuously pumping uncontaminated or low activity water into the tank, using mixer pumps to suspend the solids, continuously pumping the mixture to another tank, and stopping the water addition to allow the mixer pumps to cavitate. This process is then repeated until as much of the solids have been removed from the tank as practical. Figure 4-3 illustrates a system similar to the one used at SRS in Tank 6 in F-Tank Farm. A similar process was used to remove solids for Tank 5 but without the recirculation line.

Figure 4-3: Feed and Bleed System



As shown in Table 4-1, the direct cost would be approximately $25 million and the total overall cost would be approximately $70 million. The conceptual schedule would be similar to the schedule shown in Figure 4-1 and is estimated to span more than five years. The relatively high estimated worker dose of 5.4 person-rem shown in Table 4-1 results from the time that would be required to remove existing equipment from the tank risers and to install the required pumps.

The large estimated secondary waste volume is a major disadvantage of this process, especially considering the limited available tank space in F-Tank Farm. This system may not be effective in removing zeolite from the tank floor because the relatively large particle size and high density of zeolite results in quick settling in regions of low turbulence.

4.4 Acid Cleaning, With Robotic Support

The team reviewed a use of a variety of acids and combinations of acids as part of the evaluation. This technology would make use of a specially designed mixture of acids applied directly to the residual solids using an appropriate robotic device. Direct application of the acid without having to use a large volume moved by mixing pumps would minimize system impacts. The amount of acid used would be closely controlled to promote cleaning effectiveness and minimize impacts. By using a mixture of acids, HRRs could be targeted and corrosion impacts to the tank minimized.

A technology utilizing direct application of an acid mixture to residual solids has not been used for tank cleaning in the DOE complex. Numerous vendors can supply robotic devices that could be used.

This system would have to be developed and tested since no known field application exists. Several studies conducted by the Savannah River National Laboratory over the past eight years would be used as the starting point for flow sheet development.

In 1985, a bulk oxalic acid flow sheet was used to remove solids from Tank 24, also a Type IV tank, in H-Tank Farm at SRS. Tank 24, like Tank 18, contained significant quantities of spent zeolite resin. Removal effectiveness of the spent zeolite resin was much lower than expected due to the chemical changes to the resins over time in the high caustic environment. [DPST-85-782]

Considering such factors, the development time for this technology would be relatively long as indicated in Table 4-1 because of the research that would be necessary to develop a flow sheet and obtain the required equipment.

As shown in Table 4-1, the direct cost would be approximately $15 million and the total overall cost would be approximately $60 million. The conceptual schedule would be similar to the schedule shown in Figure 4-2 and is estimated to span more than five and one-half years, several months longer than the other methods.

This method would result in significant waste generation. Water that would be used to clean the tank and to wash the sludge to remove the neutralized acid, and the caustic required to neutralize the acid, would produce an estimated 300,000 to 400,000 gallons of waste to be processed. In addition, the resulting waste stream would have to be processed through the Caustic Side Solvent Extraction Unit and the Saltstone Processing Facility. Lengthy delays in salt batch processing and sludge batch preparation would likely result.

4.5 HRR Removal Effectiveness

Without performing additional studies with actual field tests, the effectiveness of any future technology for additional HRR removal from either the floor or walls of Tank 18 cannot be accurately predicted. Removal of all of the HRRs from Tank 18, which would include removal of all HRRs associated with corrosion products on the tank wall, is not consider realistic, nevertheless it is being assumed in this analysis for conservatism. The predicted dose reduction resulting from additional Tank 18 HRR removal is highly dependent on the specific HRRs being removed and the location of the HRRs.

Table 2-2 shows the distribution of the total inventory of HRRs in Tank 18. Among the radionuclides in Tank 18 that are important to the performance assessment results, the Pu-238 inventory is estimated to be much higher on the wall (1,200 curies) than on the floor (69 curies), with most of the 1,200 curies being in the wall corrosion film as opposed to the wall scale. The estimated Pu-238 inventory in Tank 18 provides through its decay products approximately two-thirds of the 3.2 millirem per year predicted peak groundwater dose. [SRR-CWDA-2010-00124]

None of the four technologies evaluated in detail in the 2012 SEE could be used to remove HRRs from all areas of the tank wall, if any. The 2012 SEE discusses the use of a hydro-lance for this purpose. However, the effectiveness of this process in removal of the scale and corrosion film is uncertain. The tank wall was sprayed with water in 2003 and, while this process removed all waste from the wall visible with the video technology in use at the time, there is no evidence that it removed any scale or any part of the corrosion film. [CBU-LTS-2003-00115] Additional field testing would be required to determine the effectiveness, if any, of utilizing a hydro-lance similar to that used in Tank 19 to remove HRRs from the tank wall. It should be noted that removal of HRRs from the wall is of no benefit without technology to then remove the material from the floor.

Given this situation, it is assumed for conservatism in the reference case that:

- The combined processes would remove 100 percent of the HRR inventory inside Tank 18; and
- The direct and indirect costs of spraying the tank wall would be negligible, that is, the $38 million estimated cost for using the representative technology would remain unchanged.

The benefits that would be associated with this case are discussed in the Section 5.

4.6 Reference Case

Robotic crawlers similar to the Sand Mantis would have the shortest estimated development and testing time and the lowest total cost, and would be comparable to the other technologies in terms of occupational dose and secondary waste generation. This situation, coupled with the experience in using this technology in cleaning Tank 18 and Tank 19, led to the decision to conservatively use the modified Sand Mantis as a representative technology in assessing the cost and benefits of additional HRR removal. Use of this representative technology is treated as the reference case.

5.0 BENEFITS OF ADDITIONAL HIGHLY RADIOACTIVE RADIONUCLIDE REMOVAL

This section describes the benefits of removing additional HRRs from Tank 18. It begins with a discussion of potential benefits identified in NRC guidance in the reference case and then discusses the value of the averted dose. Also discussed are the potential benefits of reducing the amount of radioactive waste disposed of onsite and reducing the dose peak predicted to occur long past the end of the 10,000-year performance period.

5.1 Consideration of Potential Benefits (Reference Case)

Given that estimated removal efficiencies for the different technologies could not be provided in a manner that would allow for differentiating between the effectiveness of the technologies, it is being conservatively assumed for this analysis that all HRRs would be removed from Tank 18. The SEE in Appendix A also judged these technologies to be approximately equal in terms of time to implement (approximately five years) and, in three cases, the direct cost to implement ($13 million to $15 million). However, as discussed in Section 4, the total estimated costs for the feed and bleed with recirculation and direct acid cleaning with robotic support are higher than the other technologies due to the indirect costs of managing larger volumes of secondary waste.

5.1.1 Representative Technology for Comparison Purposes

Given the comparability of the direct costs for the four types of technologies, a representative technology for additional waste removal – the use of a modified Sand Mantis system, an example of robotics with liquid mobilization and vacuuming – was considered in this analysis. For the sake of this analysis, it was conservatively assumed that use of this technology would remove 100 percent of the remaining HRRs on the floor in Tank 18, take five years to implement, and cost $38 million.[6]

The Special Analysis predicted that the maximum dose to a hypothetical future member of the public from the closed tank farm during the performance period would be 3.4 millirem per year approximately 10,000 years following tank farm closure, as discussed previously. The Special Analysis also predicts that of the 3.4 millirem per year dose, 3.0 millirem can be attributed to Tank 18. [SRR-CWDA-2010-00124] Therefore, it is conservatively estimated that a 100 percent reduction in the amounts of HRRs in Tank 18 would result in an averted dose to the hypothetical member of the public of approximately 3 millirem per year or 150 millirem over a 50-year period.

Consideration of the following factors based on information in the Special Analysis leads to the conclusion that the 3 mrem per year estimated averted dose is conservative: [SRR-CWDA-2010-00124]

(1) Ra-226 from decay of Pu-238 contributes 52 percent to the peak groundwater pathway dose, or 1.6 mrem in the Base Case.

[6] This technology provides the most conservative comparison because the total estimated implementation cost is the lowest among the four technologies as shown in Table 4-1. It is also conservatively assumed that any cost associated with washing of the walls would be negligible.

(2) The Pu-238 inventory in Tank 18 is the most significant contributor to predicted peak dose during the performance period through its progeny Ra-226.
(3) Over 90 percent of the Pu-238 inventory in Tank 18 is associated with corrosion products on the tank wall. Significant reduction in the corrosion products would be required regardless of the effectiveness of the technology used for cleaning of the floor.
(4) It is likely that the amount of Pu-238 on the tank wall was overestimated as discussed in the Tank 18 residual characterization report. [SRR-CWDA-2010-00117]

This estimated 3 millirem averted dose would be the most important benefit of further HRR removal. Other potential benefits were identified by considering NRC guidance on cost-benefit analyses and ALARA analyses.

5.1.2 Use of NRC Guidance on Cost-Benefit Analyses

NRC guidance in Table 3-1 of NUREG-1854 identifies potential benefits associated with performing additional radionuclide removal beyond removal performed to meet the applicable performance objective, which is 25 millirem per year. Table 5-1 lists these potential benefits and shows how they apply to Tank 18.

Table 5-1: Benefits of Additional Highly Radioactive Radionuclide Removal

Potential Benefits	Tank 18 Case
Averted long-term dose to members of the public, including potential inadvertent intruders	An estimated maximum reduction in the predicted all-pathways dose during the performance period from the closed F-Tank Farm to a member of the public of 3 millirem per year during the period of peak dose, which has been estimated to be 10,000 years after tank farm closure. This saving of 3 millirem per year would amount to a predicted 50-year averted dose of 150 millirem. 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 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 a significant increase to current worker dose as discussed in Section 6.
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	There would be no significant benefit to the public water supply from removing the entire HRR inventory from Tank 18.[7]

[7] Using the actual Tank 18 residual inventory, the Special Analysis calculated peak groundwater concentrations for radionuclides and chemicals of concern and demonstrated that no maximum contaminant levels or regional screening levels were exceeded at 100 meters, and that all concentrations were well below the maximum contaminant levels, preliminary remediation goals, and regional screening levels at the seepline. Natural resources (that is, the groundwater aquifers) would not be negatively impacted by the actual Tank 18 residual inventory because the concentrations are predicted to be within acceptable levels. Consequently, it is reasonable to conclude that there would be no significant benefits in additional HRR removal.

Table 5-1: Benefits of Additional Highly Radioactive Radionuclide Removal (Continued)

Potential Benefits	Tank 18 Case
Reduction of impact on natural resources, such as groundwater aquifers	There would be no significant benefit for groundwater aquifers from removing the entire radionuclide inventory in Tank 18 as indicated in footnote 7.
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.)

The main benefit as shown in Table 5-1 would be the reduction in predicted dose to a future hypothetical member of the public of 3 millirem per year or 150 millirem over 50 years.

5.1.3 Consideration of NRC Guidance on ALARA Analyses

DOE also considered NRC regulatory guidance in Appendix N (ALARA Analyses) of NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance, Characterization, Survey, and Determination of Radiological Criteria*. Table N.1 lists five possible benefits of additional remediation beyond that necessary to achieve the remediation goal: (1) collective dose averted, (2) regulatory costs avoided, (3) changes in land values, (4) esthetics, and (5) reduction in public opposition.

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:

$$B_{AD} = \$2000 \text{ x } PW(AD_{collective})$$

Where B_{AD} = benefit from an averted dose for a remediation action, in current U.S. dollars

\$2000 = 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 $2000 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 18 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.

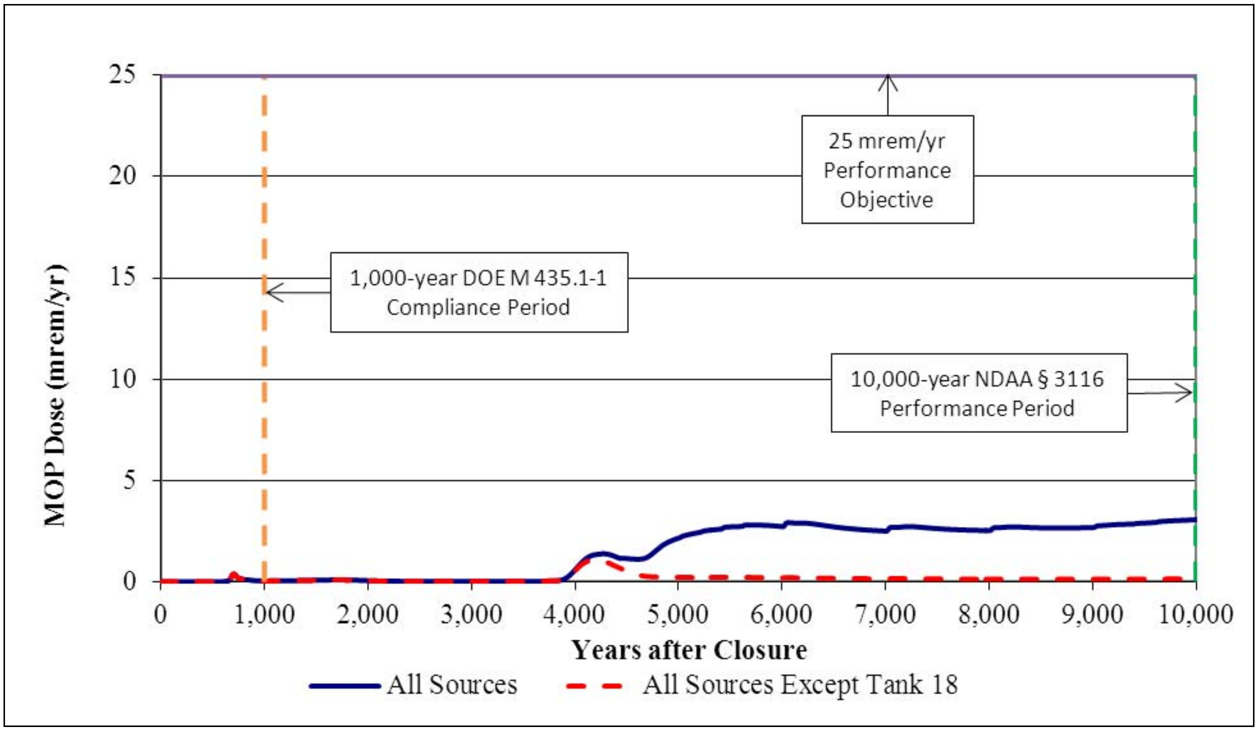
The other four potential benefits – regulatory costs avoided[8], changes in land values, esthetics, and reduction in public opposition – would not be significant factors in the case of Tank 18.

5.2 Consideration of Potential Benefits (Reference Case)

The potential averted dose in the reference case described in Section 4.7 can be inferred from Figure 5-1. This figure shows the results of modeling performed as part of the Special Analysis. [SRR-CWDA-2010-00124] The figure shows that the peak dose from the groundwater pathway in the Base Case would be reduced by approximately 3 millirem per year at 10,000 years, if 100 percent of the residuals were to be removed from Tank 18. Given that the air-dose pathway contributes 0.2 millirem to the total all-pathways dose, it would be reasonable to assume that removing all of the radionuclide inventory from Tank 18 would result in a total averted dose to a future member of the public of approximately 3 millirem per year or 150 millirem over 50 years.

Figure 5-1: Member-of-the-Public Peak Groundwater Pathway Dose Within 10,000 Years for All Sources and for All Sources Except Tank 18

Special Analysis [SRR-CWDA-2010-00124]



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

5.3 Value of the Averted Dose

Ionizing radiation is a noted 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.

5.3.1 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-2011-00059]

The potential lifetime risk of an exposed individual developing a fatal or nonfatal cancer because of his or her radiation dose (total effective dose equivalent) can be estimated using guidance issued by the Interagency Steering Committee on Radiation Standards[9]. [ISCORS-2002-2] The increased risk to an individual receiving an additional dose of 3 millirem per year for a total of 150 millirem over 50 years developing cancer would be estimated as 1.2E-04, that is, about one chance in 8,300 using this guidance.

5.3.2 Perspective on the Estimated Amount of Averted Dose

Various comparisons can be used to show that 3 millirem per year or 150 millirem over 50 years dose saving from additional HRR removal is a very small amount of dose.

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 five rem (5,000 millrem) per year in 10 CFR 835, *Occupational Radiation Protection*.
- DOE specifies an allowable dose to a member of the public of 100 millirem per year in DOE Order 458.1, *Radiation Protection of the Public and the Environment*.
- The 3 millirem per year additional dose rate is about 0.48 percent of the 620 millirem per year that the average person in the United States received in 2006 from naturally occurring background radiation and medical procedures as specified in NCRP-160, *Ionizing Radiation Exposure of the Population of the United States.*

[9]The guidance in ISCORS Report 2002-2 – *Estimating Radiation Risk from Total Effective Dose Equivalent* – 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).

- The 3 millirem per year additional dose rate is about 0.3 percent of the greater than 1,000 millirem per year that the average person living in Denver, Colorado receives from naturally occurring background radiation alone. [NCRP_01-01-2011]

Comparison to Variations in Ambient Radiation Levels Around SRS

As noted in Section 2.1.8, the site measures ambient gamma radiation levels onsite and offsite as part of the SRS environmental monitoring program. Table 2-1 shows annual totals measured in several offsite locations in 2010.

Table 2-1 shows considerable variation in the measured ambient gamma radiation levels from terrestrial and cosmic sources, which are two components of natural background radiation. As can be seen from the table, the difference between levels at the Aiken airport and the town of Williston is 46 milliroentgen per year. Because of this difference in natural background radiation levels, the potential increased risk to an individual moving from a home in Williston to a home near the Aiken airport would be around 15 times greater than the potential reduced risk associated with averting 3 millirem per year dose by removing all HRRs from Tank 18.

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 [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 member of the public in waste determination analyses is involuntary.[10]

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 one millirem per year. There would be no difference in the total increased risk of developing cancer – the main 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 higher 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 18, the estimated cost of reducing the predicted dose in the reference case to the hypothetical exposed future individual by 150 millirem over 50 years would be approximately $253 million per rem, **126,000 times higher** than the $2,000 per person-rem value.

[10]However, as discussed in Section 5.2.3, 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.

5.4 Potential Benefits From Reducing Radioactive Waste Disposed of Onsite

If additional waste were to be removed from Tank 18, it would be pretreated like other tank waste, with the sludge waste likely being vitrified for eventual disposal in an offsite geologic repository for high-level waste and the salt waste fraction being destined for treatment and the decontaminated salt solution ultimately being disposed of as low-level waste in the Saltstone Disposal Facility. The Tank 18 residuals that would be removed in connection with additional highly radioactive waste removal would be expected to be vitrified in two or three high-level waste canisters. This process would therefore reduce radioactive waste disposed of onsite by a small amount – approximately 3,900 gallons (520 cubic feet) – which can be viewed as another benefit of additional waste retrieval. Although it is not practical to quantify this benefit in monetary terms, the benefit would obviously be relatively small because of the relatively small waste volume.

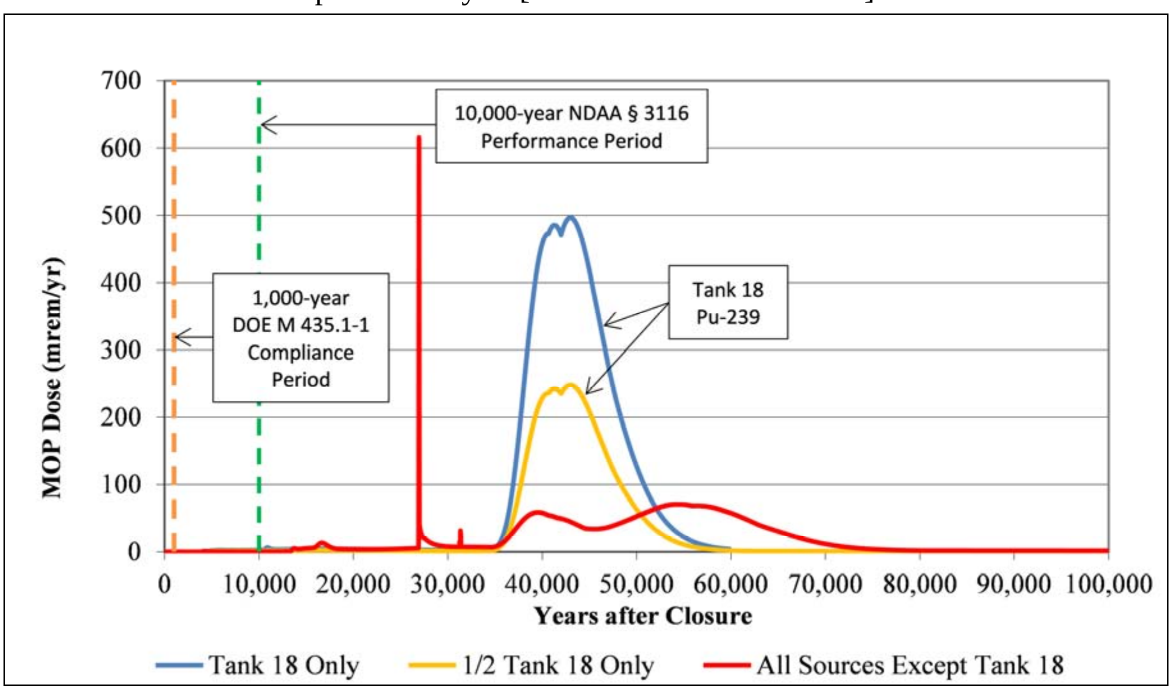
The estimated 520 cubic feet is negligible by comparison with the volume of low-level waste disposed of onsite in Fiscal Year 2011, which was 34,025 cubic meters (approximately 1,200,00 cubic feet), being less than 0.05 percent of that amount. [SRNS-STI-2012-00014]

5.5 Potential Benefits of Averting Dose Long Past the End of the Performance Period

The Special Analysis conservatively predicts in the Base Case a peak dose to the hypothetical exposed member of the public of approximately 500 millirem around 40,000 years after tank farm closure. This predicted dose results primarily from the Pu-239 present in Tank 18 at the time of closure as shown in Figure 5-2. [SRR-CWDA-2010-00124]

Figure 5-2: Member-of-the-Public Peak Groundwater Pathway Base Case Dose Within 100,000 Years for Tank 18 and for All Sources Except Tank 18

Special Analysis [SRR-CWDA-2010-00124]



5.5.1 Potential for Removal of Additional Pu-239

The reference case conservatively assumes that 100 percent of the Tank 18 inventory would be removed by use of the representative technology coupled with washing the tank wall, which would eliminate a significant portion of the 40,000-year dose peak. Note the estimated residual Pu-239 inventories in the Type I tanks will still result in a peak dose in excess of 25 millirem in similar time periods following closure using the Base Case assumptions (see Figure 5-2) However, because DOE considers it to be highly unlikely that HRR removal efficiency approaching 100 percent could be achieved with these methods, consideration was given as to whether there would be significant benefit in targeted removal of additional Pu-239 to reduce or eliminate this predicted dose. DOE concluded that there would not be significant benefit because:

- The exhaustive review of technologies that could potentially remove additional HRRs described in Appendix A did not identify any technologies that would likely be more efficient at additional HRR removal than use of the modified Sand Mantis coupled with washing the tank walls with water under high pressure.
- The Special Analysis describes sensitivity analyses which show that the uncertainty surrounding the timing of the 40,000-year dose peak is not sufficient for it to impact facility performance within the 10,000-year performance period, as discussed in Subsection 5.5.2. [SRR-CWDA-2010-00124]

5.5.2 Consideration of Uncertainties

As noted previously, the Special Analysis showed that, while there is uncertainty around the 500 millirem per year peak dose associated with the residual Pu-239 in Tank 18 there is reasonable assurance that the Pu-239 peak dose would not move forward into the 10,000-year performance period. [SRR-CWDA-2010-00124]

The Special Analysis incorporates various conservative assumptions as discussed in the report that affect the predicted magnitude and timing of the 40,000-year year dose peak. For example: [SRR-CWDA-2010-00124]

- As discussed in Section 6.3.5.3 of the report, the F-Tank Farm Base Case models Pu-239 conservatively with respect to solubility.
- Additional studies have shown Pu-239 to be less mobile in sandy soil than is assumed in the current F-Tank Farm Base Case.
- The F-Tank Farm model does not account for high pH cementitious material leachate exiting the waste tank increasing adsorption for plutonium and certain other elements, thereby increasing the distribution coefficient values.

Such conservative factors make it likely that the late Pu-239 dose peak will be both smaller and later than predicted.

In addition, the Special Analysis explains that there are multiple barriers to Pu-239 release and transport that prevent this peak near year 40,000 (and other similar Pu-239 driven peaks) from occurring much earlier, that is, within or close to the performance period. Given these multiple barriers, it is reasonable to conclude that the uncertainty surrounding the factors driving the Pu-239 peak dose after the 10,000 years is not sufficient to impact the performance objectives within the 10,000-year performance period. [SRR-CWDA-2010-00124]

Additional sensitivity analyses regarding Pu-239 release described in the Special Analysis showed that for several of the barriers to Pu-239 release the Base Case model incorporates conservative approaches/inputs and noted above and the peak doses associated with Pu-239 could occur even farther outside the 10,000-year performance period if these conservative approaches/inputs were to be eliminated. The sensitivity analyses documented in Section 6.3.6 of the Special Analysis suggest that doses associated with Pu-239 can be expected to actually occur later than currently reflected in the F-Tank Farm Base Case. [SRR-CWDA-2010-00124]

5.5.3 In Conclusion

As described in the Special Analysis, it is important to consider the conservative assumptions made for the Performance Assessment Base Case that make it likely that the 40,000-year Pu-239 dose peak will be smaller than predicted. Given these circumstances, and considering that dose peak is predicted to occur far beyond the end of the 10,000-year performance period, it would not be reasonable to undertake what would be a time-consuming and costly additional HHR removal effort for such uncertain benefit.

6.0 COSTS OF ADDITIONAL HIGHLY RADIOACTIVE RADIONUCLIDE REMOVAL

This section identifies both the direct and indirect costs to remove additional HRRs using the representative technology and discusses ALARA considerations related to this effort.

6.1 Summary of Additional Costs

DOE followed NRC guidance in NUREG-1854 in evaluation of additional costs. NRC guidance in Table 3-1 of NUREG-1854 identifies potential costs associated with performing additional radionuclide removal beyond removal performed to meet the applicable performance objective. Table 6-1 lists these potential costs and shows how they apply in this case.

Table 6-1. Costs of Additional Highly Radioactive Radionuclide Removal

Potential Costs	Tank 18 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 3.2 person-rem. 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 3.2 person-rem would be $6,400 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 estimated to be, at a minimum, approximately $38 million as described in the 2012 SEE report provided in Appendix A. This estimate includes system impacts such as management of the removed waste and the secondary waste stream, including vitrification of the high-activity fraction and the resulting impacts on the Liquid Waste Program, along with five years of additional tank maintenance costs.
Additional transportation risks	Not significant. (The only transportation involves moving samples to the Savannah River National Laboratory.)
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 200,000 to 300,000 gallons of radioactive waste which would have to be processed and treated for disposal as discussed above.

Table 6-1. Costs of Additional Highly Radioactive Radionuclide Removal (Continued)

Potential Costs	**Tank 18 Case**
Additional impacts on DOE's mission or schedule	It is estimated that Tank 18 closure would be delayed approximately five years as indicated in in Appendix A. Rescheduling Tank 18 closure would require negotiations with SCDHEC. If the presently required Tank 18 operation closure date of December 31, 2012 were to be missed in the absence of an agreed-upon schedule change, DOE could be subject to substantial penalties.[11] Devoting effort to removing additional HRRs from Tank 18 would impact the F-Tank Farm closure effort by tying up common infrastructure and taking up limited tank space, and would impact the Liquid Waste Program in other ways. Details appear in the 2012 SEE report in Appendix A.
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.

As can be seen in Table 4-1, the direct and indirect costs of additional radionuclide removal using representative technology would be, at a minimum, approximately $38 million. As noted previously **the unit cost of averted dose to the future member of the public would be approximately $253 million per rem, which would be equivalent to approximately $253,000 per millirem.**

As noted in the table, rescheduling Tank 18 closure could also be an issue with the potential for large fines if DOE were to proceed with removal of additional HRRs for Tank 18 without an approved schedule change.

DOE also considered NRC regulatory guidance in Appendix N (ALARA Analyses) of NUREG-1757, Volume 2.

[11] Failure to comply with the deadlines in the Federal Facility Agreement could result in Federal civil enforcement and substantial monetary penalties.

6.2 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 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 Tank 18 would be consistent with the ALARA principle. Appendix N (ALARA Analyses) to NUREG-1757, Volume 2 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. The second possible benefit – regulatory cost avoided – does not directly apply to the case of F-Tank Farm. The third, fourth, and fifth possible benefits would not apply to closure of the Tank 18.

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 Table 3-1 of NUREG-1854, with remediation costs being equivalent to the cost of additional HRR removal.

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 F-Tank Farm Performance Assessment as required by DOE Manual 435.1-1. Section 5.8 of the Performance Assessment notes that a final ALARA analysis will be completed to support CERCLA closure of F-Tank Farm, 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 F-Tank Farm. DOE has evaluated potential options that could be utilized if deemed necessary in the future. [SRNL-STI-2012-00079]

7.0 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 established for use as guidance in determining whether additional HRR removal from Tank 18 would be worthwhile.

7.1 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 5 of this cost-benefit analysis describes the benefits (values) of additional HRR removal from Tank 18 and Section 6 describes the associated costs (impacts). Both the benefits and the costs have been quantified to the extent practical, but it was not practical to establish the equivalent money value of the primary benefit – the estimated averted dose to a future member of the public from the closed tank farm – or the other benefit of a small reduction in radioactive waste to be disposed of onsite.

Given this limitation, it is important to place these benefits in perspective to provide a qualitative measure of their importance. This was done for the estimated averted dose in Section 5 by (1) identifying the calculated increased risk of the exposed individual developing cancer, (2) by comparing the estimated averted dose of 150 millirem over 50 years to dose limits for occupational and public exposure, and (3) by comparing the 3 millirem per year estimated dose reduction to the 620 millirem per year that the average American received in 2006 from naturally occurring background radiation and medical procedures.

A measure of the importance of the removal of the Tank 18 residuals can be provided by comparing the associated volume of the residuals in Tank 18 to the typical annual volume of radioactive waste disposed onsite. As discussed previously, this comparison showed the approximately 520 cubic feet in the Tank 18 residuals to be less than 0.05 percent of the volume of low-level waste disposed of onsite in Fiscal Year 2011.

The next section provides additional perspective on the estimated averted dose by comparing it with the occupational dose to the workers who would be involved in some aspect of removing additional HRRs from the tank if such actions were undertaken.

7.2 Additional Perspective on Occupational Dose

As shown in Table 6-1, the increased radiation dose to workers of approximately 3.2 person-rem is valued at approximately $6,400 using NRC guidance in NUREG/BR-0058. However, the 3.2 person-rem is a substantial amount of occupation dose for the site. For example, the collective worker dose at F-Tank Farm in 2011 was approximately 17 person-rem. [SRR-TFO-2012-00014] The 3.2 person-rem estimate would be approximately 20 percent of that amount.

The estimated worker dose will result from smaller doses to many people involved with the work and the related sample analyses. It is not practical to determine exactly how many people will be involved.

For comparison purposes, if 21 workers were to each receive 150 millirem each during the course of the work, the total dose would be 3.2 person-rem. This occupational dose can be compared to the 150 additional millirem that a hypothetical future inhabitant of the tank farm area is predicted to receive over a 50-year period if additional HRRs removal did not take place. That is, 21 workers would each receive an average of 150 millirem during the tank waste removal activities and sample handling and analysis to save 150 millirem dose over 50 years to a hypothetical future inhabitant of the tank farm area.

7.3 Additional Perspective on Costs

Table 5-1 identifies the estimated direct and total costs of each of the four technologies that were evaluated in detail. It is evident from this table that the estimated indirect costs of continuing tank maintenance and system impacts exceed the direct costs for each technology.

However, it is important to recognize that certain direct costs are unrelated to the particular technology. For example, no matter which technology were to be selected, extensive preparations such as preparing the tank for reentry, procedure development, engineering reviews, flow sheet preparation, installation of supporting systems and transfer lines, and readiness reviews would be necessary. Sample collection, and sample analysis would also be necessary, along with operational support and continuing monitoring and maintenance of the tank over a five-year period as well as rework of the required closure documentation as discussed in Appendix A. Consideration of these factors makes it clear that less than ten percent of the total estimated cost is technology dependent, the differing system impacts due to differing amounts of secondary waste generation and the potential penalties from missing the tank closure deadline notwithstanding.

7.4 Unit Cost of Risk Reduction

The estimated cost of risk reduction for removing additional HRRs from Tank 18 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 7-1 compares such risk reduction costs.

Table 7-1. Risk Reduction Cost Comparisons

Project	Dose Reduction (mrem Over 50 years)	Risk Reduction Factor(1)	Estimated Dollar Cost	Risk Reduction/ Cost
Tank 18 additional HRR removal	150	1.2E-04	3.8E+07	3E-12
Idaho National Laboratory Technical Area North-607 (Hot Shop Area containing approximately 77 curies in 2006) [DOE/ID-11302]	NA	3.3E-03(2)	3.4E+07(3)	8E-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(4)	6.3E+06(5)	3E-08
Idaho National Laboratory Engineering Test Reactor Complex. This complex contained 59,000 curies in 2006 with >99 percent in the reactor vessel. Alternative 3 removed the vessel and Alternative 2 grouted it in place. [DOE/ID-11272]	NA	3.3E-04(6)	2.0E+06(3)	2E-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(7)	8.08E-02	1.2E+09(8)	7E-11

LEGEND: NA = not available

NOTES:
(1) For total increased cancer risk over 50 years using 8E-04 excess cancers per rem total effective dose equivalent as recommended by the Interagency Steering Committee on Radiation Standards. [ISCORS-2002-2]
(2) Based on a 2.0E-03 for 30 years extrapolated to 50 years.
(3) In 2006 dollars.
(4) Based the total risk to a future resident over 30 years of 1.21E-01 extrapolated to 50 years.
(5) In 2009 dollars.
(6) Based the total risk to a future resident over 30 years of 2.0E-04 extrapolated to 50 years.
(7) From Table H-48 of the Final Environmental Impact Statement. [DOE/EIS-0226] This estimate is for the peak annual dose to a future member of the public (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).
(8) 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.

Table 7-1 shows that the amount of risk reduction per unit cost for removal of additional HRRs from Tank 18 would be lower than for other typical DOE remediation projects. Therefore the unit cost of averted dose from removal of additional HRRs from Tank 18 would be much higher than for the other projects.

7.5 Schedule Considerations

Another potential cost identified in Table 6-1 is associated with delaying Tank 18 closure to remove additional HRRs. DOE has already postponed grouting of Tank 18 for more than five years to try to remove additional HRRs utilizing the Sand Mantis. To do this again would require formal agreement of SCDHEC to revise the Federal Facility Agreement tank closure schedule once again using the dispute resolution process. If the schedule is not revised and DOE fails to comply with the December 31, 2012 deadline for operational closure of Tank 18, the Department could be subject to substantial penalties as indicated in Table 6-1.

While DOE does not consider schedule adherence to be an overriding concern in tank 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 18 closure unless it can be shown that there would be significant benefit in doing so.

7.6 Other Highly Radioactive Radionuclide Removal Processes

This analysis has centered on use of the improved Sand Mantis system because this comparison is more conservative than the three other technologies evaluated in detail because this technology has the lowest total cost as shown in Table 4-1. However, similar benefits and costs would apply to the three other types of technologies described in the SEE report in Appendix A, as would the conclusions discussed below.

7.7 Assumptions

Assumptions inherent in the comparison of costs and benefits discussed previously include but are not limited to:

- The modified Sand Mantis, the representative technology evaluated, was assumed in the reference case to remove 100 percent of the HRRs from the Tank 18 floor and walls, which is very conservative.
- The removal of additional HRRs would be accomplished as shown in the schedule provided in Figure 4-2.
- The secondary waste volume associated with using the modified Sand Mantis to remove additional HRRs is estimated to be approximately the 200,000 to 300,000 gallons.
- The estimated inventory of Pu-238 on the tank wall as shown in Table 2-3 is utilized even though the estimate is unexpectedly high at 17 times the estimated amount on the tank floor, which is a much higher ratio than for the other HRRs, including other plutonium radionuclides;
- Development, installation, and operation of the washing technology for the tank wall would add no additional costs.
- A reasonable measure of the significance of the benefits from the estimated reduction of 3 millirem per year or 150 millirem over 50 years to a member of the public 10,000 years

after tank farm closure can be established by consideration of the increased risk of the exposed individual developing cancer and by comparisons to dose limits, to doses from naturally occurring background radiation and medical procedures, and to the estimated occupational dose.

- A reasonable measure of the significance of the 520 cubic foot reduction in waste to be disposed of onsite is comparison with the total annual volume of radioactive waste disposed of onsite.

7.8 Uncertainty

There are uncertainties in many aspects of this analysis. Regarding the identified benefits, there are some uncertainties in the estimated dose reduction. The Special Analysis [SRR-CWDA-2010-00124] describes these uncertainties and concludes that the uncertainty in the timing of the high dose peak around 40,000 years after tank farm closure is not sufficient for this dose peak to impact performance within the 10,000-year performance period, as noted previously.

There is uncertainty in the percentage of the HRRs that could be removed from the floor and walls of the tank by use of any technology evaluated. Removal of less than the 100 percent assumed in the analysis would reduce the estimated benefit to some value below 3 millirem per year and would decrease the amount of estimated dose averted.

Uncertainties are also present in the cost estimates for implementing the process of HRR removal. For example, the direct cost estimates are rough-order-of-magnitude estimates, which are considered to be accurate with ±35 percent. However, as noted previously over 90 percent of the direct costs are independent of the technology used.

Given such uncertainties, DOE concluded that the reference case with assumed removal of 100 percent of the Tank 18 inventory coupled with the minimum associated costs regardless of technology and 35 percent reduction in the direct cost of implementing the representative technology would take the overall uncertainties into account and thereby serve as the bounding case for this analysis.

7.9 Decision Criteria

Because the benefits of additional HRR removal from Tank 18 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 this particular cost-benefit analysis, are intended to help make the decision-making process as quantitative as practical.

7.9.1 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 member of the public 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 member of the public 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.[12]

(4) Operational closure of Tank 18 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 are met, then the costs would clearly outweigh the benefits. If only one or two were to be met, then the fourth criterion would be taken into consideration.

7.9.2 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.

Criterion (1)

The dose to a member of the public following tank farm closure would be involuntary and without benefits. Occupational dose to remove additional HRRs from Tank 18 would be voluntary and expected to yield benefits as discussed in Section 5. However, these differences would not justify the occupational dose substantially exceeding the member of the public dose. It would be neither reasonable nor sensible to remove additional HRRs from Tank 18 if the worker dose to accomplish this substantially exceeded the predicted averted dose to a hypothetical member of the public 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.

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, the $2,000 per person-rem conversion factor that NRC uses in some contexts (e.g., regulatory analyses, ALARA analyses for license termination) may not be a useful metric to apply to waste determination reviews, 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

[12] For example, the criterion would be met if the unit cost of risk reduction for additional HRR removal from Tank 18 were to be 1E-06 compared to typical DOE remediation project risk reduction unit costs around 1E-09.

> 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 that the $2,000 per person-rem conversion factor should not be directly applied in this case. Rather than attempting to establish a specific monetary value for averted dose to a member of the public 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.

Criterion (3)

The statement in NUREG-1854 quoted above indicates 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)." These examples generally apply to the final stages of waste removal from underground reprocessing waste tanks. However, DOE has found such efforts to be costly and to often yield only minimal benefits in terms of averted dose to a member of the public. 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 member of the public developing cancer divided by the estimated project cost, as suggested in *The Decommissioning Handbook.* [ASME 2004]

Criterion (4)

This criterion takes into account the potential penalties that could be imposed on DOE for missing the tank closure deadline both monetary costs as well as loss of credibility. The costs associated with system impacts related to additional HRR removal have been quantified in monetary terms for comparison purposes, as discussed previously.

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 520 cubic feet is so small compared to the amount of low-level waste routinely disposed of on onsite that it would be negligible.

8.0 CONCLUSIONS

This section describes DOE conclusions and their basis, discusses whether decision criteria would be met in the bounding case when uncertainties in the estimates are taken into account, and considers a case related to the predicted 40,000-year dose peak.

8.1 DOE's Conclusion and Its Basis

DOE has determined that the costs of removing additional HRRs from Tank 18 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 to remove additional HRRs is approximately 21 times greater than the averted dose for a member of the public over 50 years, that is, 21 workers could receive an average of 150 millirem during the removal work and the associated activities. DOE considers this difference to be significant.

(2) The $253 million per rem estimated unit cost of dose reduction is 126,000 times higher than the $2,000 per person-rem value that NRC assigns to averted collective dose. DOE considers this difference to be significant.

(3) The unit risk reduction cost shown in Table 7-1 is lower than for other typical DOE remediation projects, that is, the risk reduction per unit cost is less.

Because none of the first three decision criteria are met, the costs clearly outweigh the benefits.

Other factors that reinforce this judgment include:

(1) The predicted peak dose of 3.4 millirem per year from the closed tank farm to a member of the public during the 10,000-year performance period is only 14 percent of the 25 millirem per year dose limit.

(2) The estimated 3.0 millirem per year averted dose to a future member of the public from Tank 18 is only 0.48 percent of the 620 millirem per year the average person in the United States receives from naturally occurring radiation and medical procedures.

(3) Delaying Tank 18 closure to remove additional HRRs using a technology such as the modified Sand Mantis, or to take advantage of possible advances in waste removal technologies, would have a significant adverse impact on the site's Liquid Waste Program.

(4) If the final ALARA analysis performed at the time of CERCLA closure 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, thereby extending the time and reducing the magnitude of peak dose from the residual radioactivity in F-Tank Farm.

As mentioned previously, the reference case with the modified Sand Mantis is very conservative because of the assumption of 100 percent removal of the Tank 18 inventory.

8.2 Bounding Case Considering Impacts of Uncertainty

DOE made the reference case deliberately conservative, primarily because the efficiency of the evaluated technologies in removing HRRs could not be established with accuracy. While this case could be considered bounding in its own right, DOE evaluated a bounding case that considers the impacts of uncertainty on the reference case.

As discussed previously, there are uncertainties in different aspects of this analysis. The main uncertainty that could affect the results of the analysis is the ±35 uncertainty in the estimated $13 million direct costs for implementing the representative technology. Consequently, the bounding case makes use of a 35 percent reduction in the direct costs of implementing the representative technology, which would reduce the total estimated implementation cost by approximately $4.5 million.

In this bounding case, the decision criteria would still be not be met because:

- The estimated worker occupational dose to remove additional HRRs would be approximately 20 times greater than the averted dose for a member of the public over 50 years – that is, 20 workers could receive 150 millirem dose during the removal work and the associated activities – which DOE considers to be a significant difference.
- The resulting $223 million per rem estimated unit cost of dose reduction would be 110,000 times higher than the $2,000 per person-rem value that NRC assigns to averted collective dose, a significant difference
- The unit risk reduction cost shown in Table 7-1 would increase slightly to 4E-12, which is still lower than for other typical DOE remediation projects.

8.3 Late Dose Peak Case

In the F-Tank Farm Performance Assessment, the Base Case assumptions result in a projected peak dose of approximately 500 millirem around 40,000 years following the closure of F-Tank Farm. Nearly all of this projected dose is associated with the residual Pu-239 in Tank 18.

Consideration was given as to whether the decision criteria would be met in this case. This was accomplished by considering whether the decision criteria would be met if the HRR removal effort removed one-half of the Tank 18 Pu-239[13] inventory, which, given the Base Case assumptions, would result in a late dose peak of approximately 250 millirem per year around 40,000 years after facility closure as shown in Figure 5-2 of the Special Analysis. [SRR-CWDA-2010-00124]

Under this scenario, the averted dose to the hypothetical member of the public would be approximately 250 millirem per year. Over 50 years, this dose rate would amount to a total of 12,500 millirem or 12.5 rem.

Comparison to the decision criteria for the benefits of additional HRR removal outweighing the costs would result in the following:

[13] The assumption of removing one-half of the radioactivity present in Tank 18 is for illustration purposes only. No technology or set of technologies have been selected or identified that provides confidence that this level of cleaning could be achieved on the wall and floor of Tank 18.

- The estimated worker occupational dose of 3.2 rem to remove additional HRRs would be less than the predicted 50-year averted dose of 12.5 rem, thus the first criterion would be met.
- The resulting $3.0 million per rem estimated unit cost of dose reduction would be 1,500 times higher than the $2,000 per person-rem value that NRC assigns to averted collective dose. DOE considers this difference to be significant, so the second decision criterion would not be met.
- The unit risk reduction cost would be approximately 3E-10, which is comparable with unit risk reduction cost for other typical DOE remediation projects and is not significantly greater than these comparable projects, so the third decision criteria would not be met.

Because only one of the first three decision criteria would be met in this case, the fourth decision criterion – operational closure of Tank 18 should not be delayed in the absence of significant benefit – would apply.

In order to make risk-informed decisions associated with this projected peak dose, additional science studies, experiments and both additional deterministic and probabilistic modeling was performed. This work is documented in Section 6 of the *Tank 18/Tank 19 Special Analysis for the F-Tank Farm at the Savannah River Site*. The additional sensitivity analyses regarding Pu-239 that were performed show that the Base Case model incorporates conservative approaches/inputs and the peak doses associated with Pu-239 would likely occur even farther beyond the 10,000-year performance period and would be significantly lower if these conservative modeling approaches/inputs are eliminated.

DOE considers the results of the Base Case modeling with regards to the dose associated with Pu-239 from Tank 18 beyond the performance period to be conservative relative to the magnitude of the peak dose. Therefore, the value of the benefits associated with additional HRR removal from Tank 18 would not be as high as could be interpreted by only evaluating the Base Case results. The information provided by the Special Analysis, the inherent uncertainty associated with modeling to these extended time periods, and the fact that, as previously discussed, if the final ALARA analysis completed to support CERCLA closure of F-Tank Farm 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 tank residuals. These facts lead DOE to conclude that additional removal of HRRs from Tank 18 would not provide significant benefit and therefore, operational closure of Tank 18 should not be delayed.

9.0 REFERENCES

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10 CFR 61, Subpart C, *Licensing Requirements for Land Disposal of Radioactive Waste, Performance Objectives*, U.S. Nuclear Regulatory Commission, Washington DC, January 1, 2010.

10 CFR 835, *Occupational Radiation Protection*, U.S. Department of Energy, Washington DC, May 13, 2011.

ASME 2004 (Copyright), T.S. LaGuardia, et al., *The Decommissioning Handbook*, The American Society of Mechanical Engineers, New York, NY, 2004.

CBU-LTS-2003-00115, Chapman, N.F., *Completion of Tank 18 Wash Operations to Support HLW Tank 18 Closure*, Savannah River Site, Aiken, SC, Rev. 1, August 5, 2003.

CBU-PIT-2005-00106, *Tank 19 and Tank 18 Closure Performance Objective Demonstration Document (PODD)*, Savannah River Site, Aiken, SC, Rev. 1, September 2005.

CBU-PIT-2006-00067, Bush, S.R., *The Tank Cleaning Technical Exchange 2006: Summary*, Savannah River Site, Aiken, SC, Rev. 0, July 14, 2006.

DHEC_01-25-1993, *State Industrial Wastewater Construction Permit*, South Carolina Department of Health and Environmental Control, Columbia, SC, January 25, 1993.

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

DOE Order 435.1, *Radioactive Waste Management*, U.S. Department of Energy, Washington, DC, Chg. 1, August 28, 2001.

DOE Order 458.1, *Radiation Protection of the Public and the Environment*, U.S. Department of Energy, Washington, DC, Chg. 2, February 11, 2011.

DOE/EIS-0226, *Final Environmental Impact Statement for Decommissioning and/or Long-Term Stewardship at West Valley Demonstration Project and Western New York Nuclear Service Center*, Table of Contents, Chapter 4.0 and Appendix H, U.S. Department of Energy, West Valley, New York, January 2010.

DOE/ID-11272, *Engineering Evaluation/Cost Analysis for Decommissioning of the Engineering Test Reactor Complex*, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID, Rev. 0, October 2006.

DOE/ID-11302, *Engineering Evaluation/Cost Analysis for Decommissioning of TAN-607 Hot Shop Area*, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID, Rev. 0, January 2007.

DOE/ID-11397, *Engineering Evaluation/Cost Analysis for Decommissioning of the TRA-632 Hot Cells*, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID, Rev. 0, September 2009.

DOE/SRS-WD-2010-001, *Draft Basis for Section 3116 Determination for Closure of F-Tank Farm at the Savannah River Site*, U.S. Department of Energy, Savannah River Site, Aiken, SC, Rev. 0, September 30, 2010.

DOE-WD-2005-002, *Draft Section 3116 Determination for Closure of Tank 19 and Tank 18 at the Savannah River Site*, U. S. Department of Energy, Savannah River Site, Aiken, SC, Rev. 0, September 30, 2005.

DOE-WVDP-2009, *Phase 1 Decommissioning Plan for the West Valley Demonstration Project*, Washington Safety Management Solutions and Science Applications International Corporation, West Valley, NY, Rev. 2, December 2009.

DPST-85-782, Fong, M.C.H., *Oxalic Acid Cleaning of Tank 24H*, Savannah River Site, Aiken, SC, September 9, 1985.

G-ESR-G-00051, *Waste Removal Balance of Program Systems Engineering Report*, Savannah River Site, Aiken, SC, Rev. 0, September 17, 2003.

ISCORS-2002-2, *Final Report: A Method for Estimating Radiation Risk from Total Effective Dose Equivalent (TEDE),* ISCORS Technical Report 2002-2, Interagency Steering Committee on Radiation Standards (ISCORS), Washington, DC, 2002.

LWO-RIP-2009-00009, *Industrial Wastewater General Closure Plan for F-Area Waste Tank Systems*, *Industrial Wastewater Construction Permit #17,424-IW*, Savannah River Site, Aiken, SC, Rev. 3, January 24, 2011.

ML080090405, *Path Forward for Consultation on Section 3116 Determinations for Closure of Tanks at the Savannah River Site*, U.S. Nuclear Regulatory Commission, Washington, DC, December 20, 2007.

ML103190402, *U.S. Nuclear Regulatory Commission Staff Requests for Additional Information on the "Draft Basis for Section 3116 Determination for Closure of F-Tank Farm at the Savannah River Site," DOE/SRS-WD-2010-001, Rev. 0, and on "Performance Assessment for the F-Tank Farm for the Savannah River Site," SRS-REG-2007-00002, Rev. 1*, U.S. Nuclear Regulatory Commission, Washington DC, December 3, 2010.

ML112371169, Camper, L.W., *Technical Evaluation Report Draft Waste Determination for Savannah River Site F Area Tank Farm*, U.S. Nuclear Regulatory Commission, Washington, DC, October 27, 2011.

ML112371715, *Technical Evaluation Report for F-Area Tank Farm Facility, Savannah River Site, South Carolina*, U.S. Nuclear Regulatory Commission, Washington, DC, October 27, 2011.

ML112720579, Lawrence, A., *Memorandum on Radiation Risk Estimation from Total Effective Dose Equivalents (TEDEs)*, U.S. Department of Energy, Washington, DC, August 9, 2002.

ML1032001240, *NRC Staff Comments on the Draft Basis for Section 3116 Determination and Associated Performance Assessment for the F-Tank Farm at the Savannah River Site*, U.S. Nuclear Regulatory Commission, Washington DC, December 3, 2010.

NCRP-160 (Copyright), *Ionizing Radiation Exposure of the Population of the United States (2009)*, National Council on Radiation Protection and Measurements, Bethesda, MD, March 3, 2009.

NDAA_3116, *Public Law 108-375, Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Section 3116, Defense Site Acceleration Completion*, Accessed January 4, 2011.

NRC_01-01-2011, *Fact Sheet on Biological Effects of Radiation*, U.S. Nuclear Regulatory Commission, Washington, DC, January 1, 2011.

NRMP-2005, *Natural Resources Management Plan for the Savannah River Site*, U.S. Department of Agriculture Forestry Service, Savannah River Site, Aiken SC, May 2005.

NUREG-1530, *Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy*, U.S. Nuclear Regulatory Commission, Washington, DC, December 1995.

NUREG-1757, *Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria*, Volume 2, U.S. Nuclear Regulatory Commission, Washington, DC, Rev. 1, September 2006.

NUREG-1854, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations, Draft Final Report for Interim Use*, U.S. Nuclear Regulatory Commission, Washington DC, August 2007.

NUREG/BR-0058, *U.S. Regulatory Analysis Guidelines of the Nuclear Regulatory Commission*, U.S. Nuclear Regulatory Commission, Washington, DC, Rev. 4, September 2004.

NUREG/BR-0184, *Regulatory Analysis Technical Evaluation Handbook*, U.S. Nuclear Regulatory Commission, Washington, DC, January 1997.

PIT-MISC-0040, Davis, N.R., *Tank 19 Heel Removal Systems Engineering Evaluation*, Savannah River Site, Aiken, SC, Rev. 0, October 15, 1998.

SRNL-STI-2010-00541, Hay, M.S., and King, W.D., *Alternative and Enhanced Chemical Cleaning: Basic Studies Results FY2010*, Savannah River Site, Aiken, SC, Rev. 0, January 2011.

SRNL-STI-2012-00079, Amidon, M.B., et al., *Alternate Risk Reduction Technologies in Support of F-Tank Farm Closure*, Savannah River Site, Aiken, S.C., February 2012.

SRNS-STI-2011-00059, *Savannah River Site, Environmental Report for 2010*, Savannah River Site, Aiken, SC, August 2011.

SRR-CES-2009-00022, Clendenon, G.B., *Strategy for Tanks 5 and 6 Phase II Mechanical Sludge Removal*, Savannah River Site, Aiken, SC, Rev. 0, September 21, 2009.

SRR-CES-2012-00035, Isom, W.L., *Tank 18 Systems Engineering Evaluation Pro-Formas*, Savannah River Site, Aiken, SC, February 22, 2012.

SRR-CWDA-2009-00030, *Proposal to Cease Waste Removal Activities in Tanks 18 and 19 and Entering Sampling and Analysis Phase,* Savannah River Site, Aiken, SC, Rev. 0, October 1, 2009.

SRR-CWDA-2010-00003, *Industrial Wastewater Closure Module for the Liquid Waste Tanks 18 and 19*, Savannah River Site, Aiken, SC, Rev. 2, January 2012.

SRR-CWDA-2010-00117, *Tank 18 Residual Characterization Report*, Savannah River Site, Aiken, SC, Rev. 1, October 26, 2010.

SRR-CWDA-2010-00124, *Tank 18/Tank 19 Special Analysis for the Performance Assessment for the F-Area Tank Farm at the Savannah River Site*, Rev. 0, Savannah River Site, Aiken, SC, Rev. 0, February 2012.

SRR-CWDA-2011-00054, *Comment Response Matrix for United States Nuclear Regulatory Commission Staff Comments on the Draft Basis for Section 3116 Determination and Associated Performance Assessment for the F-Tank Farm at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 1, June 2011.

SRR-CWDA-2011-00091, *Documentation of Removal of Highly Radioactive Radionuclides in Waste Tanks 18 and 19*, Savannah River Site, Aiken, SC, Rev. 0, June 2011.

SRR-CWDA-2012-00038, *Tank 18 Residual Highly Radioactive Radionuclide Inventory Distribution*, Savannah River Site, Aiken, SC, Rev. 0, February 28, 2012.

SRR-LWP-2011-00067, Gillam, J.M. and McIlmoyle, D.W., *Sludge Batch Plan in Support of System Plan Rev. 17*, Savannah River Site, Aiken, SC, Rev. 0, January 30, 2012.

SRR-LWP-2012-00010, Chew, D.P. and Hamm, B.A., *Liquid Waste System Plan Impacts from Additional Radionuclide Removal from Tank 18F*, Savannah River Site, Aiken, SC, Rev. 0, February 2012.

SRR-TFO-2012-00014, Cothran, C.M., *F Tank Farm 2011 Final Exposure Report, Quarter IV ALARA Worksheet*, Savannah River Site, Aiken, SC, Rev. 0, February 2012.

SRS-REG-2007-00002, *Performance Assessment for the F-Tank Farm at Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 1, March 31, 2010.

U-ESR-F-00041, *Tank 18 Volume Estimation Following Mantis Cleaning Operations*, Savannah River Site, Aiken, SC, Rev. 1, December 15, 2009.

WSRC-OS-94-42, Federal Facility Agreement for the Savannah River Site, http://www.srs.gov/general/programs/soil/ffa/ffa.pdf, Savannah River Site, Aiken, SC, March 9, 2010.

WSRC-RP-2001-00024, *HLW Tank 18 Waste Removal Systems Engineering Evaluation*, Savannah River Site, Aiken, SC, Rev. 0, May 22, 2001.

WSRC-TR-2003-00401, Barnes, M.J., et al., *Waste Tank Heel Chemical Cleaning Summary*, Savannah River Site, Aiken, SC, Rev. 0, September 9, 2003.

APPENDIX A

Tank 18 Residual Material Removal Options Systems Engineering Evaluation

A.1.0 OBJECTIVE

A Systems Engineering Evaluation (SEE) was performed for Tank 18 to identify the most promising technologies for removal of residual material that would potentially result in a reduction in the amount of Highly Radioactive Radionuclides (HRRs) remaining in the tank after closure. The SEE included a review of previous tank cleaning evaluations and assessed the potential for deployment of new technologies. Each selected potential technology identified was evaluated with respect to cost, schedule, personnel exposure, downstream impacts, and risks associated with implementing that technology.

A.2.0 METHODOLOGY

A SEE is a process the Savannah River Site (SRS) adopted from the National Aeronautics and Space Administration in 1998. It is a process used to select an alternative from two or more options that have been determined to be feasible to meet specific functions, selected criteria, and requirements.

The SEE Core Team reviewed previous SEEs that were performed for tank cleaning, reviewed current cleaning technologies, and researched the internet for possible technologies to clean Tank 18, specifically technologies that targeted HRRs. [PIT-MISC-0040, WSRC-RP-2001-00024, G-ESR-G-00051, CBU-PIT-2006-00067, SRR-CES-2009-00022]

A.2.1 System Engineering Evaluation Process

The SEE process used the following methodology for identifying viable options to reduce the residual inventory in Tank 18:

- Form a team
- Define the problem
- Develop an activity model
- Define the screening criteria
- Define the evaluation criteria
- Define the weighting of the evaluation criteria
- Develop a list of potential solutions
- Screen the options
- Score the options that pass screening
- Choose the top options
- Perform a sensitivity analysis
- Develop the scope of the top options
- Evaluate options with respect to cost, schedule, personnel exposure, system impacts and risks.

The process described above and shown in the model on the following pages, Figure A.1, was not meant to recommend a particular option, but to provide the necessary information to perform a formal cost-benefit analysis.

Figure A.1: Tank 18 SEE Process Model

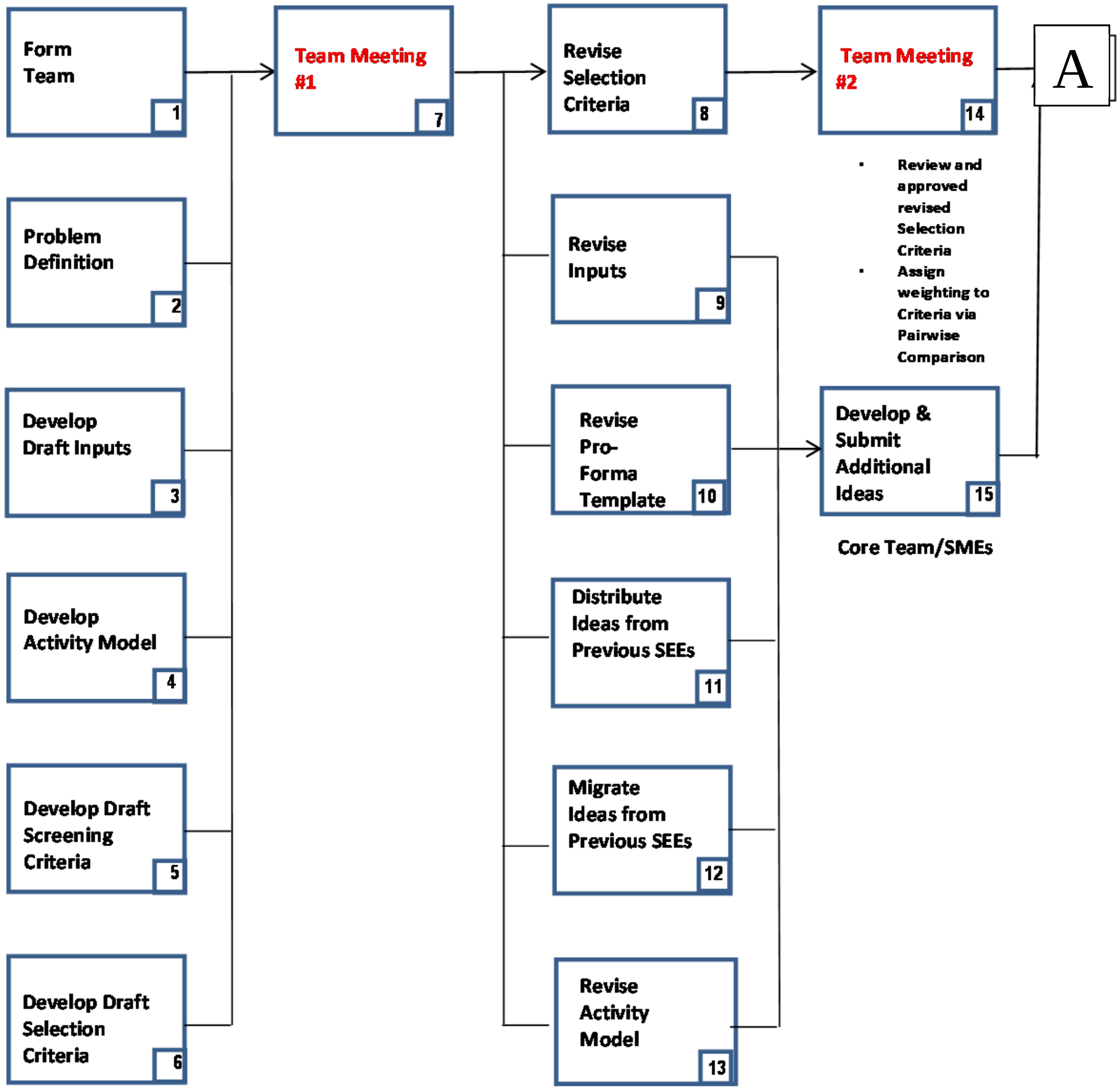
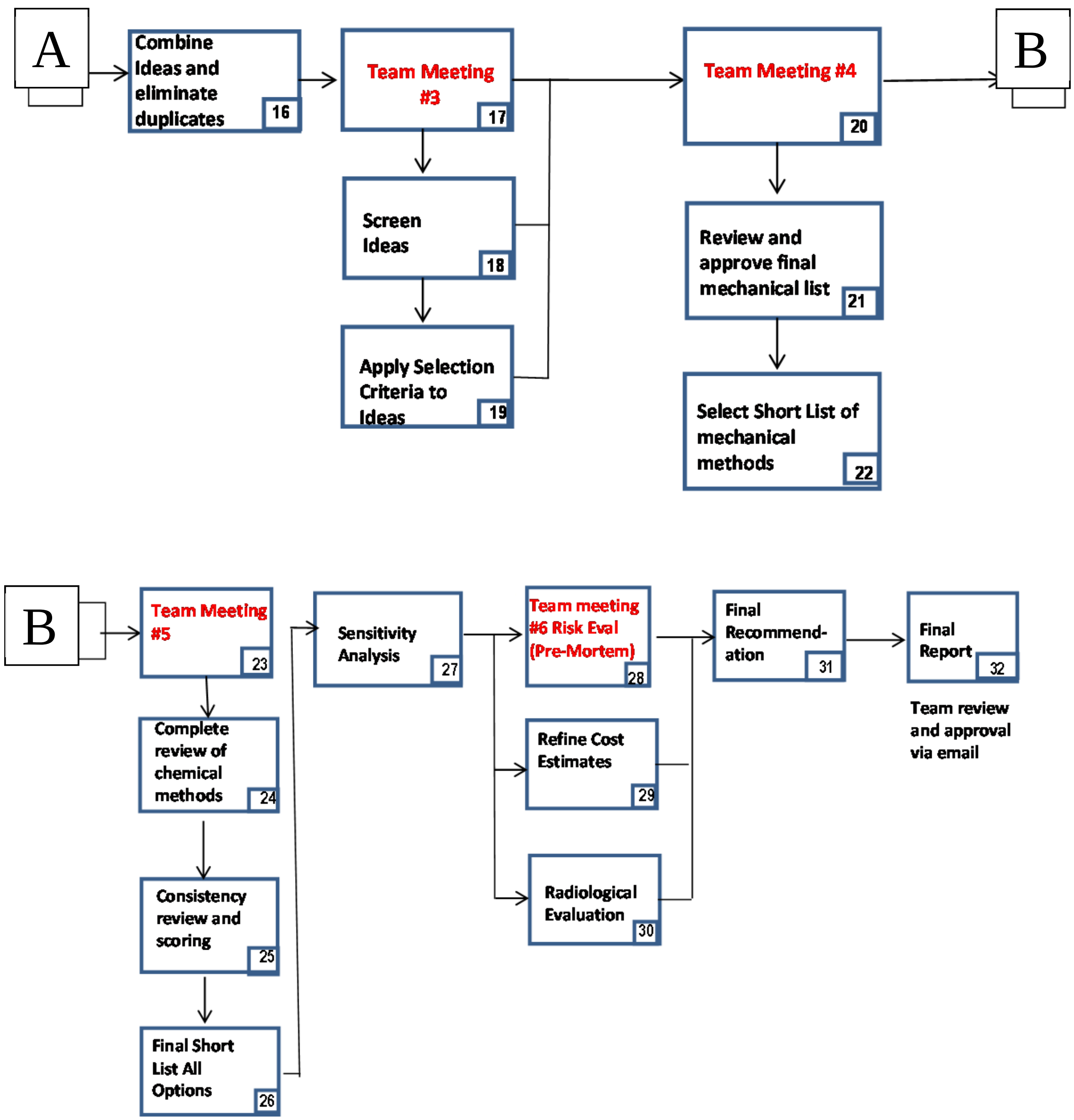


Figure A.1: Tank 18 SEE Process Model (Continued)



A.2.2 Team Members and Resources

Team members were selected for their experience, expertise, and history in the planning and operation of cleaning waste tanks in the High-Level Waste (HLW) Systems at Hanford and SRS and for their familiarity with the systems and processes in place at F-Tank Farm.

To facilitate the SEE process, a "Core Team" was identified. The function of the Core Team was to develop possible alternative cleaning methods, discuss each alternative, achieve a common understanding of each alternative, and apply the screening to each alternative and evaluate the alternatives that passed the screening criteria to arrive at a consensus score for each. The Core Team members were selected to represent a balance of technical and functional areas covered by the SEE. For the purposes of scoring, a quorum of Core Team members was present (quorum being defined as four of seven Core Team members). The list of Core Team members and Subject Matter Experts (SMEs) that supported this SEE are shown in Table A.1:

Table A.1: SEE Team Members and Subject Matter Experts

Name	Organization
Walt Isom	Core Team-Savannah River Remediation (SRR) Senior Technical Advisor SEE Team Lead
Neil Davis	Core Team- SRR Waste Removal & Tank Closure Senior Technical Advisor
Mike Harrell	Core Team-F-Tank Farm Operations
Mike Hubbard	Core Team-Waste Removal & Tank Closure Engineering
Bruce Martin	Core Team-SRR Closure and Waste Disposal Authority
John Schofield	Core Team- Washington River Protection Solutions (WRPS) Waste Retrieval in Hanford
Bill Wilmarth	Core Team-Savannah River Nuclear Solutions (SRNS), Savannah River National Laboratory (SRNL)
David Hobbs	Environmental Management Technical Expert Group (EMTEG) Observer
Gavin Winship	SRR Planning, Integration and Risk Management
Ed Urbanawiz	SRR Planning, Integration and Risk Management
Mike Augeri	SRR Technology Development
Thomas Chalker	SRR Radcon

Prior to identification of potential solutions, the team reviewed the previous cleaning history, defined the problem, and established the evaluation process. The evaluation process developed was a two-step process that used defined criteria to screen and score ideas. The screening criteria were used to eliminate ideas that were not feasible, would not solve the problem, or would not be supported by stakeholders. The evaluation criteria were used to rank the best technologies from the remaining ideas. The weighting of the evaluation criteria was determined by a pair-wise comparison process as discussed in Section A.2.6.

A.2.3 Background

Tank 18 has been cleaned using multiple technologies over the past 10 years. Pumps and agitators were used to remove the majority of the material. The final cleaning technology used was a robotic crawler that used water and a vacuum system to remove the waste. This device was made by TMR Industries of Denver, Colorado and known as a Sand Mantis. The Sand Mantis used water to break up and suspend the sludge, then used a vacuum system to transport the waste to another F-Tank Farm hub tank for further processing. The Sand Mantis was deployed into Tank 18 in early 2009 and was operated for more than 400 hours of cleaning over a three month period before the effectiveness was diminished. [SRR-CWDA-2011-00091] This operation was not continuous due to multiple system failures during this time.

The residual material left in the tank is estimated to be 1 to 3 inches deep, mainly around the outer edges near the wall. This translates to between 3,000 and 4,000 gallons of residual material. The walls were determined to have residual material, referred to as scale, with an estimated volume of 110 gallons. In addition, the walls have a thin film of corrosion products, referred to as corrosion film. If the cleaning technology selected cannot clean the walls, then a hydro-lance may need to be deployed to attempt removal of the scale and corrosion film.

Of the remaining residual material, zeolite that was used in the past to capture Cs-137 is still present in the tank. To be considered viable, any alternative chosen for additional cleaning in Tank 18 must be able to suspend and transport the residual material and zeolite to a second hub tank in F-Tank Farm to insure the tank has been cleaned to the maximum extent practical. The use of acids (e.g., oxalic acid) need be reviewed carefully not to have a negative effect on the zeolite by causing conglomerates that cannot be removed from the tank and may retain HRRs. In 1985, a bulk oxalic acid flow sheet was used to remove solids from Tank 24, also a Type IV tank, in H-Tank Farm at SRS. Tank 24, like Tank 18, contained significant quantities of spent zeolite resin. Removal effectiveness of the spent zeolite resin was much lower than expected due to the chemical changes to the resins over time in the high caustic environment. [DPST-85-782]

Based upon this information the team defined the problem as follows:

The calculated peak dose to a future hypothetical member of the public in the 10,000-year performance period for F-Tank Farm is estimated at approximately 3.4 millirem per year. Although this value is well below the performance objective value of 25 millirem per year, Tank 18 is the major contributor to the calculated dose. [SRR-CWDA-2010-00124, SRR-CWDA-2010-00117] Therefore, identify the most viable technologies to reduce the impact of the residual inventory in Tank 18.

A.2.4 Screening Criteria

The team identified five screening criteria that must be met for an alternative to be considered a viable option. The criteria were developed based upon the ability to implement the technology and to meet Federal Facility Agreement (FFA) closure requirements. These criteria are presented in Table A.2 below.

Table A.2: Screening Criteria

#	Title	Definition
1	Difficulty	The technology is too immature for this application or the degree of difficulty to mature the technology for the intended application is unreasonably high, or there is a low probability of success.
2	Cost	The project cost estimate for an alternative to achieve Turnover to Operations is believed to be > $15 million.
3	Schedule	The total schedule for project plus Operations is believed to be > 10 years.
4	Inadequate	The alternative will not solve the problem as described in the problem statement.
5	Not Supported	There is evidence that some key stakeholders will not accept an alternative due to technical, safety or other unspecified reasons.

A.2.5 Evaluation Criteria

The team identified five evaluation criteria with 12 sub-criteria to evaluate each alternative that passed the screening criteria. The criteria were developed based upon impact to the current program and the ability to meet current FFA closure commitments. The weighting of the criteria was established using a pairwise comparison and is discussed in Section A.2.6. The criteria, sub-criteria, weighting, and grading scale are presented in Table A.3.

Table A.3: Evaluation Criteria, Sub-Criteria, Weights and Scoring

Criteria	Wgt %	Sub-Criteria	Wgt %	Definition	Utility Factors Score	Utility Factors Definition
1 Complexity	6.7	1.1 Environmental	14	A measure of the difficulty of permitting the idea in Regulatory space	10	Completely supported by existing permits
					8	Requires notification
					4	Requires permit modification
					0	Requires new permit
		1.2 Safety	33.3	A measure of the difficulty of permitting the idea in Safety Documentation space	10	Completely supported by existing bases
					5	Minor Mod or DSA change required
					0	Major Mod or DSA change required
		1.3 Ops	52.8	A measure of the difficulty of designing, installing, or operating the idea	10	Easy, done it before, low rad exposure
					5	Similar to other tank intrusive tasks
					0	Complex or completely new or high rad exposure
2 Effectiveness	40.5	2.1 Volume	20	Degree of confidence that a residual heel volume of <1,000 gallons can be achieved	10	100% confident
					7	75% confident
					5	50% confident
					0	not confident
		2.2 Residual Material HRR Inventory	80	Degree of confidence that the residual material HRRs can be reduced by >50%	10	100% confident
					7	75% confident
					5	50% confident
					0	not confident
3 Technical Maturity	10.6	3.1 Industrial	66.7	A measure of the degree to which this has been used in industry	10	Has been used at similar scale in an industrial application.
					8	Has been used but at smaller scale.
					5	Has been tested or piloted.
					0	No industrial application.
		3.2 Radiological	33.3	A measure of the degree to which this has been used in a rad application	10	Used in a HLW or high gamma application at similar scale.
					8	Used in low level or smaller scale rad application.
					5	Real waste tested in rad application at any scale.
					0	No rad testing or application.
4 System Impact	25.7	4.1 Tank Space	12.2	Amount of liquid sent to the Tank Farm for evaporation	10	<100 kgal
					5	100-200 kgal
					0	>200 kgal
		4.2 Waste Disposition	32	Residual waste volume after evaporation or dry volume	10	<20 kgal
					5	20-50 kgal
					0	>50 kgal
		4.3 Flow sheet Compatibility	55.8	A measure of how well the idea integrates with the existing HLW flow sheet	10	seamless integration
					5	minor impacts
					0	results in an orphan waste or new waste form
5 Schedule	16.5	5.1 Project	50	Total schedule from present through turnover to Ops	10	<12 months
					8	13-36 months
					4	37-60 months
					0	>60 months
		5.2 Ops	50	Schedule from start of rad ops until desired end state is achieved	10	<6 months
					8	7-12 months
					2	13-24 months
					0	>24 months

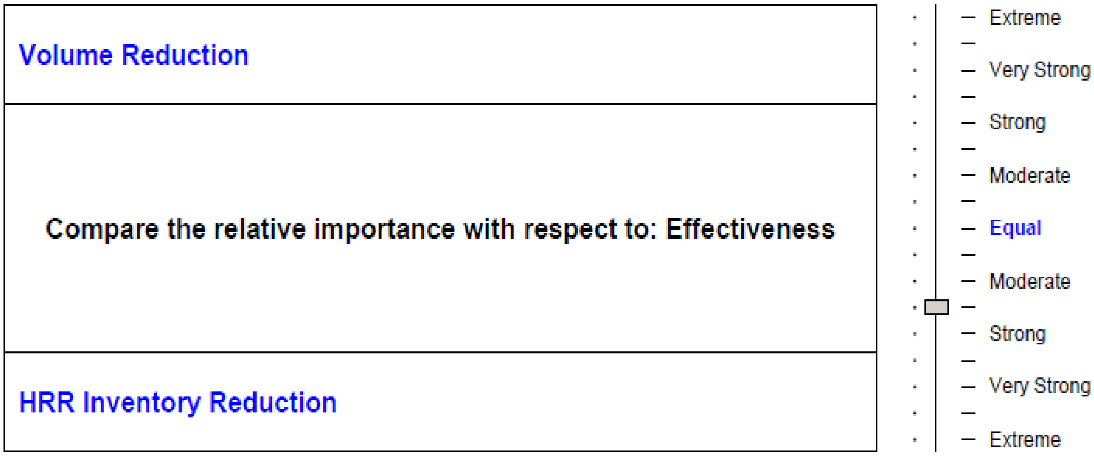
A.2.6 Pairwise Comparison Process

The team used a pair-wise comparison process to develop the weights for the evaluation criteria. The "criteria weight" is the relative importance of single criteria in relation to the other criteria. The grading criteria and sub-criteria are shown in Figure A.2. Sub-criteria weights represent their importance only as they relate to the respective grading criteria. For example, the "Volume Reduction" sub-criterion is only compared to the "HRR Inventory Reduction" sub-criteria.

Figure A.2: Evaluation Criteria Relationship Diagram

Judgments were made by the team one criterion pair at a time, performing a comparison for every possible criteria pair. Expert Choice® software was used to record and compile the results. During the comparison process, the preference of one criterion over the other was established by team consensus and entered as a judgment value. The software provided a visual representation for each of the decisions, an example of which is shown in Figure A.3. Sub-criteria were reviewed first, followed by the grading criteria.

Figure A.3: Example of Sub-Criteria Comparison



In the above example, HRR Inventory Reduction was judged to be moderately to strongly more important than Volume Reduction. This process was repeated by the team for each sub-criteria pair and then for each grading criteria pair.

The software then converts each of the judgments into a numerical score. The judgments (Equal, Moderate, Strong, Very Strong, and Extreme) are commensurate with the numerical values of one (1) through nine (9), where Equal = 1, and Extreme = 9.

The software calculates a numerical weight for each criterion. The weights are converted to a percentage reflecting each criterion's relative importance. The final criteria weights are shown in Figures A.4 through A.9. Following each figure are the key considerations that form the basis for the final weighting.

Figure A.4: Grading Criteria Weights

The team judged that "Effectiveness" was the most important criteria as shown by its relatively high weight. "System Impact" was judged to be the next most important grading criteria. There are several integrated HLW processes that must operate effectively in concert to achieve system plan and FFA commitments. System Impact criteria can potentially disrupt the coordinated processing between HLW facilities and therefore has a broader impact than other criteria such as schedule, maturity, and complexity. Schedule was judged to be the third most important criteria due to its relation to FFA commitments.

Figure A.5: Effectiveness Sub-Criteria Weights

The team judged that HRR inventory removal equates more specifically to dose reduction than volume reduction alone in Tank 18 due to the amount of zeolite in the Tank 18 residual material.

Figure A.6: System Impact Sub-Criteria Weights

HLW system flow sheet compatibility has greater potential to impact the HLW life cycle than operating evaporators (Tank Space). HLW system flow sheet has more potential to impact the HLW life cycle than waste disposition impacts because flow sheet impacts can affect more than one process.

Figure A.7: Schedule Sub-Criteria Weights

The team judged that project schedule and operating schedule were of equal importance. While these sub-criteria could be combined, they were left in the evaluation to show that both were considered.

Figure A.8: Technical Maturity Sub-Criteria Weights

Existing dose is low and will lessen importance of radiation hardening of materials, therefore the technical maturity of an option in an industrial application was judged to be more important than radiological applications.

Figure A.9: Complexity Sub-Criteria Weights

The team judged that operational complexity factors such as radiation exposure, operating / maintenance risks, and process upsets are more important than the other complexity sub-criteria. Most concepts under consideration can be implemented within the existing SRS environmental permits making the risk of requiring new or revised environmental permits low. The majority of the Material at Risk (MAR) has already been removed from Tank 18, therefore any remaining Process Safety risks are judged to be low for most options being considered.

A.2.7 Removal Technology Options

Each Core Team member was requested to submit ideas to resolve the problem. Core Team members were requested to investigate 3 areas for ideas: (1) past SEEs and evaluations for possible ideas that could have matured since last investigated; (2) discuss with subject matter experts the current cleaning methods and their effectiveness; and (3) perform internet and Retrieval Knowledge Center searches for new technologies that may have been developed since the last search.

The Retrieval Knowledge Center is a database maintained by SRNL and Pacific Northwest National Laboratory (PNNL) that documents various technologies that have been used and are being developed in the Department of Energy (DOE)-Environmental Management Complex.

A total of 54 ideas were submitted. For ideas that were submitted from previous evaluations, the original date of submission was kept; however, the idea was re-evaluated using the current screening and evaluation criteria. All ideas were documented on an input form (pro-forma) and are documented in *Tank 18 Systems Engineering Evaluation Pro Formas*. [SRR-CES-2012-00035]

A.2.7.1 Screening of Options

Of the 54 submitted ideas, 24 did not pass the screening criteria. The main reasons were technical maturity or the idea would not solve the problem.

Table A.4 lists the ideas that did not pass with the justification for removal from the process.

Table A.4: Alternatives That Failed the Screening Criteria

Idea	Process Alternative	Failure Criteria
2	Grout injection leaving heel with binding agent (includes use of mixing pumps to thoroughly mix grout and waste)	Technically immature, excessive cost (>$15 million), would probably not be accepted by stakeholders, encapsulation and binding ability is untested
3	Zeolite as Absorbent Mixed Into Grout	Technically immature, does not affect all actinides, excessive cost, stakeholders would probably not accept
4	Addition of Pu Sorbent in Grout Mixture and Construct Barrier Wall Containing Sorbent	Technically immature, excessive cost (>$15 million), stakeholders would probably not accept
5	Stainless Steel Tank in Tank, Then Grout	Key stakeholders will not support since it only delays radionuclide release (does not prevent release since stainless steel tank will eventually fail)
6	Add Multi-IX Media, Mix Tank Contents, Leave in Tank	Key stakeholders will not support since it only delays radionuclide release (does not prevent release)
11	New Spectrometer for Quick Analysis of Radiation & Composition	This technology does not solve the problem, it only helps define the problem
12	Chemical Dissolution (1-2M nitric acid)	Excessive costs (>$20 million), major system impacts (neutralization & disposal)
13	Reverse Surface Charge to Defloc Sludge Particles by Well Water Addition	Requires extensive testing (>5 years), Technically immature, costs > $15 million
14	Suspend Heel Materials with Surfactants	Technically immature for large tanks, costs > $15 million

Table A.4: Alternatives That Failed the Screening Criteria (Continued)

Idea	Process Alternative	Failure Criteria
15	Reverse Surface Charge to Defloc Sludge Particles by Acid Addition	Low technical maturity, major impact to tank integrity, difficult to control corrosion & charge in large tank
21	Dissolve Heel Materials with Ionic Liquids	Technology has not developed sufficiently to indicate effectiveness for this application, untested
23	New Radioactive Absorbent – Australian Nuclear Science	Doesn't solve problem, only removes cesium from water based upon literature search
27	Partition Tank and Remove Sludge with a Sluicing Device	Key stakeholders will not agree with method due to irreversibility and inability to verify residual material amount
29	Macerator Pump (chopping and/or grinding pump)	Does not address or resolve problem statement, no known applications that are similar to high-level waste removal
30	ARD Environmental (company specializing in robotic methods for waste cleanup)	Robotic cleaning already covered by other ideas, unable to contact company (assumed to be out-of-business)
32	Tizzy Vacuum System (SRS developed robot)	Technical maturity low compared to commercial vendor units, not worth development costs with possibility of effectiveness being no better than previous cleaning methods (i.e., Sand Mantis mechanical cleaning)
33	Ultrasonic – Use ultrasonic probes to assist with sludge suspension in conjunction with mixing pumps	Technology not developed or sized to address large scale applications (concerned about tank/equipment damage)
34	Ultrasound with Oxalic Acid Cleaning (no mixing pumps)	Technology not developed or sized to address large scale applications (concerned about tank/equipment damage), tank space affected by acid neutralization volume, corrosion issues
37	Transport the Waste by Tanker Truck	Not a retrieval method, does not solve the problem
41	Leach Radionuclides with Ammonium Hydroxide	Low technical maturity, untested, would create flammability issue in tank farms and DWPF, costs > $15 million
43	Mobile Arm Retrieval Vacuum System (MARS-V)	Cost would approach $20 million with redesign, testing, and deployment – design not yet proven
44	Chemical Dissolution with Weak Acid and Chelating Agents	Requires new processes to remove actinides, significant negative impact to ARP/MCU and SWPF effectiveness, Regulators would not support this option
45	Mobile Arm Retrieval Sluicing System (MARS-S)	No more effective than previously used Sand Mantis mechanical cleaning based upon Hanford experience
46	XAGO Hydrolance	System redesign required, effectiveness of redesigned system unknown (may not be better than previously used Sand Mantis mechanical cleaning), other arm and robotic cleaning ideas are more proven

A.2.7.2 Evaluation Process

For the evaluation process, each Core Team member individually graded each option against the criteria before the first evaluation meeting. The team met and worked to achieve a consensus score for each idea. The scores given to each option in Table A.5 are the final consensus scores agreed to by the team. During the meeting, particular emphasis was given to the development and resolution of differing opinions. In the end, no dissenting opinions from the final consensus scores existed among the team members.

From the evaluation, the top four technologies were chosen for further development with respect to cost, schedule, personnel exposure, system impacts, and risks.

The four technologies chosen were:

- Robotics /modified Sand Mantis – with liquid mobilization and vacuuming
- Articulating Arm – with liquid mobilization and vacuuming
- Recirculation line (Feed and Bleed) – mixing and recirculation with pumps
- Acid Cleaning with robotic support – direct acid cleaning controlled by robotics

Table A.5: Alternative Scoring

Idea	Process Alternative	Total Score	Scoring Notes
40	Modified Sand Mantis	8.12	None
42	Tank in Tank with Bobcat	8.10	None
31	Clean Out Submersible Crawler for Tank 18 Waste & Heel Removal	7.94	None
9	Dozer Aided Mantis	7.61	None
49	S.A. Technology Carbon Fiber Arm	7.55	Most mature of arm-based technologies
1	Use of Remote Robot with Vacuum	7.46	Dry handling impacts safety and results in a low score
39	Recirculation Line – Reuse Slurry Media	7.22	None
54	Use Robotics for Acid Addition & Transfer	7.17	Has promise due to selective acid use resulting in less impact to tank farm space and downstream processing
8	Street Sweeper/Grinder/Pumper (crawler based platform)	7.12	Will be combined with other crawler technologies
28	Houdini with Confined Sluicing End Effector (CSEE)	6.83	Used in small tanks, question ability to clean large tanks, uses large volumes of water
47	Multiple Robots	6.71	Scores were lower because this concept is less developed than using commercially available radiation-proven units
36	In-Tank Size Reduction with Transfer System	6.43	Size reduction is the only thing different about this idea when compared to using a crawler. Size reduction in a small tank inside Tank 18 would help with transfer to the next tank

Table A.5: Alternative Scoring (Continued)

Idea	Process Alternative	Total Score	Scoring Notes
48	Mechanical Conveyance of Dry Solids	6.33	Scores were lower because conveying dry material is difficult and leads to complex design, installation, and DSA issues
10	Arm with Suction - articulating arm similar to Light Duty Utility Arm (LDUA) of Modified Light Duty Utility Arm (MLDUA)	6.29	Hanford testing showed minimal effectiveness, Hanford developed Mobile Arm Retrieval System (MARS) as a substitute
50	SEC Technology Use from Tank 16	6.21	Low score due to technical immaturity, extensive testing required, DSA concerns, and difficulty transferring powders
52	Selective Leaching with Oxidizer and Inhibited Water	6.19	Scores were lower because hydrogen peroxide has significant industrial safety issues
18	Selective Leaching with Permanganate Oxidizer and Inhibited Water	6.10	Neutralizing and disposing of permanganate will impact tank farm space, DWPF, and Saltstone operations
38	Industrial Wet Vacuum	5.98	Score is lower because the idea is too complex compared to commercial units
19	Oxalic Acid with Permanganate Oxidizer	5.87	Neutralizing acid and disposing of permanganate will impact tank farm space, DWPF, and Saltstone operations
53	Oxalic Acid with Hydrogen Peroxide Oxidizer	5.83	Scores were lower because of safety issues with hydrogen peroxide and tank space required for neutralization
24	SRS Crawler with Suction Pump	5.81	Commercial crawlers are more mature and less costly to deploy
35	Tank in Tank with Mobile Wilden Pump	5.70	Technical maturity is low compared to commercial vendor units. Not worth development costs since it may not be any more effective than previous cleaning methods (Sand Mantis mechanical cleaning). DSA impacts lowered the score
16	Oxalic Acid and Citric Acid	5.67	Low score due to system impacts (sludge washing and Saltstone load) and tank space needed for neutralization, Citric acid would improve actinide removal (e.g., Pu removal)
17	Use Tank 16 Oxalic Acid Cleaning at 8 weight percent	5.51	Volume would not be reduced, HRRs would be reduced but will not impact Pu, score reduced due to amount of liquid required for neutralization and downstream processing
22	Chemical Dissolution (Russian Regime) with a Complexing Agent	5.31	This idea has not matured much since first reviewed, would cause significant safety and space issues in the tank farm
20	Add Material (bentonite clay) to Increase Specific Gravity of Slurry Media	5.17	Adding bentonite clay will impact tank farm space, DWPF, and Saltstone operations

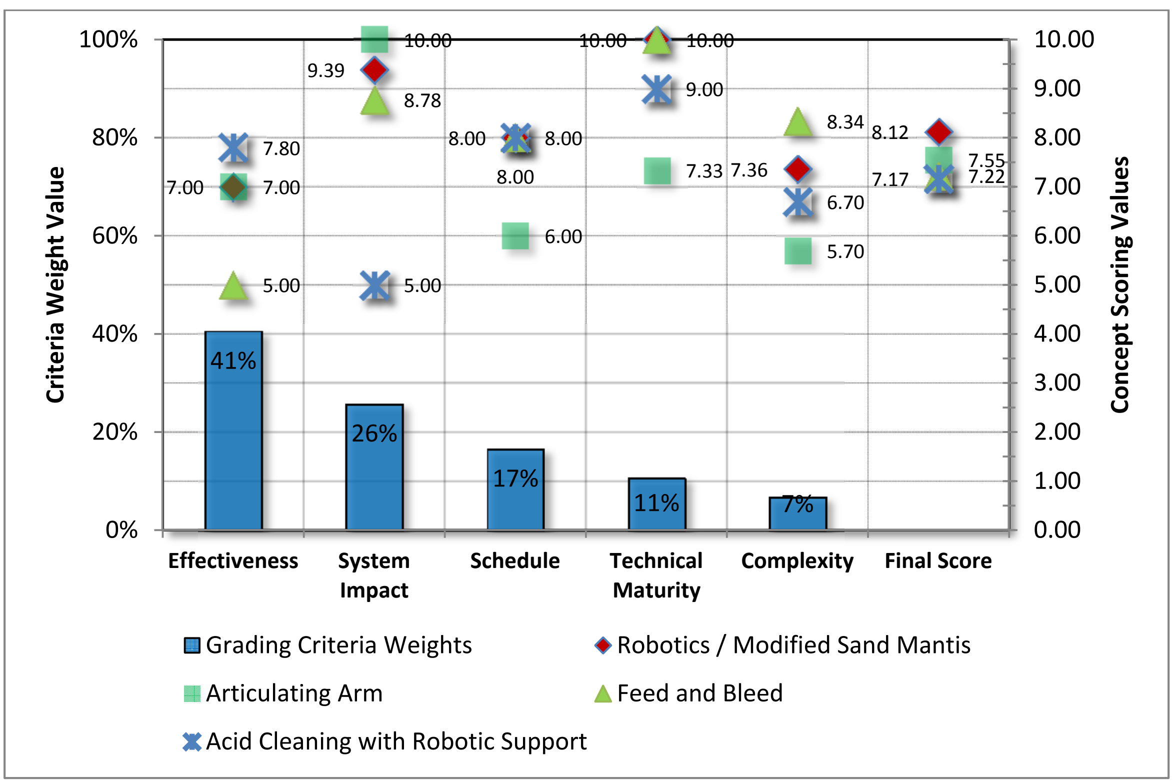
Table A.5: Alternative Scoring (Continued)

Idea	Process Alternative	Total Score	Scoring Notes
7	Add Absorbent and Dry Transfer	5.10	Low score due to technical immaturity, extensive testing required, DSA concerns, and difficulty transferring powders
26	Vertical Flygt Mixers (150-hp)	4.95	Effectiveness is questionable based upon previous use
51	Use Tank in Tank Concept to Dissolve/Transfer Vacuumed Waste	4.82	Scores were lower because system is complex, requires major DSA changes, and causes space issues due to neutralization
25	SRS Crawler with Water Monitor	4.03	Commercial crawlers are more mature and less costly to deploy

A.2.8 Sensitivity Analysis

When the evaluation was complete, a sensitivity analysis was performed to determine if reasonable changes to the criteria weights will significantly change the results of the study. Figure A.10 shows the relative weights of the grading criteria, how each of the four technologies selected for further evaluation were scored for each grading criteria, and then each options final score.

Figure A.10: Tank 18 Radiological Inventory Reduction Alternative Evaluation Primary Criteria Weights and Final Concept Scores



As seen in Figure A.10, "Effectiveness" and "System Impact" are the most influential grading criteria; therefore adjustments to these criteria weights could have the greatest impact to the final scores. Both of these criteria weights were independently adjusted by +/- 20% and the final scores recalculated to examine the impact. Figure A.11 and Table A.6 show the results of adjusting the Effectiveness criteria weight by +/- 20%.

Figure A.11: Tank 18 Radiological Inventory Reduction Alternative Evaluation Effectiveness Weight Adjusted +/- 20%

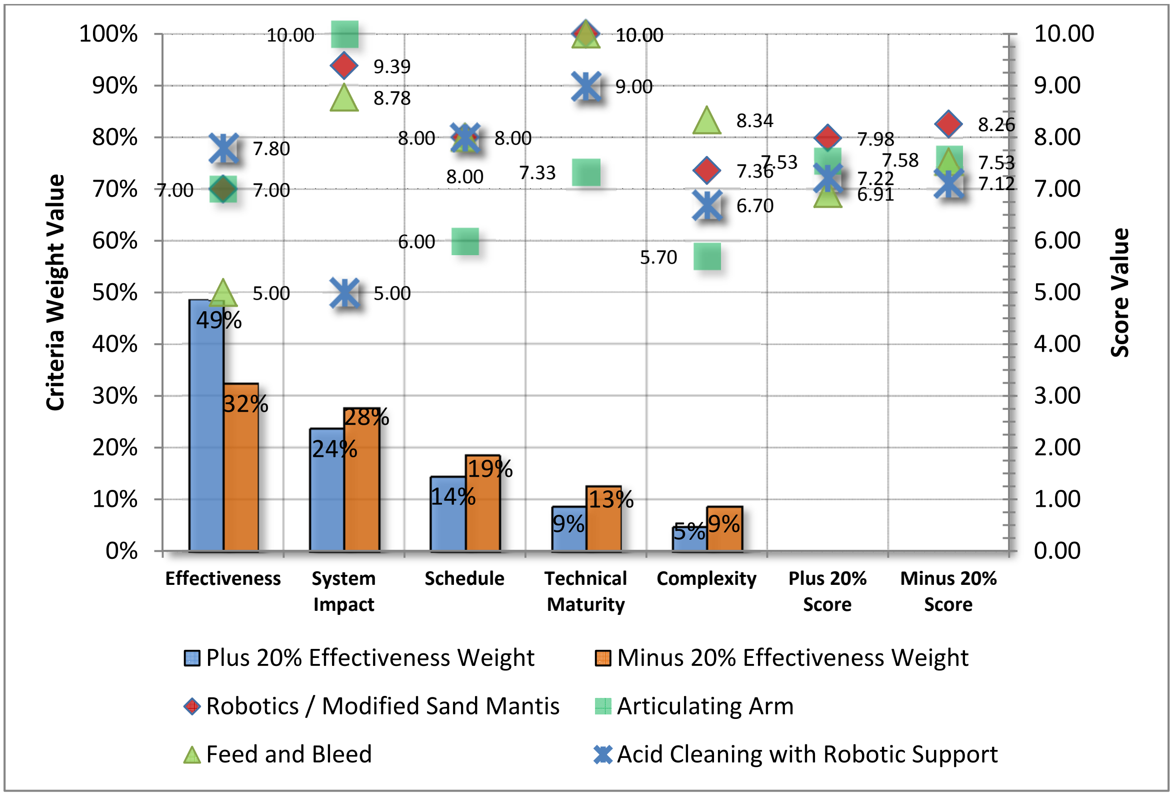


Table A.6: Effectiveness Sensitivity Summary

Concept Title	Original Score	Plus 20% Score	Minus 20% Score
Robotics/Modified Sand Mantis	8.121	7.985	8.258
Articulating Arm	7.554	7.533	7.575
Feed and Bleed	7.220	6.914	7.526
Acid Cleaning with Robotic Support	7.167	7.217	7.116

As seen in Figure A.11 and Table A.6, adjusting the Effectiveness criteria weight by +20% causes "Feed and Bleed" and "Acid Cleaning with Robotic Support" to change order. This is considered an insignificant change because the original scores for these two options are close. The -20% scores do not change order.

Due to the current technical maturity of these technologies, without performing additional studies with actual field tests, the effectiveness of any of the technologies for additional HRR removal from either the floor or walls of Tank 18 could not be accurately predicted by the team. Therefore, the team made relative comparisons between technologies when evaluating potential effectiveness

Figure A.12 and Table A.7 show the results of adjusting the System Impact criteria weight by +/- 20%.

Figure A.12: Tank 18 Radiological Inventory Reduction Alternative Evaluation System Impact Weight Adjusted +/- 20%

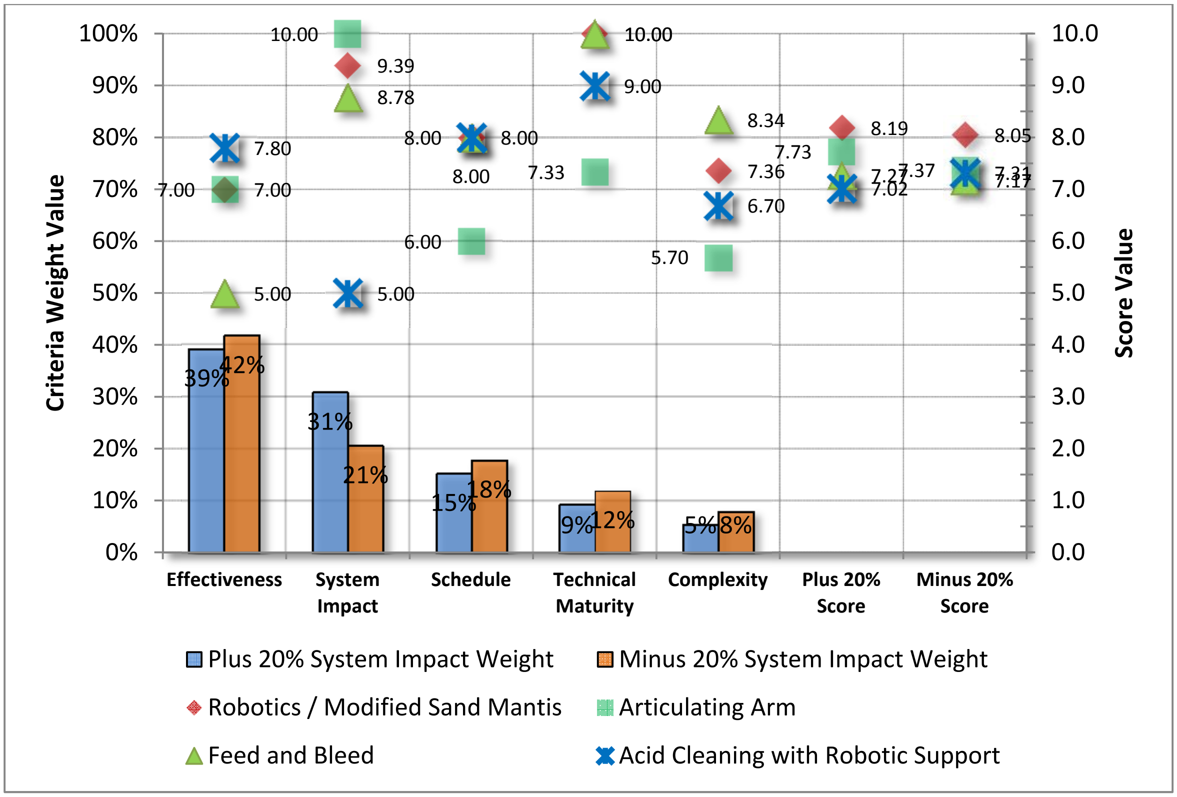


Table A.7: System Impact Sensitivity Summary

Concept Title	Original Score	Plus 20% Score	Minus 20% Score
Robotics/Modified Sand Mantis	8.121	8.188	8.055
Articulating Arm	7.554	7.734	7.375
Feed and Bleed	7.220	7.269	7.172
Acid Cleaning with Robotic Support	7.167	7.019	7.314

As seen in Figure A.12 and Table A.7, adjusting the System Impact criteria weight by +20% does not cause a change to the scoring order. However, the -20% scores cause “Feed and Bleed” and “Acid Cleaning with Robotic Support” to change order. This is considered an insignificant change because the original scores for these two options are close.

Tables A.8 through A.11 examine sub-criteria weight sensitivity. Each table shows a single sub-criteria weight adjustment and how it impacted the final scores.

Table A.8: Adjusted Effectiveness Sub-Criteria

Volume Reduction = .5; HRR Reduction = .5

Concept	Original Score	Adjusted Score
Robotics/Modified Sand Mantis	8.121	8.121
Articulating Arm	7.554	7.554
Feed and Bleed	7.220	7.220
Acid Cleaning with Robotic Support	7.167	7.045

Table A.9: Adjusted System Impact Sub-Criteria

Tank Space = .333; Waste Disposition = .333; System Flow sheet = .333

Concept	Original Score	Adjusted Score
Robotics/Modified Sand Mantis	8.121	7.850
Articulating Arm	7.554	7.554
Feed and Bleed	7.220	6.678
Acid Cleaning with Robotic Support	7.167	7.167

Table A.10: Adjusted Technical Maturity Sub-Criteria

Industrial Maturity = .5; Radiological Maturity = .5

Concept	Original Score	Adjusted Score
Robotics/Modified Sand Mantis	8.121	8.121
Articulating Arm	7.554	7.572
Feed and Bleed	7.220	7.220
Acid Cleaning with Robotic Support	7.167	7.167

Table A.11: Adjusted Schedule Sub-Criteria

Project Schedule = .75; Operating Schedule = .25

Concept	Original Score	Adjusted Score
Robotics/Modified Sand Mantis	8.121	8.121
Articulating Arm	7.554	7.389
Feed and Bleed	7.220	7.055
Acid Cleaning with Robotic Support	7.167	7.167

As seen in Tables A.8 through A.11, adjusting the sub-criteria weights causes “Feed and Bleed” and “Acid Cleaning with Robotic Support” to change order in Tables A.9 and A.11. Again, this is considered an insignificant change because the original scores for these two options are close.

The sensitivity evaluation concludes that the study is not sensitive to reasonable adjustments to the grading criteria and sub-criteria.

A.2.9 Risk Analysis (Pre-Mortem)

As part of the development of the top technologies, identification of the risks and opportunities was performed. Core Team members performed a pre-mortem analysis on each technology individually and the results are listed in Table A.12 in Attachment A.5.6. A total of 35 risks were identified, however, none were considered to be fatal flaws to that technology.

A.3.0 Results

In the following evaluations for each technology, the estimates for costs, personnel exposure, water usage, and time to implement are all based upon the work completed in F-Tank Farm on Tanks 18 and 19 using the Sand Mantis and on Tanks 5 and 6 utilizing chemical cleaning and existing pump mixing technologies.

The costs and exposure estimates for each project include the expense and impacts of obtaining and analyzing new samples in SRNL. The costs do not include any fines or penalties that may result from missing a FFA commitment date.

The impact to the system plan was determined by evaluating performing the cleaning activities in the 2014 to 2016 timeframe against System Plan, Revision 17. [SRR-LWP-2011-00067] The system plan is based upon closing tanks "just in time" to meet the FFA commitments. In certain processing scenarios it is estimated that a 1-month slip in sludge batch preparation could result from this additional residual removal. [SRR-LWP-2012-00010] This delay could result in an equal delay in the program life cycle in a worst case scenario depending when it occurred, although the actual impact is likely to be less. A 1-month slip in the program life cycle is considered to be $45 million (yearly program cost is $540 million). For the purposes of this evaluation, the team assumed a 1-month delay in processing equated to a 2-week delay in the program life cycle and assigned it a value of $20 million. This cost is associated with a reduction in processing in Defense Waste Processing Facility (DWPF) and/or Saltstone Facilities while the new waste is processed through the evaporator and while tank space is made available to prepare other tank waste for processing. The cost does not consider "time at risk" or "opportunity costs" associated with reallocating resources from other cleaning efforts.

The information below is a summary of the impacts and the supporting information is included in the attachments.

A.3.1 Robotics/Modified Sand Mantis

In the past 10 years, significant advances have been made in robotics with numerous companies building robots for cleaning tanks. Team research showed at least eight companies making robotic systems in addition to a modified Sand Mantis; however they all still use the same technology of liquid mobilization with vacuum or pump transfer. The best system could not be established by this team due to the time it would take to do a proper value engineering determination. Therefore the team chose to evaluate all robotic concepts as a whole, including a modified Sand Mantis as discussed in the Nuclear Regulatory Commission (NRC) Technical Evaluation Report (TER). [ML112371715] This option scored the highest of the group due to previous use of the Sand Mantis at SRS and the large number of vendors currently producing commercial systems.

Due to the current technical maturity of the robotic systems relative to deployment in a radioactive waste tank environment, without performing additional studies with actual field tests, the effectiveness of any of the technologies for additional HRR removal from either the floor or walls of Tank 18 could not be accurately predicted by the team. Therefore, the team made relative comparisons between this technology and other technologies when evaluating potential effectiveness.

It is estimated that it will take approximately 2 years to investigate, select, modify, and test a robotic system based upon the numerous risks realized with the Sand Mantis. This time would be only slightly shorter for the modified Sand Mantis, based upon the expected redesign needed to correct the operational issues because any technology chosen would be required to comply with the DOE rules and regulations regarding project and procurement activities prior to implementation. An additional year will be needed to perform cleaning and sampling in the field. Laboratory analysis of the residuals along with preparation and approval of closure documentation would require another 2 years, resulting in approximately a 5-year delay to grouting of the tank.

Exposure to SRS personnel is expected to be approximately 3 rem based upon previous work in F-Tank Farm with robots and the Sand Mantis.

Based upon the water usage for the Sand Mantis an estimated additional of 200,000 to 300,000 gallons of water will be needed to clean the tank. To process this water would most likely result in a 1-month delay in preparing a sludge batch for DWPF dependent upon when the cleaning was performed. This technology is not expected to be able to clean the walls so a hydro-lance will be required to clean the film off the walls. This will result in an estimated additional 50,000 gallons of water usage.

Project costs are expected to be in the $13 million range based upon previous SRS experience implementing technologies of this type. Costs to maintain the tank while waiting final grouting are estimated at $1 million per year. A 5-year delay results in an additional $5 million. The 1-month delay in processing as described above will result in a cost of an additional $20 million for a total program cost of approximately $38 million.

A.3.2 Articulating Arm

As with robotics, arm technology has also progressed significantly over the past 10 years. S.A. Technology now has a carbon-fiber arm with three-degrees of freedom that could be deployed without significant structural modification to Tank 18. This is a big advantage over the Mobile Arm Retrieval System (MARS) arm currently deployed at Hanford that would require extensive structural modifications to the tank top to deploy on Tank 18.

This technology is currently being field tested in the United Kingdom in a nuclear application. Results of this work are expected in late 2012. This technology is progressing, however, like robotics, it will still require modification and testing before it is deployed. The current design does not have sufficient reach to clean all areas of the tank.

Due to the current technical maturity of this technology, without performing additional studies with actual field tests, the effectiveness of the technology for additional HRR removal from either the floor or walls of Tank 18 could not be accurately predicted by the team. Therefore, the team made relative comparisons between this technology and other technologies when evaluating potential effectiveness.

Based upon the necessary redesign required for the arm to reach all areas of the tank, there is a risk that it will take longer to develop and test compared to robotics. This is based upon the technical difficulties experienced during the Sand Mantis maturation from the Aardvark. It is estimated that it will take 2 to 3 years to obtain a unit ready to be deployed in the field and 1 year to clean and sample the tank. Laboratory analysis of the residuals along with preparation and approval of closure documentation would require another 2 years, resulting in approximately a 5-year delay to grouting of the tank.

Exposure to SRS personnel is expected to be approximately 3 rem based upon previous work in F-Tank Farm with robots and the Sand Mantis.

Like robotics, this system will use water, estimated at 200,000 to 300,000 gallons, with a vacuum and pumping system. This technology is expected to have the ability to clean the wall film while cleaning the tank. The impact to the liquid waste system would result in about a 1-month delay in preparing a sludge batch to process the water.

Project costs are expected to be in the $15 million range based upon vendor discussions and previous Sand Mantis work at SRS. Costs to maintain the tank while waiting final grouting are estimated at $1 million per year. A 5-year delay results in an additional $5 million. The delay in processing as described above will result in a cost of an additional $20 million for a total program cost of approximately $40 million.

A.3.3 Feed and Bleed

This technology has been used at SRS in the past and as recently as the cleaning of Tanks 5 and 6. It is the most mature and understood of the technologies. It uses liquid to suspend the residual material, pumps the liquid to a settling tank and recirculates the liquid for reuse. There are advantages and disadvantages to this method. The advantage is that the tank does not have coils to interfere with the mixing, reducing the dead zones which results in less mounding of the residual material. The technology is judged to be less effective for removing residues such as zeolite that have large particle size and relatively high particle density which results in quick settling in regions of low turbulence.

Therefore, based on the presence of zeolite in Tank 18, without performing additional studies with actual field tests, the effectiveness of this technology for additional HRR removal from either the floor or walls of Tank 18 could not be accurately predicted by the team. Therefore, the team made relative comparisons between this technology and others when evaluating potential effectiveness.

This method will use an estimated 400,000 to 600,000 gallons of water to provide the minimum tank level required to operate the mixing pumps, which is significantly more liquid than the previous two methods. Obtaining at least 500,000 gallons of tank space and having to process the liquid through the evaporator has system impacts resulting in a delay of up to 2 months in preparing sludge batches to process the water through the evaporator.

Based upon the time required to disassemble and remove the existing equipment from the Tank 18 risers for pump installations, exposure is estimated at 5.4 rem to SRS personnel.

This technology is not expected to be able to clean the walls so a hydro-lance will be required to clean the film off the walls. This will result in an estimated additional 50,000 gallons of water usage.

Project costs are expected to be in the $25 million range based upon the costs to procure and install four pumps. It will require 2 to 3 years to deploy in the field due to the 12 to 18 month fabrication time for the pumps and 1 year to clean and sample the tank. Laboratory analysis of the residuals along with preparation and approval of closure documentation would require another 2 years, resulting in approximately a 5-year delay to grouting of the tank. Costs to maintain the tank while waiting final grouting are estimated at $1 million per year. A 5-year delay results in an additional $5 million. The two month delay in processing as described above will result in a cost of an additional $40 million for a total project cost of $70 million.

A.3.4 Acid Cleaning with Robotic Support

A variety of acids and combinations of acids were reviewed as part of this evaluation. In order to be effective with acid cleaning without significant downstream process impacts it will be necessary to control the type and amount of acid used. By using a mixture of acids, HRRs can be targeted and corrosion impacts to the tank can be minimized. In addition, by direct application of the acid without having to use large volumes of acid moved by mixing pumps, system impacts can also be minimized. This system would have to be developed and tested since very little field experience exists for acids applied directly to waste with zeolite. The efficiency of the acid on the residual material and impacts of acid on zeolite will need to be determined.

Due to the current technical maturity of both the acid flow sheet and the robotics delivery systems, without performing additional studies with actual field tests, the effectiveness of the technology for additional HRR removal from either the floor or walls of Tank 18 could not be accurately predicted by the team. Therefore, the team made relative comparisons between this technology and other technologies when evaluating potential effectiveness.

Several studies have been conducted at SRS by SRNL over the past eight years and will be used as the starting point for flow sheet development. [WSRC-TR-2003-00401, SRNL-STI-2010-00541] It is anticipated that 1 to 2 years of research will be needed to mature this technology and develop the flow sheet. It will take an additional 1 to 2 years to develop the equipment to deploy to the field. These activities would be conducted in parallel to reduce the time to complete cleaning so that impacts to the FFA closure commitments are minimized. This results in a project risk to the cost, schedule, and effectiveness. It will take another approximately 3 years to clean and sample the tank, analyze the residuals, and prepare closure documentation, resulting in more than a 5-year delay before the tank can be grouted.

Using acid will result in additional waste generation. Water to flush the tank, water to wash the sludge to remove the neutralized acid and caustic to neutralize the spent acid will lead to an estimated 300,000 to 400,000 gallons of waste to be processed. The resulting waste stream would then have to be processed through Modular Caustic Side Solvent Extraction Unit (MCU), Salt Waste Processing Facility (SWPF) or Small Column Ion Exchange (SCIX) and disposed of in the Saltstone Disposal Facility. This may lead to delay of up to 2 months in preparing feed batches for DWPF and the Saltstone Production Facility.

Exposure estimates for SRS personnel will be approximately 3 rem based upon the previous Tank 5 and 6 chemical cleaning.

This technology is not expected to be able to clean the walls so a hydro-lance will be required to clean the film off the walls. This will result in an estimated additional 50,000 gallons of water usage.

Project costs are expected to be in the $15 million range based upon previous Tank 5 and 6 chemical cleaning at SRS. Costs to maintain the tank while waiting final grouting are estimated at $1 million per year. A 5-year delay results in an additional $5 million. The 2-month delay in processing as described above will result in a cost of an additional $40 million for a total cost of $60 million.

A.4.0 CONCLUSIONS

A team of senior engineers and scientists from the DOE complex performed a Systems Engineering Evaluation to identify the best viable technologies to clean the residual waste in Tank 18. The four most promising technologies were chosen for further investigation and submitted for a more comprehensive analysis. These include: (1) robotic crawlers or modified Sand Mantis, (2) a carbon fiber arm with multiple degrees of freedom that uses liquid and pumps, (3) recirculation process (Feed and Bleed) using pumps, and (4) robotics with acid cleaning. The team developed cost, schedule, personnel exposure, system impacts, and project risks relative to each of these technologies.

Based on the current level of technical maturity for the technologies evaluated, and the durations required to mature and deploy the technologies, any technology that is undertaken for further Tank 18 waste removal will delay grouting of Tank 18 a minimum of 5 years from the time the additional retrieval is started. Costs to maintain the tank while waiting final grouting are estimated at $1 million per year.

Impacts to the Liquid Waste System could range from 1 to 4 months to evaporate off the excess liquids and blend the remaining waste into the existing DWPF or Saltstone feed batches for processing. Delays of this duration may result in a DWPF feed break if realized. Every month delay in processing equates to a 2-week delay in the program life cycle and has an estimated cost impact of $20 million. This cost does not consider “time at risk” or “opportunity costs” associated with reallocating resources from other cleaning efforts, nor does it include potential penalties associated with failure to comply with the FFA deadlines for the closure of Tanks 18 and 19 by December 31, 2012.

Project costs associated with the evaluated technologies range from an estimated $13 million to $27 million. Regardless of the technology selected, a minimum of approximately $10 million can be associated with costs that would be incurred by any of the technologies. These costs are associated with activities such as preparing the tank for re-entry, installation of transfer lines, operational support, procedure development, field sampling, laboratory analysis, and development of updated closure documentation.

In summary, while these in-tank robotic technologies have continued to mature over the last 10 years, they still tend to be "first of a kind" or "one of a kind" deployments. Such deployments have been few in number across the DOE Complex thus they have not been rendered into standard practice or into routine deployments. These technologies carry the risk that they may cost more and take longer to deploy than expected or prove not to be effective at removing additional HRRs from Tank 18.

A.5.0 SYSTEMS ENGINEERING EVALUATION ATTACHMENTS

The following Attachments supporting this Systems Engineering Evaluation are provided in the proceeding:

- Attachment A.5.1: Pairwise Comparison Charts
- Attachment A.5.2: Work Scopes
- Attachment A.5.3: Cost Estimates
- Attachment A.5.4: Exposure Estimates
- Attachment A.5.5: Schedules
- Attachment A.5.6: Risk Analysis
- Attachment A.5.7: Team Bios

Attachment A.5.1: Pairwise Comparison Charts

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Model Name: Tank 18 SEE 2011

Treeview

- **Goal: Identify The Best Technology To Reduce HRR Inventory In Tank 18**
  - **Complexity (L: .067)**
    - **Environmental (L: .140)**
    - **Process Safety (L: .333)**
    - **Operational (L: .528)**
  - **Effectiveness (L: .405)**
    - **Volume Reduction (L: .200)**
    - **HRR Inventory Reduction (L: .800)**
  - **Technical Maturity (L: .106)**
    - **Industrial Application (L: .667)**
    - **Radiological Application (L: .333)**
  - **System Impact (L: .257)**
    - **Tank Space (L: .122)**
    - **Waste Disposition (L: .320)**
    - **HLW System Flowsheet Compatibility (L: .558)**
  - **Schedule (L: .165)**
    - **Project Schedule (L: .500)**
    - **Operating Schedule (L: .500)**

Information Documents and Notes

Complexity (L: .067)/Technical Maturity (L: .106)

Facilitator

Complexity (L: .067)/System Impact (L: .257)

Facilitator

MJA, SRR

Potential consequeces of a "system impact" is more difficult to resolve than complexity issues.

Complexity (L: .067)/Schedule (L: .165)

Facilitator

Schedule is more important due to regulatory (FFA) committments to the stakeholder.

Environmental

A measure of the anticipated difficulty to obtain required regulatory permits or challenge compliance with existing permits.

Environmental (L: .140)/Process Safety (L: .333)

Facilitator

The team judged that process safety is more important than Env due to most process will be within existing env permits.

Environmental (L: .140)/Operational (L: .528)

Facilitator

Most concepts can be implemented within the existing SRS permits. Rad exposure and operating / maintence risks, process upsets are a better discriminator.

Process Safety

A measure of the effort required to develop process safety requirements (major DSA revision, minor DSA revision, no DSA revision) including the number of anticipated process safety controls.

Process Safety (L: .333)/Operational (L: .528)

Facilitator

The majority of MAR has been removed therefore the existing Process Safety risks are judged to be low, therefore the team judged that the operational complexity was slightly more important than process safety complexity.

Operational

A measure of the effort required to design, install, and operate the concept.

Effectiveness (L: .405)/Technical Maturity (L: .106)

Facilitator

Effectiveness is judged to be more important than technical maturity to the stakeholders based on the NRC TER.

Effectiveness (L: .405)/System Impact (L: .257)

Facilitator

Effectiveness is judged to be more important than sytem impact to the stakeholders based on the NRC TER. However, it is judged to be only slighty more important because the effectivness of cleaning tank 18 cant be accomplished at the expense of the rest of the HLW system program.

Effectiveness (L: .405)/Schedule (L: .165)

Facilitator

Effectiveness is judged to be more important than schedule to the stakeholders based on the NRC TER. However, it is judged to be only moderately more important because the effectivness of cleaning tank 18 cant be accomplished and not meet FFA commitments.

Volume Reduction

Degree of confidence that a residual heel volume of ≤ 1000 gal can be achieved.

Volume Reduction (L: .200)/HRR Inventory Reduction (L: .800)

Facilitator

HRR removal equates more specifically to dose reduction than volume.

HRR Inventory Reduction

Degree of confidence that existing HRR impact can be reduced by at least 50%.

Technical Maturity (L: .106)/System Impact (L: .257)

Facilitator

System impact is judged to be more important than technical maturity because the tech maturity can be managed within the project scope, however a system impact issue potentially impacts other HLW systems and HLW life cycle.

Technical Maturity (L: .106)/Schedule (L: .165)

Facilitator

due to potential FFA impact

Industrial Application

A measure of the degree to which this has been used for industrial applications, including consideration of the scale of application (similar scale, smaller scale, only tested or piloted, not used or tested).

Industrial Application (L: .667)/Radiological Application (L: .333)

Facilitator

Existing dose is low and will lessen importance of rad hardening of materials.

Radiological Application

A measure of the degree to which this has been used in rad applications (used in HLW or high rad, Low level or smaller scale, tested but not used, not tested or used)

System Impact (L: .257)/Schedule (L: .165)

Facilitator

System impact can delay HLW life cycle, schedule can only impact Tank 18.

Tank Space

A measure of the amount of liquid that will be sent to the tank farm requiring evaporation.

Tank Space (L: .122)/Waste Disposition (L: .320)

Facilitator

Waste disposition has greater potential to impact the HLW life cycle than operating evaporators.

Tank Space (L: .122)/HLW System Flowsheet Compatibility (L: .558)

Facilitator

HLW system flowsheet has greater potential to impact the HLW life cycle than operating evaporators.

Waste Disposition

Residual waste volume remaining in the HLW system after evaporation or dry volume requiring disposition (SPF or DWPF).

Waste Disposition (L: .320)/HLW System Flowsheet Compatibility (L: .558)

Facilitator

HLW system flowsheet has slightly more potential to impact the HLW life cycle than waste disposition.

Potential consequeces of a flowsheet impact is more difficult to resolve than a disposition issue.

HLW System Flowsheet Compatibility

A measure of how well the concept will integrate into the existing HLW processes (flowsheet). A concept that seamlessly integrates into the HLW system would be rated higher than a concept that results in impacts to the current HLW Flowsheet, creates a waste with no obvious disposition path or creates a new waste form.

Project Schedule

Estimated schedule from present through turnover to operations. A concept that can be implemented in less than 12 months would be rated better than a concept that required 60 months to implement.

Project Schedule (L: .500)/Operating Schedule (L: .500)

Facilitator

Combine

Operating Schedule

Estimated time from the start of radioactive operations until the desired end state is achieved. The desired end state is defined as less than 1000 gallons total remaining residual volume or at least 50% reduction of the current HRR impact.

Compare the relative importance with respect to: Goal: Identify The Best Technology To Reduce HRR Inventory In Tank 18

Circle one number per row below using the scale:
1 = Equal 3 = Moderate 5 = Strong 7 = Very strong 9 = Extreme

1	Complexity	9	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	9	Effectiveness
2	Complexity	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Technical Maturity
3	Complexity	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	System Impact
4	Complexity	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Schedule
5	Effectiveness	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Technical Maturity
6	Effectiveness	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	System Impact
7	Effectiveness	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Schedule
8	Technical Maturity	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	System Impact
9	Technical Maturity	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Schedule
10	System Impact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Schedule

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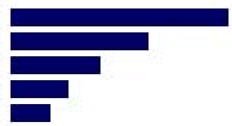
Priority Graphs

Priorities with respect to:
Goal: Identify The Best Technology To Reduce HRR Inventory In Tank 18

Effectiveness	.405
System Impact	.257
Schedule	.165
Technical Maturity	.106
Complexity	.067



Inconsistency = 0.02
with 0 missing judgments.

MJA, SRR

Attachment A.5.2: Work Scopes

A.5.2.1 Robotics/Modified Sand Mantis

Title: Use Commercially Available Robotic Systems to Reach, Acquire, and Enable Transfer of Additional Waste from Tank 18

Alternative #: 1 Robotics/Modified Sand Mantis – with liquid mobilization and vacuuming

Originator: Mike Hubbard, 241-162H, 208-3710

Description: Select, develop, and implement robotic waste removal system to remove waste from Tank 18 (See Figures A.13 through A.15 for pictures of robotic “Sand Mantis” and see Figure A.16 for pictures of other commercially available robots). Provide required tank services to support, monitor, and control waste removal within Documented Safety Analysis (DSA) controls.

Assumptions/Initial Conditions: (See Figure A.17 for riser information)

- Tank 18 initial condition is completely isolated and in Removed from Service Mode
- All services are removed with exception of ventilation
- All tank top drawings will be Non-Technical Baseline (NTB)
- Abandoned sampling and Mantis crawlers are present on tank bottom near available risers
- Receipt tank for waste will be Tank 7

Scope Elements Include:

- Select, procure, develop and test robotic waste removal equipment
- Design and field implement tank top and tank services necessary to support waste removal and place tank back in operational mode (power, transfer system and path, level monitoring, hydrogen monitoring, control room operations/alarms, sump systems, water and air systems)
- Perform system flow sheet and Consolidated Hazards Analysis (CHA) reviews to support DSA controls and design inputs
- Perform waste removal activities
- Provide the design and implementation to remove modification to re-establish removal from service and isolation

Up Front Actions:

- Procure robotic removal systems
- Perform as-found design documentation for support and tank top systems
- Develop and test robotic systems
- Perform Engineering reviews to include flow sheet and DSA controls
- Receive authorization to re-instate Tank 18 from isolation
- Provide design and implementation for tank top, transfer, and support systems
- Remove as needed abandoned riser and in-tank equipment to allow for access and movement of robotics on tank bottom. Provide disposal boxes as necessary for equipment disassembly and removal (D&R).
- Complete readiness reviews for operation

<u>Operations Phase Actions:</u>

- Operate robotic systems and transfers over estimated 3 to 6 months
- Perform waste mapping and estimates
- Perform waste sampling (may include procurement or development of additional tools)

<u>Post Operations Phase Actions:</u>

- Receive authorization for tank removal from service and isolation
- Design and implement removal for service and isolation

<u>Constructability/Costs:</u>

System requirements are assumed to be similar to requirements procured, installed, and operated using the Mantis system. However, it is assumed equipment will be operated by site personnel not under contract. Hardware requirements include:

- Robotic hardware and spares (assume four at $250,000 each)
- Transfer hose in hose from Tank 18 to Tank 7 (400 feet)
- 2-inch core, 4-inch jacket shielded
- Provide one transfer system driver (options: Standard Transfer Pump (STP), high pressure water source)
- Repair waste grinder in Tank 7 to reduce particle size of waste from Tank 18 (provide motor and connections to new transfer line hoses)
- Prepare two risers to support robotic systems
- D&R abandoned equipment from tank floor (one disposal box assumed, provision of tools to grab and gather tank floor interferences)
- Provide power system to support robotics and tank top services
- Provide alarm system hook-up to local control room
- Provide water and air systems
- Restore tank sump operations and systems
- Provide tools to support post transfer sampling ($100,000 for sampling tool and $500,000 to process)

Due to the limited duration of operations, it is assumed design and configuration management can be implemented through use of a temporary modification. Some new permanent design may be required if risers are modified or for restoration to an isolated tank. Since tank top drawings are NTB, some as found design documentation will be required to support design services.

Figure A.13: Mantis in Test Facility

Figure A.14: Mantis in Tank Prior to Cleaning

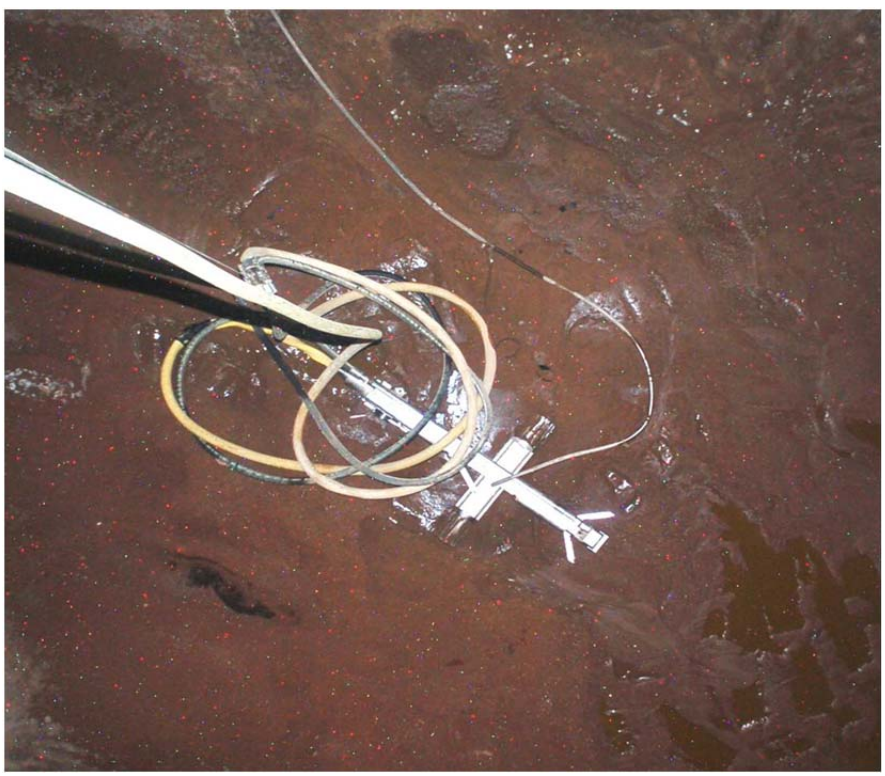


Figure A.15: Mantis After Tank 18 Cleaning

(View from New Mechanical Cleaning Riser Looking North)

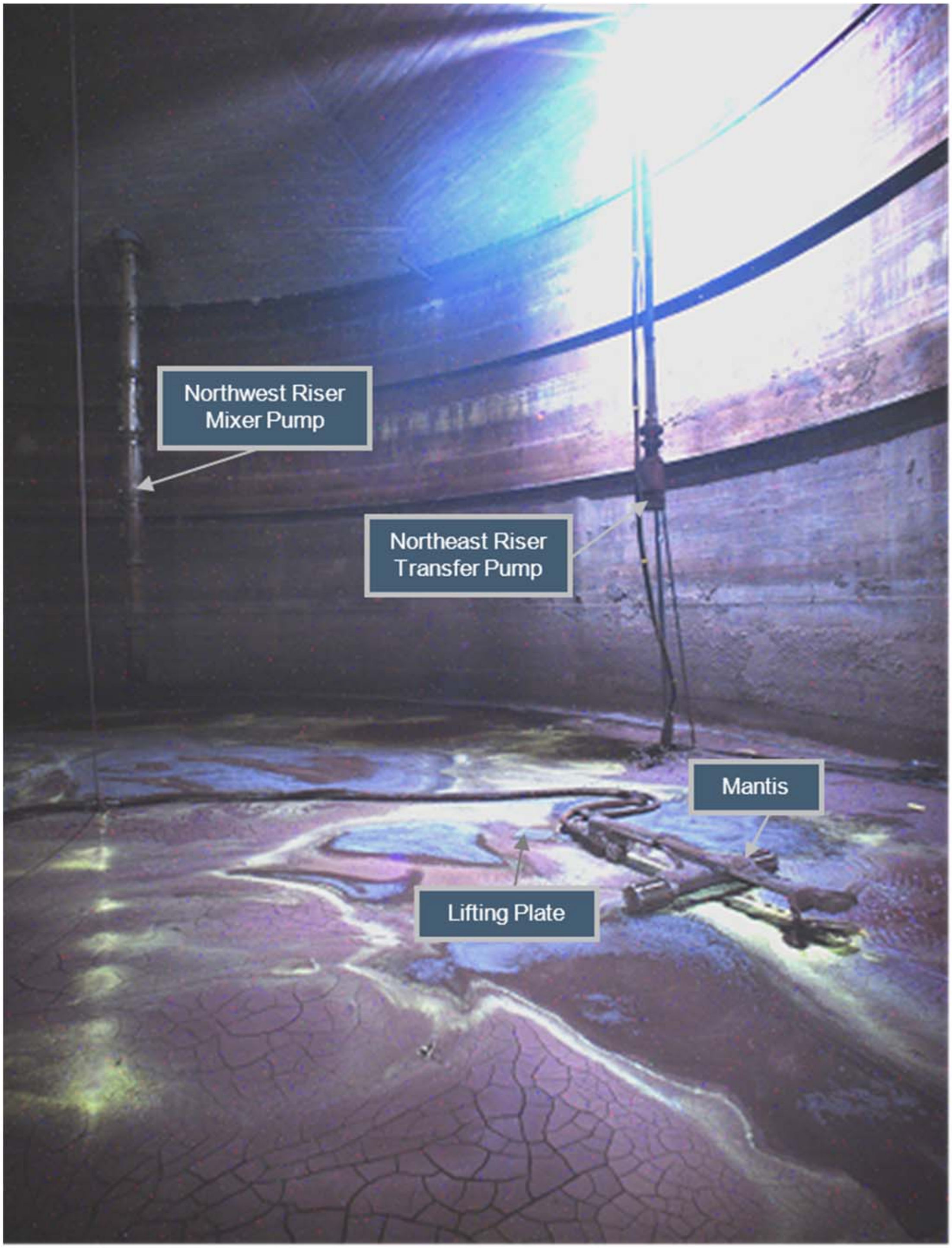
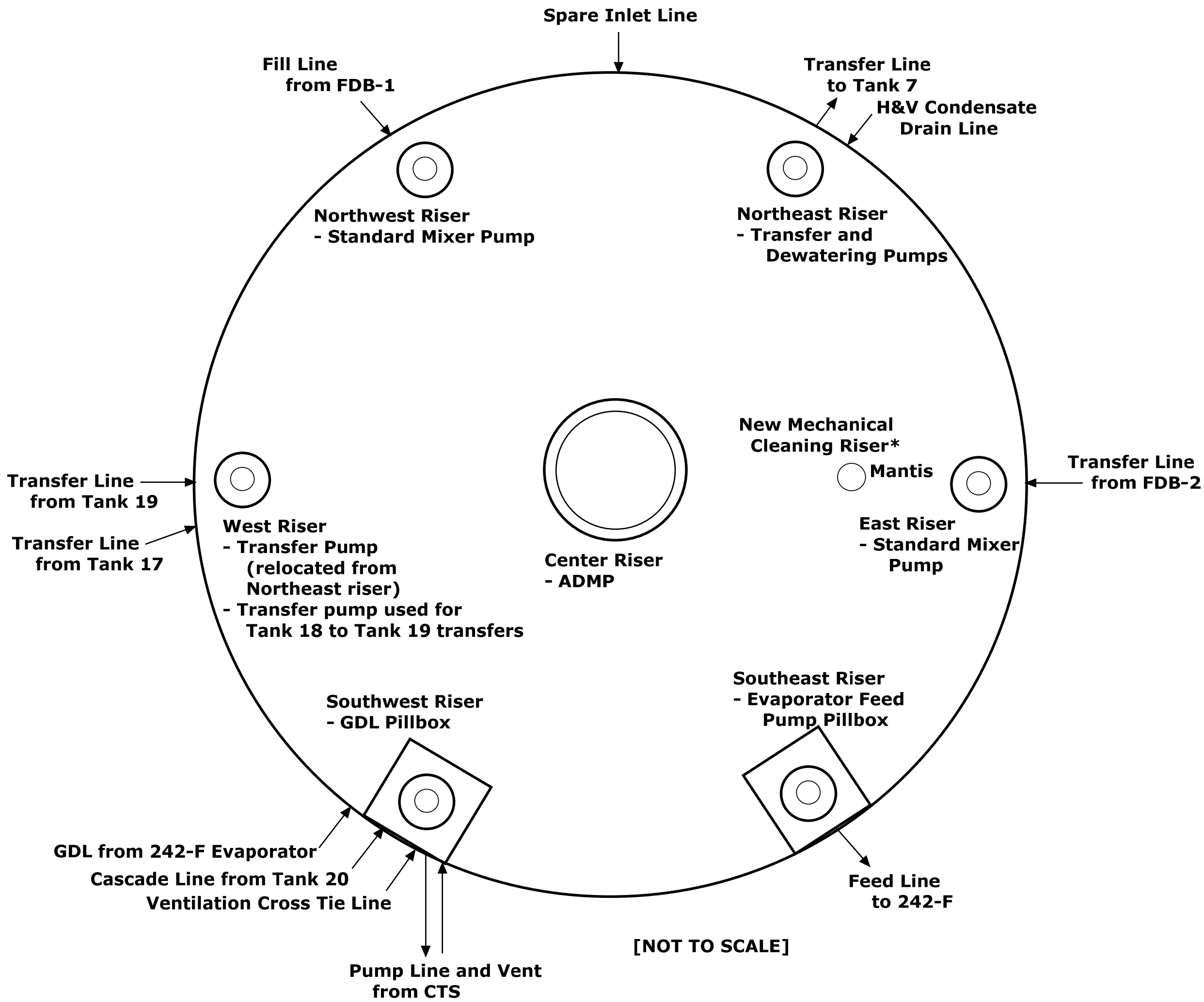


Figure A.16: Other Commercial Robotic Crawler

Figure A.17: Tank 18 Risers, Abandoned Equipment, and Transfer Lines



* The mechanical cleaning riser is a 24-inch diameter opening that was installed for mechanical cleaning equipment.

A.5.2.2 Articulating Arm

Title: Use S.A. Technology Systems Arm to Reach, Acquire, and Enable Transfer of Additional Waste from Tank 18

Alternative #: 2 Articulating Arm – with liquid mobilization and vacuuming

Originator: Walt Isom 208-8083/pager-13905

Description: Select, develop, and implement robotic arm waste removal system (See Figure A.18) to remove waste from Tank 18. Provide required tank services to support, monitor, and control waste removal within DSA controls.

Assumptions/Initial Conditions: (See previous Figure A.17 for riser information)

- Tank 18 initial condition is completely isolated and in Removed from Service Mode
- All services are removed with exception of ventilation
- All tank top drawings will be NTB
- Abandoned sampling and Mantis crawlers are present on tank bottom near available risers
- Receipt tank for waste will be Tank 7

Scope Elements Include:

- Select, procure, develop and test robotic arm equipment (See website www.bluetoad.com pages 8-12 for article on arm)
- Design and field implement tank top and tank services necessary to support waste removal and place tank back in operational mode (power, transfer system and path, level monitoring, hydrogen monitoring, control room operations/alarms, sump systems, water and air systems)
- Perform system flow sheet and CHA reviews to support DSA controls and design inputs
- Perform waste removal activities
- Provide the design and implementation to remove modification to re-establish removal from service and isolation

Up Front Actions:

- Procure robotic arm system
- Perform as-found design documentation for support and tank top systems
- Develop and test robotic arm system
- Perform Engineering reviews to include flow sheet and DSA controls
- Receive authorization to re-instate Tank 18 from isolation
- Provide design and implementation for tank top, transfer, and support systems
- Remove as needed abandoned riser equipment to allow for access and movement of arm in tank. Provide two disposal boxes as necessary for equipment D&R.
- Complete readiness reviews for operation

<u>Operations Phase Actions:</u>

- Operate robotic arm system and transfers over estimated 3 to 6 months
- Perform waste mapping and estimates
- Perform waste sampling (may include procurement or development of additional tools)

<u>Post Operations Phase Actions:</u>

- Receive authorization for tank removal from service and isolation
- Design and implement removal for service and isolation

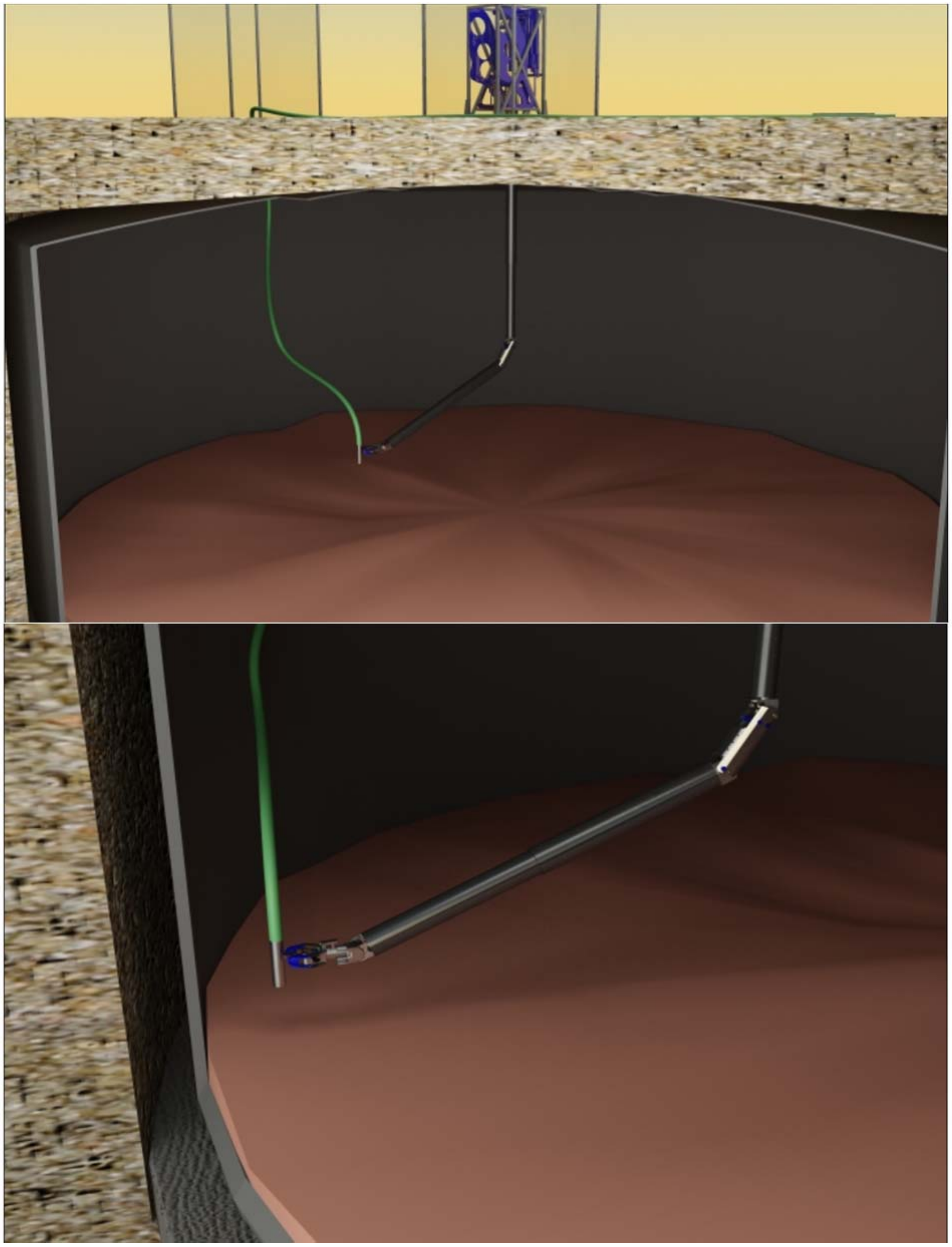
<u>Constructability/Costs:</u>

System requirements are assumed to be similar to requirements procured, installed, and operated using the Mantis system. However, it is assumed equipment will be operated by site personnel not under contract. Hardware requirements include:

- Robotic hardware and spares estimated cost $1 million and an additional $1 million in modifications for our application
- Transfer hose in hose from Tank 18 to Tank 7 (400 feet) 2-inch core and 4-inch jacket needs shielded
- Provide one transfer system driver (options: small pump)
- Reuse waste grinder in Tank 7 to reduce particle size of waste from Tank 18. Needs new motor and beads
- Prepare three risers to support robotic arm. Arm will have to be moved two times besides initial installation. Treat like Submersible Mixer Pump (SMP) movement for costing
- Need box for removal of arm when complete. Arm to be removed upon completion
- Provide power system to support robotic arm and tank top services (electrical and water)
- Provide alarm system hook-up to local control room
- Restore tank sump operations and systems
- Provide tools to support post transfer sampling $100,000 for crawler and $500,000 for SRNL analysis

Due to the limited duration of operations, it is assumed design and configuration management can be implemented through use of a temporary modification. Design Services will do designs. Some new permanent design may be required if risers are modified or for restoration to an isolated tank. Since tank top drawings are NTB, some as found design documentation will be required to support design services.

Figure A.18: Articulating Arm



A.5.2.3 Feed and Bleed

Title: Perform Additional Waste Removal from Tank 18 via Feed and Bleed Evolution Similar to the Evolution Performed in Tank 6

Alternative#: 3 Recirculation line (Feed and Bleed) - mixing and recirculation with pumps

Originator: Donnie Thaxton, 704-70F, 952-2079

Description: Provide required tank services and equipment necessary to perform a feed and bleed waste removal evolution in Tank 18 (See Figure A.19).

Assumptions/Initial Conditions: (See previous Figure A.17 for riser information)

- Tank 18 initial condition is completely isolated and in Removed from Service Mode
- All services are removed except for minimal ventilation
- All tank top drawings will be NTB
- Abandoned sampling and Mantis crawlers are present on tank bottom near available risers
- Abandoned equipment is in all available risers
- The southeast riser includes a concrete pillbox design which will require demolition and modification to accept a mixing pump
- Standard slurry pumps can be installed for mixing purposes, but SMPs cannot (Type IV tanks have not been qualified for SMP use)
- Receipt tank for waste will be Tank 7. Feed source will be a liquid return line from Tank 7
- Complete mixing of the tank requires the availability of four risers for slurry pump installation. The risers chosen for pump installation should be based upon the objective of having a mixing pump in each quadrant of the tank (to minimize dead zones)

Scope Elements Include:

- D&R of abandoned equipment in the Northwest (failed slurry pump), West (parts of two abandoned transfer pump systems), East (failed slurry pump), and Southeast (abandoned feed pump) risers including demolition of the pill box at the Southeast riser (significant radiation work) [Note: D&R of the pill box at the Southwest riser should be avoided due to excessive contamination and high radiation rates]
- Modifications to structural steel and risers to accommodate and support the mixing pumps
- D&R of equipment (abandoned transfer pump and other suspended equipment) in the Northeast riser for installation of a transfer pump (to pump material to Tank 7)
- D&R of equipment (toadstool) at the Mechanical Cleaning riser to accommodate installation of the liquid return line from Tank 7
- Procure, test, and install four standard slurry pumps
- Perform system flow sheet and CHA reviews to support design modification inputs and DSA controls development and implementation
- Design and install the tank services necessary to support operation of the waste removal equipment and returning the tank to an operational mode (power, transfer system and

path, water and air systems (including bearing water and inhibited water systems), tank level monitoring, tank vapor space hydrogen monitoring, containment sump services, controls and alarms)
- Perform waste removal activities
- Provide design to remove equipment (as necessary) and to re-establish tank isolation. At a minimum, a transport box will be needed to re-locate the four slurry pumps (one-at-a-time) to another tank (for future use)
- Implement modifications to return tank to Remove from Service Mode

Up Front Actions:

- Procure four standard slurry pumps (18 months estimated delivery)
- Perform as-found design documentation for support and tank top systems
- Perform Engineering reviews to support flow sheet and DSA controls development
- Receive authorization to re-instate Tank 18 from isolation
- Provide design and implementation for transfer, mixing, and support systems installation
- Remove abandoned riser equipment and provide demolition of pill box to allow for installation of transfer, mixing, and support systems. Provide five to six disposal boxes as necessary for equipment D&R.
- Complete readiness reviews for operation

Operations Phase Actions: (expected to occur in fiscal year 2014)

- Operate feed and bleed system and transfer solids to Tank 7 over estimated 4 to 8 weeks
- Perform waste mapping and estimates of residual waste
- Perform waste sampling (may include procurement or development of additional tools)

Post Operations Phase Actions:

- Re-locate four slurry pumps (one-at-a-time) to other tanks (for future use)
- Receive authorization for tank removal from service and isolation
- Design and implement removal for service and isolation

Constructability/Costs:

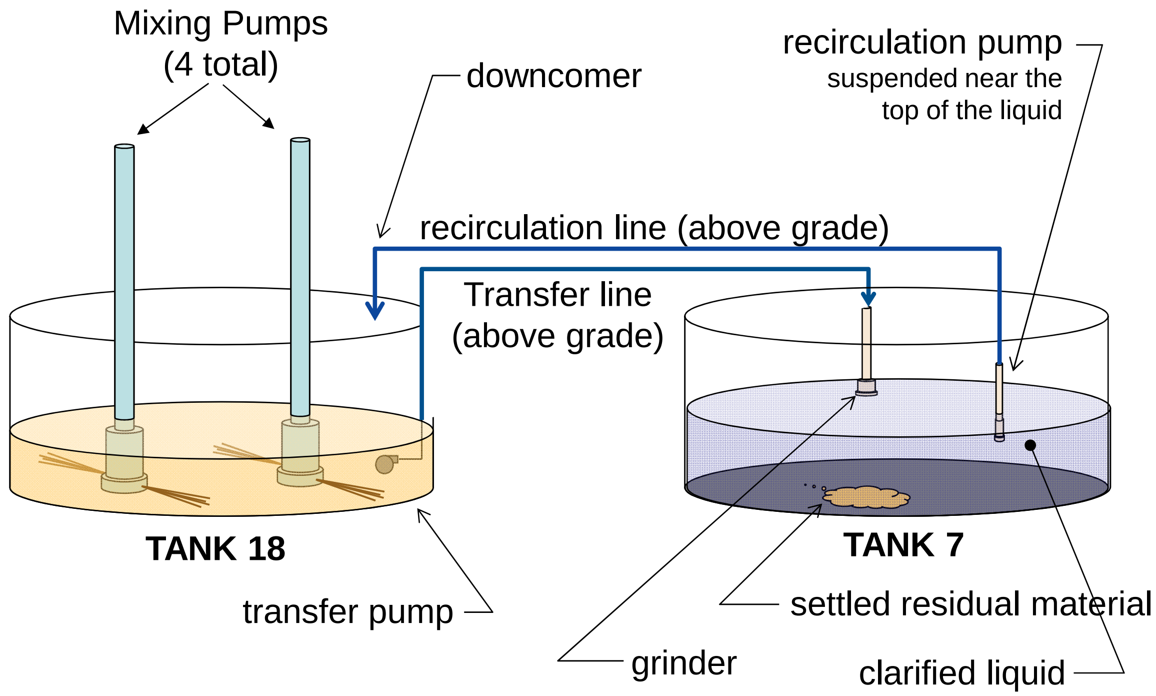
Equipment capabilities are assumed to be similar to those required to perform the feed and bleed cleaning evolution in Tank 6. Hardware requirements include:

- Four standard slurry pumps at estimated cost of $1 million each with an additional $500,000 each for modifications to support installation
- Transfer hose in hose from Tank 18 to tank 7 (400 feet) 2-inch core and 4-inch jacket with shielding
- Provide one transfer system driver from Tank 18 (STP)
- Reuse waste grinder in Tank 7 to reduce particle size of waste from Tank 18. Needs new motor and beads
- Transfer hose in hose from Tank 7 to Tank 18 (400 feet) 2-inch core and 4-inch jacket with shielding for transferring liquid from Tank 7 back to Tank 18
- Provide one transfer system driver from Tank 7, STP

- Provide power to slurry pumps and transfer pumps from the existing control room skid (Waste on Wheels skid) near Tank 5. Utilize the variable frequency drives as needed.
- Provide bearing and inhibited water from supply system near Tank 1 or install a new storage tank and supply system at Tank 18 to replace the system that was removed (assume a 2-inch line)
- Provide monitoring and alarm system hook-up to local control room
- Restore tank sump operations and systems
- Restore air supply to the tank as needed for operation of equipment and instrumentation (assume a 2-inch line)
- Provide tools to support post transfer sampling $100,000 for crawler and $1 million for SRNL analysis

Due to the limited duration of operations, it is assumed design and configuration management can be implemented through use of a temporary modification. Design Services will do designs. Some new permanent design may be required if risers are modified or for restoration to an isolated tank. Since tank top drawings are NTB, some as-found design documentation will be required to support design services.

Figure A.19: Feed and Bleed System



A.5.2.3 Acid Cleaning with Robotics

Title: Use Commercially Available Robotic Systems with Acid Spray to Reach and Enable Transfer of Additional Waste from Tank 18

Alternative #:4 Acid Cleaning with robotic support – direct acid cleaning controlled by robotics

Originator: Walt Isom 2088-8083/pager 13905

Description: Select, develop, and implement robotic waste removal system using water and acid to remove waste from Tank 18. Acid will be used directly on waste, allowing soak time, then flushed with water and vacuumed to adjacent tank. Provide required tank services to support, monitor, and control waste removal within DSA controls.

<u>Assumptions/Initial Conditions: (See previous Figure A.17 for riser information)</u>

- Tank 18 initial condition is completely isolated and in Removed from Service Mode
- All services are removed with exception of ventilation
- All tank top drawings will be NTB
- Abandoned sampling and Mantis crawlers are present on tank bottom near available risers
- Receipt tank for waste will be Tank 7

<u>Scope Elements Include:</u>

- Select, procure, develop and test robotic waste removal equipment with acid spray system
- Design and field implement tank top and tank services necessary to support waste removal and place tank back in operational mode (power, transfer system and path, level monitoring, hydrogen monitoring, control room operations/alarms, sump systems, water and air systems)
- Design acid tank and pumping system for robot. Must be diked with liner, temporary is sufficient
- Perform system flow sheet and CHA reviews to support DSA controls and design inputs
- Perform waste removal activities
- Provide the design and implementation to remove modification to re-establish removal from service and isolation

<u>Up Front Actions:</u>

- Procure robotic removal system and acid delivery system. All parts must be stainless steel for robot and hoses should be acid resistant
- Perform as-found design documentation for support and tank top systems
- Develop and test robotic system and acid delivery system
- Perform Engineering reviews to include flow sheet and DSA controls
- Receive authorization to re-instate Tank 18 from isolation
- Provide design and implementation for tank top, transfer, and support systems
- Remove as needed abandoned riser and in-tank equipment to allow for access and movement of robotics on tank bottom. Provide disposal boxes as necessary for equipment D&R.
- Complete readiness reviews for operation

Operations Phase Actions:

- Operate robotic systems and transfers over estimated 6 to 9 months
- Perform waste mapping and estimates
- Perform waste sampling (includes procurement of crawler)

Post Operations Phase Actions:

- Receive authorization for tank removal from service and isolation
- Design and implement removal for service and isolation
- Remove crawler and acid system and dispose of equipment

Constructability/Costs:

System requirements are assumed to be similar to requirements procured, installed, and operated using the Mantis system. In addition to high pressure water, an added spray of acid will be permitted. However, it is assumed equipment will be operated by site personnel not under contract. Hardware requirements include:

- Robotic hardware and spares (assume four at $350,000 each)
- Transfer hose in hose from Tank 18 to Tank 7 (400 feet)
- 2-inch core, 4-inch jacket acid resistant
- Provide one transfer system driver (options: Standard Transfer Pump (STP), high pressure water source acid resistant)
- Repair waste grinder in Tank 7 to reduce particle size of waste from Tank 18 (provide motor and connections to new transfer line hoses)
- Prepare two risers to support robotic systems
- D&R abandoned equipment from tank floor (one disposal box assumed, provision of tools to grab and gather tank floor interferences)
- Provide power system to support robotics and tank top services
- Provide alarm system hook-up to local control room
- Provide water and air systems
- Restore tank sump operations and systems
- Provide tools to support post transfer sampling ($100,000 for sampling tool and
- $1 million to process)

Due to the limited duration of operations, it is assumed design and configuration management can be implemented through use of a temporary modification. Some new permanent design may be required if risers are modified or for restoration to an isolated tank. Since tank top drawings are NTB, some as found design documentation will be required to support design services.

Attachment A.5.3: Cost Estimates

A.5.3.1 Robotics/Modified Sand Mantis

Alternative #1: Robotics/Modified Sand Mantis – with liquid mobilization and vacuuming

Savannah River Remediation - ARRA Contract
SRR Estimating
Estimate Summary Signoff Report

Line Item:
Project No.:
Log Number: L12-01-03
Project Name: Tank 18 Robotics Alternative #1
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Project Type: Operations / OPEX

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 14:48:58
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.0	Engineering/Procurement/Construction Cost	77,857	$4,271,741	$0	$363,004	$1,300,000	$50,000	$1,800,000	$7,784,745
	Escalation for Engineering/Procurement/Construction Cost		248,188	0	21,091	75,530	2,905	104,580	452,294
	Engineering/Procurement/Construction Cost Subtotal Incl.	77,857	$4,519,929	$0	$384,095	$1,375,530	$52,905	$1,904,580	$8,237,039
	Engineering/Procurement/Construction Cost DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$18,110
	Engineering/Procurement/Construction Cost Fee @ 8.25% of Subtotal Including Escalation								$679,556
	Subtotal including Escalation and Indirect Costs								$8,934,704
	Engineering/Procurement/Construction Cost Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$1,340,206
	Engineering/Procurement/Construction Cost DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Engineering/Procurement/Construction Cost Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$446,735
	Engineering/Procurement/Construction Cost Schedule Contingency @ 5.00% of Subtotal Including Escalation								$446,735
	Engineering/Procurement/Construction Cost								$11,168,380
2.0	Operational Support	23,660	$1,368,121	$0	$0	$0	$0	$0	$1,368,121
	Escalation for Operational Support		79,488	0	0	0	0	0	79,488
	Operational Support Subtotal Incl. Escalation & Pension	23,660	$1,447,608	$0	$0	$0	$0	$0	$1,447,608
	Operational Support DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$3,183
	Operational Support Fee @ 8.25% of Subtotal Including Escalation								$119,428
	Subtotal including Escalation and Indirect Costs								$1,570,219
	Operational Support Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$235,533
	Operational Support DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Operational Support Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$78,511
	Operational Support Schedule Contingency @ 5.00% of Subtotal Including Escalation								$78,511
	Operational Support								$1,962,773

File Name: Tank 18 Sampling Alternative #1 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #1\Working Estimate\Tank 18 Sampling Alternative #1 Rev 0.pws

Page 1 of 2

Line Item:
Project No.:
Log Number: L12-01-03
Project Name: Tank 18 Robotics Alternative #1
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Savannah River Remediation - ARRA Contract
SRR Estimating
Estimate Summary Signoff Report

Project Type: Operations / OPEX

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 14:48:58
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost

Total Cost for Tank 18 Robotics Alternative #1 . . . (Rounded) **$13,131,000**

Approval Signatures

Project Owner ____________________ Date ________

Estimating Manager ____________________ Date ________

Estimator ____________________ Date ________

File Name: Tank 18 Sampling Alternative #1 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #1\Working Estimate\Tank 18 Sampling Alternative #1 Rev 0.pws

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: **08**
P6 Budget Class Description: **FY12-Q1**
Log Number: L12-01-03
Project Name: **Tank 18 Robotics Alternative #1**
Project Manager: **W. Isom**
Estimate Type: **ROM**
Pricing: **FY12 Wages / Material**

Est. Description:

Estimated by: **Wigington**
Est. Rev.: **0**
Time: 14:49:29
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
0.0	Total Scope Cost	101,517	5,639,862	0	363,004	1,300,000	50,000	1,800,000	9,152,866
1.0	Engineering/Procurement/Construction Cost	77,857	4,271,741	0	363,004	1,300,000	50,000	1,800,000	7,784,745
1.1	Construction	41,984	1,768,327	0	363,004	100,000	0	100,000	2,331,331
1.1.1	PD&CS Construction	41,984	1,768,327	0	363,004	100,000	0	100,000	2,331,331
1.1.1.1	PD&CS Total Direct Work	33,321	1,215,197	0	363,004	100,000	0	100,000	1,778,201
1.1.1.1.1	PD&CS Direct Work	26,699	940,899	0	315,959	100,000	0	100,000	1,456,858
1.1.1.1.1.1	Initial Mobilization / D&R Work	7,250	256,755	0	100,480	0	0	0	357,235
1.1.1.1.1.2	Piping Systems	4,436	162,042	0	45,046	0	0	0	207,088
1.1.1.1.1.3	Electrical / I&C Systems	1,148	41,216	0	11,500	0	0	0	52,716
1.1.1.1.1.4	Mechanical Systems	1,601	57,314	0	5,000	100,000	0	0	162,314
1.1.1.1.1.5	Misc. Material / Equipment / Support costs	1,760	55,529	0	117,218	0	0	100,000	272,747
1.1.1.1.1.8	Demobilization of Tank Sampling work	10,504	368,043	0	36,715	0	0	0	404,758
1.1.1.1.2	Craft Support	6,621	237,188	0	47,045	0	0	0	284,233
1.1.1.1.4	Casual Overtime / 2nd Shift Differential for PD&CS Manuals	0	37,110	0	0	0	0	0	37,110
1.1.1.2	Construction NonManual Support	6,997	446,759	0	0	0	0	0	446,759
1.1.1.3	Component Testing	1,666	106,371	0	0	0	0	0	106,371
1.2	Engineering	10,368	722,796	0	0	1,200,000	50,000	1,700,000	3,672,796
1.2.1	PD&CS Design Services	8,329	582,864	0	0	1,200,000	0	0	1,782,864
1.2.2	Subcontract A/E Design	0	0	0	0	0	0	0	0
1.2.3	Other Design Support (SRNL)	0	0	0	0	0	0	1,700,000	1,700,000
1.2.3.1	Other Group Costs (In Support of PD&CS Engineering)	0	0	0	0	0	0	1,700,000	1,700,000
1.2.4	SMS Support	0	0	0	0	0	50,000	0	50,000
1.2.5	Radiation Engineering	1,652	116,619	0	0	0	0	0	116,619
1.2.6	Process Control Services (PCS)	387	23,313	0	0	0	0	0	23,313
1.3	Project Support	25,505	1,780,617	0	0	0	0	0	1,780,617
1.3.1	Project Management	1,423	120,089	0	0	0	0	0	120,089
1.3.2	Project Controls	7,595	480,368	0	0	0	0	0	480,368
1.3.3	Estimating	865	60,043	0	0	0	0	0	60,043

File Name: **Tank 18 Sampling Alternative #1 Rev 0**
File Location: X:\Tank 18 Alternatives\Alternative #1\Working Estimate\Tank 18 Sampling Alternative #1 Rev 0.pws

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: 08
P6 Budget Class Description: FY12-Q1
Log Number: L12-01-03
Project Name: Tank 18 Robotics Alternative #1
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Est. Description:

Estimated by: Wigington
Est. Rev.: 0
Time: 14:49:29
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.3.4	Project QA / QC Field Inspection	2,121	161,594	0	0	0	0	0	161,594
1.3.6	Waste Determination / Regulatory	13,500	958,524	0	0	0	0	0	958,524
2.0	Operational Support	23,660	1,368,121	0	0	0	0	0	1,368,121
2.01	Conceptual Design	0	0	0	0	0	0	0	0
2.02	Project Support	3,610	267,268	0	0	0	0	0	267,268
2.03	Design Authority	735	49,278	0	0	0	0	0	49,278
2.04	Operations Support	16,245	880,079	0	0	0	0	0	880,079
2.06	Technical Support	882	63,989	0	0	0	0	0	63,989
2.07	Start-Up / Testing	2,188	107,507	0	0	0	0	0	107,507

File Name: Tank 18 Sampling Alternative #1 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #1\Working Estimate\Tank 18 Sampling Alternative #1 Rev 0.pws

A.5.3.2 Articulating Arm

Alternative #2: Articulating Arm – with liquid mobilization and vacuuming

Line Item:

Savannah River Remediation - ARRA Contract
SRR Estimating
Estimate Summary Signoff Report

Project No.:
Log Number: L12-01-04
Project Name: Tank 18 Articulating Arm Alternative #2
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Project Type: Operations / OPEX

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 14:54:06
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.0	Engineering/Procurement/Construction Cost	79,013	$4,360,358	$0	$382,397	$2,100,000	$100,000	$1,800,000	$8,742,756
	Escalation for Engineering/Procurement/Construction Cost		253,337	0	22,217	122,010	5,810	104,580	507,954
	Engineering/Procurement/Construction Cost Subtotal Incl.	79,013	$4,613,695	$0	$404,615	$2,222,010	$105,810	$1,904,580	$9,250,710
	Engineering/Procurement/Construction Cost DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$20,338
	Engineering/Procurement/Construction Cost Fee @ 8.25% of Subtotal Including Escalation								$763,184
	Subtotal including Escalation and Indirect Costs								$10,034,232
	Engineering/Procurement/Construction Cost Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$1,505,135
	Engineering/Procurement/Construction Cost DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Engineering/Procurement/Construction Cost Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$501,712
	Engineering/Procurement/Construction Cost Schedule Contingency @ 5.00% of Subtotal Including Escalation								$501,712
	Engineering/Procurement/Construction Cost								$12,542,790
2.0	Operational Support	21,320	$1,295,002	$0	$0	$0	$0	$0	$1,295,002
	Escalation for Operational Support		75,240	0	0	0	0	0	75,240
	Operational Support Subtotal Incl. Escalation & Pension	21,320	$1,370,242	$0	$0	$0	$0	$0	$1,370,242
	Operational Support DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$3,013
	Operational Support Fee @ 8.25% of Subtotal Including Escalation								$113,045
	Subtotal including Escalation and Indirect Costs								$1,486,300
	Operational Support Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$222,945
	Operational Support DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Operational Support Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$74,315
	Operational Support Schedule Contingency @ 5.00% of Subtotal Including Escalation								$74,315
	Operational Support								$1,857,874

File Name: Tank 18 Sampling Alternative #2 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #2\Working Estimate\Tank 18 Sampling Alternative #2 Rev 0.ows

Page 1 of 2

Line Item:
Project No.:
Log Number: L12-01-04
Project Name: Tank 18 Articulating Arm Alternative #2
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Savannah River Remediation - ARRA Contract
SRR Estimating
Estimate Summary Signoff Report

Project Type: Operations / OPEX

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 14:54:06
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
	Total Cost for Tank 18 Articulating Arm Alternative #2 . . . (Rounded)								$14,401,000

Approval Signatures

Manager Projects, Design, and Construction	Date
Project Owner	Date
Project Manager	Date
Project Engineering Manager	Date
Project Engineer (Design Services)	Date
Construction	Date
Process Control Services (PCS)	Date
Project Controls	Date
Start-Up & Testing	Date
Estimating Manager	Date
Estimator	Date
SRNL	Date

File Name: Tank 18 Sampling Alternative #2 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #2\Working Estimate\Tank 18 Sampling Alternative #2 Rev 0.pws

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: 08
P6 Budget Class Description: FY12-Q1
Log Number: L12-01-04
Project Name: Tank 18 Articulating Arm Alternative #2
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Est. Description:

Estimated by: Wigington
Est. Rev.: 0
Time: 14:54:34
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
0.0	Total Scope Cost	100,334	5,655,361	0	382,397	2,100,000	100,000	1,800,000	10,037,758
1.0	Engineering/Procurement/Construction Cost	79,013	4,360,358	0	382,397	2,100,000	100,000	1,800,000	8,742,756
1.1	Construction	41,609	1,753,644	0	382,397	100,000	0	100,000	2,336,041
1.1.1	PD&CS Construction	41,609	1,753,644	0	382,397	100,000	0	100,000	2,336,041
1.1.1.1	PD&CS Total Direct Work	33,023	1,205,449	0	382,397	100,000	0	100,000	1,787,846
1.1.1.1.1	PD&CS Direct Work	26,461	933,566	0	335,719	100,000	0	100,000	1,469,285
1.1.1.1.1.1	Initial Mobilization / D&R Work	7,410	263,215	0	127,860	0	0	0	391,075
1.1.1.1.1.2	Piping Systems	4,436	162,042	0	45,046	0	0	0	207,088
1.1.1.1.1.3	Electrical / I&C Systems	1,148	41,216	0	11,500	0	0	0	52,716
1.1.1.1.1.4	Mechanical Systems	1,601	57,314	0	5,000	100,000	0	0	162,314
1.1.1.1.1.5	Misc. Material / Equipment / Support costs	1,760	55,529	0	117,218	0	0	100,000	272,747
1.1.1.1.1.8	Demobilization of Tank Sampling work	10,106	354,249	0	29,095	0	0	0	383,345
1.1.1.1.2	Craft Support	6,562	235,071	0	46,678	0	0	0	281,749
1.1.1.1.4	Casual Overtime / 2nd Shift Differential for PD&CS Manuals	0	36,812	0	0	0	0	0	36,812
1.1.1.2	Construction NonManual Support	6,935	442,773	0	0	0	0	0	442,773
1.1.1.3	Component Testing	1,651	105,422	0	0	0	0	0	105,422
1.2	Engineering	10,389	724,257	0	0	2,000,000	100,000	1,700,000	4,524,257
1.2.1	PD&CS Design Services	8,345	584,042	0	0	2,000,000	0	0	2,584,042
1.2.2	Subcontract A/E Design	0	0	0	0	0	0	0	0
1.2.3	Other Design Support (SRNL)	0	0	0	0	0	0	1,700,000	1,700,000
1.2.3.1	Other Group Costs (In Support of PD&CS Engineering)	0	0	0	0	0	0	1,700,000	1,700,000
1.2.4	SMS Support	0	0	0	0	0	100,000	0	100,000
1.2.5	Radiation Engineering	1,656	116,854	0	0	0	0	0	116,854
1.2.6	Process Control Services (PCS)	388	23,360	0	0	0	0	0	23,360
1.3	Project Support	27,015	1,882,458	0	0	0	0	0	1,882,458
1.3.1	Project Management	1,626	137,214	0	0	0	0	0	137,214
1.3.2	Project Controls	8,678	548,866	0	0	0	0	0	548,866
1.3.3	Estimating	989	68,605	0	0	0	0	0	68,605

File Name: Tank 18 Sampling Alternative #2 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #2\Working Estimate\Tank 18 Sampling Alternative #2 Rev 0.pws

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: 08
P6 Budget Class Description: FY12-Q1

Log Number: L12-01-04
Project Name: Tank 18 Articulating Arm Alternative #2
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Est. Description:

Estimated by: Wigington
Est. Rev.: 0
Time: 14:54:34
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.3.4	Project QA / QC Field Inspection	2,221	169,249	0	0	0	0	0	169,249
1.3.5	Procurement Support	0	0	0	0	0	0	0	0
1.3.6	Waste Determination / Regulatory	13,500	958,524	0	0	0	0	0	958,524
2.0	Operational Support	21,320	1,295,002	0	0	0	0	0	1,295,002
2.01	Conceptual Design	0	0	0	0	0	0	0	0
2.02	Project Support	3,837	286,429	0	0	0	0	0	286,429
2.03	Design Authority	735	49,278	0	0	0	0	0	49,278
2.04	Operations Support	14,645	807,884	0	0	0	0	0	807,884
2.06	Technical Support	882	63,989	0	0	0	0	0	63,989
2.07	Start-Up / Testing	1,221	87,422	0	0	0	0	0	87,422

File Name: Tank 18 Sampling Alternative #2 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #2\Working Estimate\Tank 18 Sampling Alternative #2 Rev 0.pws

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A.5.3.3 Feed and Bleed

Alternative #3: Recirculation line (Feed and Bleed) - mixing and recirculation with pumps

Savannah River Remediation - ARRA Contract
SRR Estimating
Estimate Summary Signoff Report

Line Item:
Project No.:
Log Number: L12-01-05
Project Name: Tank 18 Feed and Bleed Alternative #3
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Project Type: Operations / OPEX

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 14:57:40
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.0	Engineering/Procurement/Construction Cost	154,274	$8,336,158	$0	$1,118,893	$6,000,000	$120,000	$1,900,000	$17,475,050
	Escalation for Engineering/Procurement/Construction Cost		484,331	0	65,008	348,600	6,972	110,390	1,015,300
	Engineering/Procurement/Construction Cost Subtotal Incl.	154,274	$8,820,488	$0	$1,183,900	$6,348,600	$126,972	$2,010,390	$18,490,351
	Engineering/Procurement/Construction Cost DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$40,652
	Engineering/Procurement/Construction Cost Fee @ 8.25% of Subtotal Including Escalation								$1,525,454
	Subtotal including Escalation and Indirect Costs								$20,056,457
	Engineering/Procurement/Construction Cost Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$3,008,468
	Engineering/Procurement/Construction Cost DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Engineering/Procurement/Construction Cost Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$1,002,823
	Engineering/Procurement/Construction Cost Schedule Contingency @ 5.00% of Subtotal Including Escalation								$1,002,823
	Engineering/Procurement/Construction Cost								$25,070,571
2.0	Operational Support	19,653	$1,192,102	$0	$0	$0	$0	$0	$1,192,102
	Escalation for Operational Support		69,261	0	0	0	0	0	69,261
	Operational Support Subtotal Incl. Escalation & Pension	19,653	$1,261,363	$0	$0	$0	$0	$0	$1,261,363
	Operational Support DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$2,773
	Operational Support Fee @ 8.25% of Subtotal Including Escalation								$104,062
	Subtotal including Escalation and Indirect Costs								$1,368,199
	Operational Support Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$205,230
	Operational Support DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Operational Support Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$68,410
	Operational Support Schedule Contingency @ 5.00% of Subtotal Including Escalation								$68,410
	Operational Support								$1,710,248

File Name: Tank 18 Sampling Alternative #3 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #3\Working Estimate\Tank 18 Sampling Alternative #3 Rev 0.ews

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Line Item:
Project No.:
Log Number: L12-01-05
Project Name: Tank 18 Feed and Bleed Alternative #3
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Savannah River Remediation - ARRA Contract
SRR Estimating

Estimate Summary Signoff Report

Project Type: Operations / OPEX

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 14:57:40
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost

Total Cost for Tank 18 Feed and Bleed Alternative #3 . . . (Rounded) **$26,781,000**

Approval Signatures

Manager Projects, Design, and Construction	Date
Project Owner	Date
Project Manager	Date
Project Engineering Manager	Date
Project Engineer (Design Services)	Date
Construction	Date
Process Control Services (PCS)	Date
Project Controls	Date
Start-Up & Testing	Date
Estimating Manager	Date
Estimator	Date
SRNL	Date

File Name: Tank 18 Sampling Alternative #3 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #3\Working Estimate\Tank 18 Sampling Alternative #3 Rev 0.ows

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: 08
P6 Budget Class Description: FY12-Q1
Log Number: L12-01-05
Project Name: Tank 18 Feed and Bleed Alternative #3
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Est. Description:

Estimated by: Wigington
Est. Rev.: 0
Time: 14:58:23
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
0.0	Total Scope Cost	173,927	9,528,259	0	1,118,893	6,000,000	120,000	1,900,000	18,667,152
1.0	Engineering/Procurement/Construction Cost	154,274	8,336,158	0	1,118,893	6,000,000	120,000	1,900,000	17,475,050
1.1	Construction	87,221	3,682,593	0	1,118,893	0	70,000	200,000	5,071,485
1.1.1	PD&CS Construction	87,221	3,682,593	0	1,118,893	0	70,000	200,000	5,071,485
1.1.1.1	PD&CS Total Direct Work	69,223	2,533,468	0	1,118,893	0	70,000	200,000	3,922,360
1.1.1.1.1	PD&CS Direct Work	55,467	1,963,345	0	1,020,725	0	70,000	200,000	3,254,071
1.1.1.1.1.1	Initial Mobilization / D&R Work	13,352	475,337	0	310,480	0	0	0	785,817
1.1.1.1.1.2	Piping Systems	8,544	311,537	0	89,092	0	0	0	400,629
1.1.1.1.1.3	Electrical / I&C Systems	2,258	81,068	0	115,000	0	0	0	196,068
1.1.1.1.1.4	Mechanical Systems	6,501	232,839	0	20,000	0	0	0	252,839
1.1.1.1.1.5	Civil / Structural Work	4,264	144,692	0	6,500	0	70,000	0	221,192
1.1.1.1.1.6	Misc. Material / Equipment / Support costs	2,760	87,946	0	436,702	0	0	200,000	724,649
1.1.1.1.1.7	Demobilization of Tank Sampling work	17,788	629,927	0	42,951	0	0	0	672,878
1.1.1.1.2	Craft Support	13,756	492,755	0	98,167	0	0	0	590,923
1.1.1.1.4	Casual Overtime / 2nd Shift Differential for PD&CS Manuals	0	77,367	0	0	0	0	0	77,367
1.1.1.2	Construction NonManual Support	14,537	928,139	0	0	0	0	0	928,139
1.1.1.3	Component Testing	3,461	220,986	0	0	0	0	0	220,986
1.2	Engineering	24,907	1,736,944	0	0	6,000,000	50,000	1,700,000	9,486,944
1.2.1	PD&CS Design Services	20,470	1,432,542	0	0	6,000,000	0	0	7,432,542
1.2.2	Subcontract A/E Design	0	0	0	0	0	0	0	0
1.2.3	Other Design Support (i.e. SRNL)	0	0	0	0	0	0	1,700,000	1,700,000
1.2.3.1	Other Group Costs (in Support of PD&CS Engineering)	0	0	0	0	0	0	1,700,000	1,700,000
1.2.4	WSMS Support	0	0	0	0	0	50,000	0	50,000
1.2.5	Radiation Engineering	3,595	253,688	0	0	0	0	0	253,688
1.2.6	Process Control Services (PCS)	842	50,715	0	0	0	0	0	50,715
1.3	Project Support	42,146	2,916,621	0	0	0	0	0	2,916,621
1.3.1	Project Management	3,452	291,185	0	0	0	0	0	291,185
1.3.2	Project Controls	18,417	1,164,765	0	0	0	0	0	1,164,765

File Name: Tank 18 Sampling Alternative #3 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #3\Working Estimate\Tank 18 Sampling Alternative #3 Rev 0.pws

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: 08
P6 Budget Class Description: FY12-Q1
Log Number: L12-01-05
Project Name: Tank 18 Feed and Bleed Alternative #3
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Est. Description:

Estimated by: Wigington
Est. Rev.: 0
Time: 14:58:23
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.3.3	Estimating	2,096	145,588	0	0	0	0	0	145,588
1.3.4	Project QA / QC Field Inspection	4,680	356,559	0	0	0	0	0	356,559
1.3.6	Waste Determination / Regulatory	13,500	958,524	0	0	0	0	0	958,524
2.0	Operational Support	19,653	1,192,102	0	0	0	0	0	1,192,102
2.01	Conceptual Design	0	0	0	0	0	0	0	0
2.02	Project Support	5,907	461,085	0	0	0	0	0	461,085
2.03	Design Authority	735	49,278	0	0	0	0	0	49,278
2.04	Operations Support	6,646	349,203	0	0	0	0	0	349,203
2.06	Technical Support	4,177	225,029	0	0	0	0	0	225,029
2.07	Start-Up / Testing	2,188	107,507	0	0	0	0	0	107,507

File Name: Tank 18 Sampling Alternative #3 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #3\Working Estimate\Tank 18 Sampling Alternative #3 Rev 0.pws

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A.5.3.4 Acid Cleaning with Robotic Support

Alternative #4: Acid Cleaning with robotic support – direct acid cleaning controlled by robotics

Savannah River Remediation - ARRA Contract
SRR Estimating
Estimate Summary Signoff Report

Line Item:
Project No.:
Log Number: L12-01-06
Project Name: Tank 18 Acid Cleaning Alternative #4
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Project Type: Operations / OPEX

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 15:44:56
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.0	Engineering/Procurement/Construction Cost	74,589	$4,133,480	$0	$361,273	$1,750,000	$100,000	$2,550,000	$8,894,753
	Escalation for Engineering/Procurement/Construction Cost		240,155	0	20,990	101,675	5,810	148,155	516,785
	Engineering/Procurement/Construction Cost Subtotal Incl.	74,589	$4,373,635	$0	$382,263	$1,851,675	$105,810	$2,698,155	$9,411,538
	Engineering/Procurement/Construction Cost DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$20,692
	Engineering/Procurement/Construction Cost Fee @ 8.25% of Subtotal Including Escalation								$776,452
	Subtotal including Escalation and Indirect Costs								$10,208,682
	Engineering/Procurement/Construction Cost Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$1,531,302
	Engineering/Procurement/Construction Cost DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Engineering/Procurement/Construction Cost Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$510,434
	Engineering/Procurement/Construction Cost Schedule Contingency @ 5.00% of Subtotal Including Escalation								$510,434
	Engineering/Procurement/Construction Cost								$12,760,852
2.0	Operational Support	25,844	$1,494,279	$0	$10,000	$0	$0	$0	$1,504,279
	Escalation for Operational Support		86,818	0	581	0	0	0	87,399
	Operational Support Subtotal Incl. Escalation & Pension	25,844	$1,581,097	$0	$10,581	$0	$0	$0	$1,591,678
	Operational Support DPPI @ $0.2031 per $100 of Subtotal Including Escalation & Fee								$3,499
	Operational Support Fee @ 8.25% of Subtotal Including Escalation								$131,313
	Subtotal including Escalation and Indirect Costs								$1,726,491
	Operational Support Contractor Contingency (80/20) @ 15.00% of Subtotal Including Escalation								$258,974
	Operational Support DOE Part A - Project Contingency Included in Contractor Contingency								$0
	Operational Support Technical and Programmatic Risk Assessment @ 5.00% of Subtotal Including Escalation								$86,325
	Operational Support Schedule Contingency @ 5.00% of Subtotal Including Escalation								$86,325
	Operational Support								$2,158,113

File Name: Tank 18 Sampling Alternative #4 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #4\Working Estimate\Tank 18 Sampling Alternative #4 Rev 0.ows

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Line Item:
Project No.:
Log Number: L12-01-06
Project Name: Tank 18 Acid Cleaning Alternative #4
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Savannah River Remediation - ARRA Contract
SRR Estimating

Estimate Summary Signoff Report

Project Type: **Operations / OPEX**

Estimated by: Wigington
Est. Rev.: 0
Run Date: 24-Jan-2012
Run Time: 15:44:56
Report Name: SRR General Operating Summary Signoff with Contingencies Level 3 B&R

WBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost

Total Cost for Tank 18 Acid Cleaning Alternative #4 . . . (Rounded) **$14,919,000**

Approval Signatures

Project Owner	Date
Estimating Manager	Date
Estimator	Date

File Name: Tank 18 Sampling Alternative #4 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #4\Working Estimate\Tank 18 Sampling Alternative #4 Rev 0.pws

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: 08
P6 Budget Class Description: FY12-Q1
Log Number: L12-01-06
Project Name: Tank 18 Acid Cleaning Alternative #4
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Est. Description:

Estimated by: Wigington
Est. Rev.: 0
Time: 15:46:13
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
0.0	Total Scope Cost	100,433	5,627,759	0	371,273	1,750,000	100,000	2,550,000	10,399,032
1.0	Engineering/Procurement/Construction Cost	74,589	4,133,480	0	361,273	1,750,000	100,000	2,550,000	8,894,753
1.1	Construction	38,650	1,627,414	0	361,273	150,000	0	100,000	2,238,688
1.1.1	PD&CS Construction	38,650	1,627,414	0	361,273	150,000	0	100,000	2,238,688
1.1.1.1	PD&CS Total Direct Work	30,675	1,118,209	0	361,273	150,000	0	100,000	1,729,483
1.1.1.1.1	PD&CS Direct Work	24,579	865,709	0	317,988	150,000	0	100,000	1,433,697
1.1.1.1.1.1	Initial Mobilization / D&R Work	6,610	234,558	0	92,860	0	0	0	327,418
1.1.1.1.1.2	Piping Systems	4,436	162,042	0	65,046	0	0	0	227,088
1.1.1.1.1.3	Electrical / I&C Systems	1,148	41,216	0	11,500	0	0	0	52,716
1.1.1.1.1.4	Mechanical Systems	1,701	60,896	0	5,000	150,000	0	0	215,896
1.1.1.1.1.5	Misc. Material / Equipment / Support costs	1,760	55,529	0	116,981	0	0	100,000	272,510
1.1.1.1.1.8	Demobilization of Tank Sampling work	8,924	311,468	0	26,601	0	0	0	338,069
1.1.1.1.2	Craft Support	6,096	218,352	0	43,285	0	0	0	261,637
1.1.1.1.4	Casual Overtime / 2nd Shift Differential for PD&CS Manuals	0	34,148	0	0	0	0	0	34,148
1.1.1.2	Construction NonManual Support	6,442	411,281	0	0	0	0	0	411,281
1.1.1.3	Component Testing	1,534	97,924	0	0	0	0	0	97,924
1.2	Engineering	9,956	694,074	0	0	1,600,000	100,000	2,450,000	4,844,074
1.2.1	PD&CS Design Services	7,998	559,702	0	0	1,600,000	0	0	2,159,702
1.2.2	Subcontract A/E Design	0	0	0	0	0	0	0	0
1.2.3	Other Design Support (SRNL)	0	0	0	0	0	0	2,450,000	2,450,000
1.2.3.1	Other Group Costs (In Support of PD&CS Engineering)	0	0	0	0	0	0	2,450,000	2,450,000
1.2.4	SMS Support	0	0	0	0	0	100,000	0	100,000
1.2.5	Radiation Engineering	1,587	111,985	0	0	0	0	0	111,985
1.2.6	Process Control Services (PCS)	372	22,387	0	0	0	0	0	22,387
1.3	Project Support	25,983	1,811,992	0	0	0	0	0	1,811,992
1.3.1	Project Management	1,501	126,662	0	0	0	0	0	126,662
1.3.2	Project Controls	8,011	506,660	0	0	0	0	0	506,660
1.3.3	Estimating	913	63,329	0	0	0	0	0	63,329

File Name: Tank 18 Sampling Alternative #4 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #4\Working Estimate\Tank 18 Sampling Alternative #4 Rev 0.pws

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Savannah River Remediation

SRR Estimating

Estimate Summary Level Report

P6 Budget Class: 08
P6 Budget Class Description: FY12-Q1
Log Number: L12-01-06
Project Name: Tank 18 Acid Cleaning Alternative #4
Project Manager: W. Isom
Estimate Type: ROM
Pricing: FY12 Wages / Material

Est. Description:

Estimated by: Wigington
Est. Rev.: 0
Time: 15:46:13
Date: 24-Jan-2012
Report Name: SRR General FY12 Summary Level without Escalation by Tree Level

Estimate EBS Element	Description	Hours	Labor $'s	Constr. Equip.	Bulk Material	Engr. Equip.	Contract Services	SRNS Scope	Total Cost
1.3.4	Project QA / QC Field Inspection	2,058	156,816	0	0	0	0	0	156,816
1.3.6	Waste Determination / Regulatory	13,500	958,524	0	0	0	0	0	958,524
2.0	Operational Support	25,844	1,494,279	0	10,000	0	0	0	1,504,279
2.01	Conceptual Design	0	0	0	0	0	0	0	0
2.02	Project Support	3,873	289,469	0	0	0	0	0	289,469
2.03	Design Authority	809	54,239	0	0	0	0	0	54,239
2.04	Operations Support	17,872	968,241	0	10,000	0	0	0	978,241
2.06	Technical Support	882	63,989	0	0	0	0	0	63,989
2.07	Start-Up / Testing	2,406	118,341	0	0	0	0	0	118,341

File Name: Tank 18 Sampling Alternative #4 Rev 0
File Location: X:\Tank 18 Alternatives\Alternative #4\Working Estimate\Tank 18 Sampling Alternative #4 Rev 0.pws

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Attachment: A.5.4 Exposure Estimates

A.5.4.1 Robotics/Modified Sand Mantis

Alternative #: 1 Robotics/Modified Sand Mantis – with liquid mobilization and vacuuming

Title: Use Commercially Available Robotic Systems to Reach, Acquire, and Enable Transfer of Additional Waste from Tank 18

Dose from similar jobs previously performed:

Assumptions: Hose-in hose transfer line used to transfer waste from Tank 18 into Tank 7 will be shielded as previously done. Line will be flushed and blown down with air after waste removal activities are completed. Obtaining a total of 16 dry samples and shipping to lab for analysis via cask.

Riser preparation (2X): 150 mrem X 2 = **300 mrem**

Remove equipment from tank floor (include removal of Mantis): **200 mrem**

Install / remove Robotic hardware (4X): 135 mrem X 4 = **540 mrem**

Transfer of material: No Radiation Work Permit to track dose. Rates were below 5mrem/hour during transfer due to shielding.

Install / Remove transfer system (Standard Transfer Pump): **150 mrem**

Sampling activities: **750 mrem**

Analysis in SRNL : **750 mrem**

Camera Mapping: **50 mrem**

HEPA filter change out (assume one-time evolution): **70 mrem**

Removal / Disposition of hose-in-hose transfer line: **100 mrem**

Total estimated whole body dose for scope: **3,200 mrem**

NOTE: The total estimated whole body dose is adjusted by an additional approximately 10% for miscellaneous work not shown in major activities.

A.5.4.2 Articulating Arm

Alternative #: 2 Articulating Arm – with liquid mobilization and vacuuming

Title: Use S.A. Technology Systems Arm to Reach, Acquire, and Enable Transfer of Additional Waste from Tank 18

Dose from similar jobs previously performed:

Assumptions: Hose-in hose transfer line used to transfer waste from Tank 18 into Tank 7 will be shielded as previously done. Line will be flushed and blown down with air after waste removal activities are completed. Obtaining a total of 16 dry samples and shipping to lab for analysis via cask. Installation and removal of a STP.

Riser preparation: Clean out three risers, to include removal of three slurry pumps: 150 mrem X 3 = **450 mrem**

Install / Remove Arm (2X): 135 mrem X 2 = **270 mrem**

Transfer of material: No Radiation Work Permit to track dose. Rates were below 5mrem/hour during transfer due to shielding.

Install / Remove transfer system (STP): **150 mrem**

Sampling (using arm): **750 mrem**

Analysis in SRNL : **750 mrem**

Camera Mapping: **50 mrem**

HEPA filter change out (assume one-time evolution): **70 mrem**

Removal / Disposition of hose-in-hose transfer line: **100 mrem**

Total estimated whole body dose for scope: **2,800 mrem**

NOTE: The total estimated whole body dose is adjusted by an additional approximately 10% for miscellaneous work not shown in major activities.

A.5.4.3 Feed and Bleed

Alternative #: 3 Recirculation line (Feed and Bleed) - mixing and recirculation with pumps

Title: Perform Additional Waste Removal from Tank 18 via Feed and Bleed Evolution Similar to Evolution Performed in Tank 6

<u>Dose from similar jobs previously performed:</u>

Assumptions: Hose-in-hose will be solid line with no ability to flush line. Shielding will be comparable to what was used during the Tank 6 to Tank 7 recycle transfer. System will use two hoses with no flushing ability of the hose-in-hose system once waste removal is completed. Obtaining a total of 16 dry samples and shipping to lab for analysis via cask.

Riser preparations: Clean six risers, to include removal of three slurry pumps: 150 mrem X 6 = **900 mrem**

Install support steel for new slurry pumps: Assume working dose rate of 2mrem/hour/person X 4 people X 4 hours/day X 4 days/week X 4 weeks **= 500 mrem**

Install / Remove four slurry pumps: 100 mrem X 4 = **400 mrem**

Remove the equipment on the bottom of the tank = **200 mrem**

Transfer of material: This will include operator & RCO surveillance, camera inspections, and HEPA change out (1 time) during recycle transfer**: 600 mrem**

HEPA filter change out (assume one-time evolution): **70 mrem**

Sampling activities: **750 mrem**

Analysis in SRNL : **750 mrem**

Camera Mapping: **50 mrem**

Removal / Disposition of hose-in-hose transfer line: **750 mrem**

Total estimated whole body dose for scope: **5,400 mrem**

NOTE: The total estimated whole body dose is adjusted by an additional approximately 10% for miscellaneous work not shown in major activities.

A.5.4.4 Acid Cleaning with Robotic Support

Alternative #: 4 Acid Cleaning with robotic support **–** direct acid cleaning controlled by robotics

Title: Use Commercially Available Robotic Systems with Acid Spray to Reach and Enable Transfer of Additional Waste from Tank 18.

Dose from similar jobs previously performed:

Assumptions: Hose-in-hose transfer line used to transfer waste from Tank 18 into Tank 7 will be shielded as previously done. Line will be flushed and blown down with air after waste removal activities are completed. Included is the installation and removal of a Standard Transfer Pump. Obtaining a total of 16 dry samples and shipping to lab for analysis via cask.

Riser preparations: to include removal of two slurry pumps: 150 mrem X 2 = **300 mrem**

Disassemble and remove equipment from tank floor (include removal of Mantis): **200 mrem**

Install / remove Robotic hardware (4X): 135 mrem X 4 = **540 mrem**

Install / Remove transfer system (STP): **150 mrem**

Transfer of material: No Radiation Work Permit to track dose. Rates were below 5mrem/hour during transfer due to shielding.

Sampling activities: **750 mrem**

Analysis in SRNL : **750 mrem**

Camera Mapping: **50 mrem**

HEPA filter change out (assume one-time evolution): **70 mrem**

Removal / Disposition of hose-in-hose transfer line: **100 mrem**

Total estimated whole body dose for scope: **3,200 mrem**

NOTE: The total estimated whole body dose is adjusted by an additional approximately 15% for miscellaneous work not shown in major activities and extended work durations due to addition of chemical personal protective equipment.

Attachment A.5.5: Schedules

Figure A.20 through Figure A.23 provide the estimated schedules for the four alternatives evaluated in detail.

Figure A.20: Schedule: Alternative #1—Robotics/Modified Sand Mantis

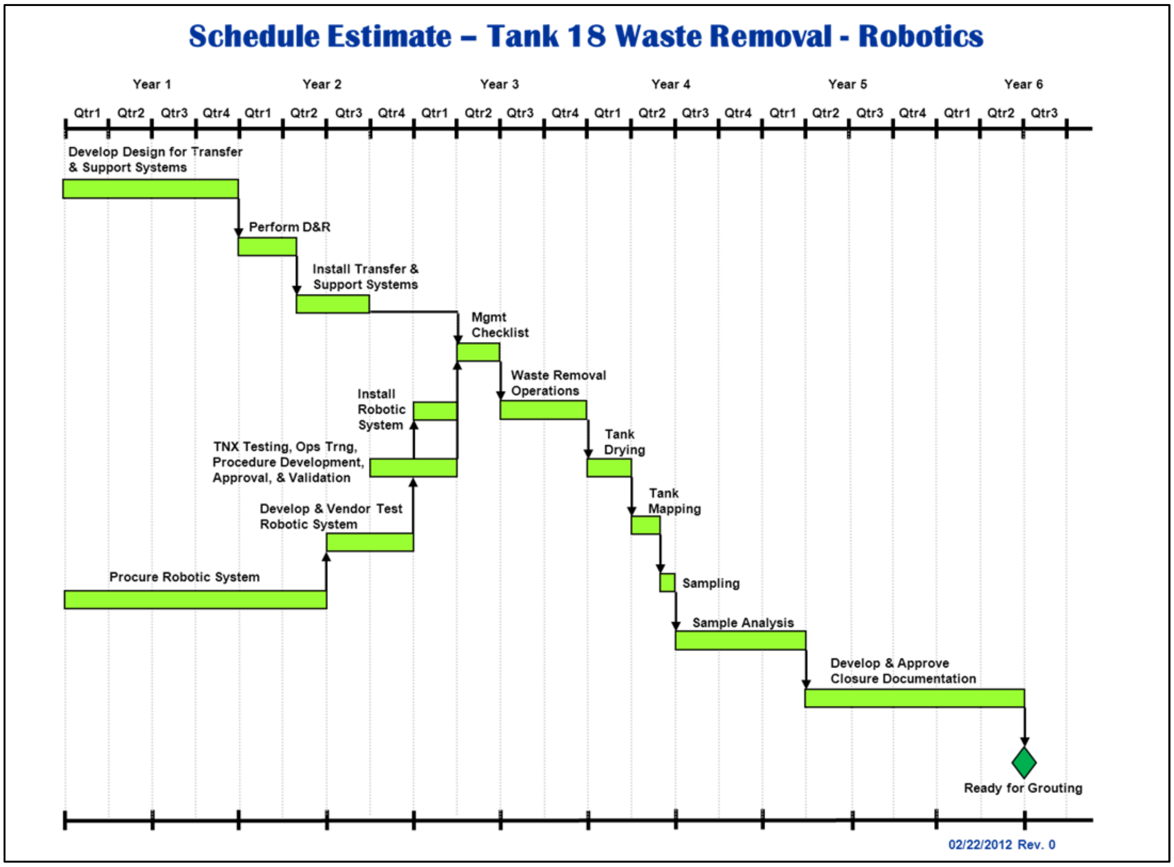


Figure A.21: Schedule: Alternative #2—Articulating Arm

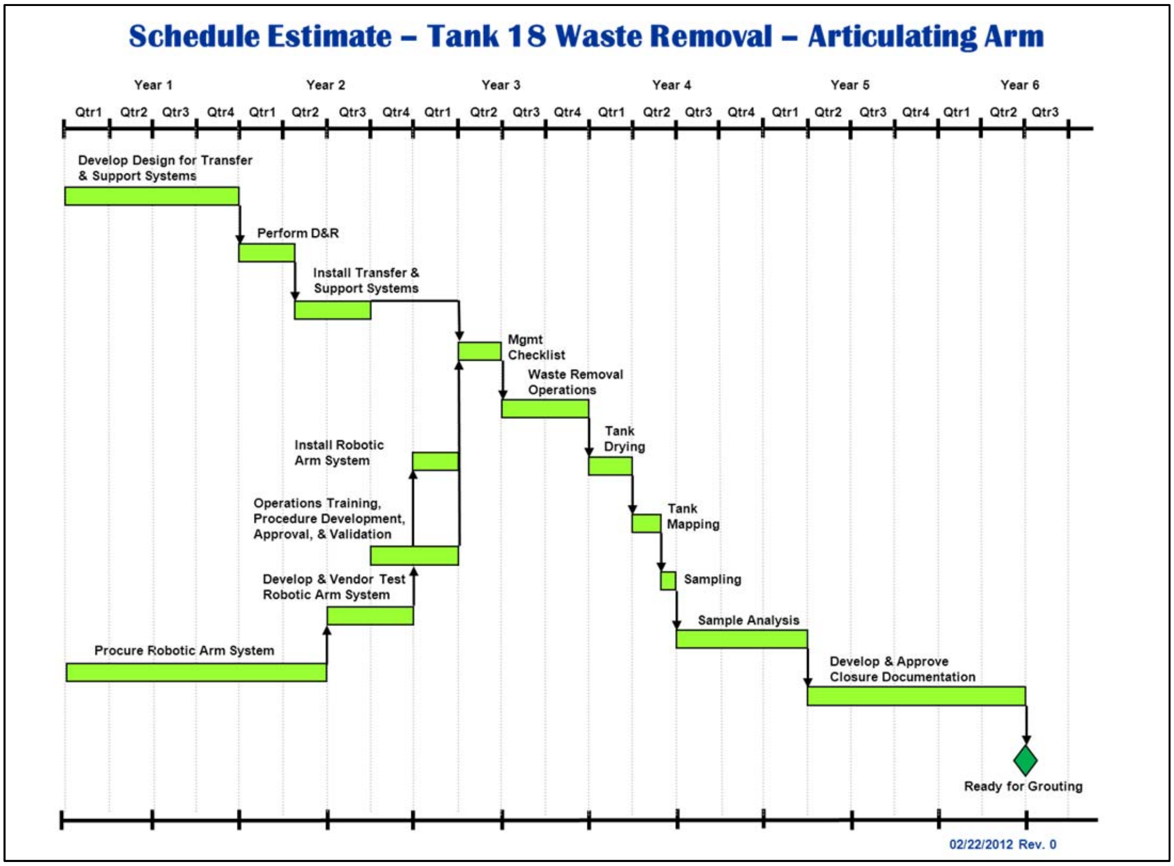


Figure A.22: Schedule: Alternative #3—Feed and Bleed

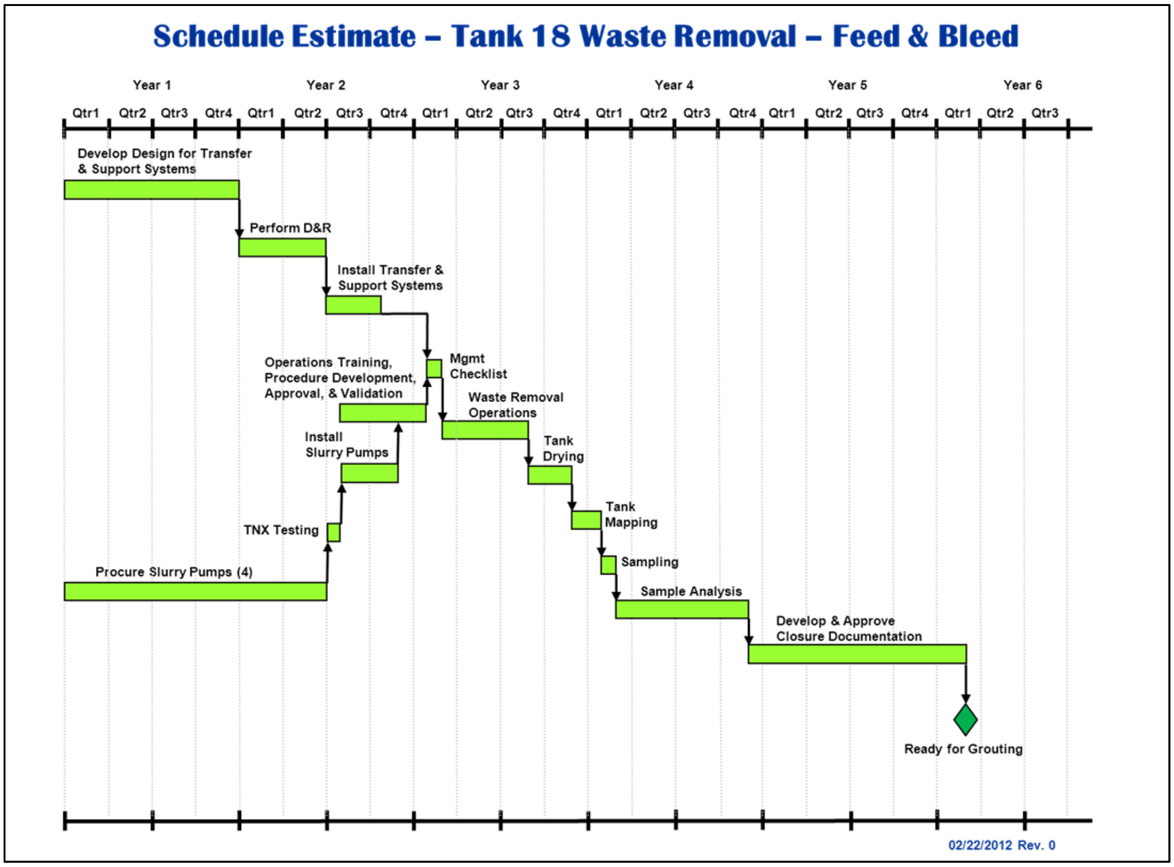
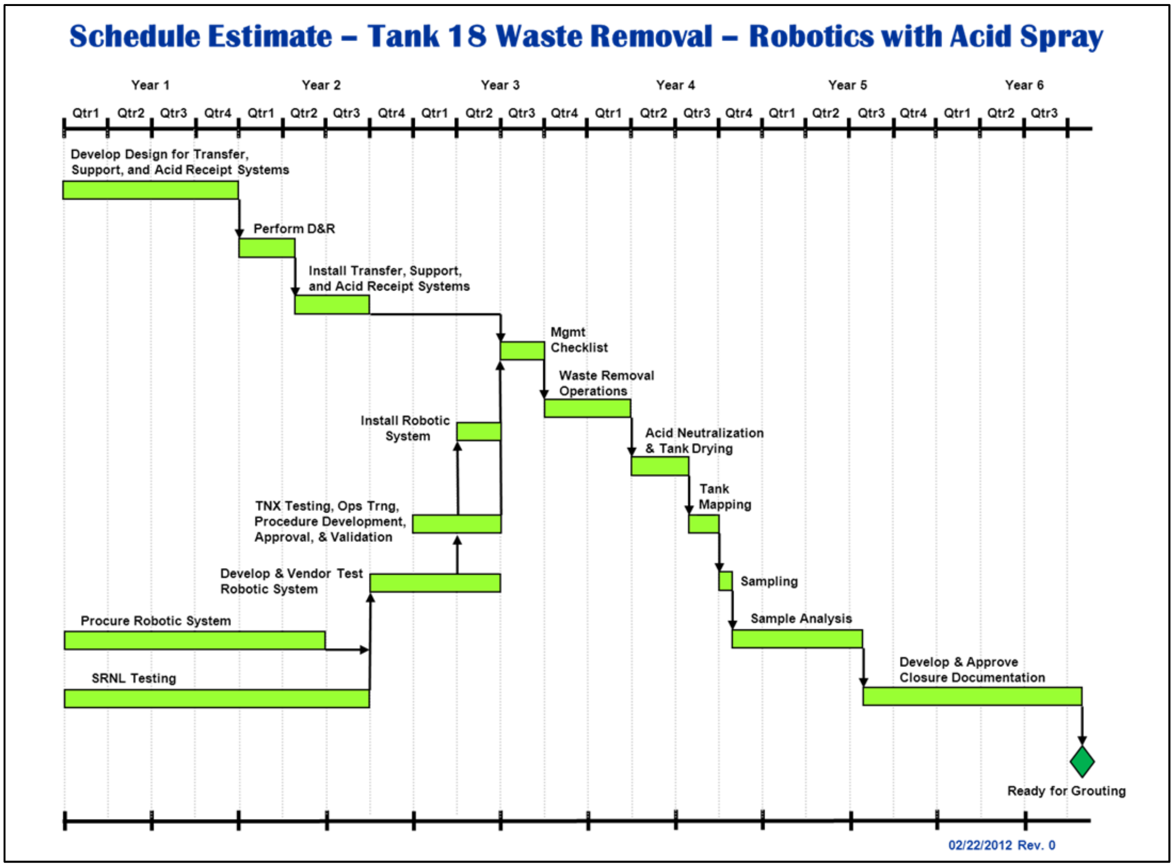


Figure A.23: Schedule: Alternative #4—Acid Cleaning with Robotic Support



Attachment A.5.6: Risk Analysis

Table A.12: Pre-Mortem Results

			Applicability to Options Yes/No			
#	**Risk**	**Handling**	**Robot**	**Robot + Acid**	**Arm**	**Pumps**
1	Catastrophic failure damages tank/equipment.	• Design to avoid catastrophic failure • Perform testing • Perform design reviews	Y	Y	Y	Y
2	Blinding/failure of the ventilation system	• PM Prior to cleaning	Y	Y	Y	Y
3	Cannot reach all areas of the tank	• Perform testing • Perform design reviews • If a cable tether is employed, plan for tether management • If pumps are used evaluate dead zone/Effective Cleaning Radius	Y	Y	Y	Y
4	Interference with current operations (no receipt tank)	• Accept; System Plan will be adjusted if feasible	Y	Y	Y	Y
5	Regulator rescinds decision (new stakeholders)	• Accept	Y	Y	Y	Y
6	Vendor takes longer/costs more	• Incentivize vendor contract • Use proven vendor	Y	Y	Y	Y
7	Sampling shows cleaning had no effect. (or previous sampling plan was ineffective)	• Accept	Y	Y	Y	Y
8	Waste composition changed prior to deployment	• Verify early by sampling that material has not changed	Y	Y	Y	Y
9	Performance Assessment rules change	• Accept	Y	Y	Y	Y
10	Energetic compounds are formed	• Verify early by sampling that energetic compounds are not forming within the material • Pre-wet if material is dry before cleaning	Y	Y	Y	Y
11	New technology is found	• Accept; Monitoring for new technologies is required by the Consent Order	Y	Y	Y	Y
12	Grinder will not work when started	• Early repair or replacement existing grinder as appropriate • Test grinder operation early in project	Y	Y	Y	Y

Table A.12: Pre-Mortem Results (Continued)

#	Risk	Handling	Applicability to Options Yes/No: Robot	Robot + Acid	Arm	Pumps
13	Major contamination incident	• Exercise appropriate radiological controls • Perform design reviews • Address decontamination and decommissioning in design	Y	Y	Y	See risk #32 for Pumps
14	Cleaning method causes tank failure	• Perform testing at Training and Experimental Test Facility (TNX) • Account for avoidance of this in design	Y	Y	Y	N
15	Tether management problems	• Include appropriate tether management in vendor design • Perform design reviews • Perform testing at TNX • Remove riser and tank interferences prior to deployment	Y	Y	N	N
16	Regulations change (e.g., 25 mrem is reduced to 10 mrem)	• Accept	Y	Y	Y	Y
17	Design flaw results in ineffective cleaning	• Perform design reviews • Perform vendor testing and testing at TNX • Specify a larger design margin • Take lifting plates into account during design	Y	Y	Y	N
18	Transfer leaks/release	• Perform design reviews • Perform testing upon installation.	Y	Y	Y	Y
19	Insufficient motive force causes transfer line pluggage	• Perform design reviews • Perform testing • Provide a flushing capability • Representative simulant selection for testing • Specify a larger design margin	Y	Y	Y	Y
20	Consolidated Hazards Analysis Process (CHAP) identifies additional controls	• Perform CHAP early	Y	Y	Y	N

Table A.12: Pre-Mortem Results (Continued)

#	Risk	Handling	Applicability to Options Yes/No: Robot	Robot + Acid	Arm	Pumps
21	Poor reliability/effectiveness (or lower life expectancy) increases costs (multiple units/replacements)	• Perform design reviews • Perform testing • Provide a flushing capability • Specify a larger margin • Require previous industrial experience as part of vendor selection criteria. • Where replaceable tools are used (e.g. arm) ensure the above strategies are also applied to the tools	Y	Y	Y	N
22	Acid corrodes a hole in tank	• Apply appropriate design and operational controls • Perform testing as necessary	N	Y	N	N
23	Industrial accident (acid leak)	• Apply appropriate design and industrial safety controls	N	Y	N	N
24	Acid changes material (precipitates new compounds)	• Test on sampled material • Perform advanced planning (integration with System Plan)	N	Y	N	N
25	Acid is ineffective at dissolving material or HRRs	• Test on sampled material	N	Y	N	N
26	Robot is not designed correctly to handle acid	• Require previous vendor experience • Perform design verification of material selection • Perform quality control checks and testing	N	Y	N	N
27	Acid is not compatible with service equipment	• Perform material compatibility evaluations	N	Y	N	N
28	Operation damages tank equipment (e.g., High Liquid Level Conductivity Probes)	• Perform testing	N	N	Y	N
29	Hydraulic leak occurs	• Perform design reviews • Utilize Current DSA controls	Y	Y	Y	N
30	Failure prevents equipment removal	• Develop recovery plan for removal prior to deploying	Y	Y	Y	N
31	Equipment operation damages tank top	• Perform design reviews	N	N	Y	N
32	Exposure and contamination release during "pill box" riser work	• Evaluate drilling new as opposed to using existing riser	N	N	N	Y

Table A.12: Pre-Mortem Results (Continued)

#	Risk	Handling	Applicability to Options Yes/No			
			Robot	Robot + Acid	Arm	Pumps
33	Existing abandoned equipment has to be removed (to avoid silt build up/formation of tape “balls”) resulting in additional exposure and contamination	• Remove equipment that could damage pumps	N	N	N	Y
34	Pump heat input is too high into the feed and bleed material	• Account for heat build-up during design • Perform heat calculations	N	N	N	Y
35	Feed and bleed method impacts operations due to large volume of liquid transfer	• Define method of feed and bleed • Determine transfer path • Evaluate for impact with respect to the System Plan and integrate	N	N	N	Y

Attachment A.5.7: Team Bios

Walter Isom

Walter Isom has a Bachelor of Science Degree in Mechanical Engineering, is a Professional Engineer in South Carolina and has a Master's Degree in Business Administration. He has over 30 years of experience at SRS in Operations, Maintenance, Design Authority, Project, and System engineering. During his tenure at SRS he has supported numerous facilities and processes including Savannah River National Lab, Plutonium/Uranium separations and metal processing, Naval Fuel fabrication, Salt Waste processing, Sludge Waste processing, and Waste Retrieval. He has been the Waste Removal and Tank Closure Chief Engineer for the past 3 years.

Neil Davis

Neil Davis has a Bachelor of Science Degree in Civil Engineering and a Master's Degree in Business Administration. He has over 30 years of experience at SRS in Operations, Engineering, Planning, and Project Management. During his tenure at SRS he has worked in the Tank Farm as a Facility Manager, in Engineering as the Technology Development Manager, and is currently the Deputy Program Manager for Waste Removal and Tank Closure.

John Schofield

John Schofield has a Bachelor of Science in Chemical Engineering from Kansas State University, and has 41 years of experience in the nuclear industry, 35 of which have been at Hanford and the remaining time with Allied General Nuclear Services, New England Nuclear, and at Idaho Falls. His experience includes irradiated fuel reprocessing operations, source production, and waste management. He has spent the past 8 years with the waste retrieval engineering.

Bruce Martin

Bruce Martin has a Bachelor of Science Degree in Mechanical Engineering from the United States Military Academy. He has over 23 years of experience at SRS in project management, maintenance, design authority, and regulatory interface positions. During his career at SRS he has primarily worked in the waste tank farms developing technical baseline documents, removing waste for sludge processing, and cleaning waste tanks in preparation for closure. He has worked in the Closure and Waste Disposal Authority organization for the past 6 years.

Mike Hubbard

Mike Hubbard has a Bachelor of Science Degree in Electrical Engineering. He has over 31 years of experience at SRS in Maintenance, Design Authority, Project, and Safeguards & Security engineering. For 20 years, he served in increasing levels of responsibility for site wide safeguards & security and fire systems Maintenance, Operation, and Project activities. Since 2001, he has served as a Design Authority engineer and manager for tank farm waste removal activities. These waste removal activities included the successful completion of bulk waste removal efforts from five SRS waste tanks.

Mike Harrell

Mike Harrell has 29 years of SRS experience in the roles of Operations, Maintenance, Training, and Waste Removal and Tank Closure Project Support. He supported the design and construction of waste removal in six tanks and chemical cleaning in two. He was an active team member of the

Mechanical Cleaning of Tanks 18 and 19 supporting the design, build, installation, and operation of the TMR Sand Mantis system.

David Hobbs

David Hobbs has a Bachelor of Science in Chemistry and PhD in Inorganic Chemistry and currently serves as a Senior Advisory Scientist in the Environmental Management Directorate at SRNL. He has more than 27 years of experience in research and development activities in support of high-level waste operations at SRS focused in the areas of radiochemical separations, actinide and corrosion chemistry, energetic materials, and in-situ analytical methods. He serves as the technical lead for the development of monosodium titanate and modified monosodium titanate for strontium and actinide separations. David is a member of the Environmental Management Technical Expert Group that reports to the Assistant Secretary of Energy.

Bill Wilmarth

Bill is currently an Advisory Scientist in the Environmental Management Directorate at the SRNL. Dr. Wilmarth received his doctorate degree in Chemistry from the University of Tennessee, Knoxville in 1988. Dr. Wilmarth received his Bachelor of Science in chemistry from Clemson University in 1983. Dr. Wilmarth has made significant contributions in the physiochemical understanding of high-level waste and has led in the development of several process flow sheets for the removal of strontium, cesium, and the actinides. Dr. Wilmarth has served as a technical lead for the deployment of ion exchange materials and solvent extraction for removal of cesium from wastes stored at SRS and Hanford. Additionally, Dr. Wilmarth and his co-workers developed a strontium and actinide removal flow sheet for use in the River Protection Program at the Hanford reservation. Dr. Wilmarth began his career at SRS in 1988 as a research chemist in the Actinide Technology Section of the Savannah River Laboratory. His research interest included actinide solvent extraction and ion exchange supporting the F–Canyon and FB-Line plutonium processing mission. Dr. Wilmarth and others performed research into the pyro chemical processing of plutonium leading to a product acceptable for purification at SRS. Dr. Wilmarth has also served as the SRNL Regulatory manager (1991 to 1997). In this capacity, Dr. Wilmarth managed the implementation and oversight programs for safety analysis, chemical hygiene, environmental compliance, radiation protection and waste certification activities. Most recently, Dr. Wilmarth established the Environmental Management Technical Integration Office to support the DOE Office of Innovation and Development.