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Risk Benefit Evaluation of Residual Heel Removal in Tanks 19 and 18

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1.0 INTRODUCTION

F Area Waste Tanks 19 and 18 underwent extensive cleaning efforts to remove their waste to the maximum extent practical. The tanks underwent a “Two Phase, Three Step” approach to remove the wastes contained in the tanks. The first phase was a two step approach that removed the bulk liquid (step 1) followed by the removal of the bulk waste (saltcake waste for Tank 19 and bulk sludge waste for Tank 18) (step 2). The second phase (step 3) was the removal of heel waste.

This study evaluated three methods for further removal of residual waste (material that is remaining after Phase 2, Step 3). Residual waste removal may remove more of the remaining radionuclide inventory in Tanks 19 and 18 (reducing the potential future dose from the closed tanks), but in doing so, increases radiological exposure risk to SRS workers, has significant costs, and impacts other scheduled SRS site activities. This study quantified the radiological exposure risks to SRS workers, costs, and schedule impacts associated with residual waste removal and compares the radiological exposure risks and costs to the potential benefit.

2.0 BACKGROUND

2.1 Previous Tank 19 Waste Removal Efforts

During the first step, *bulk liquid removal*, a fixed length transfer jet in Tank 19 was used to remove the bulk liquid. After removing the bulk liquid, two mixer pumps and a telescoping transfer jet (TTJ) were inserted into Tank 19 to start the second step, *saltcake removal*. Inhibited water (IW) was added to the tank to dissolve the saltcake into a salt solution; the two mixer pumps agitated the salt solution; and a steam eductor transferred the solution out of the tank. Saltcake removal was concluded after four campaigns that included IW addition, solution agitation and solution transfer. The third step, *heel removal*, was accomplished by using three 50-HP rotating submersible mixer pumps. These pumps were placed inside the tank to agitate the remaining material with liquid added to the tank. To eliminate the introduction of new water into the waste tank system a strategy was developed that added 280 Kgal of existing tank farm liquid into Tank 19 as the transport medium. After mixing the tank farm liquid with the material in Tank 19, the slurry was transferred to Tank 18 where it was allowed to settle. After settling in Tank 18, the transfer medium in Tank 18 was decanted back to Tank 19 and used as the new batch of transfer medium; to start the process over again. This batch mode of recirculation was used forty-six times until the removal process was no longer effective (Reference 1). Table 1 provides a summary of the current contents in Tank 19.

Table 1
Current Tank 19 Contents (Reference 2)

Parameter	Kgal
Wet Solids	15.1
Free Liquid	1.8
Total Residual Waste	16.9

2.2 Previous Tank 18 Waste Removal Efforts

During the first step, a Telescoping Transfer Pump (TTP) in Tank 18 was used to remove the bulk liquid. After completion of the bulk liquid removal, three 150-HP mixing pumps were inserted into Tank 18 to prepare for sludge removal, the second step of waste removal. Radioactive salt solution and IW were added to the tank and the mixer pumps exerted a sweeping liquid jet action on the sludge to promote its mixing and allow the particles to be suspended for transferring. A TTP was used to move the sludge slurry solution out of Tank 18 into the Tank Farm system. Seventeen separate sludge slurry transfers, combined into four campaigns, were executed to complete this step. The final cleanup step, heel removal, was accomplished by using a single more powerful mixer pump called an Advanced Design Mixer Pump (ADMP), which was mounted in the center of the tank; combined with a centrifugal transfer pump, a dewatering pump and a transfer system routed to Tank 7. Unlike the heel removal step in Tank 19, the transfer batches were not set up to be "recirculating", but were a once through scheme only. After six transfer batches the operation was concluded when a point of diminishing returns was realized (Reference 3). Table 2 provides a summary of the current contents in Tank 18.

Table 2
Current Tank 18 Contents (Reference 4)

Parameter	Kgal
Wet Solids	4.3
Free Liquid	2.4
Total Residual Waste	6.7

3.0 METHODS FOR RESIDUAL WASTE REMOVAL

To develop a risk benefit analysis, tank cleaning methods previously used throughout the DOE complex were considered and grouped into three general approaches – mechanical, robotic, and chemical. Based on previous studies undertaken at SRS (References 5 and 6) one method from each general approach was selected. For the *mechanical method* large, tank top mounted hydraulic mixers and a transfer system was selected. For the *robotic method* a remote controlled crawler and a transfer system successfully used at the Oak Ridge National Laboratory (ORNL) was selected. For the *chemical method* Oxalic Acid (OA) which has been used with measured success at SRS was selected. Each method is described below and evaluated based on radiological risk to SRS workers, financial cost, and schedule impacts.

Each of these three methods is evaluated separately with the same initial tank conditions. Namely, the tanks are in a state of "ready for closure" meaning that the tanks have been isolated from the tank farm transfer system. Therefore, the financial cost to install supporting equipment and systems (e.g., electrical power, ventilation, and transfer system) are included in the evaluation of each method. Also, all points of access into the tanks via the tank risers contain failed or abandoned equipment. Therefore, if an access point is needed to install new equipment then the failed or abandoned equipment currently located in that tank riser has to be removed, decontaminated, and disposed of properly. The activity associated with the removal and

decontamination of failed or abandoned equipment is evaluated based on historical SRS worker exposure data.

In addition to radiological risk and financial cost, there is also a schedule impact associated with each method. Any activities added to the SRS site activities schedule will have adverse schedule impacts on the current SRS site activities schedule. This impact is quantified by estimating the work duration associated with each method based on a reference project schedule.

Of the three items evaluated for each method: radiological risk, financial cost, and schedule impact; the schedule impact is the most subjective but is included to acknowledge this potential influence on SRS site activities.

3.1 Mechanical Method - Large Tank Top Mounted Hydraulic Mixers and Transfer System

3.1.1 Description

The scope of work associated with this method for residual waste removal includes:

- Evaluation and selection of mixing and transfer equipment,
- Removal of failed or abandoned equipment to provide access to the tank,
- Disposition (transport, decontamination, and disposal) of failed or abandoned equipment,
- Potentially drill new riser(s) in the tank top for access to solids that are difficult to remove,
- Develop design for modifications of existing tank systems and installation of new equipment,
- Perform physical modifications and install new equipment,
- Develop new procedures,
- Perform residual waste removal operations,
- Sample and analyze residual material, and
- Perform fate and transport modeling for the performance evaluation.

This method would be similar to the process used in Phase 2, Step 3, for Tank 19. Three new mixing pumps would be used to agitate the contents of the tank solids with the transfer medium liquid. This slurry would then be transferred to another tank (serving as the receipt tank) via a TTP. However, to provide sustained mixing, the three pumps would run continuously (contrary to step 3 for Tank 19 where the pumps were shut down when a minimum liquid level was reached). The recirculation system would also be continuous (contrary to the step 3 process for Tank 19 where a batch mode of operation was used). During this process, operations personnel would have to be dedicated to this operation to properly monitor the transfer activity in accordance with the safety basis. Periodically, the liquid level in the tank being cleaned would be brought down to a lower level to allow for inspection and determination of removal effectiveness. If difficult to remove areas are identified in Tank 19, then hydraulic lancing would be performed to dislodge and breakup masses of material inside the tank. In the case of Tank 18, these areas are already known and will be subjected to hydraulic lancing before the slurry and recirculation process begins.

3.1.2 SRS Worker Radiological Exposure Risk Analysis

The majority of radiological exposure received by SRS waste tank workers is associated with the removal and decontamination of equipment from a waste tank. For this method, five risers must be used. Four risers in the tank being cleaned (one riser for each of the three mixer pumps and one riser for the TTP) and one riser for the receipt tank (for the transfer pump). Therefore, equipment located in each riser must be removed and decontaminated for disposal, and new equipment must be installed.

To evaluate the radiological exposure to SRS workers for implementing this residual waste removal method, previous work evolutions involving the removal and decontamination of equipment from the waste tanks was used. In June, 2003, the ADMP in Tank 18 was removed to modify its pump screen. The radiological exposure to workers from this work evolution was approximately 300 mrem (Reference 7). Therefore, the removal of equipment from a tank riser is estimated to cause the exposure of 0.3 rem to SRS workers. From November, 1999, through August, 2000, three mixer pumps removed from Tank 40 were decontaminated. Tank 40 contained sludge heel material obtained from waste removal efforts on Tanks 17, 18, 19, and 20. Therefore, the radiological exposures received from decontamination activities for the pumps removed from Tank 40 are considered representative of potential radiological exposure from the decontamination of equipment removed from Tank 19 or Tank 18. The personnel radiological exposure associated with only the decontamination of each pump was obtained from Reference 8 and is presented in Table 3. Based on Table 3, the average radiological exposure to decontaminate one pump is approximately 1.2 rem. Therefore, the estimated radiological exposure to SRS workers for the removal and decontamination of equipment from a single tank riser is 1.5 rem (= 0.3 rem + 1.2 rem).

Table 3
Historical Exposures for Tank 40
Slurry Pump Decontamination

Slurry Pump Location	Radiological Exposure, rem
Tank 40 H Riser	1.01
Tank 40 G Riser	1.31
Tank 40 B-6 Riser	1.24
Total	3.56
Average	1.19

This residual waste removal method would require the removal and decontamination of equipment in four risers of the tank to be cleaned and in a single riser in the receipt tank. Therefore, the estimated radiological exposure would be 7.5 rem (= 5 x 1.5 rem) for Tank 19, and 7.5 rem for Tank 18, residual waste removal activities.

Note that some additional activities that would result in further radiological risks have not been addressed. Some of these other activities include sampling, new riser port installation, providing transfer paths, return to service of tank utilities (air, water, H&V, etc.) and disposal of decontaminated equipment removed from the tanks. Though the radiological exposures to SRS workers from these activities are not minor, they have not been included in this evaluation because of the significant exposures associated with the major activities of removal and decontamination of equipment. Thus, the radiological risks provided above are considered to be conservative – that is, exposures to SRS workers are expected to be at least the value discussed above.

3.1.3 Financial Cost Analysis and Schedule Impact

Tanks 19 and 18 had been previously prepared for closure. Outfitting these tanks for residual waste removal activities at this present time would necessitate activities similar to those required to outfit a tank for waste removal. Cost estimates for Project S-W183, F & H Area Tank Farm Reconfiguration, were developed in 2000 to reconfigure Tanks 1, 2, 3, 4, 5, and 6 for waste removal activities. Because Tank 5 only contains sludge material, the costs associated with the reconfiguration of Tank 5, Reference 9, was used as a basis to develop an order of magnitude cost estimate.

In addition to the costs estimated from Reference 9, other costs have been estimated for the following activities. These costs, per tank, are:

Drilling an access port for a hydraulic lance .... $100,000.
Hydraulic lance tooling .... $50,000.
Sampling and analysis (3 samples per tank) ...... $525,000.
Fate and Transport Analysis .... $25,000.
Transfer recirculation system ………... ………$300,000.
Total “Other Costs” per tank........................... $1,000,000.

Appendix A, Table A-1, details the cost estimates for this method. To have a consistent base of comparison for the three methods being evaluated, an escalation factor of 3.15% per year is used for five years to obtain 2005 dollars. An unburdened and burdened project cost has been computed. Project burdened costs include Essential Site Services (ESS), General and Accounting (G & A), Management Reserve (MR) and contingency costs. These project burdened cost factors were obtained from Reference 9 and are provided in Appendix A. The “Other Costs” provided above are labeled as such in Table A-1.

Rounding the costs given in Table A-1 to the nearest $100,000, the unburdened project cost is $10,200,000 and the burdened project cost is $14,500,000 per tank.

The schedule for the activities necessary to implement this method of residual waste removal has also been estimated. The scheduled activities for waste removal from Tank 11, Reference 10, is used as a reference case and adjustments are made to the reference case to reflect the activities associated with this removal method. Appendix B provides the details for this adjustment and the results are shown in Table B-2. It is estimated that 23 months per tank is required to implement this removal method.

3.2 Robotic Method – Remote Controlled Crawler and Transfer System

3.2.1 Description

This method is based on a system that was used at the Oak Ridge National Laboratory (ORNL) for the Gunite and Associated Tanks (GAAT) Remediation Project (Reference 11). The two major pieces of equipment associated with this method are a Confined Sluicing End Effector (CSEE) and a remote controlled crawler. The CSEE is a rotating water-jet cutter equipped with a vacuum head. The CSEE would be used to dislodge and mobilize sludge mounds. The crawler is a robust, tracked work platform equipped with a plow blade, spray nozzles, camera, and lights. Effective cleaning was realized at ORNL when the crawler pushed sludge toward the CSEE which was held stationary near the tank floor. The CSEE was relocated to different risers to obtain complete coverage of the tank floor.

At SRS, the crawler would be deployed from the center riser which would house a containment structure that includes maintenance systems and tether management systems for the required hydraulic hoses, water line, and electrical power and control cables. During residual waste removal operations, hydraulic lancing would be performed, as necessary, using the CSEEs and the crawler plow blade would push residual solids to a CSEE where solids would be delivered into the transfer system. Because the tanks at SRS are 85 feet in diameter (the ORNL tanks are no larger than 50 feet in diameter) it is assumed that one CSEE would be located in each quadrant of the tank, requiring four CSEEs in each tank.

The scope of work associated with this method of residual waste removal includes:

- Evaluation and selection of specific crawler and transfer equipment,
- Removal of failed or abandoned equipment to provide access to the tank,
- Disposition (transport, decontamination, and disposal) of failed or abandoned equipment,
- Develop design for modifications of existing tank systems and installation of new equipment,
- Perform physical modifications and install new equipment,
- Develop new procedures,
- Perform residual waste removal operations,
- Sample and analyze residual material, and
- Perform fate and transport modeling for the performance evaluation.

3.2.2 SRS Worker Radiological Exposure Risk Analysis

The implementation of this method requires the removal and decontamination of equipment and piping in four perimeter risers plus the center riser. Using the radiological exposure estimate of 1.5 rem per riser developed in section 3.1.2, the estimated radiological exposure to SRS workers is 7.5 rem per tank. As noted in Section 3.1.2, additional radiological exposure to SRS workers for other activities associated with the removal of tank farm waste was not included in this estimate.

3.2.3 Financial Cost Analysis and Schedule Impact

The implementation of this method would require the installation of the robotic crawler at the center riser and the installation of four CSEEs at four perimeter risers to ensure full tank floor coverage. Appendix A, Table A-2, provides the details for estimating the costs associated with this method. Rounding the costs given in Table A-2 to the nearest $100,000, the unburdened project cost is $14,600,000 and the burdened project cost is $20,200,000 per tank.

A schedule has been developed and is presented in Appendix B. The results are shown in Table B-3. A schedule of twenty-four months is estimated to implement this removal method for Tank 19. This includes eight months for the design, development, testing and training on the use of the robotic equipment. The schedule for Tank 18 does not include the eight months of pre-engineering effort; because it is assumed that this work was already done to support Tank 19 residual waste removal.

3.3 Chemical Method - Oxalic Acid (OA) Cleaning and Transfer System

3.3.1 Description

Heel removal using OA has been conducted twice at SRS. The first time was on Tank 16H in late 1979 and early 1980. The second time was on Tank 24H in mid 1985. Each effort took several years of preplanning. Before OA cleaning can be considered for future cleaning activities, the following safety analysis activities must be done (Reference 12):

1. Perform accident analyses associated with using OA in the waste tanks.
2. Conduct a Nuclear Criticality Safety Evaluation.
3. Complete the Heel Removal Process Flow Sheet Model report and associated process flow diagram to consider downstream process/facility impacts.
4. Finalize the Consolidated Hazard Analysis for the Acid Sludge Heel Removal Process.
5. Conduct structural integrity analyses for the use of OA.
6. Perform corrosion testing.
7. Update Documented Safety Analysis and Technical Specification Requirements.

It is estimated that these safety analysis activities would take approximately 8 months to complete, based on Reference 12, at an estimated cost of approximately $3,000,000. One-half of this cost is included as part of the Engineering cost associated with this method per tank (see section 3.3.3).

Once the technical issues are resolved, implementation of this method would entail the placement of two 150-HP hydraulic mixers and a transfer pump, as well as a hydraulic lance to break up larger pieces of sludge to make the acid cleaning more effective. The OA would be added in batches, along with running the mixer pumps, to promote maximum exposure of the residual sludge to the acid. The acid solution would be transferred out to a selected tank where it would be neutralized per applicable requirements. This process would be repeated as required.

The scope of work associated with this method of residual waste removal includes:

- Pre-engineering activities, detailed above,
- Removal of failed or abandoned equipment to provide access to the tank,
- Disposition (transport, decontamination, and disposal) of failed or abandoned equipment,
- Develop design for modifications of existing tank systems and installation of new equipment,
- Perform physical modifications and install new equipment,
- Develop new procedures,
- Perform residual waste removal operations,
- Sample and analyze residual material, and
- Perform fate and transport modeling for the performance evaluation.

3.3.2 SRS Worker Radiological Exposure Risk Analysis

The implementation of this method requires the removal and decontamination of equipment in three risers to install two mixing pumps and a transfer pump. Using the radiological exposure estimate of 1.5 rem per riser developed in section 3.1.2, the estimated radiological exposure to SRS workers is 4.5 rem per tank. As noted in Section 3.1.2, additional radiological exposure to SRS workers for other activities associated with the removal of tank farm waste was not included in this estimate.

3.3.3 Financial Cost Analysis and Schedule Impact

The implementation of this method would require the installation of two slurry pumps to provide sufficient agitation of the acid slurry mixture and a transfer pump. Appendix A, Table A-3, provides the details for estimating the costs associated with this method. Rounding the costs given in Table A-3 to the nearest $100,000, the unburdened project cost is $11,100,000 and the burdened project cost is $15,700,000, per tank.

A schedule has been developed and is presented in Appendix B. The results are shown in Table B-4. A schedule of twenty months is estimated to implement this removal method for Tank 19. This duration includes eight months for the resolution of the technical and safety issues. The duration schedule for Tank 18 does not include the eight months for resolution of technical and safety issues because the efforts for Tank 19 also includes Tank 18.

4.0 BENEFIT ANALYSIS

The potential release of radioactivity from Tank 19 and Tank 18 was evaluated to determine whether the stabilized residual waste in the closed tanks will comply with 10 CFR Part 61, Subpart C performance objectives relating to the protection of the general population. Compliance was demonstrated in Reference 13 by estimating the potential annual dose to an adult residing in proximity to the F Area Tank Farm. The analysis presented in Reference 13 assumes that members of the public construct a dwelling near the F Area Tank Farm on the Savannah River Site (but outside the F Area Tank Farm). The location of the residential dwelling is assumed to be downgradient near Fourmile Branch just downstream of the seepline for the entire 10,000-year period of analysis. The resident is assumed to use Fourmile Branch for recreational purposes and sustenance. Ten potential exposure pathways, listed below, were identified and evaluated to present an "all-pathways" dose.

1. Incidental ingestion of contaminated soil from shoreline deposits
2. Direct irradiation from the seepline
3. Air inhalation at the seepline
4. Dermal contact with Fourmile Branch
5. Drinking water from Fourmile Branch
6. Ingestion of fish from Fourmile Branch
7. Direct radiation from Fourmile Branch
8. Ingestion of milk from cows fed vegetation grown on soil irrigated with Fourmile Branch water
9. Ingestion of meat from cows fed vegetation grown on soil irrigated with Fourmile Branch water
10. Ingestion of produce irrigated with Fourmile Branch water

The results from Reference 13 are shown in Table 4.

Table 4
Estimated All Pathways Dose

Source of Contamination	Potential Dose to an Individual (mrem/yr)
Tank 18 only	0.04
Tank 19 only	0.009

For purposes of this risk/benefit analysis, complete removal of the residual waste is assumed, though it is not practical. Complete removal of the residual waste eliminates any potential exposure from the tank. Therefore, the benefit of complete residual waste removal is an exposure savings of 0.04 mrem per year for Tank 18 and 0.009 mrem per year for Tank 19. For cost benefit calculations, a 50 year exposure is used which conservatively assumes that an adult receives the annual exposure for fifty years or 2 mrem (50 year exposure) from Tank 18 and 0.45 mrem (50 year exposure) from Tank 19.

5.0 COMPARATIVE ANALYSIS

Table 5 summarizes the radiological exposure risk and financial cost considerations, and the potential hypothetical dose savings for each residual waste removal method; and provides comparison ratios for Tank 19 and Tank 18 for the three methods evaluated for residual waste removal.

Table 5
Considerations for Further Residual Waste Removal

Residual Waste Removal Method	Financial Cost ($)[1]	Cumulative Worker Risk (mrem)[2]	Potential 50 Year Dose Savings to an Individual[3] (mrem)		Financial Cost – to – Potential Benefit Ratio ($ / mrem)[4]		Worker Risk – to – Potential Benefit Ratio (present mrem / future mrem)[5]	
			Tank 18	Tank 19	Tank 18	Tank 19	Tank 18	Tank 19
Mechanical	10,200,000	~ 7,500	2	0.45	5,100,000	22,700,000	3,750	16,700
Robotic	14,600,000	~ 7,500	2	0.45	7,300,000	32,400,000	3,750	16,700
Chemical	11,100,000	~ 4,500	2	0.45	5,550,000	24,700,000	2,250	10,000

[1] Project unburdened cost in dollars, rounded to $100,000.
[2] Risk from waste removal part of the cleaning operations only. Does not include radiological exposure associated with disposal.
[3] Future hypothetical member of the public.
[4] Dollars spent for one future potential mrem exposure saved.
[5] Present day radiological exposure received by workers for one future potential mrem exposure saved.

Radiological risk, financial cost, and schedule impact can be quantified by analysis. However, there are other factors not easily quantifiable but are nevertheless important considerations when evaluating residual waste removal methods. These other considerations are 1) likelihood of success, 2) adverse impacts on downstream SRS facilities and 3) technical risks which include i) existing safety analysis impacts, ii) compatibility of equipment with existing SRS systems and iii) SRS personnel operational experience. Each of the three evaluated methods was assessed by knowledgeable SRS personnel based on these other considerations. Appendix C provides the details of this assessment. Because of its extensive use at SRS, the mechanical method has limited technical risk while the other methods have significant technical risk. These technical risks include SRS integration and operational experience risks for the robotic method and safety analysis risk (criticality and hydrogen controls) for the chemical removal method. The chemical removal method also has significant adverse downstream impacts to existing SRS systems because of the current lack of liquid storage space and processing concerns with the Tank Farm Evaporators and the DWPF. The mechanical and robotic methods are manpower intensive and thus have significant impact on facility operations.

6.0 CONCLUSIONS

The heightened exposure risk and the greater financial burden incurred from residual waste removal outweighs the insignificant benefit of potential dose savings. As illustrated in Table 5, the present day risk to SRS workers from radiological exposure is 2,250 times to 16,700 times greater than the 50-year radiological risk to an individual in the future. The financial cost of residual waste removal to save one mrem of a 50-year exposure to an individual in the future ranges from $5,100,000 to $32,400,000 of unburdened project cost.

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Appendix A - Cost Data Used for Financial Analysis

Table A-1
Cost Estimate for Mechanical Method per Tank

Work Elements for TEC	**Cost**	**Notes**
A. Waste Removal		
Engineering	635,797	1
Tank Top Services	187,695	2
Pump Cable and Splicing	43,942	2
Install H & V Skid	201,343	2
Purchase H & V Skid	146,707	2
TTP - Electrical	19,166	3
TTP Spray Chamber	226,681	3
D & R Fixed Length Jet	37,115	2
Transfer Line Tie-In	65,216	2
Transport Sleeve Fabrication	53,407	2
Tank Top Structural Steel	17,900	2
3 Slurry Pumps	1,421,741	4
2 Transfer Pumps	775,282	5
Decontamination	95,700	2
Radcon Support	189,810	2
Protective Clothing	272,916	2
B. Tank Isolation	329,108	2
C. Project Support	441,644	1
Subtotal	5,161,170	
Escalation (3.15 % per year for 5 years)	865,735	6
TEC unburdened costs	6,026,905	
Project Adders - ESS and G & A (13.7 % of Total)	825,686	7
Management Reserve and Contingency (20 % of Total)	1,205,381	8
TOTAL TEC with burden	8,057,972	
Work Elements for OPC		
Waste Removal	1,358,583	9, 10
Tank Isolation	761,649	10
Project Support	627,066	9, 10
Subtotal	2,747,298	
Escalation	460,832	6
Other Costs (Section 3.1.3)	1,000,000	11
OPC unburdened costs	4,2 08,130	
Project Adders - ESS and G & A (37.3 % of Total)	1,569,632	7
Management Reserve and Contingency (16 % of Total)	673,300	8
TOTAL OPC with burden	6,451,062	
TOTAL UNBURDENED COSTS	10,235,035	
TOTAL BURDENED COSTS	14,509,034	

Notes for Table A-1:

1. Cost estimate from Reference 9 is based on the two phase, three step approach for waste removal. This estimate is only for the residual waste removal step which is assumed to cost one-half of the Reference 9 estimate for these work elements. These costs are included in the three methods being evaluated. Subtotal costs: $1,077,441.
2. These cost elements are used without adjustment in the three methods being evaluated and are combined as Tank Top Support Services costs. Subtotal costs: $1,640,859.
3. These costs are only applicable to the Mixer Pumps method. Subtotal Costs: $245,847.
4. Only three mixing pumps will be used; therefore, the cost element is adjusted by 75% of the value in Reference 9.
5. Two transfer pumps are required for this method; therefore the cost element is doubled from Reference 9.
6. Escalation costs. Subtotal costs: $1,326,567
7. These are the burdened project cost factors for Essential Site Services and General and Accounting. Subtotal costs: $2,395,318.
8. These are the burdened project cost factors for Management Reserve and Contingency. Subtotal costs: $1,878,682.
9. Per note 1, these costs are adjusted by 50% from the Reference 9 cost estimate.
10. These costs are combined and presented as Operations costs. Subtotal costs: $2,747,298
11. These are the additional costs identified in Section 3.1.3 of this document and are presented as Other Costs.

Table A-2
Cost Estimate for Robotic Crawler per Tank

Description	Cost	Cost	Notes
Modified Light Duty Utility Arm	1,630,000		1
Crawler (Houdini II)	2,075,000		1
Confined Sluicing End Effector	1,300,000		1, 2
Ultra High Pressure Pump	275,000		1
Hose Management Arm	175,000		1
Subtotal	5,455,000		1
Crawler and Equipment Costs		5,455,000	
Engineering and Support		2,077,441	3
Tank Top Support Services		1,640,859	4
Subtotal		9,173,300	
Escalation (3.15 % per year for 5 years)		1,538,729	5
Estimated TEC (unburdened)		10,712,029	
ESS and G & A (13.7 % of Total)		1,467,548	6
MR and Contingency (20 % of Total)		2,142,406	7
Estimated TEC (burdened)		14,321,983	
Operations		2,747,298	8
Other Costs		550,000	9
Subtotal		3,297,298	
Escalation (3.15 % per year for 5 years)		553,089	5
Estimated OPC Costs (Unburdened)		3,850,387	
ESS and G & A (37.3 % of Total)		1,436,194	6
MR and Contingency (16 % of Total)		616,062	7
Estimated OPC Costs (Burdened)		5,902,643	
Total Costs (unburdened)		14,562,416	
Total Costs (burdened)		20,224,626	

Notes:

1. Unique equipment costs taken from Reference 11, Table 12-3, and totaled as Crawler and Equipment Costs.
2. Value provided in Table 12-3 of Reference 11 is doubled to reflect four CSEEs.
3. See Note 1 from Table A-1 plus $1,000,000 for design and testing (based on Table 12-2 of Reference 11 - $12.8 M was spent for preliminary design and selection.) Assuming cooperation and lessons learned with ORNL personnel only $2M is estimated or $1M per tank.
4. See Note 2 from Table A-1
5. Escalation costs. Subtotal costs: $2,091,818.
6. Project burden costs for ESS and G&A. Subtotal costs: $2,903,742.
7. Project burden costs for MR and Contingency. Subtotal costs: $2,758,468
8. See Note 10 from Table A-1
9. See Note 11 from Table A-1, less $450,000 (hydraulic lance performed by CSEEs and no recirculation system assumed)

Table A-3
Cost Estimate for Oxalic Acid per Tank

Description	Cost	Notes
OA Services	542,839	1
Two slurry pumps	947,827	2
Transfer Pump	387,641	3
Subtotal – equipment and services	1,878,307	4
Engineering and Support	2,577,441	5
Tank Top Support Services	1,640,859	6
TEC Subtotal	6,096,607	
Escalation (3.15 % per year for 5 years)	1,022,645	7
Estimated TEC (unburdened)	7,119,252	
ESS and G & A (13.7 % of Total)	975,338	8
MR and Contingency (20 % of Total)	1,423,850	9
Estimated TEC (burdened)	9,518,440	
Operations	2,747,298	10
Other Costs	700,000	11
Subtotal	3,447,298	
Escalation (3.15 % per year for 5 years)	578,250	7
Estimated OPC Costs (Unburdened)	4,025,548	
ESS and G & A (37.3 % of Total)	1,501,529	8
MR and Contingency (16 % of Total)	644,088	9
Estimated OPC Costs (Burdened)	6,171,165	
Total Costs (unburdened)	11,144,800	
Total Costs (burdened)	15,689,605	

Notes:

1. Obtained from Reference 14, dated 1975, [$250,000 escalated at 3.15 % for 25 years to start with 2000 dollars].
2. 50% of Reference 9 cost to reflect two slurry pumps.
3. Reference 9 cost to reflect one transfer pump,
4. Subtotal presented as OA Equipment and Services.
5. See Note 1 from Table A-1 plus $1.5M to estimate safety analysis efforts (one-half of $3 M estimate to reflect a cost per tank, section 3.3.1)
6. See Note 2 from Table A-1
7. Escalation costs. Subtotal costs: $1,600,895.
8. Project burden costs for ESS and G&A. Subtotal costs: $2,476,867
9. Project burden costs for MR and Contingency. Subtotal costs: $2,067,938.
10. See Note 10 from Table A-1
11. See Note 11 from Table A-1, less $300,000 (no recirculation system assumed)

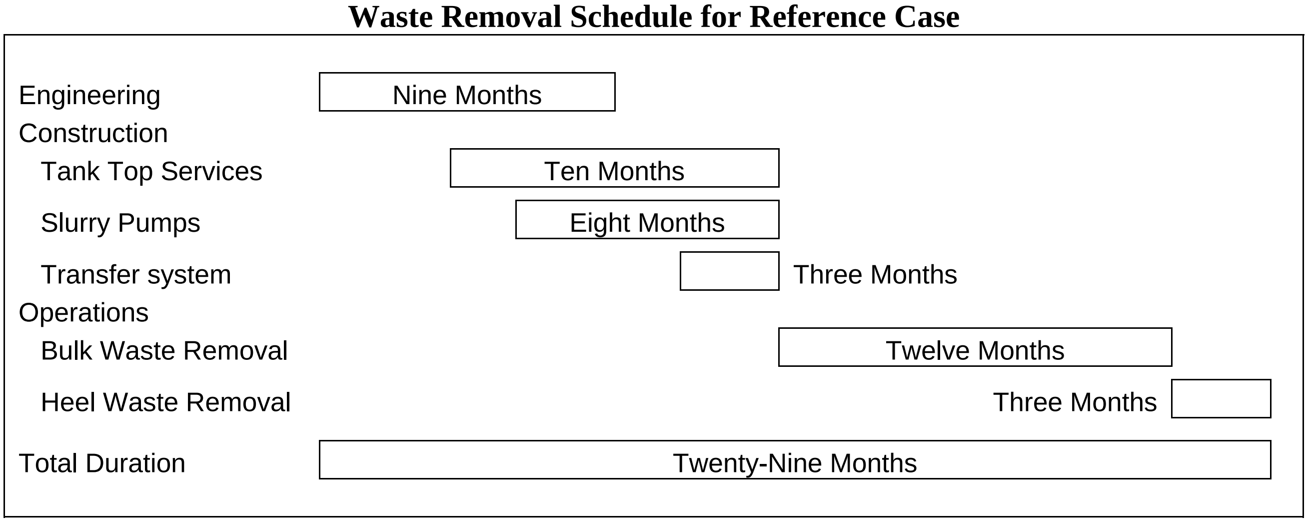
Appendix B - Schedule Analysis

To estimate a schedule for the activities associated with the various residual heel removal methods, a reference case is used and then adjusted to reflect a schedule for each method. The reference case shown is the schedule for the on-going waste removal activities in Tank 11. Two phases of heel removal has been completed for Tank 11 and further heel removal efforts are pending. Table B-1 provides a listing of the major activities and the time for completion based on Reference 10. Figure B-1 illustrates the schedule to recognize the overlaps that exist between the various activities.

Table B-1
Waste Removal Data for Reference Case

Schedule Activity	Schedule Dates	Duration
Engineering (Tank 11 Design)	12/02/2002 – 08/19/2003	9 Months
Construction, Startup, Turnover		
Tank Top Services	03/20/2003 – 01/12/2004	10 Months
Four Slurry Pumps	04/21/2003 – 01/12/2004	8 Months
Transfer System	10/06/2003 – 01/13/2004	3 Months
Operations		
Bulk Waste Removal	02/09/2004 – 02/10/2005	12 Months
Heel Removal	02/23/2005 – 05/21/2005	3 Months
Total Duration	12/02/2002 – 05/21/2005	29 Months

Figure B-1
Waste Removal Schedule for Reference Case



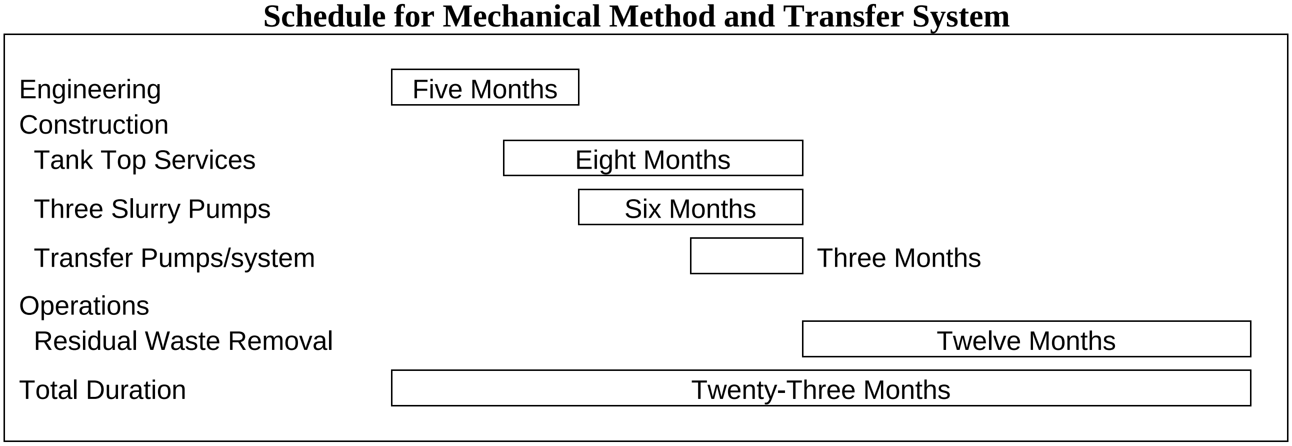
Mechanical Method - Mixer Pumps and Transfer System

This method is similar to the Reference Case except that three slurry pumps, rather than four, are used which will reduce the time required for engineering, construction, startup, and turnover activities. The residual waste removal effort by operations is estimated to span twelve months to effectively remove the residual material. Table B-2 provides the estimated activity duration data. Figure B-2 provides a schedule.

Table B-2
Duration Data for
Mechanical Method and Transfer System

Schedule Activity	Duration	Remarks
Engineering	5 Months	One-half of reference case to reflect fewer pumps
Construction, Startup, Turnover		
Tank Top Services	8 Months	Reduced two months from the base case and starts three months after the start of Engineering activities
Three Slurry Pumps	6 Months	Reduced two months from the reference case and finishes with tank top services
Transfer System	3 Months	Same as reference case and finishes with tank top services
Operations		
Residual Waste Removal	12 Months	Expected duration
Total Duration	23 Months	= 3 + 8 + 12

Figure B-2
Schedule for Mechanical Method and Transfer System



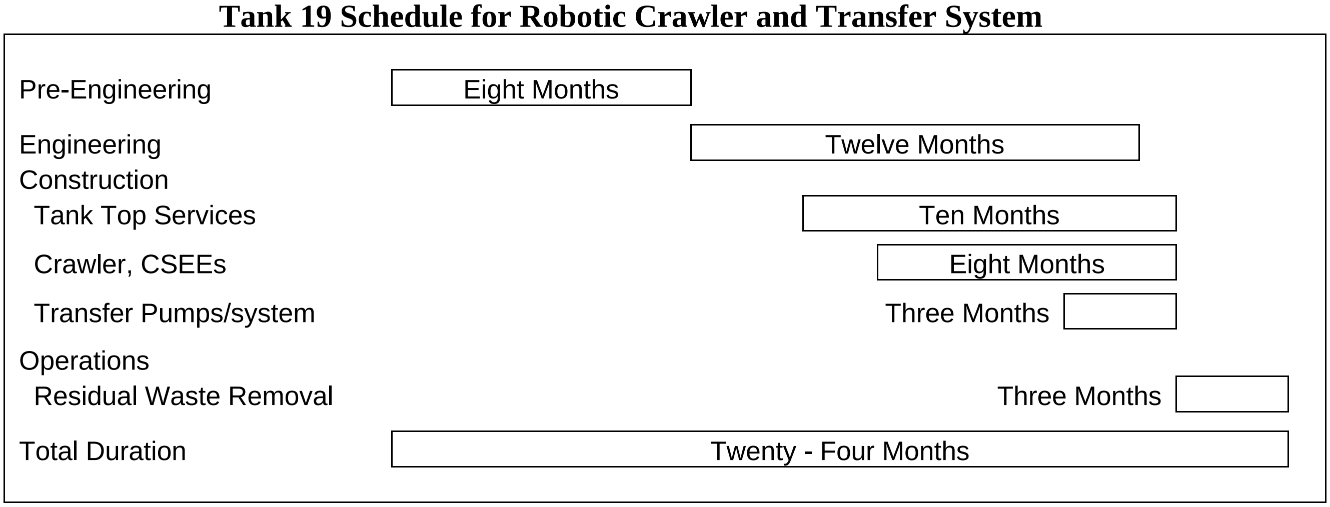
Robotic Method – Remote Controlled Crawler and Transfer System

This method requires a significant amount of pre-engineering effort for design, testing, and training on the crawler and the use of the Confined Sluicing End Effectors (CSEEs). The pre-engineering effort is estimated to take eight months. During the implementation phase, the durations for the activities associated with engineering, construction, startup, turnover and operations are assumed to be equal to the Reference Case. Table B-3 provides the activity duration data for Tank 19 which includes the pre-engineering effort and is illustrated in Figure B-3. Note that the pre-engineering effort may not be necessary for Tank 18 because of the lessons learned on Tank 19 and is not included for Tank 18.

Table B-3
Duration Data for
Robotic Crawler and Transfer System

Schedule Activity	Duration	Remarks
Pre-Engineering	8 Months	Design and testing
Engineering	12 Months	Starts after pre-engineering
Construction, Startup, Turnover		
Tank Top Services	10 Months	Starts 3 months after engineering
Crawler and CSEEs	8 Months	Finishes with Tank Top Services
Transfer System	3 Months	Finishes with Tank Top Services
Operations		
Residual Waste Removal	3 Months	Same as reference case (heel removal)
Total Duration	24 Months	= 8 + 3 + 10 + 3

Figure B-3
Tank 19 Schedule for Robotic Crawler and Transfer System



Chemical Method - Oxalic Acid Cleaning and Transfer System

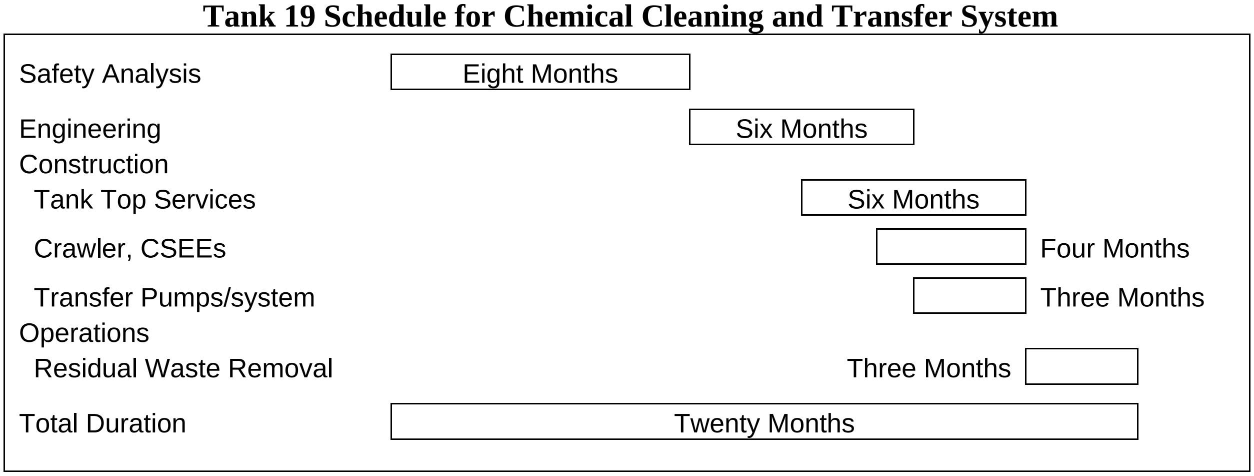
To implement this removal method several activities must be completed to update the Documented Safety Analysis (DSA) and Technical Specification Requirements (TSRs). These activities include performing accident analyses, conducting Nuclear Criticality Safety Evaluations, conducting structural integrity analyses, and performing corrosion testing. After the DSA and TSRs have been updated, implementation of this method would entail the placement of two 150-HP hydraulic mixers and a transfer pump, as well as a hydraulic lance to break up larger pieces of sludge to make the acid cleaning more effective.

The safety analysis efforts are estimated to take eight months and are performed prior to Engineering activities. During the implementation phase, the durations for the activities associated with engineering, construction, startup, turnover and operations are assumed to be less than the Reference Case to reflect fewer pumps being installed. Table B-4 provides the activity duration data for Tank 19 and is illustrated in Figure B-4. Note that the safety analysis efforts are expected to address both tanks; thus, the schedule duration for Tank 18 would not include this effort.

Table B-4
Duration Data for Chemical Cleaning and Transfer System

Schedule Activity	Duration	Remarks
Safety Analysis	8 Months	Update DSA and TSRs
Engineering	6 Months	Starts after safety analysis efforts
Construction, Startup, Turnover		
Tank Top Services	6 Months	Starts 3 months after engineering
Two Slurry Pumps	4 Months	Finishes with Tank Top Services
Transfer System	3 Months	Finishes with Tank Top Services
Operations		
Residual Waste Removal	1 Month	Expected duration
Total Duration	20 Months	= 8 + 3 + 6 + 3

Figure B-4
Tank 19 Schedule for Chemical Cleaning and Transfer System



Appendix C – Other Considerations

In addition to radiological risks, financial costs, and schedule impacts, there are other considerations. These include: 1) Likelihood of success, 2) Downstream SRS facility impacts, and Technical risks which include i) Safety Analysis impact, ii) Integration with existing SRS systems, and iii) SRS operational experience. Each of the residual waste removal methods are assessed based on these considerations using the scoring methodology that follows.

1. Likelihood of success - Complete removal of residual waste
   5 – Very High Probability → 1 – Very Low Probability

2. Facility impact on downstream SRS systems (manpower impacts not considered)
   5 – No known impacts → 1 – Significant potential impacts

3 Technical Risks:
   i) Safety Analysis Impact
      5 – None; 3 – Potential Impact; 1 – Significant Impact

   ii) Integration with existing SRS systems
      5 – Highly compatible with SRS systems → 1 – Not Compatible with SRS systems

   iii) SRS operational experience
      5 – Very Familiar → 1 – No Familiarity

A number of knowledgeable SRS personnel with tank farm experience assessed each of the evaluated methods of residual waste removal using the criteria specified above. The results of the assessment are presented below. Note that the higher the score the more favorable the residual waste removal method.

Table C-1
Assessment of Other Considerations

Other Considerations	**Residual Waste Removal Method**		
	Mechanical	**Robotic**	**Chemical**
1. Likelihood of Success	2.9	3.3	3.9
2. Downstream SRS Facility Impacts	4.4	4.0	1.4
3. Technical Risks			
i. Safety Analysis Impact	4.4	2.9	1.6
ii. Integration with SRS systems	4.8	3.4	2.1
iii. SRS Operational Experience	4.9	2.3	2.5
Technical Risks Subtotal	14.1	9.6	6.2
Total	21.4	15.9	11.5