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## **HIGH-LEVEL WASTE MECHANICAL SLUDGE REMOVAL AT THE SAVANNAH RIVER SITE – F TANK FARM CLOSURE PROJECT**

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### **ABSTRACT**

The Savannah River Site F-Tank Farm Closure project has successfully performed Mechanical Sludge Removal (MSR) using the Waste on Wheels (WOW) system for the first time within one of its storage tanks. The WOW system is designed to be relatively mobile with the ability for many components to be redeployed to multiple waste tanks. It is primarily comprised of Submersible Mixer Pumps (SMPs), Submersible Transfer Pumps (STPs), and a mobile control room with a control panel and variable speed drives. In addition, the project is currently preparing another waste tank for MSR utilizing lessons learned from this previous operational activity. These tanks, designated as Tank 6 and Tank 5 respectively, are Type I waste tanks located in F-Tank Farm (FTF) with a capacity of 2,840 cubic meters (750,000 gallons) each. The construction of these tanks was completed in 1953, and they were placed into waste storage service in 1959. The tank's primary shell is 23 meters (75 feet) in diameter, and 7.5 meters (24.5 feet) in height. Type I tanks have 34 vertically oriented cooling coils and two horizontal cooling coil circuits along the tank floor. Both Tank 5 and Tank 6 received and stored F-PUREX waste during their operating service time before sludge removal was performed.

DOE intends to remove from service and operationally close (fill with grout) Tank 5 and Tank 6 and other HLW tanks that do not meet current containment standards. Mechanical Sludge Removal, the first step in the tank closure process, will be followed by chemical cleaning. After obtaining regulatory approval, the tanks will be isolated and filled with grout for long-term stabilization.

Mechanical Sludge Removal operations within Tank 6 removed approximately 75% of the original 95,000 liters (25,000 gallons). This sludge material was transferred in batches to an interim storage tank to prepare for vitrification. This operation consisted of eleven (11) Submersible Mixer Pump(s) mixing campaigns and multiple intraarea transfers utilizing STPs from July 2006 to August 2007. This operation and successful removal of sludge material meets requirement of approximately 19,000 to 28,000 liters (5,000 to 7,500 gallons) remaining prior to the Chemical Cleaning process. Removal of the last 35% of sludge was exponentially more difficult, as less and less sludge was available to mobilize and the lighter sludge particles were likely removed during the early mixing campaigns. The removal of the 72,000 liters (19,000 gallons) of sludge was challenging due to a number of factors. One primary factor was the complex internal cooling coil array within Tank 6 that obstructed mixer discharge jets and impacted the Effective Cleaning Radius (ECR) of the Submersible Mixer Pumps. Minimal access locations into the tank through tank openings (risers) presented a challenge because the available options for equipment locations were very limited. Mechanical Sludge Removal activities using SMPs caused the sludge to migrate to areas of the tank that were outside of the SMP ECR. Various SMP operational strategies were used to address the challenge of moving sludge from remote areas of the tank to the transfer pump.

This paper describes in detail the Mechanical Sludge Removal activities and mitigative solutions to cooling coil obstructions and other challenges. The performance of the WOW system and SMP operational strategies were evaluated and the resulting lessons learned are described for application to future Mechanical Sludge Removal operations.

### **INTRODUCTION**

SRS, one of the facilities in the DOE complex, was constructed during the early 1950s to produce nuclear materials (such as plutonium, uranium and tritium). The site covers approximately 800 square kilometers (310 square miles) in South Carolina and borders the Savannah River. SRS is located in Aiken,

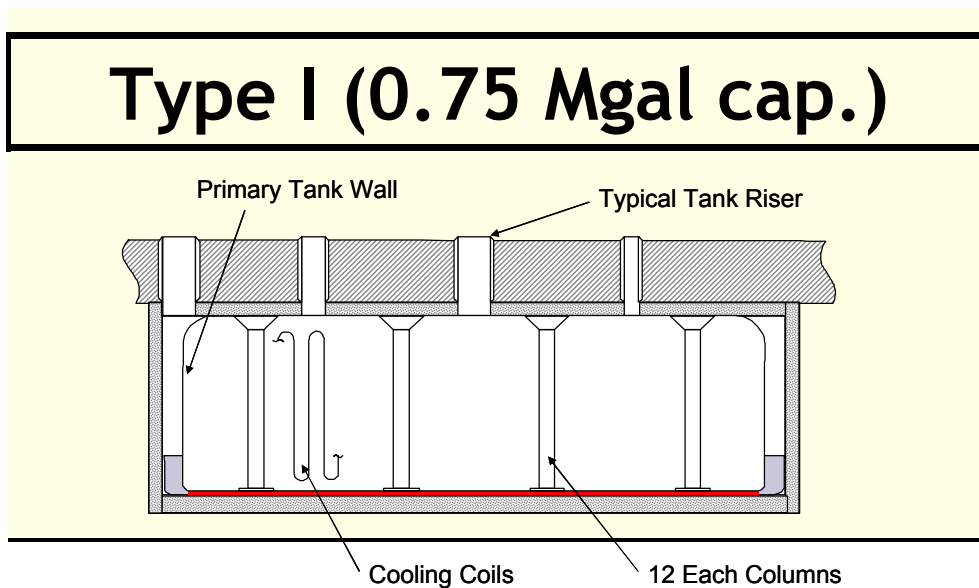
Allendale, and Barnwell counties of South Carolina. The site is approximately 19 kilometers (12 miles) south of Aiken, South Carolina, and 24 kilometers (15 miles) southeast of Augusta, Georgia. The tank farms were constructed to receive HLW generated by various SRS production, processing, and laboratory facilities. The use of the tank farms isolates these wastes from the environment, SRS workers, and the public. In addition, the tank farms enable radioactive decay by aging the waste, clarification of waste by gravity settling and removal of soluble salts from waste by evaporation. The tank farms also pretreat the accumulated sludge and salt solutions (supernate) to enable the management of these wastes at other SRS facilities (i.e., Defense Waste Processing Facility (DWPF) and Saltstone Disposal Facility (SDF)). These treatment facilities convert the sludge and supernate to more stable forms suitable for permanent disposal.

The F-Tank Farm (FTF) is a 90,000 square meter (22-acre) site consisting of 22 waste tanks, 2 evaporator systems, transfer pipelines, 6 diversion boxes, and 3 pump pits. Tanks 5 and 6 are located in FTF.

The Federal Facility Agreement (FFA) between the SCDHEC, the DOE, and EPA was issued to “govern the corrective/remedial action process for site investigation through site remediation and describe procedures for the process.” The FFA establishes the regulatory framework for the operation, new construction, and eventual closure of the liquid waste tank systems. [Reference 1]

The FFA results in enforceable timetables for the closure of tanks as well as provisions for new construction and prevention and mitigation of releases or potential releases from the tank systems. SRS tanks such as Tanks 5 and 6 that do not meet secondary containment standards, as established in the FFA, must be removed from service per the FFA schedule. There are a total of 24 tanks at SRS that do not meet the secondary containment standards and are scheduled for closure by 2022. Twelve of these non-compliant tanks are in F Tank Farm. Two F Tank Farm tanks, Tank 17 and Tank 20 have been previously closed, and Tanks 5 and 6 (along with Tanks 18 and 19) are the next tanks scheduled for closure .

Tanks 5 and 6 are two of eight Type I tanks in the FTF. A typical Type I tank is shown in Figure 3. These waste tanks have a nominal operating capacity of 2,840 cubic meters (750,000 gallons).



**Figure 1 – SRS Type I Underground Tank**

The primary liner for Type I tanks are cylinders made of 12.7 mm (½ inch) American Society of Testing Materials (ASTM) A285-50T carbon steel. The inner radius of the primary container is 11.4 meters (37.5 feet), and the inner height is 7.5 meters (24.5 feet). The walls of the primary container are welded to the top and bottom of the waste tank by a 12.7 mm (0.5 inch) thick, curved knuckle plate. An 24.4 meter (80 foot) inner diameter vault surrounds the Type I tank primary container, creating a .8 meter (2.5 foot) wide

annulus (the upper portion is formed by the concrete vault while the bottom is formed by the 1.6 meter (5 foot) carbon steel shell). The vault is formed by a reinforced concrete roof and walls that surround the primary container and connect to the base slab. A layer of backfill covers the top of the waste tank. Twelve concrete and steel columns support the roof of a Type I tank. These columns were made from steel pipes welded to a steel bottom plate. The pipes are 12.7 mm (½ inch) thick carbon steel with a .6 meter (2 foot) outside diameter, and are filled with concrete. The columns have flared capitals at the top filled with concrete. The bottom of the columns is cylindrical and has eight 25 mm (one inch) thick stiffeners on each column. The columns are welded to the top and bottom of the primary container.

The Type I tanks are equipped with a cooling system. The tanks have 34 vertical cooling coils that are supported by hanger and guide rods that are welded to the primary liner. Two horizontal cooling coils extend across the bottom of the tanks and are supported by guide rods welded to the bottom of the primary liner. The cooling coils are 5.1 cm (2-inch) diameter schedule 40 carbon steel seamless pipe.

### HLW PROCESSING SUMMARY

Tank 5 began receiving high heat waste in March 1959 and became filled by May 1960. Tank 6 began receiving high heat waste in November 1964 and became filled by October 1966. The liquid waste levels in both tanks fluctuated over the following decades as supernate was periodically decanted to feed the 1F evaporator system, and fresh waste was periodically added.

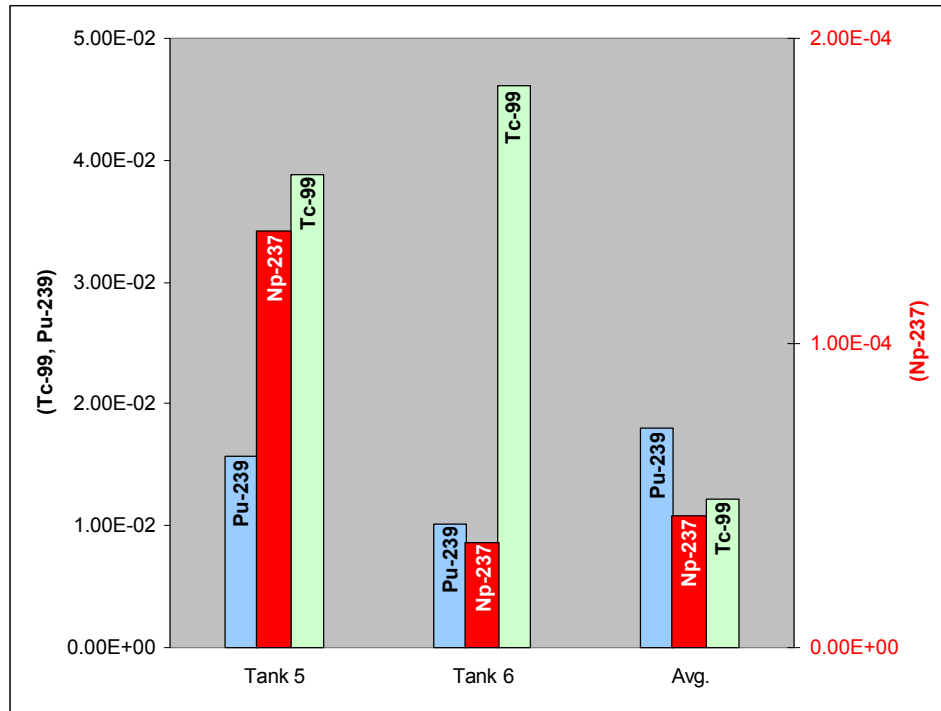
The waste stored in waste tanks generally fall into two categories: high heat waste (HHW) which contains the majority of the fission products; and low heat waste (LHW) which results from purification processes and from dissolving aluminum cladding from reactor fuels. Tanks 5 and 6 received mostly HHW and therefore contain sludge with some of the highest radionuclide concentrations in FTF.

The concentrations of radiological constituents in the sludge in Tanks 5 and 6 (decayed to 2005) are estimated using data from the SRS Waste Characterization System and special calculations (Table 1) [Reference 2]. The concentrations of some radionuclides expected to be important to the performance assessment in Tanks 5 and 6 sludges are compared to the average concentrations of the other tanks in F Tank Farm in Table 2.

**Table 1 – Tanks 5 and 6 Sludge Radiological Concentrations for Selected Constituents**

	Sr-90 (Ci/gal)	Tc-99 (Ci/gal)	Cs-137 (Ci/gal)	U-232 (Ci/gal)	U-235 (Ci/gal)	U-238 (Ci/gal)	Np-237 (Ci/gal)	Pu-239 (Ci/gal)	Pu-240 (Ci/gal)	Pu-241 (Ci/gal)	Pu-242 (Ci/gal)
Tank 5	8.41E+01	3.88E-02	5.94E+00	1.76E-06	3.42E-06	8.10E-05	1.37E-04	1.57E-02	3.76E-03	2.51E-02	1.11E-06
Tank 6	1.10E+02	4.62E-02	7.71E+00	2.15E-06	2.67E-06	9.97E-05	3.46E-05	1.02E-02	3.55E-03	3.97E-02	6.98E-06

**Table 2 – Comparison of Tanks 5 and 6 Sludge Concentrations to the Average Concentrations of Other FTF Tanks (Curies/Gallon)**



The typical closure process steps for the F-Tank Farm Type I tanks are:

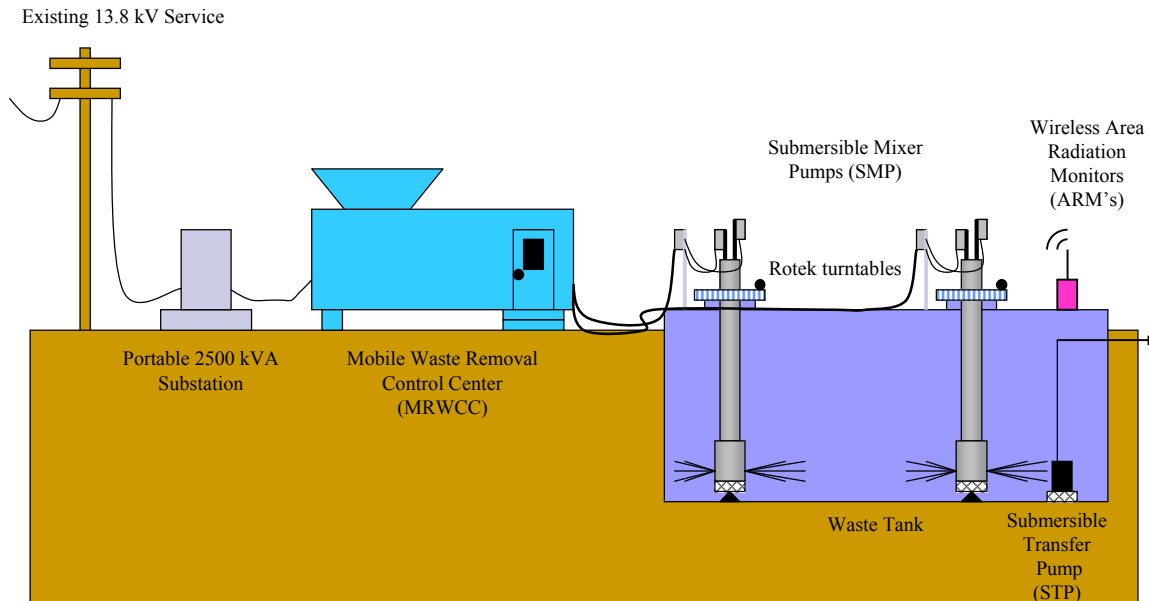
- 1.) Mechanical Sludge Removal
- 2.) Chemical Cleaning Process – utilizing 8 wt% Oxalic Acid
- 3.) Characterization and DOE/Regulatory Reviews
- 4.) Tank Grouting

The SRS F-Tank Closure Project has successfully completed Mechanical Sludge Removal in Tank 6 utilizing the Waste-on-Wheels (WOW) system and is currently preparing Tank 5 for the next MSR campaign.

After Tanks 5 and 6 are cleaned, the estimated inventory used in the FTF Performance Assessment for that tank will be compared and evaluated against the actual inventory for that tank, which will be developed from an estimate of the residual material volume combined with analytical data from a statistically based sampling program. During the closure process for each tank, the actual tank inventory will be used to determine projected dose and risk impacts for that tank.

### **WASTE-ON-WHEELS (WOW) System**

The Waste-On-Wheels (WOW) concept is to reduce waste processing cost by developing mobile and reusable equipment that can be utilized for processing two waste tanks simultaneously. This approach saved the cost of updating or refurbishing installed equipment on tanks that were scheduled to be decommissioned. The WOW system consists of a Mobile Substation (25KVA) that provides power and a Mobile Waste Removal Control Center (MWRCC) that provides local control and monitoring capabilities during Mechanical Sludge Removal. These mobile units have the capability of being co-located near any tank or tanks scheduled for Sludge Removal. These mobile units can be co-located near any tank or tanks scheduled for processing. Figure 2 shows the outline of the WOW major components.



**Figure 2 – WOW Major Components**

In addition, the WOW system consists of re-usable Submersible Mixer Pumps (SMPs) for suspending sludge and Submersible Transfer Pumps (STPs) that are used for final sludge removal. The design allows Mechanical Sludge Removal mixing and removal operations to be performed on two tanks simultaneously. Once a tank or tanks are processed, the mobile units and mixing pumps can be relocated to another set of tanks or another tank farm for reuse. The submersible transfer pump (STP) is not being reused due to the inexpensive material design and motor windings and wiring being susceptible to failure when exposed to an intense radiation field.

### **Submersible Mixing Pumps (SMPs)**

The Submersible Mixer Pumps (SMPs) are new designed pumps that were utilized by F Tank Farm Closure Projects to complete Mechanical Sludge Removal in Tank 6. The pumps are Curtiss-Wright, variable speed, single stage centrifugal, 440 VAC, 3 phase power, and rated at 305 HP at 1400 RPM. The pumps have two 180 degree discharge 10.2 cm (4 inch) diameter nozzles that provide approximately 29,000 liters/minute (7600 GPM) flow rate at 1400 RPM. The SMPs utilize the product to cool the motor and lubricate the upper and lower bearings. The two discharge nozzles give the SMPs the capability to produce an effective cleaning radius (ECR) of approximately 15.2 meters (50 feet). The pump column is a 46 cm (18 inch) diameter, 10.4 meter (34 feet) long stainless steel pipe that is welded to a motor/pump assembly transition piece on one end and the top support connection flange on the other. Pump configuration is shown in Figure 3.

To achieve the most effective mixing, the SMPs are rotated utilizing a turn table assembly. The turn table provides the motive force for oscillating mode and in addition provides repositioning capabilities for stationary indexing operation. The turntables are rotated by a reversible, single speed, 1 horsepower motor. The reversible motor allows directional change to facilitate oscillations of the SMP for mixing operations. The reversible motor is directly coupled to a Boston 600-to-1 gear reducer. The gear reducer turns a drive gear that meshes with a ring gear attached to the perimeter of the SMP bearing plate.

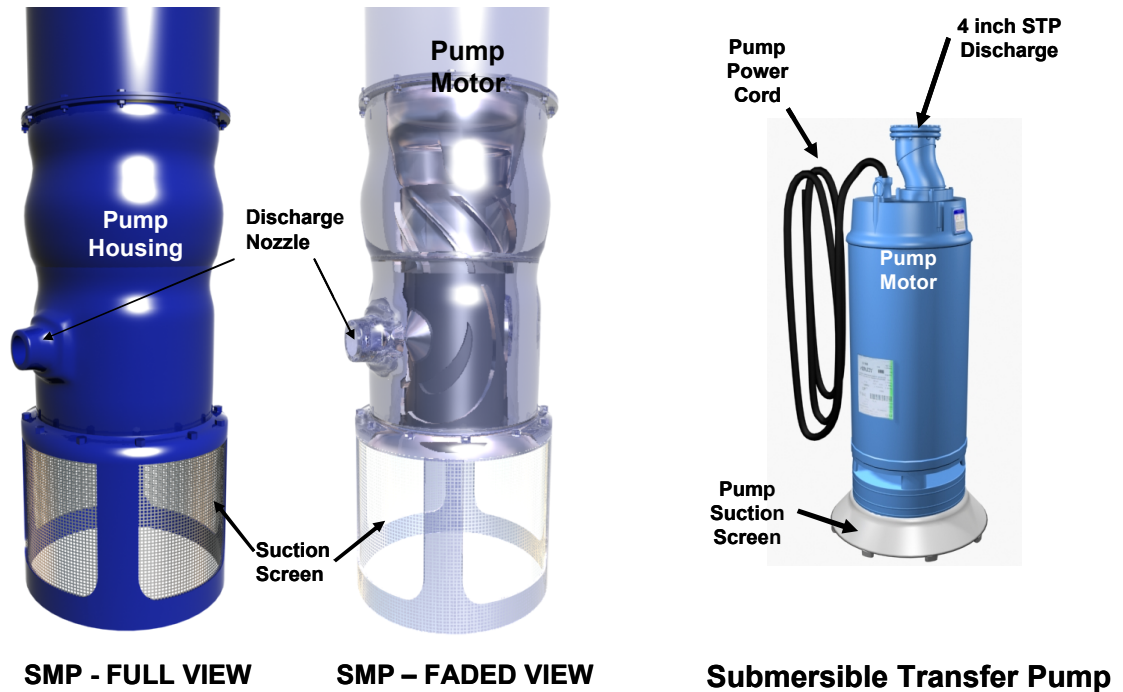


Figure 3 - Submersible Mixing Pump Full View

### Submersible Transfer Pump (STP)

Transfer capabilities during Tank 6 Mechanical Sludge Removal were achieved by utilizing a Submersible Transfer Pump (STP) [Figure 3]. The submersible pump is a 15 HP, 460VAC, 3450 RPM, 950 liters/minute (250 gpm), Tsurumi single-stage, centrifugal pump that has the capability of being located at any elevation within the primary tank. The Tank 6 STP during MSR was placed as close to the Waste Tank Floor as possible to achieve a liquid level after transfer of < 7.6 cm (3 inches). To filter out large sludge particles, the pump suction is screened to prevent clogging within the cooling channel for the motor. The pump discharges into a pipe-inside-a-pipe assembly. The pump is connected to a 10.2 cm (4 inch) discharge pipe that overlaps a 7.6 cm (3 inch) pipe connected to a stationary discharge valve manifold in the riser. In addition, the submersible transfer pump is located inside a 56 cm (22 inch) diameter sleeve pipe (Caisson) that has been inserted into the tank and rests on the tank floor. The 56 cm (22 inch) diameter caisson was required to protect the STP from direct discharge from the SMP or falling debris created by impact of the SMP on other equipment. The 56 cm (22 inch) diameter pipe rests on three spacer legs [19 cm (7.5 inch) clearance] that are designed to allow the caisson to straddle interferences on the tank bottom while still resting on the bottom of the tank.

### Mechanical Sludge Removal Process

The first step in each mechanical sludge removal phase was to transfer supernate (liquid waste) into Tank 6 to a level of approximately 3 meters (120 inches). Supernate was used as the slurry media to minimize the amount of water added to the tank farm. Tank storage space in the tank farms was very limited. The liquid level was raised to 3 meters (120 inches) to cover the SMP weep holes so that the cooling/lubricating liquid was not discharged into the tank vapor space. Experience showed that the

HEPA filters in the tank ventilation system became moisture-loaded when the liquid was discharged from the weep holes into the tank vapor space. The second step in the cleaning phase was to operate the two SMPs to mix the tank contents. The SMPs were operated in either index mode or oscillation mode. The purpose of the indexing mode was to aim the stationary SMP discharge jets at the mounds of sludge for the purpose of eroding and moving the sludge solids. The purpose of the oscillating mode was to put the solids in suspension to create a slurry for eventual transfer out of the tank.

After mixing the contents of the tank, the slurry was transferred out of the tank using the STP. During the transfer, the SMPs continued to operate as long as possible to keep as many solids suspended in the slurry. The SMP speed was reduced when the liquid level was approximately 1.2 meters (4 feet), and they were stopped when the liquid level was approximately .9 meters (3 feet) prior to nozzle exposure to prevent waste aerosolization. The STP was operated at maximum speed until a tank level of approximately 10.2 cm (4 inches) when the speed was reduced to prevent cavitation. The transfer continued until the STP lost prime at approximately 7.6 cm (3 inches).

The configuration of the residual sludge following each cleaning phase was used to trend sludge removal progress. Sludge mapping was performed via FTF Closure Engineering, operations personnel and the FTF facility surveillance and monitoring organization. Sludge mapping typically began at a liquid level of approximately 71 cm (28 inches). Camera inspections to support sludge mapping were conducted from Risers 2, 5, 7, and Center. As the slurry was transferred out of the tank, exposed solids were mapped corresponding to the liquid level from a radar level transmitter. Sludge mapping consisted of hand-drawing a field sketch contour map of the exposed solids. The field sketch was then converted to a computer program grid topography map. Each grid square of the computer program topography map corresponded to .1 square meter (one square foot) of tank floor area. The summation of the heights of sludge in each grid was used to calculate the volume of sludge remaining after each cleaning cycle. The remaining sludge volumes after each cleaning phase are shown in Figure 4.

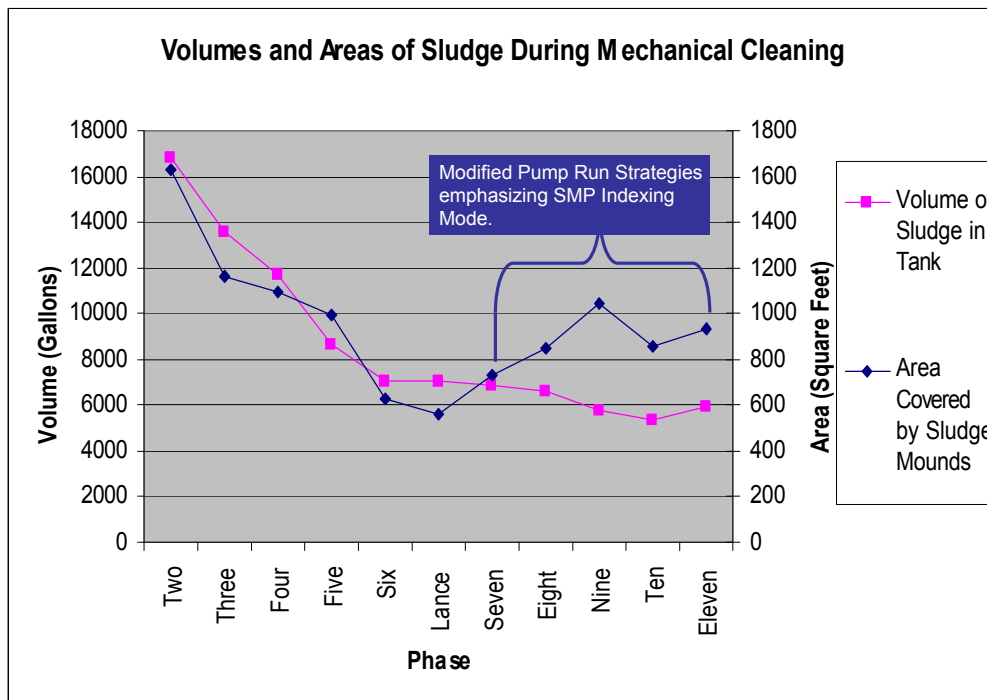


Figure 4 – Remaining Sludge Volumes



The configuration of the remaining sludge was evaluated to determine the mixer operational strategy for the cleaning phase. Solids were allowed to settle in the receipt tank (Tank 7), and then supernate was transferred from Tank 7 back into Tank 6 to be reused as the slurry media for the next cleaning phase. In addition to the mechanical sludge removal phases, water lancing was performed in the southwest region of Tank 6 for the purpose of dislodging the sludge mound and moving the sludge to regions of the tank that could be impacted more effectively by the SMPs. The sludge was effectively moved by the water lance leaving an approximately 2.4 meter (8-foot) diameter area with no visible sludge. However, subsequent mixer operations moved much of the sludge back to the southwest region of the tank. There was not a significant increase in sludge removal effectiveness during subsequent sludge removal phases following water lancing.

### **Lesson Learned**

During the course of Tank 6 Mechanical Sludge Removal, much was learned about the process that may benefit other sites. The following are the more significant lessons learned.

The operation of two SMPs became less effective during the later part of the Mechanical Sludge Removal (MSR) campaign. Due to the large maze of waste tank cooling coils and tank column supports, the SMP Effective Cleaning Radius (ECR) was reduced from 15.2 meters (50 feet), the design and tested ECR, to approximately 7.0 meters (23 feet). With this 50% reduction in the ECR, the sludge removal process became more difficult as more waste was removed. Eleven cleaning phases were performed in Tank 6 with an average of approximately 11,400 liters (3,000 gallons) of sludge being removed through phase six when approximately 26,500 liters (7,000 gallons) remained. After the completion of phase six, the average sludge retrieval rate reduced to approximately 760 liters (200 gallons) per cleaning phase.

With these issues that caused reduction in the ECR, pump run strategies were modified to compensate for the migration of sludge into unaffected areas of the primary tank. The oscillation/indexing mode runtime strategies were 70% and 30% respectively of the SMP run total hours during the initial phases; however, during sludge mapping activities, evidence showed oscillating runs resulted in a “pushing” effect of the material over time rather than mixing. As a result, pump run strategies were adjusted to emphasize indexing operations which had greater success at dislodging more material for removal. The most effective strategy to disperse the sludge mounds was to aim (index) a discharge jet of one SMP at the mound while the other SMP oscillated. When both SMP jets were aimed at a mound, the force of the jets seemed to cancel out each other, resulting in less movement of the sludge.

In addition, pump run hours were reduced based on evaluations of sludge material removed vs. SMP run time data. Initially, SMPs were operated for over 300 hours to suspend the sludge prior to initiating a transfer of the slurry out of the tanks. However, later cleaning phases in Tank 6 indicated that shorter mixing durations of approximately 60 hours were as effective as cleaning phases with 300-hour mixer run times.

With these strategy changes, data showed the sludge material continued to be removed at a rate of approximately 760 liters (200 gallons) per phase; however, the material was being spread more evenly over the primary tank floor as shown in Figure 4.

Waste tank cooling coils posed another obstruction issue for Mechanical Sludge Removal in Tank 5. Based on operating experience in Tank 6, the decision was made to install a third SMP in Tank 5 to improve the efficiency of sludge removal. A review of construction drawings and historical engineering technical documents indicated that supply/return piping to the cooling coils was field run near the tank floor. The field routes were not documented on as-built drawings, so visual inspections of the conditions under the SMP risers were performed. The inspections indicated that installation of the third SMP would be hindered by an array of cooling coils that extended (5 feet) above the tank floor directly under the riser. In order for the third SMP to be installed as designed and to achieve maximum ECR capability, sections of the cooling coils would have to be removed. The risk vs. benefit of removing the cooling coil sections was evaluated by FTF Closure Engineering and the project team. Radiological hazards were a concern. However, FTF Closure Engineering and Construction Engineering researched hydraulic cutting tool

technology and designed a remote, hydraulic cooling coil cutting device. Utilizing well-planned ALARA techniques as well as interference lessons learned from Tank 6 Mechanical Sludge Removal during installation of SMPs, the cooling coil cutter was successfully operated to cut and relocate cut coil sections away from the SMP risers.

## CONCLUSIONS

The FTF Closure Projects has successfully performed Mechanical Sludge Removal using the Waste on Wheels (WOW) system for the first time to complete the initial step of the tank closure process for Tank 6. Approximately 75% of the original sludge waste volume was removed from July 2006 to August 2007. Sludge removal during the latter phases became exponentially more difficult as less and less sludge was available to mobilize and cooling coils and column supports presented obstructions. To compensate for the waste migration and loss of ECR efficiency, SMP operations were modified to perform more Indexing operations to provide a more dislodging effect during the last five phases.

Cooling Coil obstruction lessons learned were successfully applied by designing, constructing and utilizing a cooling coil cutter to assist with SMP installation. The lessons learned from Tank 6 will be applied to the Tank 5 Mechanical Sludge Removal process.

## REFERENCES

- 1.) *Federal Facility Agreement For The Savannah River Site*, WSRC-OS-94-42, August, 1993.
- 2.) H.Q. Tran, *Projected F-Tanks Radionuclide Concentrations at Closure*, LWO-PIT-2006-00069, Revision 0, April 17, 2007.