Waste on Wheels Bulk Waste Retrieval System
A Program for Accelerating Waste Removal from Savannah River Waste Tanks

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ABSTRACT

Retrieval of High Level Waste (HLW) from Savannah River Site (SRS) tanks is performed to support closure of the tanks as required by the Federal Facilities Agreement and to support vitrification of HLW as required by the Site Treatment Plan. SRS retrieves the waste in two phases: bulk waste removal and heel removal. The project cost of bulk waste removal was about $20 million per tank and required about 42 months to complete before the actual waste removal operation could begin. The bulk waste removal operation typically removes sludge down to the last 10,000 gallons (about 3 inches in SRS tanks). Given that there are 49 tanks at SRS and that the budget is shrinking, there was a strong financial driver to reduce the cost of bulk waste removal.

The previously used method for bulk waste removal was to install four slurry pumps with a capacity of 1,200 GPM per pump. Each pump location required about $2.5 million of new infrastructure. Each pump also had a service life of about 2,000 hours, thus the pumps were at the end of their useful life after use in one tank.

To reduce the cost and make a step change improvement in the bulk waste removal phase, SRS completed an extensive Systems Engineering Evaluation in 2003 that resulted in a recommendation to develop an advanced design slurry pump with the following attributes:

- 10,000 hour service life
- effective cleaning radius of 50 feet in typical SRS sludge
- fit through a 24 inch diameter riser
- be supported by the tank floor or a tanktop platform

The new approach and advanced pump design was envisioned to produce the highest performance pump ever deployed in an SRS waste tank allowing the tanks to be cleaned with two pumps instead of the customary four. The contract for four pumps was awarded to Curtiss-Wright Electro-Mechanical Corporation (EMD). Four pumps have since been deployed in two tanks and are staged to start in two more. A second order for four more pumps has been placed with EMD. The pumps are being assembled for delivery starting in October 2006 with initial deployment scheduled for the third quarter of 2007.

The purpose of this paper is to present the unique design of the pumps, the performance of the pumps during testing, how the pumps performed during initial waste retrieval campaigns in two SRS tanks, and identify the projected cost and schedule savings achievable with SRS's novel "Waste on Wheels" bulk waste retrieval system.

INTRODUCTION

The Savannah River Site (SRS) is owned by the United States Department of Energy (DOE) and is currently operated and managed by the Washington Savannah River Company (WSRC). Since beginning operations in the early 1950s, uranium and plutonium recovery processes have generated about 120 million gallons of liquid high-level radioactive waste that has been volume reduced via evaporation to about 36 million gallons.

This waste is stored in heavily shielded underground carbon steel storage tanks in two tank farms located in the central portion of the site. The F-Area Tank Farm is located on 22 acres and consists of 22 HLW tanks and two evaporators, one of which is shut down. The H-Area Tank Farm is located on 45 acres and consists of 29 HLW tanks and three evaporators, one of which is shut down. The tanks are interconnected via an extensive underground shielded transfer system such that any one tank can be transferred to any other tank in either tank farm.

The 51 tanks at SRS were built using four different designs. The four designs are known as Type I, II, III and IV. Only the Type III tanks meet all current regulatory standards. The Type I, II and IV tanks do not meet standards for full secondary containment and are therefore subject to a closure schedule as outlined in the Federal Facilities Agreement (FFA). All SRS HLW tanks employ a flat bottom design. The tanks range in volume from 750,000 to 1,300,000 gallons, in diameter from 75 feet to 85 feet, and in height from 24.5 feet to 34.25 feet. All but eight of the tanks have a 2.5 foot wide annulus with a secondary tank or pan to contain leaks. The primary tank has interior roof support columns and an extensive system of horizontal and vertical cooling coils. Each tank has at least six access risers two feet in diameter or larger. Eleven of the tanks have leaked waste into the annulus, although none of the newer fully compliant tanks have leaked. The tanks leaked due to nitrate induced stress corrosion cracking.

SRS WASTE DESCRIPTION

General

In the past, SRS fabricated and irradiated aluminum clad fuel assemblies and targets. These were dissolved in the two "Canyon" chemical separation facilities to recover uranium, plutonium and other radioactive isotopes of interest. The remaining materials, consisting of fission products and dissolved metals, were of no value and were therefore discarded as HLW. This acidic waste stream was neutralized with sodium hydroxide to prevent corrosion of the carbon steel waste tanks. Neutralization of the waste causes the formation of insoluble precipitates (sludge) that settle to the bottom of the SRS HLW tanks and a supernatant liquid consisting of sodium salts. After evaporation of the supernate, the waste is stored in one of three physical forms: sludge, saltcake, and concentrated supernate that is primarily a caustic liquor. Throughout its history, SRS has made a concerted effort to segregate salt and sludge in the HLW tanks. At the time of this paper, the SRS HLW tanks contained about 36,000,000 gallons of waste and about 426,000,000 Curies of radioactivity.

Sludge

Sludge consists of stable and radioactive fission products, actinide elements, and other elements added in the separation processes. The principle insoluble constituents of sludge are the oxides and hydroxides of iron, aluminum and manganese. As the waste ages and cools, these insoluble components settle to the tank bottom. Sludge layers accumulated in SRS tanks vary from a few inches thick to over 60 inches. The sludge contains sufficient fission product inventory to cause boiling if the temperature is not managed.

The physical properties of SRS sludge have been measured using actual sludge samples as well as sludge simulants. SRS sludge behaves as a non-Newtonian fluid. Analysis of flow curves suggests that the sludge slurries can best be characterized as a Bingham plastic with a fairly well defined yield stress. Once the yield stress is exceeded, the material flows much like a Newtonian fluid. Measurements of yield stress and consistency (or apparent viscosity) have been obtained as a function of weight percent solids. In general, SRS sludge slurries exhibit a yield stress of between 10 and 300 dynes/cm^2 and a consistency of between 3 and 70 centipoise, depending on weight percent solids. The volume of sludge generated since the start of operations in the 1950s is estimated to be about 3,000,000 gallons of settled sludge, about 8% of the total SRS inventory. Sludge contains about 203,000,000 Curies of radioactivity or 48% of the total SRS inventory.

Salt

The supernatant liquid above the settled sludge layer consists primarily of soluble sodium salts and radioactive components (e.g., cesium nitrate). This supernate is volume reduced to about 30% of its original volume via evaporation. The evaporator bottoms are transferred to salt receipt tanks where the sodium salts, primarily sodium nitrate and sodium nitrite, precipitate as salt cake while the concentrated sodium hydroxide remains as a liquid. Cs-137 remains in the concentrated supernate and is the primary radionuclide associated with the salt. Virtually all of the insoluble material is partitioned with the sludge, however, a small amount is inadvertently carried over into the salt. This is estimated to be about 2 volume %. The amount of supernate generated since the start of operations in the 1950s is estimated to be about 120,000,000 gallons. This has been volume reduced via evaporation to about 33,000,000 gallons of saltcake and concentrated supernate, about 92% of the total SRS inventory. Salt contains about 223,000,000 Curies of radioactivity or 52% of the total SRS inventory.

WASTE RETRIEVAL DRIVERS

Federal Facilities Agreement

The SRS Federal Facility Agreement (FFA) was executed in 1993 by the DOE and State and Federal agencies. The FFA provides standards for secondary containment, for responding to leaks, and provision for removal from service of leaking or non-compliant HLW tanks. Tanks scheduled to be removed from service may continue to be used but must adhere to a schedule for removal from service and closure. A revised “F/H Area HLW Removal Plan and Schedule” was submitted to the Regulators in 2002. The schedule provides end dates for the operational closure of each non-compliant tank and commits SRS to close the last non-compliant tank no later than FY22.

Site Treatment Plan

The SRS Site Treatment Plan (STP) describes the development of treatment capacities and technologies for mixed waste. This allows DOE, regulatory agencies, the States, and other stakeholders to efficiently plan mixed waste treatment and disposal by considering waste volumes and treatment capacities on a national scale. The STP requires that SRS submit a schedule for processing backlogged and currently generated waste via the Defense Waste Processing Facility (DWPF). In addition, SRS has committed that:

> "Upon beginning full operations, DWPF will maintain canister production sufficient to meet the commitment for removal of the backlogged and currently generated waste inventory by 2028."

Thus the FFA and STP constitute two different but very important legal and regulatory drivers to complete waste removal from the SRS HLW tanks by no later than 2028.

HISTORY OF WASTE REMOVAL AT SRS

Sluicing

SRS removed the sludge from seven HLW tanks using a high pressure sluicing system during the late 1960s. This campaign served two purposes: (1) to remove the sludge such that these tanks could then begin service as salt tanks, and (2) to demonstrate sludge removal in support of the bedrock storage program where the sludge was planned to be pumped underground into the underlying bedrock for final waste disposition. The sluicers consisted of two opposed 0.25 inch diameter nozzles rotated continuously at 1/5 rpm on a mast extending from the tank floor to above the tank top. A supply of fresh water is pumped through the nozzles at 2,800 to 3,000 psig which delivered about 100 gpm per nozzle. With this arrangement, an effective cleaning radius for SRS sludge of 20 feet was observed. The slurried sludge tended to return to the sluicer mast thus a transfer pump was mounted on each mast. The mast also served as the discharge pipe for the transfer pump. The transfer pump suction was positioned about 6 inches above the tank floor with the high pressure nozzles about two inches below. Four of these sluicer/transfer pump assemblies were deployed in each tank. For the operation, the high pressure sluicers were started at 500 psig. This pressure was increased in 500 psig increments every hour. The transfer pumps were started ten minutes after sluicer startup. The liquid level in the tank was maintained stable for the first three hours of operation and then lowered as the volume of sludge in the tank was reduced. After about five hours of operation, the sluicers were shut down and all but one transfer pump. This pump was lowered to the tank bottom while still operating to get the overall tank level as low as possible.

The overall operation required about 6 hours per tank after several months of equipment installation. The residual sludge level was one to two inches. The water added to sludge removed ratio averaged about 5:1. At the time, this was thought to be excessive thus additional technology demonstrations were planned.

Mechanical Agitation

This demonstration took place in Tank 16H during the early 1980s. Four slurry pumps were used in five different risers to remove most of the sludge from the tank. Each pump operated at 1,200 gpm through two opposed discharge nozzles. These pumps fit through a 24 inch diameter riser. The pumps were rotated at about 1/5 rpm. The pumps were 45 feet tall with an internal shaft connecting the motor above the tank top to the pump impeller at the bottom of the pump column. The shaft was supported by bearings every five feet along the shaft and lubricated by filling the column with bearing water (a very dilute solution of water and sodium nitrite/sodium hydroxide). Bearing water leaked into the tank via the top and bottom bearings during pump operation. The sludge removed to water added ratio was improved to about 3:1 which was slightly better than sluicing but much of this improvement was consumed by the bearing water leakage. Slurry pumps also had a tendency to fail after about 1,500 hours of operation. The failure mechanism was failure of the bottom bearing such that the bearing water leak rate became unacceptably high. The failure was thought to arise from excessive vibration caused by shaft alignment, bent shafts, etc.

Density Gradient

At this point in the SRS waste removal history, the focus shifted from sludge removal to salt removal. Because salt is soluble, other than the small fraction of insoluble material that is inadvertently carried over into the salt, it was thought that much less agitation would be required as compared to sludge removal. A process referred to as Density Gradient was therefore demonstrated in Tank 19F during 1980-1981. This process involved mining a shaft through the saltcake down to the tank bottom. A 10 gpm transfer jet was then placed in the bottom of the well. Fresh water was then added to the tank to cover all exposed salt. Then the transfer jet was started simultaneously with the addition of 10 gpm water. As the salt dissolved, the denser solution migrated to the bottom of the well where it was jetted out of the tank. This process was operated in a continuous fashion as long as the dense salt solution being removed from the tank was near saturation. This process worked well for most of the tank, however, insoluble material tended to settle on the salt surface as the surrounding salt was dissolved and thus reduced the dissolution rate to unacceptably low rates.

At the same time as the Density Gradient demonstration in Tank 19F was in progress, a Mechanical Agitation demonstration was conducted in an adjacent tank, Tank 20F. Two of the Tank 16H generation slurry pumps were installed. These pumps provided a rapid dissolution rate as well as enough agitation to sweep away insoluble material from the salt surface. At the end of these demonstrations, it was decided to use slurry pumps for both salt and sludge removal with the baseline of four pumps for each sludge tank and two pumps for each salt tank.

Mechanical Seals

The issue of bearing water leakage from the slurry pumps remained until the late 1980s when mechanical seals were developed and deployed on the slurry pumps in Tank 42H. These seals were fitted to the top and bottom of the pump column to significantly reduce bearing water leakage. The leak rate was reduced from gallons per minute per pump to cubic centimeters per minute per pump.

Tilt Pad Bearings

The standard slurry pump design was further improved by the replacement of the internal shaft support bushings with tilt pad bearings. This was first demonstrated in Tank 7F in the late 1990s and then repeated on Tank 11H in the early 2000s. Both sets of pumps have accumulated about 4,000 operating hours without failure of the lower seal.

Quad Volute Slurry Pumps

These pumps were developed for sludge washing applications where several hundred thousand gallon batches of sludge are water washed to remove soluble salts prior to vitrification. These pumps use a 300 horsepower motor, fit through a 36 inch riser, and operate at 5,000 gpm via two opposed discharge nozzles. These pumps are operated intermittently during the batch washing process and have lasted several years while accumulating about 4,000 hours of operation.

Advanced Design Mixer Pump (ADMP)

This pump was developed jointly by Hanford and SRS. One prototype was built and extensively tested for over 2,200 hours at the SRS test tank. In the late 1990s, the pump was refurbished and installed in the center riser of Tank 18F (an 85 foot diameter tank with no cooling coils). The ADMP uses a 300 horsepower motor, operates at 10,400 gpm through two opposed discharge nozzles and fits through a 39 inch diameter riser. Tank 18F started with 42,000 gallons of sludge and the sludge volume was reduced to 4,000 gallons via six waste removal batches. The ADMP accumulated about 2,000 hours of operating time and was still operating at the end of the Tank 18F waste removal campaign.

Cost History

There are six steps or phases associated with taking a waste tank from an operational status to a closed status as shown below in Table I. The cost range for each phase is also shown. The high and low ends of each range depend on the size of the tank, the nature of the waste, and other physical properties specific to each tank.

Table I – Cost History of SRS HLW Tank Closure

	Project Cost ($ x 1,000,000)	
Phase	**Low**	**High**
Bulk waste removal	12	21
Mechanical heel removal	1	5
Chemical heel removal	3	6
Water washing	1	1
Annulus cleaning	0	3
Isolation	1	1
Grouting	4	5
Total	**22**	**42**

As the above table indicates, the major cost is the bulk waste removal phase. The high range is driven by the sludge tanks which require much more equipment than salt dissolution. There are currently 14 tanks that are in the waste retrieval phase as well as 35 tanks that have not started the waste retrieval process. Given the above estimate range, it can be concluded that there is “to go” waste retrieval cost of over $1 billion.

SYSTEMS ENGINEERING EVALUATION

Given the previous discussion, there was a significant driver for re-evaluating waste retrieval technologies and techniques given the potential for change in regulatory requirements and the significant “to go” costs. With this in mind, a comprehensive Systems Engineering Evaluation (SEE) was initiated in 2002 and completed in 2003. The SEE made specific recommendations for each phase of waste removal and tank closure, however, this paper focuses on the recommendations for bulk waste removal as that is the major cost element. The SEE recommended a Submersible Mixer Pump (SMP) (Guardiani, et. al., US Patent 5 674 057, 1997) for this application. The factors leading to this recommendation were:

- Typical slurry pumps require a bearing water system to provide lubrication to the pump shaft, the SMP uses the waste it is pumping for cooling and lubrication;
- Typical slurry pumps require supporting steel structures to distribute the pump weight on the tank top, the SMP is a floor mounted pump that requires no steel supports;
- Slurry pumps have a 45 foot long shaft that is very difficult to align and balance, thus vibration eventually destroys the mechanical seals and/or internal support bearings; the SMP has no shaft as the impeller is mounted directly to the rotor;
- The typical slurry pump has an effective cleaning radius in SRS sludge of about 25 feet, the SMP has an effective cleaning radius of up to 50 feet thus two or three SMPs can do the work of four standard slurry pumps;
- The typical slurry pump can fit through a 24 inch diameter riser however the larger slurry pumps that have an effective cleaning radius similar to the SMP require a 36 inch diameter riser, the SMP will fit through a 24 inch riser;
- The slurry pump column has several sets of bolted flanges and other fittings that render the pumps difficult to decontaminate, the SMP has a smooth finish with virtually no exposed fittings and is very easy to clean and move to a second tank; and
- The life expectancy of a typical slurry pump is less than 2,000 hours thus it is consumed by the end of a waste retrieval campaign in one tank, the SMP is designed to last 10,000 hours thus it can be used on five different bulk waste retrieval campaigns before it reaches the end of its design life.

A Request for Proposal was sent to several pump suppliers to provide a pump with the attributes listed above. Ultimately, the contract was awarded to Curtiss-Wright Electro-Mechanical Division in 2004.

SUBMERSIBLE MIXER PUMP DESIGN AND TESTING

The basis for the design development of an advanced technology slurry pump, referred to as a Submersible Mixer Pump (SMP), to support the “Waste-on Wheels” bulk waste removal concept was basically dictated by three requirements which forced the design beyond the technologies employed in slurry pumps to that point. The pump needed to be hydraulically “power dense” to achieve a cleaning radius adequate to allow the tanks to be emptied using only two slurry pumps, instead of four, while maintaining a 22.5-inch overall insertion diameter. This insertion size would allow the pumps to be installed into any of four tank types on the SRS. The requirement for 10,000 hours of operational service life prevented the use of several of the design features standard in the existing slurry pump designs including mechanical shaft seals, line shaft drive systems used to couple a submerged impeller to a motor mounted above the tank riser, and the selection of materials to withstand the overall radiation exposure (approximately $1x10^{10}$ rads) associated with being installed in a waste tank for 10 years. And finally, the design was developed to meet the requirement for the pump to be moved from tank-to-tank and to be mounted in a variety of different configurations.

SMP System Design

The SMP was designed to operate in the high dose radiation process fluid for a minimum of 10,000 hours of intermittent operation at 100% rated capacity with minimal or no maintenance. Materials used in the SMP design were selected based on ten years of total exposure inside the waste tank environment. The tank and process fluid parameters considered for the design of the SMP are summarized in Table II.

Table II – SMP Operating Environment

	Minimum	**Rated**	**Maximum**
Temperature:			
a) Operating (process fluid)	20 °C	75 °C	75 °C
b) Ambient (tank air)	20 °C	105 °C	105 °C
Specific Gravity	1.0	1.25	1.5
Viscosity (μ)	3 cP	20 cP	50 cP
pH	7	- - -	14
Weight Percent Solids	0	- - -	17
Yield Stress	10 $dynes/cm^2$	- - -	300 $dynes/cm^2$
Radiation Rate:			
a) Process Fluid	- - -	$1X10^9$ rads/yr	- - -
b) Vapor Space	- - -	$1X10^8$ rads/yr	- - -

Due to the desire to move the SMPs from tank-to-tank, consideration was given to the ease and effectiveness of decontamination of the unit after it has been in service in a waste tank. Along these lines, the hydraulics and internal motor components were designed to be self-draining with minimal internal waste retention. The internal motor/pump assembly is also equipped with a flush line which allows the internal surfaces of the motor and hydraulic components to be washed down prior to removal. In addition, all external surfaces of the SMP which contacts the process fluid are processed to achieve a 125 μ-inch surface finish and the number of external features has been kept to a minimum to facilitate external decontamination.

The basic operational arrangement of the SMP requires the insertion of the pump down through a riser opening into the underground waste tanks which are approximately 40 feet deep. To accomplish this, the motor/pump assembly is attached to a length of structural piping which allows the SMP to be inserted all the way to the tank floor. In addition to providing the structural attachment for the motor/pump assembly, the column houses all of the motor wiring and the piping associated with the flush system. Again, this internal routing arrangement helps to minimize external features.

The SMP, as shown in Figure 1, is designed to be used in a variety of different waste tank configurations including two unique mounting arrangements – resting on the tank floor or suspended from the tank riser above the tank floor. To rest the SMP on the tank floor, while allowing it to be rotated during operation so that the discharge jets "sweep" the entire tank floor, the bottom of SMP screen is fitted with a mounting foot. This foot supports the entire weight of the SMP, provides capability for angular misalignment to the tank floor and serves as the bearing interface that allows the entire SMP assembly to be rotated while the foot stays stationary on the tank floor.

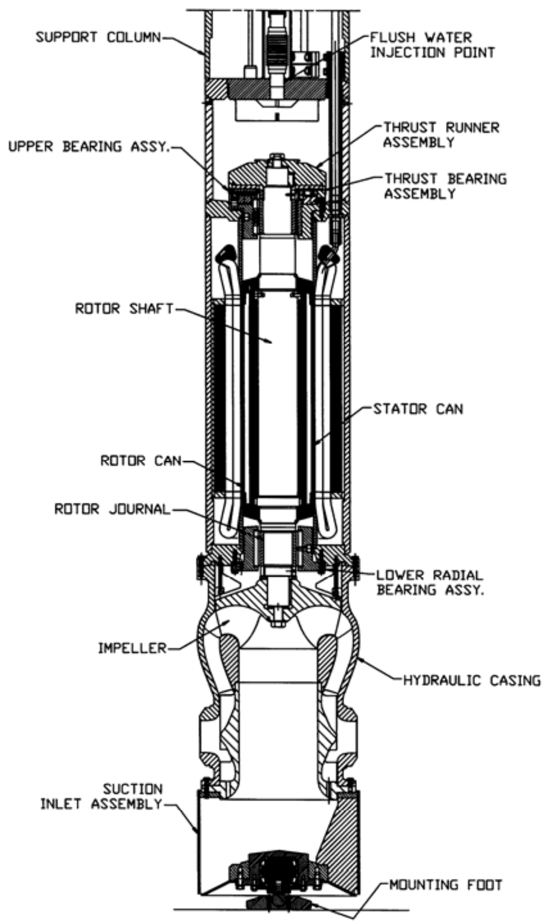

Figure 1 – SMP motor/pump arrangement

Hydraulic Design

To mobilize the high density solids (sludge) settled on the bottom of the waste tanks using only two slurry pumps, an effective cleaning radius of 50 feet is required. Translated into hydraulic requirements for the SMP, a nozzle discharge coefficient, U_0D (product of the average nozzle exit velocity and the nozzle diameter) of 29.0 ft^2/s is needed based on the properties of typical sludge found in the tanks at SRS. Further, this performance was required across the range of fluid viscosities (3 to 50 cP) and specific gravities (1.0 to 1.5) of potential process fluid.

Assuming the slurry pump to have two 4.4-inch diameter discharge nozzles, the required average exit velocity and flow rate is calculated to be:

$$U_0 \text{(average velocity)} = \frac{(29.0\,\text{ft}^2/\text{s})}{\frac{4.4\,\text{in}}{12\,\text{in/ft}}} = 79.1\,\text{ft/s} \qquad \text{(Eq. 1)}$$

$$Q\text{(flowrate)} = AU_0 = \frac{\pi}{4}\left[\frac{4.4\,\text{in}}{12\,\text{in/ft}}\right]^2 (79.1\,\text{ft/s}) = 8.35\frac{\text{ft}^3}{\text{s}} \qquad \text{(Eq. 2)}$$

$$= 3{,}748\,\text{GPM per nozzle} = 7{,}496\ \text{GPM total}$$

To meet these requirements while maintaining the 22.5-inch overall diameter, a conventional tangential or radial discharge casing could not be used. Instead, a bottom suction, single stage hydraulic design with a centrifugal impeller, diffuser and a casing with two, radially opposed, horizontal discharge nozzles was developed as shown in Figure 2.

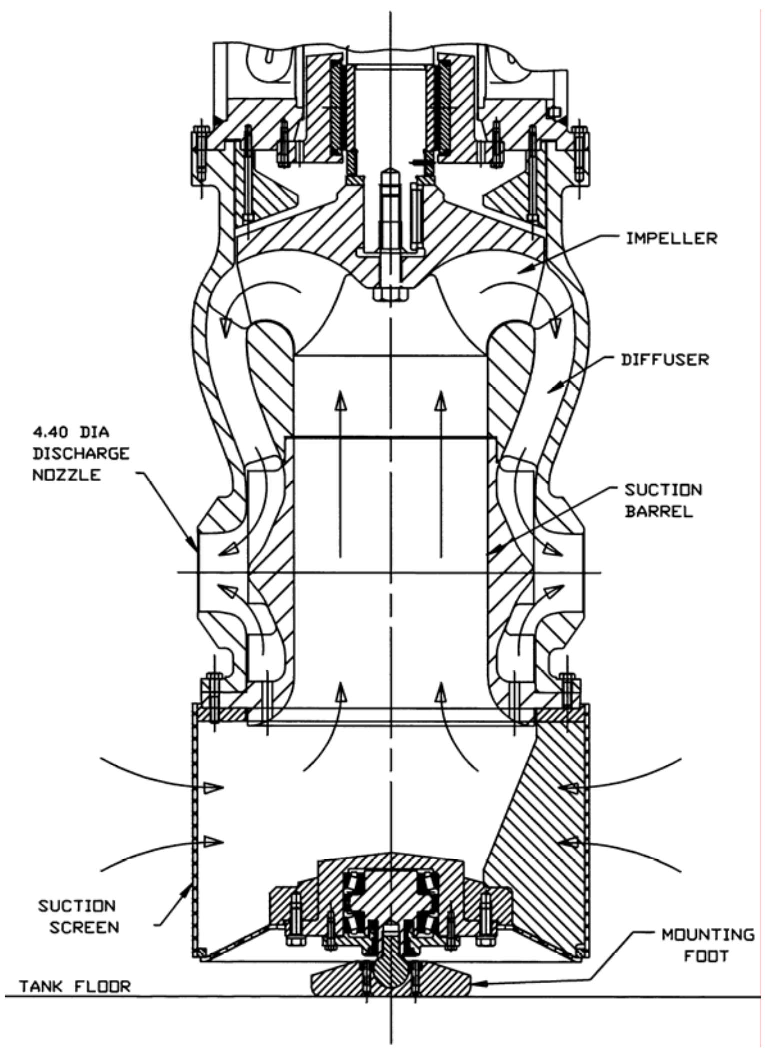

Figure 2 – SMP Hydraulic Configuration

With this arrangement, the process fluid is drawn in through an inlet suction screen and then vertically upward into a suction barrel with a contoured bell-mouth entrance into the impeller. From the impeller, the fluid is discharged radially outward with a slight downward bias to assist in reducing turning losses and to maintain the 22.5-inch diameter. Immediately downstream of the impeller, the hydraulic casing directs the fluid downward into the inlet of the diffuser section, where equally spaced vanes condition the flow into a more axial direction and the flow velocities are reduced prior to entering the casing-nozzle area.

The flow is then split and guided toward each of the two discharge nozzles in such a way as to balance the flow uniformly around the circumference of the nozzles. This results in a cancellation of flow momentum except that which is oriented directed outward from the nozzle, thus forming a well-developed, cohesive jet without tendency toward rotation or bias either up-down or side-to-side. To further the jet development, a contoured protrusion on the inner diameter of the annular space directs the flow from the vertical direction out, horizontally through the nozzles. The fluid then exits the casing though nozzle extensions which complete the formation of the discharge jets.

To develop the required hydraulic contours and confirm the hydraulic performance, Computational Fluid Dynamics (CFD) analysis was performed on the entire pump system including the jet/tank interface to demonstrate the cohesiveness of the jets emanating from the nozzles and their penetration into the tank volume. The results were used to characterize the jets by predicting direction, swirl, bias and dissipation rate as the jet traverses the tank as shown in Figure 3.

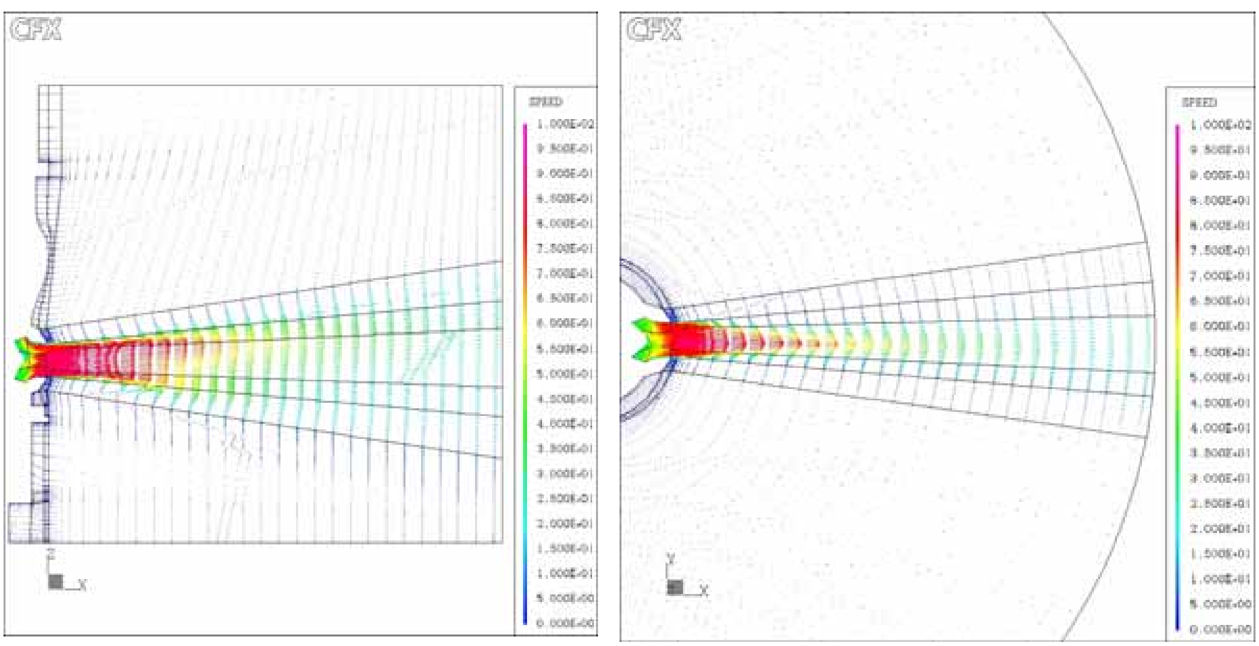

Figure 3 – CFD results for jet/tank interface

With the relatively high losses associated with the aggressive turning and conditioning of the flow leaving the impeller and toward the formation of the discharge jets, it was determined that the impeller needed to develop approximately 115 ft of head. This, along with required flow rate of 7,496 GPM, established the operating speed and impeller brake horsepower at maximum viscosity (50 cP) and specific gravity (1.5) to be 1,400 RPM and 305 HP, respectively. To accommodate the solids anticipated to be encountered during operation and to provide maximum self-draining capability, an open impeller was designed.

Another key consideration of the hydraulic design was to minimize submergence requirements in order to allow the SMP to operate as long as possible during waste tank pump-down. The optimized submergence of the impeller, along with the ability to reduce the operating speed of the pump via the variable frequency drive, allows the SMP to be used at low tank levels. The hydraulic design alone results in a suction lift condition at full speed at most operating conditions.

Motor Design

To meet the speed and torque requirements established by the hydraulic analysis, a 305 HP, 460 V, 4-pole, squirrel cage, submersible, canned induction motor was developed. The motor was designed to operate on variable frequency, 3-phase power, which allows the speed of the SMP to be adjusted between 400 and 1400 RPM to offer maximum operational flexibility and allows the SMP to be operated at a reduced speed while the tank level is lowered during waste transfer.

The motor is similar to a conventional squirrel cage induction machine with the exception that both the rotor and stator assemblies are hermetically sealed using .025 inch thick welded Hastelloy cans. These cans allow the process fluid to be used for both motor cooling and bearing lubrication while not penetrating the motor internals.

The insulating materials used in the SMP motor conform to a class ‘N’ insulation system and allows for normal, continuous operating temperatures up to 200 °C with allowable excursions above this. The materials were chosen based on their suitability for the radiation exposure levels expected for 10 years service in a waste tank without detrimental degradation.

The internal circulation of process fluid through the motor is established by the pressure developed by the impeller, where a small percentage of the overall impeller flow (approximately 80 GPM) is drawn from the main process flow and is directed through an annular gap around the impeller and up through the motor. The fluid is then divided into two paths through the lower radial bearing with the largest portion of the fluid passing through the bearings and a lesser portion passing through two bypass holes in the bearing housing. The two flow paths then rejoin in the lower rotor cavity and pass through the annular gap between the non-rotating stator can and the rotating can on the rotor assembly. This is the region where the majority of the heat developed in the motor is transferred to the process fluid. The fluid then passes through the upper radial bearing and then radially outward through the thrust bearing into a large cavity above the rotor where it is ejected directly back into the waste tank through two discharge holes.

This motor cooling and lubricating arrangement allows the motor to be situated immediately adjacent to the hydraulics with the impeller mounted directly on the rotor shaft cantilevered only 6 inches from the lower radial bearing. The resulting short-shafted configuration offers excellent rotor dynamic stability and reduced bearing loads over the entire operating range compared to traditional long-shaft pumps. And because the process fluid is deliberately introduced into the motor, which is hermetically isolated, no mechanical shaft seal is required thus eliminating both of the primary sources of failure of the traditional long-shaft style slurry pumps.

Bearing Design

Two radial bearings and a single axial thrust bearing support the rotor assembly in the motor. Each bearing is a hydrodynamic, process fluid lubricated, fluid film type design. To withstand the abrasivity of the solids encountered in the waste tanks (primarily various oxide and hydroxide forms of iron, manganese, aluminum, calcium, nickel, uranium and plutonium along with zeolite) all of the running surfaces of the bearings are made of silicon carbide.

The upper and lower radial bearing assemblies each have four silicon carbide inserts (pads) retained in stainless steel holders. Each pad is independently self-adjusting to accommodate misalignment with the mating silicon carbide rotor journals that are secured to the rotor assembly. The four pads are secured in a rigid housing that encapsulates the pads and serves as the structural interface between the bearings and the stator assembly. To allow the radial bearings to operate in the range of viscosities required, including the worst case scenario of testing in water with a viscosity of .38 cP, each radial bearing pad is preloaded. To accomplish this preload, the effective diameter of the pads is manufactured slightly larger than the mating journal diameter. This creates a "wedge" at the entrance of each pad which aids in developing and maintaining the fluid film.

A single-acting thrust bearing is integrated into the upper radial bearing housing as shown in Figure 4. It is a six-shoe Kingsbury type design with silicon carbide inserts which run against a solid, silicon carbide plate which is fitted and keyed to the top of the rotor assembly in a thrust runner assembly. The pad assemblies are load self-equalizing to accommodate any misalignment of the mating components during operation while maintaining uniform load across all six pads. Similar to the preloading on the radial bearing pads, each thrust shoe is contoured with cylindrical crowns which serve to optimize the fluid film thicknesses during operation.

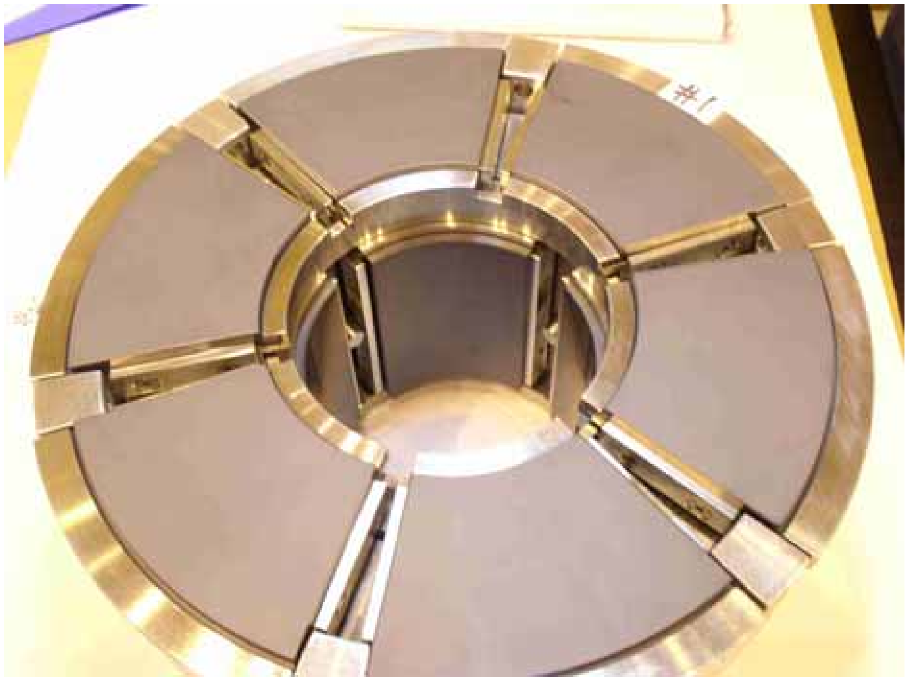

Figure 4 – Upper radial/thrust bearing

Qualification Testing

To demonstrate the suitability of the SMP design prior to installing it in the tank, the first SMP manufactured was demonstrated in a Qualification Test. This test, included the operation of the SMP for ten days in a full-scale test tank in a mixture of kaolin clay and sand with approximately 17 weight % solids to simulate the viscosity and abrasivity of the waste encountered in the waste tanks. Upon completing the run in the kaolin/sand slurry, including 96 hours at full speed operation, the SMP was completely disassembled and inspected for areas of detrimental wear. The wear was quantified and extrapolated to determine the system's suitability for 10,000 hours of service in the waste tanks.

This disassembly also provided an opportunity to evaluate the effectiveness of the internal flushing by inspecting the internal components of the motor/pump assembly for remaining kaolin clay. This inspection found insignificant amounts of kaolin inside the motor/pump assembly, primarily dispersed in trace amounts throughout. In no locations, including in the bearing assemblies (the areas of most concern from an operational and decontamination standpoint), was the kaolin found to accumulate in concentrations greater than a thin film.

SUBMERSIBLE MIXER PUMP DEPLOYMENT – A.K.A. THE "WOW" PROCESS

The SMPs were initially deployed in Tanks 5F and 6F, two per tank. The pumps were mounted on the tank floor thus eliminating the need for tanktop support structures. The pumps required no bearing water or cooling water thus the entire bearing water system used for standard slurry pumps was eliminated. The variable speed drives for the four SMPs as well as all alarms and indications were placed in a mobile skid mounted motor/instrument control center. A mobile skid mounted 2,500 kVA substation was placed adjacent to a nearby 13.8 KeV utility pole. All cabling was routed on the ground in flexible conduit between the substation, the mobile motor control center and the SMPs. The use of mobile equipment eliminated the need for cable trays, long cable runs and modifications to permanent building and control rooms. The above configuration is known as the Waste on Wheels or WOW process. The equipment and SMPs are truly mobile, portable and easy to re-deploy on the next tank. This was demonstrated in 2005 when the Tank 5F SMPs were relocated to Tank 4F. The SMPs had >80% of their design life remaining after the move and the move was performed at a fraction of the radiation exposure to personnel when compared to similar evolutions at SRS. The smooth stainless steel finish was easily decontaminated. At the completion of the waste retrieval campaign in Tanks 5F and 6F, the WOW equipment will be removed and moved to the next group of tanks leaving behind no evidence that the equipment was ever there. At this point in the WOW program, it appears that bulk sludge removal can be achieved on future tanks for about one half of the historical cost.

OPERATIONAL DATA & PERFORMANCE

Two SMPs were operated in Tank 5F for about 600 hours over the course of two waste retrieval batches. The sludge volume was reduced from 34,000 to 16,000 gallons. The SMPs were then relocated to Tank 4F where they were needed before the Tank 5F waste removal campaign was completed. There were no indications of wear or degradation at the time of the move.

Two SMPs were operated in Tank 6F for about 1,900 hours over the course of six waste retrieval batches. The sludge volume was reduced from 25,000 to 7,000 gallons. The SMPs are still installed in Tank 6F and additional waste retrieval batches are planned. There are no indications of wear or degradation at this time.

While the SMPs have performed well, the waste retrieval results thus far are less than expected. This is due to the routing of several horizontal tank cooling coils that have essentially blocked the flow from the SMPs from affecting the sludge in one portion of each tank. The cooling coils are two inch diameter pipe, six inches on center, and mounted on a vertical support to a height of about 3 feet above the tank floor. The coils essentially form a "wall" that almost completely surrounds one quadrant of the tank. At the time of this paper, SRS was implementing a two-pronged approach to use a combination of water sluicers and a third SMP in this quadrant of the tank.

The exact arrangement of the coils was unknown until most of the sludge was removed to expose the coils. Based on observations in the remainder of Tanks 5F and 6F, it is clear that two SMPs would have easily cleaned each tank except for the unfortunate arrangement of the coils.

THE NEXT STEP

SRS is currently evaluating the need for a third order of four SMPs that may be needed to clean the remaining Type I, II and IV tanks. SRS is also evaluating a different design of the SMP that was originally developed for some of the Hanford tanks. This design fits through a 36 inch riser and is being considered for the SRS Type III tanks which typically have several risers that are 36 inches in diameter as well as two 48 inch diameter risers. The larger version of the SMP is expected to operate at a lower speed and draw less power and is therefore attractive to SRS.