

HIGH-LEVEL WASTE MOBILIZATION AND REMOVAL AT THE WEST VALLEY DEMONSTRATION PROJECT

(Formerly Titled: *Challenges and Accomplishments in the Mobilization and Transfer of High-Level Radioactive Waste at the West Valley Demonstration Project*)

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ABSTRACT

The West Valley Demonstration Project (WVDP) has used a process to vitrify high-level radioactive waste (HLW) in borosilicate glass since June 1996. This process is composed of waste mobilization and removal from two large, underground HLW storage tanks; transfer into the Vitrification Facility; and processing the HLW with glass-former chemicals into a molten borosilicate glass that is poured into stainless steel canisters. After 32 months of operation, approximately 88% of the Cesium-137 and Strontium-90 activity have been removed from the HLW tanks and successfully processed into glass-filled canisters. These operations have removed 1.3 million liters (L) of HLW slurry from the HLW tanks over the course of 102 waste transfers. From these transfers, 58 melter feed batches have been prepared and over 230 canisters of vitrified waste have been produced.

Throughout waste mobilization and removal operations, improvements to the systems were made to optimize waste removal. Equipment replacements within the HLW tanks and transfer system presented unique maintenance, safety, radiological, and contamination-control opportunities in the removal of very large, highly radioactive pumps while minimizing personnel radiation doses. In addition, waste mobilization and removal operations resulted in many "lessons learned" that may benefit others who are or will be performing similar operations.

INTRODUCTION

The WVDP is managed and funded by the United States Department of Energy (DOE) in cooperation with the New York State Energy Research and Development Authority (NYSERDA) and is being conducted at the site of the first and only operating commercial spent nuclear fuel reprocessing center in the United States. Nuclear Fuel Services operated the facility in West Valley, New York, between 1966 and 1972, reprocessing 640 metric tons of commercial and defense fuels using the plutonium-uranium extraction (PUREX) process. After plutonium and uranium recovery, the remaining HLW was neutralized with sodium hydroxide for safe storage in the 2.8-million L, carbon steel, underground storage tank, designated Tank 8D-2. The 2 million L of HLW consisted of insoluble hydroxides and other salts that precipitated out of the solution to form a sludge layer on the tank bottom and a liquid supernatant, composed of mostly sodium nitrate and sodium nitrite, above the sludge. In addition, approximately 31,000 L of acidic thorium-uranium extraction (THOREX) waste was stored in a 50,000-L underground, stainless steel, storage tank identified as Tank 8D-4. This waste resulted from reprocessing one core of

mixed uranium-thorium fuel from the Indian Point No. 1 Nuclear Plant (Reference 1).

The WVDP was created by the West Valley Demonstration Project Act of October 1, 1980, Public Law 96-368. The Act directed the DOE to carry out a HLW management demonstration project at the Western New York Nuclear Service Center in West Valley, NY. Under the Act, the DOE is responsible for the removal of the HLW from the underground storage tanks and solidifying it into a waste form suitable for transportation to a Federal repository for final disposal. The West Valley Nuclear Services Company, Inc. (WVNS), a subsidiary of the then Westinghouse Electric Corporation, was selected as the site's prime contractor and has managed operations from February 1982 to the present.

Early in the project, it was decided to pretreat the liquid HLW prior to vitrifying it into a borosilicate glass waste form for long-term stability. Pretreatment was necessary to remove those salts from the HLW that have a detrimental effect on the final vitrified HLW form, notably sodium sulfate. Without pretreatment, the quantity of vitrified waste would have increased over tenfold to maintain the sulfate at acceptable concentrations in the glass. Pretreatment (Reference 2) consisted of removing the Cesium-137 from the HLW PUREX supernatant to produce a low-level radioactive waste (LLW) liquid that was then concentrated and solidified with portland cement and other admixtures. The pretreatment process removed over 99.99% of the cesium from the liquid supernatant, capturing the activity onto UOP IONSIV[®] IE-96 zeolite. The spent zeolite was stored under an alkaline liquid in HLW Tank 8D-1, which serves as the spare HLW tank for Tank 8D-2.

Following supernatant processing, five mobilization pumps were installed into the PUREX HLW within Tank 8D-2 to agitate the settled sludge and dissolve additional salts into the sludge wash solution. Three of these sludge washings were performed with liquid processing following each wash to remove Strontium-90 and plutonium, as well as the Cesium-137 onto a mix of UOP IONSIV[®] IE-96 and TIE-96 zeolites. The acidic THOREX waste was added to, and neutralized in, HLW Tank 8D-2 just prior to the third sludge wash so that most of its salts could be processed into a LLW cement waste form and not increase the vitrified waste volume. This pretreatment processing was performed from April 1988 to May 1995. It resulted in "washed" PUREX and THOREX sludge in HLW Tank 8D-2; 65,300 kg of spent zeolite stored in its sister tank, Tank 8D-1; and 19,877 square, 270-L drums of cemented salt solution meeting the Nuclear Regulatory Commission (NRC) criteria for LLW.

The last processing operation prior to vitrifying the HLW involved consolidating the spent zeolite in Tank 8D-1 with the washed sludge in Tank 8D-2. Five mobilization pumps installed within the 8D-1 HLW tank were used to mobilize the stored zeolite while a multi-stage, long-shafted, centrifugal pump transferred the waste through an in-line grinder to reduce the zeolite particle size from 20 to 50 mesh (840 to 300 microns) to approximately 50 microns or less before the slurry was combined with the washed sludge in Tank 8D-2. Approximately 90% of the zeolite was removed in 18 different transfer campaigns from July 1995 to November 1996. The

amount of zeolite transferred was estimated by the use of radiation probes placed along the transfer piping, within the shielded trench, and in-tank video inspections of the remaining solids.

Its removal is summarized in Table I. With over 95% of the HLW activity residing in the main HLW tank, 8D-2, the waste was ready to be mobilized within the tank and removed for transfer into the Vitrification Facility.

Table I. Zeolite Removal Progress

Transfer	Number of Mobilization Pumps Operated More Than 10 Hours	Sum of All Mobilization Pump Hours	Percent of Original Zeolite Removed	Cumulative Percentage Removed
1	5	166	25.9	25.9
2	5	158	3.3	29.2
3	5	163	2.0	31.2
4	3	45	2.0	33.2
5	3	43	5.2	38.4
6	4	221	4.4	42.8
7	4	227	5.2	47.9
8	4	191	5.4	53.3
9	4	213	6.2	59.6
10	3	78	2.9	62.4
11	3	186	9.9	72.3
12	2	101	3.2	75.6
13	2	135	5.3	80.8
14	3	129	2.4	83.2
15	4	169	3.2	86.4
16	1	66	1.8	88.3
17	2	80	1.0	89.2
18	1	33	0.1	89.3

HIGH-LEVEL WASTE MOBILIZATION AND TRANSFER

The HLW Mobilization and Transfer System consists of mobilization pumps and a slurry transfer pump installed into the HLW storage tank, the pump pit above the transfer pump where the pump motor and process piping valves and instrumentation are located, and the transfer trench that contains the transfer pipelines connecting the pump pit to the Vitrification Facility. The relative locations of each of these features are illustrated in Figure 1.

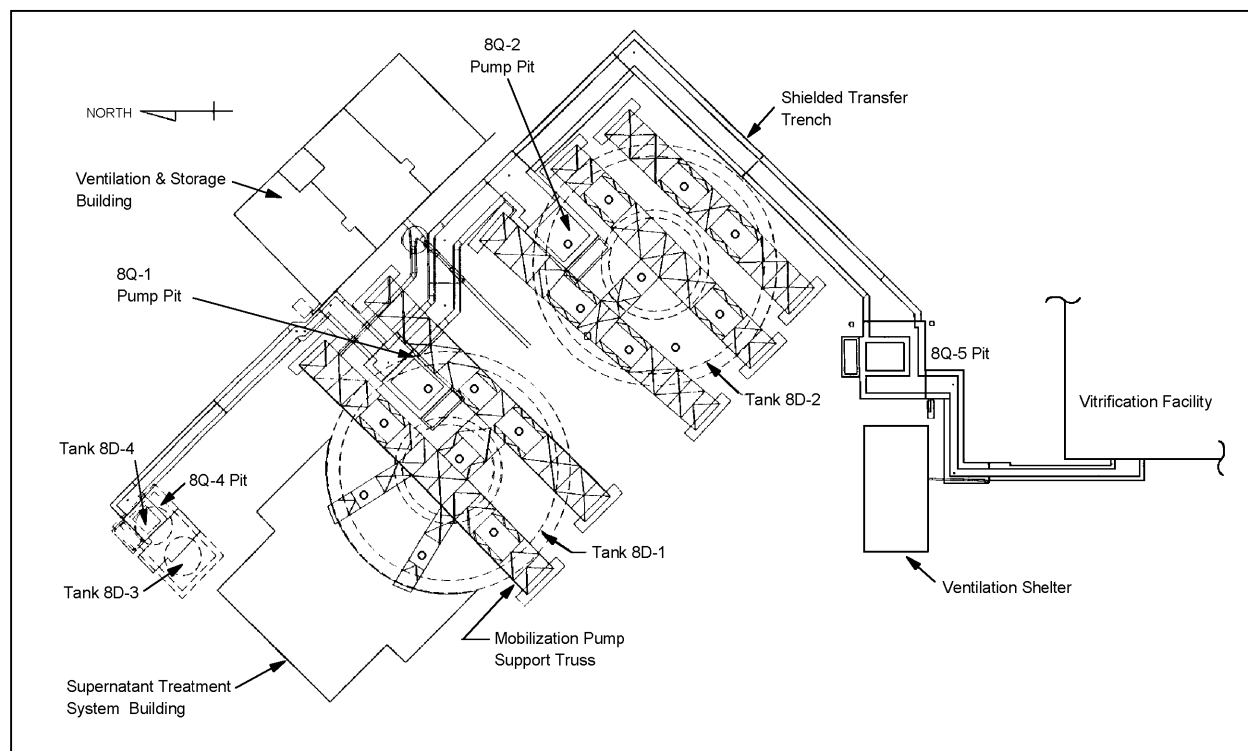


Fig 1. Waste Tank Farm Facilities Supporting Vitrification

High-Level Waste Tank Description

The HLW tank containing the waste is a 2.8-million-L, underground, carbon steel storage tank. The tank is 21 m in diameter and 8.2 m high, with wall thicknesses ranging from 11 mm to 17 mm. It is contained within a 0.60-m-thick concrete vault and a 1.6-m-high secondary containment pan as shown in Figure 2. The original tank had only one large, 0.61-m-diameter, riser pipe that extended from the tank top up above the grade of the earthen cap over the tank's concrete vault. The tank was constructed with an elaborate internal gridwork structure (Figure 3) that reinforces the tank bottom, supports the tank roof, and provides access for six columns from the concrete vault floor to support the vault roof. The structural gridwork in the tank bottom consists of a reinforcing network of wide flange beams with the upper flanges 0.91 m above the tank floor. The beams are supported by girders of varying lengths and widths underneath the beams. The girders are attached to the tank bottom with 3.8-cm-diameter rods with reinforcing disks where the rods meet the tank floor. There are 45, 21.9-mm-diameter pipes located on a 3.05-m grid that connects the wide flange beams to the tank top and provides support for the roof and its exterior structural reinforcing above. In addition, the tank contains four inactive air circulators, thermowells, a heat exchanger, and level/density probes. The internal gridwork and structures make waste mobilization and retrieval quite challenging. Based on the 1/6-scale sludge and zeolite mobilization and removal test program (Reference 3), it was determined that as many as five mobilization pumps were needed to mobilize the solids deposited on the tank bottom so that the solids could be pumped out of the tank to the Vitrification Facility.

Consequently, eight additional 71-cm-diameter risers were remotely installed to the tank top to provide for pump installations, and three trusses were constructed over the tank to support the pumps and distribute the weight outboard of the underground concrete vault. The location of these risers with the original five installed mobilization pumps, single slurry-transfer pump, and the floating-suction decant pump, previously used for supernatant and sludge wash pretreatment operations (Reference 2), are illustrated in Figure 3.

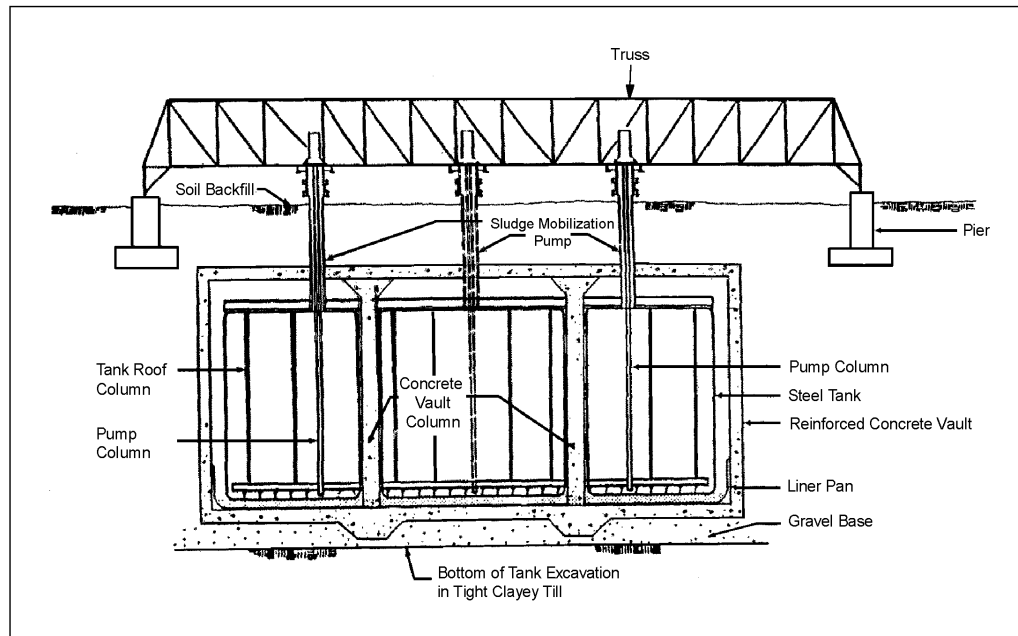


Fig 2. HLW Tank with Installed Mobilization Pumps

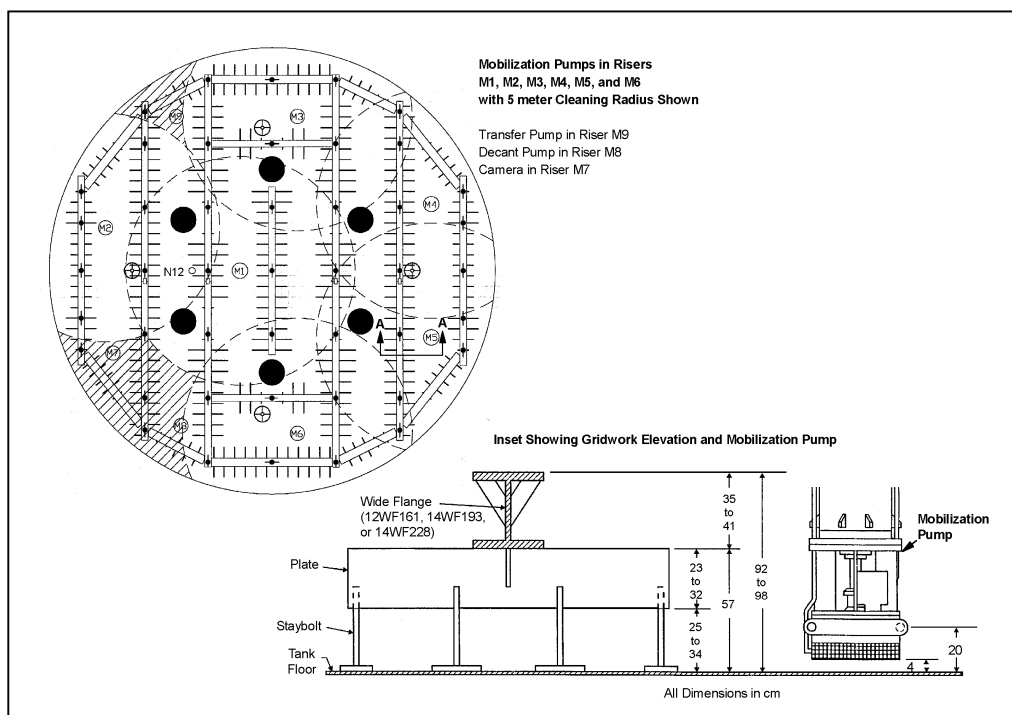


Fig 3. HLW Tank 8D-2 Bottom Internal Gridwork

Waste Composition

Prior to the start of HLW Vitrification, the primary HLW storage tank, Tank 8D-2, contained a mixture of washed sludge solids and zeolite with a liquid supernatant. Table II summarizes the waste composition prior to vitrification.

Table II. HLW Composition

Oxide	Approximate Weight Percent
Fe ₂ O ₃	35.5
SiO ₂	20.8
Na ₂ O	14.4
ThO ₂	10.4
Al ₂ O ₃	7.1
MnO	2.3
P ₂ O ₅	1.8
CaO	1.3

The sludge consists of insoluble metal hydroxides, with ferric hydroxide being the major constituent. The sludge mass was estimated at 100,000 kg with a 3.35 specific gravity (SG). Based on sludge sampling and analysis, the particle size of the sludge was generally less than 100

microns. The predominant radionuclides in the sludge are Strontium-90 and isotopes of thorium and uranium. The activity of the Strontium-90 was estimated to be 5.81 million curies (January 1, 1996, basis).

Approximately 57,000 kg of zeolite, containing approximately 5.5 million curies of Cesium-137 and trace quantities of plutonium and Strontium-90, were transferred into the HLW tank following completion of HLW pretreatment. Pretreatment operations reduced the quantity of salts in the waste and significantly reduced the amount of vitrified waste that must be produced. The zeolite is UOP IONSIV[®] Type IE-96 and TIE-96 which was size-reduced by passing it through an in-line grinder after it was removed from its storage tank on the way into the HLW tank feeding the Vitrification Facility. The grinder was designed to size-reduce the 20- to 50-mesh zeolite particles (840 to 300 micron) to less than a 50-micron particle size. This smaller size made the zeolite easier to homogeneously mix with the sludge, which has a similar particle size, easier to mobilize and remove from the HLW tank, easier to sample in the Vitrification Facility, and quicker to analyze the waste samples in the WVDP's Analytical and Process Chemistry (A&PC) Laboratory. The HLW tank also contained approximately 870,000 L of supernatant liquid, essentially an inorganic salt solution, from previous sludge-wash operations. The inorganic salt composition of the HLW liquid is shown in Table III, with the major constituents as sodium nitrite and sodium nitrate. The SG of the liquid was 1.016, its temperature was approximately 60°C (140°F), and its pH was approximately 11.

Table III. Inorganic Salt Composition of the HLW Supernatant

Analysis	Weight Percent
Na	35.0
NO ₂	25.0
CO ₃	22.0
NO ₃	8.9
SO ₄	1.1
K	0.94
B	0.43
Cr	0.33
U	0.13
P	0.046

The spare HLW tank, Tank 8D-1, contained 520,000 L of excess liquid resulting from pretreatment and zeolite transfer operations. This liquid had a SG of 1.016, its temperature was approximately 30°C (85°F), and its pH was approximately 10.5.

Waste Mobilization and Removal Equipment

The mobilization pumps, installed in the HLW tank to "mobilize" the solids deposited on the tank bottom and mix them with the supernatant, are long-shafted, centrifugal pumps with an overall length of 15.3 m. There is a single impeller that draws material up into the pump suction that is fitted with a strainer to avoid drawing in large particles or tank debris. This suction is

positioned between 2.5 cm and 10 cm from the tank bottom (Figure 3). Two tangential, 3.8-cm-diameter nozzles discharge the pumped liquid from the volute at an elevation from 18 cm to 25 cm above the tank bottom. Each nozzle discharges 2270 L/min. at the 100%-rated pump speed of 1800 rpm. The driveline bearings are cooled and lubricated by a water column enclosing the drive shaft and pressurized with clean water. The pump column utilizes mechanical seals at the top and bottom to maintain the pressurized water column. A 150-hp motor powers the pump and is supplied by a variable frequency drive (VFD) to provide speed adjustments. The entire pump-motor assembly rotates so that the two, tangentially oriented discharge jets sweep the tank bottom in either a clockwise or counter-clockwise direction to mobilize waste within a 4- to 10-m radius around each pump, depending on the physical characteristics of the waste solids. The gearmotor that rotates the entire pump assembly is also supplied with a VFD to control rotational speed of the pump jets, typically 1/4 to 1 rpm. Currently, six of these mobilization pumps are installed in HLW Tank 8D-2 at the locations shown in Figure 3.

The slurry transfer pump is a 13-stage, long-shafted, vertical turbine approximately 12 m long. Its radial inlet suction extends from approximately 7 to 9 cm above the tank bottom. Two concentric strainers prevent large solids or debris from entering the pump. The driveline bearings are immersed within the process slurry passing up the pump column around the shaft. It is equipped with a 20-hp motor located in a concrete shielded pump pit directly over the pump column. The motor is remotely replaceable and is supplied with a VFD to provide flow control. The pump has a capacity of 380 L/min. with a 60-m head. The long pump column is reinforced to be able to pump waste slurry with the mobilization pumps operating within the HLW tank. The pump is equipped with a tachometer sensor to measure shaft speed, and vibration sensors to monitor pump wear.

Transfer Pump Pit

An underground concrete pump pit, located immediately over the HLW tank vault roof, contains a stainless steel-lined bottom and houses the HLW transfer pump head, discharge piping, and motor. Temperature, pressure, and flow sensors are installed on the pump discharge jumper. Remotely replaceable jumpers connect the equipment within the pit to the piping. In addition, the pit contains primary and spare transfer lines to both the spare HLW tank and the Vittrification Facility, as well as a recirculation line back to the HLW tank below. Valves equipped with position-indicating switches provide isolation between the various piping jumpers contained within the pit. These valves are manually actuated by extended T-handles that pass through the concrete pit covers. The position switches are connected to a programmable logic controller (PLC) that ensures proper valve positioning prior to pump operations. The pit is both ventilated and drained by a pipe connecting the pit floor with the HLW tank underneath. The pit is supplied with compressed air and water to flush equipment and piping. The in-line grinder, used to size-reduce the zeolite as it was transferred from the spare HLW tank following HLW pretreatment, is also located within the pit with its motor and cooling water lines. The pit is accessible by removing one or more of the six keyed concrete covers over top of the pit. A weather shelter is erected over the pit covers to provide protection for personnel actuating pit valving. A mobile

crane is used to remove pit covers and service pit equipment. Immediately adjacent to the transfer pump pit is an underground utility pit that provides the isolation valving and backflow protection for the water and compressed air that passes into the pump pit.

Transfer Trench

The transfer trench is a partially below-grade, seismically designed, concrete structure that connects the HLW tank pump pits together and with the Vitrification Facility. The trench stretches over 70 m from the pump pit to the Vitrification Facility. The trench has removable concrete covers and is insulated above ground to prevent line freezing. All transfer piping within the trench is 5 cm stainless steel, with 10 cm stainless steel secondary containments jacketing the primary pipelines. The piping slopes toward a low point in the pump pit where the line drains back to the HLW tank and secondary-containment piping leak detectors are located. Valving within the pump pit allows for draining the secondary-containment jacket in the event it receives liquid. The trench also has high-point vents and exterior valving to test the integrity of the secondary containment. Radiation probe penetrations exist to monitor the activity of the liquid passing through the transfer piping.

HIGH-LEVEL WASTE MOBILIZATION AND REMOVAL

Over 102 transfers of waste from the HLW tank to the Vitrification Facility have been performed from the first transfer on June 24, 1996, to September 30, 1998. These transfers made up 58 batches of feed for the melter and contained 10.3 million curies of Cesium-137 and Strontium-90. The first transfers were performed with the tank level at 2.5 m. The tank level was progressively reduced to approximately 25 cm at the last transfers. Initially, transfers were performed with a higher liquid level in the HLW tank to limit the waste concentration of the transfer until the shielding adequacy of the pit and trench could be verified by measurements and until vitrification radioactive operations could be evaluated during the controlled start-up. Following successful vitrification (start-up) operations, the excess liquid in the HLW tank was progressively decanted to the spare HLW tank, leaving the highly radioactive zeolite and sludge with a smaller amount of liquid with which to slurry. This allowed transfers of more concentrated HLW and subsequently minimized waste concentration in the Vitrification Facility.

During this period, liquids were also added to the HLW tank. Waste from laboratory analysis of vitrification samples was returned to the HLW tank. Overheads (distillates) from concentrating the waste in the Vitrification Facility make-up tank were returned after a 20 to 50 volume reduction in the Liquid Waste Treatment System (LWTS) evaporator. In addition, the clean water used to pressurize the mobilization pump columns was added to the tank's volume since some of the mobilization pumps' lower mechanical seals leaked up to 18 L/min. It is estimated that approximately 1.3 million L of water were added to the tank due to mobilization pump column leakage. Part of this liquid was volume-reduced in the Integrated Radwaste Treatment System (IRTS) and returned to the HLW tanks, and some excess liquid was decanted to the spare HLW tank. Having the spare HLW tank to hold the excess liquid and the ability to process the liquid from the spare tank to reduce its volume was critical to maintaining the waste concentration in the primary HLW tank supplying the Vitrification Facility.

Typical High-Level Waste Transfer

A typical HLW transfer is performed by filling and pressurizing the mobilization pump columns with water then starting the operable mobilization pumps in the HLW tank. Pump positioner and pump speeds, as well as the starting sequence and relative start times, are planned prior to the transfer based on prior transfer performance data, tank level, in-tank video camera surveillance, and previous mobilization pump operating parameters. When necessary, mobilization pump rotation is stopped at a specific location or rotated (swept) through a partial arc to focus one discharge jet at a specific tank region and mobilize solids accumulated beyond the normal cleaning radii of the installed mobilization pumps. Mobilization pumps are generally operated between 30 minutes and 8 hours (normally 1 to 3 hours) prior to the start of the HLW transfer, to hydraulically lift the settled solids off the tank bottom and slurry them with the supernatant. The mobilization pumps continued to operate throughout the waste transfer, typically 30 to 60 minutes, then were shut down. A typical HLW transfer is performed at a 380-L/min. rate with generally 15,000 to 19,000 L transferred. The transfer pump is operated and monitored via a PLC. A chart recorder displays transfer pump current, waste flowrate, and pump discharge pressure to provide online trending of the key process parameters. The online radiation probe is monitored on a chart recorder and compared to previous transfers. Based on the radiation probe output, the mobilization pump speeds, pump positioner speeds and/or rotational direction, and transfer pump speed are adjusted to maximize the effectiveness of the waste transfer.

Based on the Vitrification Facility's time to concentrate the waste by evaporation, transfers within a single vitrification feed batch occur approximately 2½ days apart.

Waste Mobilization and Removal Effectiveness

From the first waste removal on June 24, 1996, through September 30, 1998, 5.70 million curies of the estimated 5.80 million curies of Cesium-137 originally stored on zeolite in this HLW tank since 1995/1996 have been removed for a 98% recovery. Sludge/Strontium-90 recovery has been slightly less with 4.98 million curies removed through September 30, 1998, for a greater than an 86% recovery. This is not surprising since the sludge was deposited into the tank from spent fuel reprocessing operations between 1966 and 1972 and has consolidated over the years. Despite pretreatment sludge washing operations and adding a sixth mobilization pump into the HLW tank, and based on in-tank video camera inspections, there continued to be an accumulation of solids under the M-7/M-8 riser area (Figure 3) on the tank bottom. This area was apparently at the edge of the cleaning radii of the adjacent three mobilization pumps in the M-1, M-2, and M-6 risers. Originally, these accumulated solids became visible above the tank liquid at a level of 56 cm in mid-April 1998. But, by continuing to direct or fix the adjacent mobilization pump jets at this area periodically while processing down the tank level, the height of the accumulated solids has been reduced to less than 2 cm. Mobilization and removal of these solids and radioactivity will continue in Fiscal Year 1999 (FY1999).

PROCESS IMPROVEMENTS

A number of both hardware and operational improvements were incorporated into the HLW mobilization and transfer process during the past 32 months. Some improvements proved quite challenging to implement while continuing to operate the process.

Hardware Improvements

Approximately four months prior to the first HLW transfer to the Vitrification Facility, one of the five installed mobilization pumps in the primary HLW tank failed. The reason for the failure is unknown, but through testing it was determined that the key securing the pump's impeller to the 15-m-long shaft had apparently sheared rendering the pump inoperable. The impeller-to-volute clearances are tight; less than 2 mm, with 15 m of shaft above the pump. Possibly differential thermal expansion between the 17-4 PH shaft and the 304 stainless steel pump column, resulting from just filling the column with water prior to pump startup, caused the impeller to impact the volute and shear the key, or perhaps some foreign object was drawn into the 9.5-mm-square openings in the pump suction screen and wedged between the impeller and volute. Although too late for this pump, all nine remaining mobilization pumps were modified by replacing the easily accessible motor coupling key so that the motor coupling key would fail prior to shearing the impeller key, which is just above the bottom of the HLW tank and extremely inaccessible. In addition, impeller-to-volute clearances were expanded slightly on the other pumps to allow for some additional differential growth between the shaft and pump column, resulting in somewhat lower output. Design specifications for spare pumps were modified to specify a Nitronic-50™ shaft material that has a coefficient of thermal expansion much closer to the 304 stainless steel pump column. Temperature control of the water supplied to the pump columns, so that the water would be at the same temperature as the tank internal temperature, was also considered but was not thought to be cost effective with the other modifications made.

The mobilization pumps have performed very well, although the major complaint is that the water-filled columns providing lubrication and cooling to the nine driveline bearings leak clean water into the HLW tank creating more waste liquid to process. Operable mobilization pump leakage rates vary from none to 19 L/min. In the past, two pumps leaked at over 50 L/min. which rendered them inoperable until modifications were incorporated into the pumps. The source of the leak is the lower mechanical seal between the pump shaft and the pressurized water column. Replacement pump specifications have required a different mechanical seal that prohibits torquing the bellows portion of the seal if the seal faces stick during pump startup. To reduce the leakage with the previously inoperable pumps, a 14-m-long spray assembly was developed to spray a small but controlled amount of water at each internal bearing. The spray assembly is installed into the pump column that uses approximately 15 L/min. with a supply pressure of 7.7 kg/cm². The concept was tested before actual deployment into the WVDP mobilization pumps at the Savannah River Site's (SRS) Mobilization Pump Test Facility by the Westinghouse Savannah River Company (WSRC). The successful deployment of this system has allowed the WVDP to again operate these pumps without the immediate need to replace them. This innovative modification has avoided significant costs in dollars, labor, and radiological dose.

Mobilization pumps were originally installed into the HLW tanks based on best available survey data and as-built data on the tanks themselves. The pump suctions were approximately 10 cm above the tank bottom with the discharge jets just below the girder portion of the tank bottom reinforcing (Figure 3). All pumps have since been lowered to within 4 cm of the tank bottom to provide additional clearance between the jet centerlines and the tank structural gridwork. This has improved the effective solids mobilization radius of each pump and allows them to be operated at lower tank levels.

Variable frequency drives (VFDs) were added to the mobilization pump rotary gearmotor positioners to be able to adjust the rotational speed of the entire pump assembly which allows the pump discharge jets to turn at any speed up to 2 rpm. This was found to be helpful in operating in one of two modes: slow rotational speeds for a maximum solids cleaning radius around each pump by scouring solids up from the tank bottom, and faster speeds to better retain the solids in suspension once lifted off the tank bottom. The VFDs were also used on the rotary positioners of the mobilization pumps near the transfer pump suction to limit the amount of solids jetted to the transfer pump so as to avoid plugging its suction strainer with solids without having to reduce the actual mobilization pump motor speed and limit jet velocity. By running the pump positioners at a faster speed, the discharge jets sweep by the transfer pump suction quicker, so plugging the strainer with solids is reduced.

In-tank video cameras were deployed with lights and remotely operated pan-tilt assemblies to monitor waste removal progress, observe mobilization pump operation and lower seal in-leakage, and estimate remaining waste volumes. Two cameras on opposite sides of the tank worked very well, especially with supplemental lighting added.

A simple radiation probe installed along the HLW transfer line inside its shielded trench proved valuable to monitor the Cesium-137 concentration in the waste being removed. Radiation probe output was used as the basis for adjustments to mobilization pump speeds, pump positioner speeds and rotational directions, and the transfer pump flowrate/speed, to maximize the concentration of the waste being removed. Radiation probe readings were also useful to indicate when debris built up around the transfer pump suction, limiting solids removal.

Due to the volumes of water being added to the HLW tanks as a result of leaky mobilization pump seals, the utility water system was replaced with a demineralized water supply system to limit unwanted chemical addition, primarily calcium, to the waste. The demineralized water supply is sized to provide faster pump column filling and accommodates the leakage rate of all mobilization pumps in either HLW tank. This system will also supply the remotely operated sluicer which is currently being installed into the spare HLW tank to aid in zeolite heel removal.

Operational Improvements

Use of the mobilization pumps to mobilize solids in hard-to-reach areas of the tank bottom have been improved by aiming the jets at the desired region. Alternatively, the pump positioner moves the pump over a limited arc, causing the submerged pump jets to concentrate on a

particular area of the tank. By utilizing the in-tank video camera and the above techniques, accumulated solids have been mobilized where they were previously unmovable. In addition, the VFD on the mobilization pump motor itself has allowed the pump output to be increased to utilize the entire motor capacity. This feature allows increased jet velocity; helpful when aiming or sweeping the jets at an area of unmobilized waste solids.

Other key operational improvements were necessitated by solids occasionally plugging the transfer pump suction/inlet which made pump performance unacceptable. Utility water and compressed air are piped into jumpers within the pump pit for flushing the pipelines. These air and water services also became useful in clearing the transfer pump inlet when it became fouled and were highly effective in clearing the suction strainer, especially the compressed air.

MAJOR CHALLENGES

The major challenges encountered during HLW mobilization and removal centered on the removal of highly contaminated, 12- to 15-m-long pumps from the HLW tanks. Both mobilization and transfer pumps were removed and replaced. The length of the pumps, together with their contamination levels and resulting radiation fields, presented some unique challenges to the Engineering, Operations, and Radiation Protection staffs.

Relocation of Mobilization Pump

The first transfers of HLW to the Vitrification Facility were performed with four mobilization pumps agitating the waste in Tank 8D-2; the fifth pump, in the M-5 riser, was inoperable. After approximately two months of HLW transfers, the chemical analyses of the waste received in the Vitrification Facility indicated incomplete mobilization of the solids in the HLW tank. Plans had been developed to attempt to repair the failed pump by replacing the lower 5 m with new equipment, but this would take considerable time. To accomplish increased mobilization more quickly, it was decided to install a new, sixth mobilization pump in the vacant and adjacent M-4 riser next to the inoperable pump. Unfortunately, no spare pumps were immediately available, so to expedite HLW removal, it was decided to remove a zeolite mobilization pump from Tank 8D-1 and install it into the primary HLW tank to better mobilize tank solids.

Techniques were developed to decontaminate the pump as it was being removed from its HLW tank and provide a 16-m radiological containment for the pump during relocation. Two crews worked in two containment tents, one tent above the other, to sufficiently decontaminate the pump and lift it into its containment system. The pump was swung over to the other HLW tank with a 230-metric-ton mobile crane where two more crews, again in piggyback containment tents, removed the pump containment and guided the mobilization pump into its new riser. Shortly thereafter, the pump became operational and significantly aided in mobilizing HLW tank solids during subsequent transfers to the Vitrification Facility. Mockups using the actual pump containment system with a simulated pump were performed to ensure readiness and to train all personnel involved in this difficult job. Despite a 5 R/hr gamma field, 1 m away from the pump bottom, the entire relocation was performed with a whole body collective dose of less than 300 mR.

Replacement of Inoperable Mobilization Pump

HLW mobilization and removal operations continued with five operating mobilization pumps during most of 1997, but as the HLW inventory became smaller, analytical data again indicated that the expected mass of solids in the tank were not being fully mobilized. It was decided that the inoperable pump would have to be replaced with a spare pump that had been fabricated earlier in the year. Removal of this pump was more difficult than the first one removed since it was highly contaminated with both high-energy beta and gamma emitters. In addition, a limited amount of high-activity solids were expected to be found trapped in the pump column due to the lower mechanical seal leakage path. The pump had also sat with its bottom end submerged in the tank solids, inoperable for approximately two years, while the other mobilization pumps agitated the waste. With the sheared impeller key on this pump, it could not be operated to attempt to dislodge solids packed in and around its suction.

The containment system employed earlier on the first mobilization pump relocation was employed with minor improvements learned from its first use. A much more aggressive water decontamination system was developed and deployed into the riser around the pump to reduce the radiation levels to workable limits. Additional decontamination of the pump internals and the suction proved necessary due to the greater than 100 R/hr gamma field measured at the pump bottom. In response to these measurements, an air sparge was established through the existing sluicer ring under the pump suction while an electric gearmotor was used to slowly rotate the pump shaft. As it turned out, the slow shaft speed caused the impeller to rotate despite the sheared impeller/shaft key. The pump shaft was raised and lowered with the impeller slowly turning to scrape solids off the bottom and top of the volute cavity and help eliminate them from inside the pump casing, all the while sparging compressed air under the pump inlet. In addition, the area just above the impeller was purged with both compressed air and water.

Decontamination efforts proved to be sufficient to meet preestablished radiological limits. The pump was successfully raised out of the tank into its containment system and repositioned in an open riser in the spare HLW tank where it could potentially be repaired or further decontaminated in the future. Despite internal and external decontamination efforts, the pump's lower mechanical seal area still had a hot spot of 8 R/hr gamma. However, due to the extensive mockups, innovative hardware design, and personnel preparation, the combined whole body dose for the 12 major participants in the relocation totaled less than 400 mR.

Pump removal was the difficult task; especially during Western New York's most severe winter months of January through March. The spare mobilization pump was subsequently installed and became operational on April 21, 1998. Its operation, along with the other five operating mobilization pumps, improved agitation of the tank solids in that region of the HLW tank.

High-Level Waste Transfer Pump Replacement

The HLW transfer pump in the primary HLW tank that supplies the Vitrification Facility began to develop difficulties in November 1997 after 45 transfers of waste, which constitutes approximately 100 hours of pump operation. The pump began running rougher in general and, under certain circumstances, would rapidly bind up and then turn at a low speed while making a

loud grinding noise. It appeared as though a foreign object had become wedged in between one of the 13 pump stages or the lower bearings had worn, allowing the impellers to contact the volutes. There was no installed spare in the HLW tank; in fact, the spare was still being fabricated. A pump pit entry was made to obtain radiation surveys, replace the pump thrust bearing, install vibration sensors, and perform other diagnostic activities. Although the work may have reduced the problem somewhat, it was clear that the pump would soon have to be replaced. Since the actual cause of the problem was not known with certainty, WVDP engineers thoroughly reviewed the entire pump design, identified potential problem areas, and proposed modifications to the pump fabricator who was just finishing the spare pump. All the modifications were incorporated into the spare prior to its completion.

Three engineering teams were formed; one to decontaminate and prepare the pump and pit area for pump removal, one to develop a technique and the hardware to lift the pump as a single unit into a containment box suitable for on-site storage, and one to oversee testing and installation of the replacement pump. Meanwhile, the pump was operated with increasing difficulty through eight more transfers of HLW from the storage tank. Two more months of HLW processing were completed before the pump became fully inoperable at the end of January 1998 and the engineering teams used this time to prepare for its replacement.

The removal plan consisted of remotely hoisting the entire 12-m-long pump up into a herculite-lined waste box, semi-remotely sealing the bottom box closure, lifting the boxed pump up from the pump pit, and placing the entire assembly inside a precast concrete vault that was being fabricated for this purpose. The pump would be stored in this manner until size-reduced in the future with other excess reprocessing equipment.

The pump column piping and jumpers in the pit were first flushed with hot water to remove gross deposits of residual waste. The jumpers were removed and the pump nozzles trimmed to minimize the pump envelope size. An access hole was then bored through the pump-mounting flange to permit decontamination of the upper part of the pump and the inside of the tank riser. The access also was used to lower a probe to establish radiation levels and decontamination effectiveness. A 420-kg/cm² spray ring was installed in the riser under the pump to decon the pump exterior as it was raised out of the tank. Pump removal mockups were performed to ensure the procedures, personnel, and hardware were all ready.

On March 20, 1998, the pump was remotely hoisted into its containment box after its final decontamination. Operations were monitored by two video cameras positioned in the pump pit. The inner sleeving was remotely gathered and sealed and the bottom closure was slid in place and quickly secured with clamps. The entire assembly was then lifted out of the Waste Tank Farm (WTF), upended to a horizontal position, and placed in the shielded vault. All removal activities were performed like clockwork due to the extensive mockups and worker preparedness. The radiation dose to remove the pump was under 150 mR; with the entire job, from pit preparations to installing the new transfer pump, resulting in less than 300 mR.

The new pump was installed into the HLW tank just two days after removal of the failed pump. It became operational again on March 30, 1998, with its first HLW transfer.

The replacement transfer pump included design improvements to address potential causes of the original failure, plus its suction was completely redesigned to attempt to minimize suction plugging and maximize suction velocity to the extent possible. The replacement pump had a dual strainer with the outer strainer having over three times the area of the original. Its suction also had a radial inlet instead of a bottom inlet. Laboratory tests performed at the Westinghouse Science and Technology Center (WSTC) on the new design confirmed its ability to remove larger particle solids from the HLW tanks. This replacement pump has operated flawlessly since it was placed into service.

LESSONS LEARNED

The 1/6-scale testing (Reference 3) performed at the WVDP from 1985 to 1986 provided the basis for selection of mobilization and transfer equipment for both sludge and zeolite. Small-scale mixing pumps were used with actual zeolite and kaolin clay to simulate the PUREX sludge. The testing demonstrated that five mobilization pumps, with a sluicer that can be positioned at various locations in the tank, can mobilize and remove over 95% of the waste. These test results closely mirror the actual zeolite and HLW sludge removal efforts to date. Although the tests had their limitations, such as not simulating the consolidation of sludge over time with the associated decay heat present, the testing provided very valuable information that resulted in an effective HLW mobilization and transfer system. The sludge mobilization testing seems to better reflect actual operational experience than the zeolite removal testing. This may be due to reuse of the zeolite in the 1/6-scale testing which may have broken down the zeolite into smaller particle sizes which are fluidized easier, or perhaps the zeolite that was stored in the actual HLW tank for up to seven years has changed characteristics or agglomerated into larger-size particles that are more difficult to fluidize. Another factor to be considered is the degree of conservatism to apply to the test data for use as design inputs. If the testing indicated the need for five operating pumps, should six or more be installed to ensure adequate mobilization of the entire tank bottom? This factor should be considered especially in light of the real possibility of pump failures and the difficulty in their replacement. Obviously, there is a balance that must be struck between a bare bones design and an overly conservative and costly design.

The second area recognized is the balance between a simple system, with a low installed cost, and a more involved system with provisions for easy equipment servicing. Having the transfer pump motors, pump tachometer, and valve position switches inside the heavily shielded pump pits was an easy, cost-effective design. But after operating the system for nearly three years, replacement and adjustment of valve position switches, and replacing one transfer pump, a few lessons learned would be:

Position as much equipment as possible outside the pump pit so it can be serviced easier; i.e., valve position switches, pump motors, tachometer, pressure transmitter, temperature indicator, etc. Having these outside the pit eliminates the need for entries into potentially

highly contaminated areas and keeps more equipment clean.

The shielded pump pit should be easy to access if required for maintenance or service, however, the WVDP transfer pit covers must be removed with a specially leased, 230-metric-ton crane due to the weight of the covers and the required reach. If redesigning a similar system, consideration should be given to an overhead gantry or monorail crane/hoist, or reducing the weight of individual covers while increasing their number to maintain the equivalent amount of shielding. At the WVDP, a weather shelter is located directly over the pump pit covers and must be removed prior to pit cover removal. Certainly a larger, more costly weather enclosure could have been built around the covers so they could be removed within it. The enclosure could also serve as a radiological containment for pit entries.

All rotating equipment, inaccessible within pump pits, should be fitted with vibration sensors and tachometers, including spares. These will allow personnel to monitor for equipment wear, predict remaining lifetimes, and establish limits at which equipment is secured prior to reaching a damage threshold. In addition, tachometers are essential in determining the actual speed at which the equipment is operating in diagnostic work and are useful in measuring how freely the equipment turns in coast down mode.

Another area that sometimes receives inadequate attention during design phases is the radiological requirements needed to replace a highly contaminated piece of equipment; i.e., a 15-m, 4,000-kg mobilization pump that is reading over 100 rads/hr gamma at the bottom where it was pumping sludge and zeolite. To remove highly contaminated pumps, it was decided to fabricate and deploy high-pressure (420-kg/cm^2) spray rings down into the HLW tank's risers to decon the pumps as they were being removed instead of utilizing the 14-kg/cm^2 spray nozzles built into the risers. Deployment of the spray rings was more difficult, but much more effective in decontamination, than the low-pressure spray system. Prior to installing any equipment into a HLW tank, the equipment's failure at the most inappropriate time should be anticipated and a recovery plan with appropriate equipment (or at least the conceptual design of it) should be available to address the situation. This concept could be taken to the extreme; clearly a balance again is needed to plan for the most likely failures and those with the highest consequences.

Mockups have been extremely valuable in the removal and replacement of highly contaminated equipment. The WVDP has invested considerable resources to construct two outdoor platforms with heights of 14 m and 17 m as well as an indoor platform. These platforms are used to simulate the height of the HLW tank and its riser connection. Prior to most equipment being installed into the HLW tanks, the components are first installed in the platforms where they undergo final testing and checkout while personnel are trained in the operation of the systems. Equipment tested in these platforms includes a HLW supernatant decant pump, replacement HLW transfer pump, dual-arm camera system, and the mast-mounted delivery system with its remotely operated sluicer arm and dual-camera arm systems. Equipment removal from the HLW tanks is also mocked up and practiced using these facilities. Remote tooling, hardware, fixtures, and contamination-control systems are checked out and adjusted until the equipment and personnel are ready to perform the actual "hot" work. In addition, key activities are practiced to

minimize and determine stay times so that realistic dose estimates can be developed and proper radiological hold points can be incorporated into the field work instructions. The extensive use of mockups has resulted in better hardware design, more operator input into the jobs they perform, increased ownership in the activity, safer operations, reduced worker doses, and less unanticipated situations in the field. Mockups have been performed in conjunction with the relocation, size-reduction, and replacement of 15-m-long mobilization pumps; the replacement of the original HLW transfer pump; and the potential future replacement of the HLW supernatant decant pump. Mockups will continue to be utilized at the WVDP in order to perform highly contaminated work safely and with worker doses as low as reasonably achievable (ALARA).

CURRENT AND FUTURE WASTE HEEL REMOVAL

As shown in Table IV, there is approximately 0.66 million curies of mostly Cesium-137 remaining on zeolite in the spare HLW tank, Tank 8D-1, and 0.76 million curies of predominantly Strontium-90 remaining in the sludge within the primary HLW tank, Tank 8D-2, supplying the Vitrification Facility.

Table IV. Cesium and Strontium Processing Summary as of September 30, 1998

	Cs-137 (MCi)	Sr-90 (MCi)	Cs-137 and Sr-90 (MCi)
Processed-to-Date Through Batch 67, HLW Transfer 58	5.70	4.98	10.68
Remaining in Tank 8D-1	0.56	0.10	0.66
Remaining in Tank 8D-2	0.03	0.73	0.76
Totals	6.29	5.81	12.1

January 1, 1996, Activity Basis

Fiscal Year 1999 waste removal efforts are focused on waste removal from the spare HLW tank (Figure 4). To support removal of as much of the remaining zeolite as possible, the mobilization pumps have been lowered further under the tank bottom gridwork to maximize their jet effectiveness and provide pump operability at lower tank levels. An inoperable mobilization pump, temporarily stored in this tank, has been removed and replaced with a new mobilization pump. In addition, upgrades have been made to replace the mobilization pump VFDs, and VFDs have been added to the pump positioner gearmotors to adjust pump rotation within the risers between 0 to 2 rpm. One mobilization pump had leaked column water at a >50 L/min. rate, which rendered the pump inoperative. To address this problem, a driveline bearing-spray assembly was designed, fabricated, tested, and installed into this pump column to spray a small quantity of water at each of the eight internal bearings. The pump is now operable, although the water addition rate is approximately 15 L/min. In the big picture, this water addition can be managed by existing processes therefore replacement of this expensive and highly contaminated pump has been avoided. The five operating mobilization pumps are currently being used to mobilize the zeolite within the tank so that the transfer pump can remove the slurry and transport it to the main HLW tank.

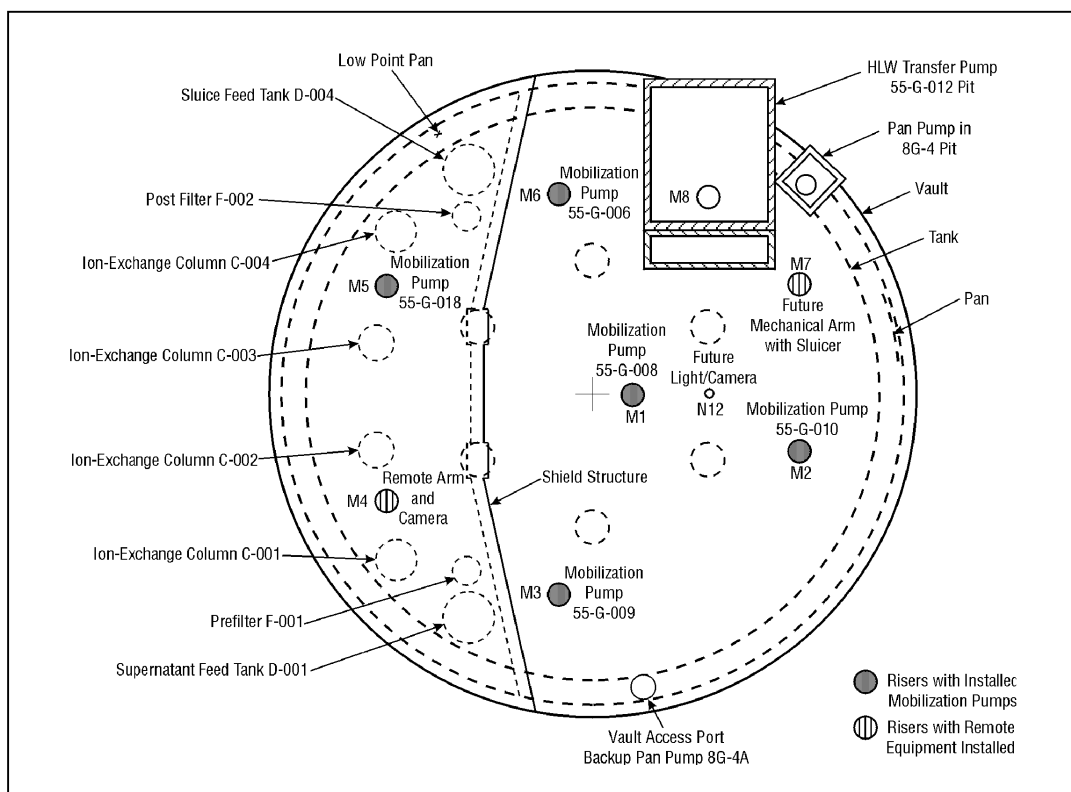


Fig 4. HLW Tank 8D-1 Plan View

A remotely operated and positioned sluicer assembly is being installed into an empty tank riser to aid in zeolite removal. The sluicer is supplied with clean, demineralized water at 7 kg/cm^2 or it

can utilize the radioactive tank liquid. Its functions are to wash off internal tank surfaces, move deposited zeolite under this area of the tank back to where the mobilization pumps can draw it into the agitated slurry, sluice or feed zeolite to the transfer pump suction in the adjacent riser, and clear the inlet to the transfer pump of debris if required. The sluicer assembly also features two radiation-resistant cameras with lights positioned on pan/tilt units on the end of arms. These arms traverse up and down the deployment mast and will position the in-tank cameras to monitor tank clean-out activities. An in-tank video camera is also in place in the M-4 riser, and another camera installation is planned for the N-12 riser. By September 30, 1999, it is expected that less than 3% of the original radioactivity, or a maximum of 160,000 curies of Cesium-137, will remain in the spare HLW tank. Other, more advanced, waste-removal equipment is being developed to assist in its subsequent removal.

Waste mobilization and removal from the primary HLW tank, Tank 8D-2, will resume after sufficient zeolite is added to it from the spare HLW tank. Removal efforts in FY1999 include the use of the six mobilization pumps and the addition of either a seventh mobilization pump or a sluicing arm in the M-7 riser (Figure 3). The equipment in the M-7 riser is needed to mobilize the accumulated solids remaining on the tank bottom in this area, at the limit of the adjacent mobilization pump jets. It is projected that by the end of FY1999, less than 0.76 million curies will remain in this HLW tank. Processing from this tank will continue in FY2000 and FY2001 using existing mobilization pumps and more advanced, waste-removal equipment currently being developed.

SUMMARY AND CONCLUSION

The WVDP has successfully mobilized and transferred approximately 88% of its HLW from its underground storage tanks to the Vitrification Facility where the waste was processed into over 230 borosilicate-glass-filled containers. This processing was performed over a 32-month period using up to six, 150-hp mobilization pumps to agitate and suspend the sludge and zeolite in the HLW tank while the transfer pump sent the slurry to the Vitrification Facility. There were 102 HLW transfers performed to prepare 58 batches of melter feed. The average batch included 178,000 curies of Cesium-137 and Strontium-90 which are the major radionuclides. At the start of waste processing, a single transfer of HLW from the storage tank contained enough waste to produce a melter batch. As waste mobilization and transfers continued, the resulting HLW became more dilute so that two or three transfers were required to make up batches after approximately 9 million curies (79% of the estimated tank activity) were removed. Waste dilution continued to require eight HLW transfers to produce the last vitrification batch of Calendar Year 1998 (CY1998).

Many improvements to the original installed mobilization and transfer system were incorporated during waste processing. In-line radiation probes were used to monitor and trend the activity of the waste being pumped so that mobilization and transfer pump operations could maximize waste removal. Mobilization pumps were lowered in the tank to maximize the effectiveness of their jets under the tank's bottom gridwork and increase the waste mobilization radius around each pump, as well as allowing pump operation at lower tank levels. Mobilization pump column

water infiltration into the HLW tank was minimized by water supply system modifications and the utilization of a custom spray assembly to cool and lubricate mobilization pump driveline bearings instead of maintaining liquid-filled pump columns. Mobilization pump gearmotor-driven positioners were outfitted with VFDs to be able to utilize the pump jets to both scour the solids off the tank bottom at slow rotational speeds and then better suspend the solids at the higher rotational speeds. In-tank cameras and lights provided visual verification of the effective waste mobilization and removal process and indicated areas where additional solids mobilization was required. The previous utility water system supplying seal water to the mobilization pumps was replaced by a high-capacity demineralized water system to minimize the calcium addition to the waste. Two mobilization pumps were added to the tank; one to replace an adjacent failed pump which had left a portion of the tank solids inadequately mobilized, and another to provide additional tank waste mobilization.

Operational improvements included the backflushing of the HLW transfer pump with either water or compressed air when its inlet strainer became fouled with solids or debris. Mobilization pumps were fixed or aimed in certain directions to mobilize hard-to-reach solids within the tanks while visually confirming the pumps' effectiveness with the in-tank video camera. Vibration monitors were added to the transfer pump and were monitored for signs of accelerated pump wear.

The major challenges encountered during waste mobilization and removal were:

- Relocating a contaminated, 15 m long mobilization pump from the spare HLW tank to compensate for an inoperable mobilization pump.

- Removal and replacement of the highly contaminated inoperable mobilization pump.

- Replacement of the HLW transfer pump with an improved version after the original pump became inoperable.

Each of the above three tasks involved very detailed planning to safely perform the hardware change with minimal disruption to the ongoing processing and yet maintain worker radiation doses ALARA. Remote equipment and operations were used where feasible in all three tasks. Prior to performing these difficult radioactive activities, multiple mock-ups were performed to demonstrate the operation of the equipment; verify the adequacy of work instructions, radiological containments, and dose estimates; and ensure worker familiarity with the equipment and activities.

Many lessons were learned during waste mobilization and removal operations and many more will undoubtedly be forthcoming during future activities to remove the remaining waste heels from the HLW tank bottoms. Waste recovery to date has been challenging but relatively

straightforward; future waste recovery will be necessarily slower due to the small amount spread over such large tank surfaces. Plans call for new equipment to be installed into both large HLW tanks. Remotely operated sluicers with the capability to wash tank internal surfaces and move solids across the tank bottom are planned for both tanks in CY1999. The sluicers are equipped with dual-camera arms to monitor sluicer operations and waste removal effectiveness. The sluicers will be used with mobilization pumps to remove as much of the waste heels as possible over the next year while the next generation of waste removal equipment is being developed for future deployment. Current plans anticipate final waste heel removal by the end of FY2001, subject to approval of a tank-closure plan that allows approximately 2% of the original waste to be left behind and stabilized.

The WVDP's progress and accomplishments in mobilizing, removing, and vitrifying the HLW over the last 32 months showcase the discipline of our processing operations groups, the innovative engineering approaches to challenges that always arise along the way, and the overall reliability of the processing systems.

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