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Contractor for the U.S. Department of Energy
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Dissolution/Re-Suspension of Stored Radioactive Waste and On-Site Transport/Handling for Conditioning Waste Retrieval

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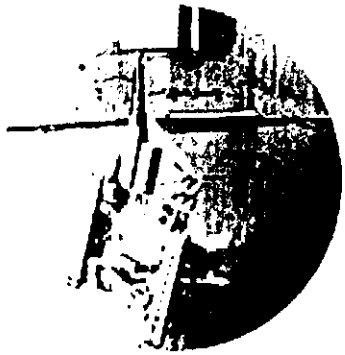
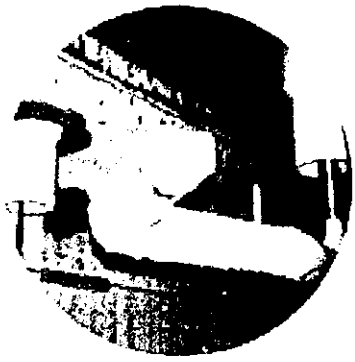
Dissolution/Re-Suspension of Stored Radioactive Waste and On-Site Transport/Handling for Conditioning –

Waste Retrieval





Developed by
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For the International
Atomic Energy Agency
Vienna, Austria

3. WASTE RETRIEVAL AND TRANSFER PROCESSES

The four primary functions in a waste retrieval system are as follows:

- accessing all of the waste within the tank configuration
- mobilizing all of the waste, which can have varying physical properties
- removing the bulk and residual mobilized waste
- transferring the waste to storage or processing equipment.

Selection of retrieval and transfer systems must include all of these functions. Limitations on any one of these areas affect the whole process. This section categorizes according to function many available retrieval and transfer processes, with positive attributes and limitations. Additional information on these systems is referenced in the annexes.

3.A Access Waste Technology for accessing waste can be divided into two categories: local and global delivery systems. Local systems have a limited effective range and must be moved around the waste volume to be effective. Local systems include high-pressure water jets and mechanical systems, positioned by vehicle and manipulator arms. Global systems have sufficient range to access the entire volume from one or more fixed locations. Examples include long-range sluicing jets and far-reaching mixer pumps.

3.A.1 Long-Range Sluicing Jets Far-reaching water jets or sluicers have one or more through-the-air water jet nozzles with water supplied by a local or remote pump. Clean or contaminated liquid (such as supernate from other waste tanks) may be used. Commercial pan-and-tilt mechanisms used to direct the stream are readily available and can be located in a tank where most advantageous. More than one station provides greater flexibility in accessing waste, especially when there are obstructions in the tank. These systems have been used at the Hanford Site (Washington, United States), Savannah River Site (SRS) (South Carolina, United States), and elsewhere (Annex 6 and 8). An array of fixed nozzles directed near the tank bottom at The Mining and Chemical Combine (MCC) at Zheleznogorsk (Russia) covers the entire tank floor without the need to steer the nozzles. (Annex 9).

A borehole miner with an extendible nozzle (~3 meters) was used at the Oak Ridge National Laboratory (ORNL) (Tennessee, United States). This technology is a specially designed mast-mounted sluicer that uses higher-than-normal pressure to sluice (1000 pounds per square inch vs. 150 pounds per square inch) coupled with a 10-foot extendible nozzle to increase effective range sufficient to access an entire tank volume.

Global sluicing systems mobilize the waste which must flow to a fixed retrieval pump for removal. Heavier solids often settle to the bottom before reaching the pump and may have to be removed using a different process (Annex _).

3.A.2. Far-Reaching Mixers Large mixers work in a bulk liquid environment, agitating liquid to mobilize and entrain solids so they can be pumped out of the tank. Several types of mixers are available. As with sluicers, heavier solids may settle out before they can be pumped from the tank and may have to be removed using a different process.

3.A.2.a. Long-Shaft Mixer Pumps Generally, a long-mixer pump can be described as a centrifugal, dual-jet pump located near the solid waste, beneath the liquid, with a long drive shaft connected to a motor above the storage vessel. The pumps are rotated, causing the jet streams to sweep across tank floor, mobilizing waste across the entire effective range of jet streams. These systems are effective for bulk waste retrieval. The long drive shafting has at times resulted in vibration-induced bearing and seal failure (Annex 4). One possible alternative is a submersible mixer pump.

3.A.2.b. Submersible Mixer Pumps Powered by close-coupled submersible motors, submersible mixer pumps may be either a centrifugal pump or horizontal ducted turbine. The pumps may be rotated or used in

a fixed position. These pumps have been used for waste retrieval in Tank 19, a large tank at SRS. Limitations involved with this approach include limits on motor size when the system is placed inside the tank and flammable gas ignition concerns (Annex 5).

3.A.2.c. Air-Operated Vacuum Lift and Blow This mixer pulls process liquid into a small vessel by vacuum, then pressurizes and discharges the fluid as a jet. Several nozzle and suction arrangements are available. AEA Technology and American Russian Environmental Services (ARES) have produced such systems. They have been used at ORNL and SRS and are being tested for use at the Hanford Site. Aerosol generation from the vacuum system is a top issue at SRS (Annex 2 and 3).

3.A.2.d. Air Buoyancy Mixers The buoyancy of air bubbles in liquid is used to establish bulk convection flow. Air sparging is a simple bubble stream. The same stream is amplified by using a chimney to concentrate lift as in an airlift circulator. Airlift circulators are standard in tanks at the Mining and Chemical Combine, Zheleznogorsk, the Hanford Site, and elsewhere. Airlift circulators are typically applied to enhance cooling and to eliminate stratification of liquid layers. The Pulsair™ pulsed air system amplifies lift by generating very large, coherent bubbles. Pulsair™ is more vigorous than airlift circulators and can mobilize sludge if enough generation plates are installed. This method was used successfully at ORNL to mobilize lighter weight sludge for pipeline transfers (Annex 1).

3.A.3. Long Reach Manipulation Local placement of retrieval processes for complete waste access is accomplished by the use of a manipulator arm from one or more fixed locations. This provides positioning without contacting the waste surface and as such simplifies removal for maintenance. In addition, work can be done high on tank walls and throughout the storage volume. Such systems require extensive support infrastructure and a large initial investment.

3.A.3.a Modified Light Duty Utility Arm (MLDUA) This system was used to deploy retrieval tools into the Gunite and Associated Tanks (GAATs) at ORNL. These seven tanks are 25 or 50 feet in diameter. Because the MLDUA has a 25-feet reach, four placements were required in the 50-foot tanks to achieve complete coverage. (Annex 1).

3.A.3.b. Gray Pilgrim EMMA Arm The Fernald Environmental Management Project (Ohio, United States) silo projects have considered using a Gray Pilgrim tendon-controlled long-reach arm to access two 80-feet-diameter silos. Located in the center of the silo, supported from a bridge structure, the arm could access the entire silo and deploy solid waste mobilization and removal tools. This design proceeded through concept only.

3.A.3.c. Advanced Waste Retrieval System The West Valley Demonstration Project (New York, United States) has developed a retrieval arm with a 15-foot reach that is mounted on a universal Mast Mounted Tool Deployment System. This system can be inserted through a 24-inch access port, or riser, and is designed to vacuum sludge residue from the tank floor using a steam jet eductor (Annex 12).

3.A.4 Remote Controlled Vehicles Here, local placement of retrieval process is done using a vehicle that maneuvers across the waste surface or tank bottom. While the ability to successfully move through and across the waste in a tank is an issue, it is not the most significant issue in designing and deploying these systems. The two largest issues are umbilical management and recovery of the vehicle for maintenance. Both require extensive engineering and careful planning, especially if the waste presents a significant personnel hazard when adhering to the vehicle or its cables.

3.A.4.a. Houdini Vehicle This 1000-pound, 4 foot by 5 foot tracked vehicle that folds to fit through a 24-inch access riser. It has been used successfully at ORNL in conjunction with the MLDUA to clean out seven 25- and 50-foot-diameter tanks. It uses a plow blade to move sludge and has a small arm that can handle the same mobilization and removal tools as the MLDUA. (Annex 1)

3.A.4.b. Trac Vehicle The Trac vehicle is being considered by the Hanford Site's River Protection Project for sludge waste retrieval from a 75-foot-diameter tank with about 8 feet of sludge. The system has a hydraulic-powered pump mounted between the tracks to pump out sludge as water is added to form slurry.

3.A.4.c. ARD Crawler ARD has developed several crawlers for tank cleaning. One, with large rubber tires was designed for use in the Hanford Site sludge tanks and is self-righting if tipped over.

3.A.4.d. Tarzan Walker The Tarzan was developed for the West Valley Demonstration Project to move through vertical support columns inside a tank by gripping and releasing the columns. This design proceeded through concept only.

3.A.5 Cable Positioning Systems A cable positioning system uses the coordinated movement of a series of cables to position a vehicle. Two cables are needed for flat wall maneuvering. Three or more cables can position a platform in space.

3.A.5a. STE-2 Retrieval System A cable positioning system has been developed for cleaning the STE-2 rectangular waste tanks at La Hague, France (Annex___[This annex will be done by others[_).

3.A.5.b. Cable Wall Cleaning System Two-cable wall decontamination systems are commercially available.

3.B Mobilize Waste Defined as the change in waste form to allow removal from the tank, waste mobilization entails either mixing solids with liquids into a pumpable slurry or, if the solids are caked, eroding the solids so they can be mixed into a pumpable slurry. Pumping is not the only way to remove waste, but it is the most common method.

3.B.1 Hydraulic Water Jet The hydraulic water jet ranges from high volume sluicers, such as a fire hose (high volume, low pressure), to high pressure, low volume jets. Generally, the effective range is inversely proportional to pressure. Low pressure water jets have sufficient range to be used as "global" systems. High pressure systems (5,000 to 50,000 pounds per square inch) are locally deployed, in general, because of the short effective ranges.

3.B.1.a. Confined Sluicing Confined sluicing is a high pressure water jet combined with immediate removal of the slurried waste to minimize the resident water volume in the tank during retrieval. This is especially important when the tank is suspected of leaking. An example of this technology is the Confined Sluicing End Effector used at ORNL (Annex 1).

3.B.1.b. Light Weight Scarifier This tool was a combination of 50,000 pounds per square inch water jet mobilization and a high velocity air conveyance waste removal system (Annex_____).

3.B.1.c. Low Pressure Sluicing Jets Both global and local mobilization can be accomplished using low pressure jets (100 pounds per square inch). To be used for long range sluicing, the volume has to be near 100 to 200 gallons per minute. Much lower flow rates can be used for local mobilization when the sludge is easily mobilized (Annex 6, 7, and 9).

3.B.2 Pneumatic Air Jet Air jet mobilization has only been used for loosening dry soils. The possibilities for mobilizing wet sludge where water levels need to be kept to a minimum as a result of potential leaks has not been fully explored.

3.B.2.a. Air Lance Excavation Commercial air lances are available for loosening soils for dry soils excavation. Adaptation has to be made for remote use inside tanks.

3.B.3 Mechanical – Crushing, Digging Mobilization by mechanical means is a simple concept but generally has not been planned for use in high hazard tanks owing to maintenance and deployment issues. A simple but successful mechanical method using the Houdini vehicle was employed by ORNL. Sellafield (England) is planning a major mechanical campaign for retrieval of solid parts from silo storage.

3.B.3.a. Houdini Vehicle The Houdini vehicle was deployed in the ORNL GAATs. The initial plan was to use a small remote-controlled arm to handle a scarifying end-effector (the Confined Sluicing End Effector).

However, the vehicle's plow blade and shear weight proved effective in mobilizing the 2- to 4- inch-thick hard-pan sludge encountered. (Annex 1).

3.B.3.a.1 Plow Blade Moving Waste The Houdini vehicle is equipped with a plow blade having a rubber scraper on its lower edge. It was intended to be used to move the slurry over to the CSEE being held by the MLDUA. It proved, also, to be useful for breaking off plates of hard-pan sludge (Annex 1).

3.B.3.a.2 Tread Crushing of Waste Once again proving that equipment operators will find the most effective use of available equipment, the ORNL operators of Houdini found that simply driving the 1000-pound vehicle over loosened plates of hard-pan sludge crushed the sludge into a pumpable slurry. This became the baseline method of mobilizing hard-pan sludge in the GAATs (Annex 1).

3.B.3.b Grab and Drag – Sellafield Silo Retrieval The Sellafield silo retrieval operation is planning to do a fully mechanical retrieval operation. The top will be removed from the silo. A support structure for crane operations will be installed along with a contamination enclosure. Cable suspended drag buckets will be used to move the material to a location under the grab. From there, grab clamshells will grip the material and lift it out of the silo (Annex_[will be done by others____).

3.B.4. Chemical, Thermal Breakdown Chemical addition and thermal heating can be used to mobilize waste.

3.B.4.a. Acid Sludge Softening Currently SRS uses oxalic acid (and is considering a mixture of oxalic and citric acids) to partially dissolve plutonium-uranium extraction sludge that has hardened and is not mobile. This will be used in conjunction with bulk agitation to create pumpable slurry. Similarly, salt wastes can be partially dissolved using water or possibly a weak acid (carbonic) (Annex 11).

3.B.4.b. Thermal Conditioning of Salt Heating water can increase its ability to dissolve salt wastes. Similarly, heating brine can prevent formation of a solid phase. [NO examples]

3.C Remove Waste Removal of waste is simply acting on mobilized waste to take it out of the tank. The most straightforward and inexpensive method is pumping. Several pump types are available. Air conveyance is an option where water is undesirable, such as in a leaking tank. Mechanical methods have a low tolerance to objects imbedded in the waste, such as level measuring tapes, and have contamination confinement issues.

3.C.1. Hydraulic–Liquid Pumps Several types of pumps are listed below. In addition, the TORE® solids fluidisation and transportation device is also discussed. This new technology enhances the performance of hydraulic-liquid pumps (Annex_____).

3.C.1.a Centrifugal Pumps This is the most common pump type. It can have either an external to the tank motor driving a long shaft or be a close-coupled submersible system (Annex 4).

3.C.1.b Water Jet Eductor Water-powered jet pumps range from low pressure drives (100 pounds per square inch) to the high pressure (10,000 pounds per square inch) system used by ORNL at GAAT. High pressure systems add less water during pumping but require more sophisticated drive pumps and generally need to use clean water. Lower pressure systems are less expensive and are more amenable to use of recycled contaminated liquids (Annex 1).

3.C.1.c Steam Jet Eductor A standard for years at the Hanford Site, SRS, and Idaho National Engineering and Environmental Laboratory (INEEL) (Idaho, United States), the steam-jet eductor's high specific drive energy results in minimum net water addition during pumping. SRS and INEEL still use the systems, while the Hanford Site has moved to centrifugal pumps. A steam-jet eductor requires a separation tank to vent off gasses. A local pump is used to pump the slurries to their destination if it is farther than a few hundred feet (Annex 7).

3.C.1.d Double-Diaphragm Positive Displacement Pumps This is a simple, air-operated positive displacement pump. It has relatively low pump rates but can lift waste more than 60 feet. It is rugged and

reliable but susceptible to fouling from heavy solids (sand and gravel). It has been used at SRS in Tank 17 for removing residual waste (Annex 6) and for removing slurry out of a uranium ore tank in Iraq (Annex_____).

3.C.1.e Pitbull™ Pneumatic Pump This pump, an adaptation of a commercially available pump, consists of a chamber with a foot check valve. A vacuum is placed on the chamber as it draws liquid and slurry into the chamber. The chamber is then pressurized, closing the foot valve and forcing the liquid in the chamber up a tube that extends to the bottom of the chamber, up and out of the tank. A check valve in the discharge line keeps that material from falling back into the chamber. This unit has not been used in the field, but has been extensively tested for pumping capability and resistance to plugging (vs. the double diaphragm pump). It is more robust than the double diaphragm pump when moving gravel-like solids (Annex 5).

3.C.1.f Fluidic Pumps These pumps use either a fluidic check valve or fluidic amplifier to fill a charge vessel under vacuum and discharge the liquid under pressure. This system allows pumping to occur without introducing moving parts into the tank. The fluidic diode pump is similar in function to the Pitbull™ pump except that the system check valves are fluidic diodes with no moving parts versus mechanical check valves. The diodes are full flow in one direction and 25% flow when reversed. The other type of fluidic pump is a reverse flow diverter (RFD) where liquid is drawn into the charge vessel through jet pump suction. When the charge vessel discharges, the jet pump pulls in more liquid increasing the flow. This type is limited in pump discharge head. Both are made by AEA Technology (Annex 2 and 3).

3.C.1.g Special Purpose Pumps, such as Moyno Pumps There are several special purpose pumps, such as the Moyno. The Moyno pump is a positive displacement pump based on a wobbling drive plate. It effectively removes slurries but cannot handle larger materials. This is a commercially available unit.

3.C.1.h The TORE® Solids Fluidisation and Transportation Device This device is a hydraulic conveyor of solids that can be added to a hydraulic-liquid pump to enhance its ability to remove solid materials from the bottom of underground tanks. By attaching this device to a jet pump, which supplies the required motive force for transfer, the TORE® creates a precessing vortex core under the foot of the central tube to mix the solid material. The mixed waste is drawn into the TORE and discharged. With no moving parts, this technology could provide a simple and effective way to remove solids that become mounded near the pump interface during retrieval (MEPRO 2001).

3.C.2 Pneumatic – Air Conveyance Air conveyance is a process that uses a rapid flow of air to entrain solids and liquids and carry them off the tank floor and/or out of the tank. These systems have the advantage of scavenging free liquids so they are not available to leak. However, these systems add significant complexity to the retrieval system support equipment.

3.C.2.a Blower-Driven System Blower-driven air conveyance uses a blower mounted externally to the tank. This type of system can achieve the highest flow rates resulting in excellent retrieval effectiveness, but it requires significant ex-tank de-entrainment facilities with shielding (Annex_____).

3.C.2.b Eductor-Driven System Eductors generate less air velocity than blowers but require less contaminated infrastructure outside the tank. An air-driven system still needs a de-entrainer. Water-driven systems can be used for short transfers as is, but for longer transfers, they require an air separator and booster pump (Annex_____).

3.C.3 Mechanical Systems Mechanical removal is simple in concept, but for highly radioactive waste, it presents many difficulties in confinement. Mechanical systems are also sensitive to foreign objects imbedded in the waste. In addition, conversion to a transferable waste form or container will be needed.

The traditional excavation method is to use an extractor. For highly contaminated waste, a significant confinement envelope is needed. Typically, this type of system requires the top of the tank to be removed. (Annex__[Provided by Sellafield]___).

3.D Transfer Waste Waste transfer is simply moving waste that has been removed from a tank to a destination tank or facility. This can be done using the in-tank removal system or a separate out-of-tank transfer system. The most straightforward and inexpensive method is pumping. While pumping is effective, plugs or blockages can occur in the transfer pipes (Annex 10). For smaller amounts of waste, containers can be used. Liquid- and solids-only containers for highly radioactive waste exist. Currently containerized slurry transport equipment is rare. Containers have contamination confinement issues.

3.D.1 Pumping and Transfer Lines

3.D.1.a. Direct Pumping A removal pump in the tank is used to move the waste through the pipeline to the destination tank in one operation. This is the most straightforward method, but longer pipelines require higher pressures and greater pumping power (Annex_____).

3.D.1.b Indirect Pumping Waste is delivered to a staging tank, where a dedicated transfer pump moves the waste through the transfer line. More than one stage may be needed to move the waste to its final destination (Annex_____).

3.D.1.c. Temporary Lines In some cases, existing pipelines cannot support safe transfers. When, the expense of installing a new permanent pipeline is not justified, a temporary, high-pressure hose-in-hose technology can be installed for a safe conventional transfer (Annex_____).

3.D.2 Liquid Vessels A liquid transfer cask can be used to transfer materials. Many have been used in the United States for high-activity waste. However, these vessels are no longer licensed. Transportation safety is the primary issue.

3.D.2.a. LR-56 (French) Tank Truck This is a truck-mounted shielded cask with a capacity of 200 gallons. It has provisions for rinsing the cask after transfer but not for solids transfer.

3.D.2.b. Low-Activity Vessels Liquid waste that does not present a direct high radiation hazard has been transferred by lightly shielded vessels located on a truck or trailer bed. ORNL has used this method for moving waste from 5,000-gallon tanks to a receipt tank.

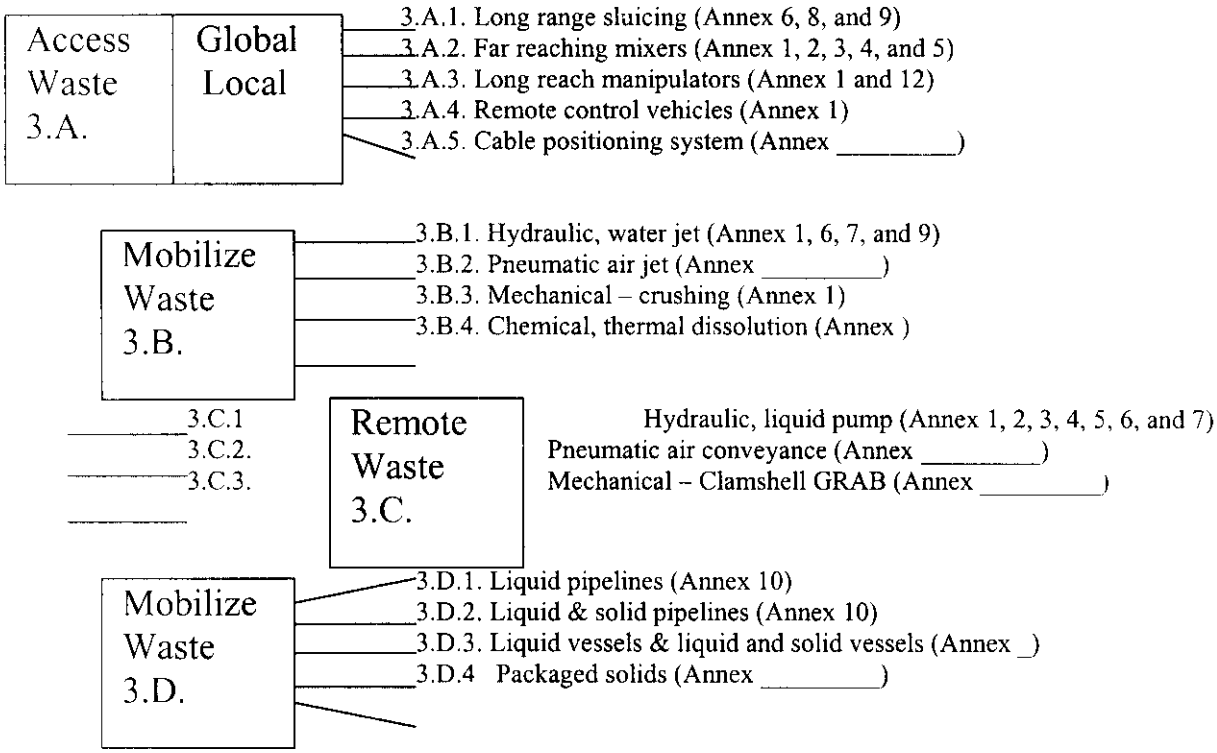
3.D.3 Vessels for Liquid and Solids Except for the low-activity vessels described in Section 3.D.2.b, no vessels designed for solid/liquid slurries have been identified. This is gap in available waste transfer technology. This capability will be required for final retrieval of high-activity tanks with a small remaining volume.

3.D.4 Vessels for Dry Solids Solid particles can be packaged for transfer after liquids have been removed. This is conventional packaging in drums and solid waste containers.

3.D.4.a Drums These are standard drum containers for solid waste. Removal of liquids from the waste is required for safe use of drums as containers. When shielding is required, 30-gallon drums with a 55-gallon drum overpack filled with high density concrete can be used.

3.D.4.b TRU-Packs TRU-Packs are solid waste shipping containers, designed to be sealed sufficiently to transport solid waste containing transuranic alpha contamination. They are generally used for contaminated hardware.

Waste retrieval process Function Figure 3.1



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MEPRO LTD. 2001. *MEPRO Limited - Process & Products Division: The TORE ® Solids Fluidisation and Transportation Device.* Bulletin 03, MEPRO Limited, Montrose, Scotland.

ANNEX 1

Waste Mobilization and Removal
from Oak Ridge National Laboratory
Gunite and Associated Tanks
by Pete Gibbons and Kristin Manke

Statement of Problem

Waste type: Approximately 85,000 gallons of sludge was stored in seven Gunite and Associated Tanks (W-3, W-4, W-6, W-7, W-8, W-9, and W-10) at the Oak Ridge National Laboratory in Tennessee. This waste varied from thick viscous waste to easily flowable liquid. In addition, the tanks contained dried waste that had the consistency of chalk (Lloyd et al. 2001). The sludge contained approximately 63,000 Ci (Lloyd et al. 2001). The radioactivity came from uranium, plutonium, thorium, and other long-lived isotopes, as well as high concentrations of cesium-137 and strontium-90, which have relatively short half-lives (ORR 1998). The tanks also contained organic materials in trace amounts and heavy metals.

Rainwater had leaked into the tanks, adding approximately 250,000 gallons of wastewater. This water accumulated on top of the sludge layer. This supernate was radioactive, due to dissolved metal salts. The supernate and the tank walls contained an estimated 15,000 Ci (Lloyd et al. 2001).

A retrieval campaign 10 years earlier in some of the tanks used long range sluicing jets and conventional pumps. The campaign recovered 90% of the sludge, leaving hardened material in some of the tanks.

Tank TH-4, also part of the gunite tank group, was filled to capacity with supernate and 2 to 3 feet of sludge (TFA 2001d).

Storage arrangements: The 16 Gunite and Associated Tanks Gunite and Associated Tanks have capacities ranging from 1,500 to 170,000 gallons. The gunite tanks were constructed using gunite. The associated tanks are located near the gunite tanks were constructed from stainless steel.

These gunite tanks involved in the waste retrieval effort were W-3, W-4, W-6, W-7, W-8, W-9, W-10, and TH-4. The tank walls were built in three layers. An outer wall approximately 6-inches thick was made of gunite, a mixture of cement, sand, and water sprayed through a nozzle over a steel reinforcing framework. The next layer was made of asphalt or bitumen embedded in the gunite provided the leak barrier. This layer was approximately 0.5-inches thick. The inner wall was composed of gunite, approximately 2-inch thick (Blank et al. 1998). In tank W-5, remote inspections showed that the interior walls had deteriorated. Pieces of the gunite wall had fallen from the walls, exposing the metal mesh underneath (Roeder-Smith 2001).

The tanks were oriented vertically with domed tops. The top of the dome was located about 6 feet (1.8 m) below the ground surface (GAAT 2001). The tanks (except for TH-4) ranged in diameter from 25 to 50 feet, and had nominal capacities ranging from 42,500 to 170,000 gallons (Lloyd et al. 2001). Tank TH-4 is 20 feet in diameter and 9.1 feet tall with a nominal capacity of 14,000 gallons. These tanks were built to collect, neutralize, store, and transfer the liquid portion of radioactive and/or hazardous chemical waste (GAAT 2001).

Reasons for retrieval: The chemicals and radioactive materials in these tanks, which are located near buildings in the center of the Oak Ridge National Laboratory complex, could have harmed the environment if they were released (DOE 1998b). As the tanks aged, the possibility of the waste leaking to the surrounding soil and groundwater increased. The cumulative risk was too great to leave this waste in these tanks (TFA 2001).

Objectives: The objectives of the retrieval activity were to remove the hazards associated with these tanks by 1) removing sludge and tank heel without adding large volumes of water or placing excessive stress on the deployment system or the tank, 2) cleaning gunite tank walls by removing dried waste and "shaving" off layers of contaminated concrete, and 3) rinsing waste off of residual hardware inside the tank.

Retrieval Strategies

Sampling: From May through August 1995, the waste in eight gunite tanks (W-3, W-4, W-5 through W-10) was sampled to determine the appropriate retrieval strategy. Analysis of the samples began immediately upon receipt, and data validation was completed in December 1995.

The characterization staff

- Retrieved samples from almost any location within a tank using existing risers.
- Obtained sufficient samples to determine waste heterogeneity or homogeneity.
- Inspected tank walls, using an in-tank video system. They determined if the conditions of the walls presented retrieval limitations and determined the current state of the walls.
- Obtained tank wall samples to determine contamination in the surface and to a 1/4-inch wall depth.
- Estimated the sludge volume.

Waste samples were taken using pole samplers and the tank characterization system. This simple system uses a floating boom to retrieve samples. The boom was lowered into the tank via a riser, and floated on the water within the tank. The boom was used to deploy a clamshell grab sampler, video camera and lights, a wall chip sampler, a sonar depth finder, and a sonar transponder.

Several difficulties arose in obtaining the samples. The clamshell sampler was not heavy enough to sink into the denser sludge. The wall chip sampler was plugged by wet concrete dust, allowing only very small samples to be collected from the walls of tanks W-5 and W-8.

More information on tank waste sampling is available in *Results of 1995 Characterization of Gunite and Associated Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee*. ORNL/ER/Sub/87-99053/79. http://www.tanks.org/ttgdoc/DE96012206.pdf. (ORR 1996).

Waste characterization: The waste was characterized using Oak Ridge National Laboratory procedures or U.S. Environmental Protection Agency methods modified to incorporate radiological considerations. In some cases, changes to the procedures were required to incorporate additional safety measures or to handle unusual sample consistency.

The analyses performed included

- Metal analyses
- Mercury analyses
- Carbon analyses
- pH determination
- Volatile organic studies (gas chromatograph/mass spectrometer)
- Nonhalogenated volatile organic analyses
- Capillary column techniques
- Anion determination
- Microwave digestion
- Radioisotope determinations
- Densities.

More information on the characterization of the waste can be found in *Results of 1995 Characterization of Gunite and Associated Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee*. ORNL/ER/Sub/87-99053/79. http://www.tanks.org/ttgdoc/DE96012206.pdf. (ORR 1996).

Infrastructure upgrade: Very little of the support systems for the 50-year-old tank farms remained serviceable. While the tanks remained sound, generally, services were needed. All of the waste was transferred using new, temporary transfer lines. Several 30-inch risers were added to each tank for equipment access, although the Houdini was deployed through existing 24-inch risers. Utilities were brought into the area. A work platform (or bridge) was staged over each tank to support retrieval equipment.

Downstream process: The retrieved waste was moved to active storage tanks. This required a temporary connection to a 1-mile-long transfer line. The requirements for slurry transfer through this line were 5-10 wt%

solids. Controls needed to be established to achieve this. First, pulsed-air and propeller mixers were installed in the consolidation tank to float the lighter solids for transfer with the liquids to the receipt tanks. This continued during consolidation to make room in the consolidation tank and to take full advantage of availability of the site transfer system. Then, after the lighter sludge had been transferred and all other waste had been moved to the consolidation tank, the system was reconfigured to move heavier solids to a nearby active stainless steel process tank. From there, the site transfer system was used. It did not suspend high settling rate solids. Any remaining sludge could be size-reduced using nitric acid if needed for transfer.

At the storage tanks, the waste is dried and packed for shipment to a repository. Therefore, no chemical interactions were considered, beyond safe storage.

Distribution of Retrieval Process

Technologies involved: The retrieval strategy for the Gunite and Associated Tanks involved the following technologies:

- Modified Light-Duty Utility Arm
- Houdini system
- Confined Sluicing End Effector
- Flygt mixer
- Pulsed-air mixer
- Russian pulsating mixer pump.

Modified Light-Duty Utility Arm: Using a robotic arm capable of moving through 12-inch risers, this system deploys a variety of tools. The arm is capable of lifting 200-pound payloads and reaching 50 feet horizontally and 15 feet vertically (WPI 1997). By adding tools to the arm, such as a parallel-jaw gripper end-effector, the arm's reach can be extended slightly (Heel Retrieval Guide 2001).

The system consists of a utility arm, skid-mounted deployment system, vertical positioning mast and housing, hydraulic power unit, control system, tank riser interface and containment system, and decontamination spray ring. The system is a slightly different design than the original arm developed for another waste site (HRG 2001).

The Modified Light-Duty Utility Arm was developed by SPAR Aerospace, Ltd. with technical direction from the Tanks Focus Area and the Robotics Crosscutting Program (both part of the U.S. Department of Energy) (DOE Success).

Houdini System: The Houdini vehicle positions retrieval and characterization tools inside confined radioactive spaces, such as underground tanks. Because the system can be deployed through tank openings smaller than the vehicle itself, it was named after the magician Harry Houdini, who was renowned for getting into and out of tight spaces.

This system consists of a tethered track vehicle, Tether Management and Deployment System, and the Power Distribution and Control Unit (Vesco et al. 2001).

The stainless steel vehicle, which looks similar to a miniature bulldozer, is able to fold into an approximately 22-in. wide rectangle, allowing it to pass through 24-in.openings in tank roofs (called risers). Inside the tank, it unfolds to approximately 4-ft wide and 5-ft long (WPI 1997; Vesco 2001). The vehicle moves via continuous tracks with rugged tread (WPI 1997). It is teleoperated, which means it is controlled directly by an operator in a remote location. Onboard camera systems are used to provide the operator with an in-tank view (Burks et al. 1997). The controls to the vehicle as well as power and hydraulics are passed through a 135-ft tether. The 1,000-lb vehicle is also skid steered, meaning its speed and direction are controlled by the relative position of two joysticks, each of which corresponds to one tread's motion (DOE 1998b).

The vehicle is equipped with a squeegee-tipped plow blade and a six degree-of-freedom manipulator arm. The plow blade is used to maneuver sludge and to peel hardened waste off the floor (Burks et al. 1997). The arm, which has a

250-lb payload, is used to deploy tools, recover non-pumpable objects and clean the retrieval tools (DOE Success; Burks et al. 1997).

The Houdini vehicle concept was first proposed by researchers at Carnegie Mellon University's Robotics Institute. Carnegie Mellon researchers worked with RedZone Robotics, Inc. during the early design stages. RedZone produced a prototype (Houdini I) and a second version (Houdini II) based on lessons learned at Oak Ridge for the Robotics Crosscutting Program. Houdini II is discussed here. The technology was tested and deployed under the auspices of the U.S. Department of Energy's Tanks Focus Area.

Confined Sluicing End Effector: The Confined Sluicing End Effector (CSEE) was developed and deployed to mobilize and remove residual radioactive waste. This system was used to mobilize and pump solids and accompanying liquids to a nearby receipt tank.

The CSEE, deployed on either a manipulator arm or remotely controlled vehicle, was equipped with three rotating jets mounted 120 degrees apart. As the jets rotated, a short-range stream of water was focused on and dislodged the solid waste. The rotating jets delivered water with a pressure of up to 10,000 psig. An electric motor rotated the jets at speeds from 0 to 500 rpm to cut hardened sludge (Lloyd et al. 2001).

The jets directed the dislodged material and water to an intake or suction port. The water jets were angled so they collided inside the inlet port that leads through a short hose to a waterjet eductor pump. The pump is also powered by 10,000 psi waterjets. This collision canceled the energy of the jets and confined the water and dislodged materials at lower pressures. A screen over the port protected the pump and transfer line from potentially plugging objects, such as tools, plastic film, or wire, in the waste.

The retrieval system was operated from a control room in a trailer outside of the tank radiation zone. In-tank cameras were used to provide operators with an in-tank view.

The CSEE was developed by Waterjet Technology Inc., Pacific Northwest National Laboratory, the University of Missouri at Rolla, and the Westinghouse Hanford Company under the auspices of the U.S. Department of Energy's Tanks Focus Area.

Flygt Mixer: The Flygt Mixer uses a propeller, similar in concept to an outboard motor on a boat, to mix tank waste. The propeller creates long-range currents capable of mixing over 20,000 gal/min of tank waste (TMS database 2001).

The following companies were involved in developing and deploying the mixer: Flygt, Oak Ridge National Laboratory, Westinghouse Savannah River Company, and Pacific Northwest National Laboratory (TMS database 2001).

Pulsed-air Mixer: This system uses an array of horizontal, circular plates, positioned a few inches from the tank floor. Pipes connected to the plates supply discrete pulses of air or inert gas to the underside of each plate. The air pulses rapidly create bubbles that quickly rise to the surface. This action prevents the settling of waste solids and mobilizes soft to moderately strong cohesive sludge, ranging in consistency from maple syrup to peanut butter (DOE 1999b; TFA 2001f).

The following companies were involved in developing and deploying the system: PulsAir Systems, Inc., Pacific Northwest National Laboratory, and University of Washington (DOE 1999b).

Russian Pulsating Mixer Pump: This system mobilizes and retrieves sludge using three different types of pumps: a jet pump, mixing pump, and transfer pump. Once in the tank, a vertical drive-screw system raises and lowers the selected pump to mix the waste at various levels in the tank. A key benefit of the pulsating mixer pump is that additional liquids are not introduced into the tank during the mobilization and retrieval efforts (TFA 2001c).

The following companies were involved in developing and deploying the system: Bechtel Jacobs, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, National Energy Technology Laboratory (formerly known as the Federal Energy Technology Center), and American Russian Environmental Services (TFA 2001c).

Process: The CSEE deployment system, either the Modified Light-Duty Utility Arm or the Houdini vehicle, was put into the tank. When the deployment system was ready, the CSEE was deployed through a tank riser by the Hose Management Arm. This arm holds the CSEE, conveyance hose, and jet pump. It tracks the movement of the CSEE and supports the load from the conveyance line and the high-pressure hose. Once the CSEE was in the tank, the Modified Light-Duty Utility Arm or the Houdini vehicle grasped the CSEE. Inserting the deployment system first ensured that the CSEE was grasped before it reached the tank waste. This prevented premature submersion of the CSEE that could cause plugging of the water jet nozzles with waste materials.

Video cameras able to function within the high radiation field were also deployed. These cameras provided the operators with an in-tank view, allowing them to operate the remote systems inside the tank.

With the CSEE and associated equipment placed in the tank, dewatering began. During this process, the CSEE jets were operated at ~150 psig to prevent nozzle plugging while the supernate was drawn off using the jet pump. Dewatering usually took 1 to 2 days.

When the sludge layer was revealed, pressure to the cutting jets was increased as necessary to break up and suspend the waste for sluicing. Typical cutting pressures ranged from 1000 to 4500 psig. Higher pressures were generally ineffective and caused the MLDUA to bounce around and set off position control alarms and faults. No positioning problems were encountered with the Houdini.

The system was most efficient at removing sludge when the waste was deep enough to partially submerge the CSEE, avoiding three-phase (solid, liquid, and gas) pumping. For the final 1 to 3 inches of waste, the Houdini plowed "waves" of waste to the end effector as it was held by the MLDUA. A coordinated effort with the MLDUA to position the CSEE and the Houdini to plow sludge to the CSEE along with an advanced sludge retrieval process resulted in successful waste removal.

The CSEE was used at pressures of 6500 psig to scarify the gunite walls of tanks W-3 and W-4 (Lloyd et al. 2001). Removing the dried sludge on the tank walls as well as a layer of gunite with the CSEE was done to reduce the in-tank radiation. Scarifying the walls reduced the radiation levels by 20%. However, problems did occur during scarifying. The CSEE only retrieved 50 to 70% of the 1-inch layer of gritty, hardened wall scale and gunite that accumulated in the bottom of the tank. Another end effector was designed and used to retrieve an additional 10 to 20% of the material (Blank et al. 1998). The other walls were scarified with the Gunite Scarifying End Effector; this end effector is similar in design to the CSEE but can provide higher water pressures and a larger footprint for faster cleaning.

The Houdini vehicle is lowered through a riser near the tank wall, while the Modified Light-Duty Utility Arm was deployed in the center. Once through the riser, the Houdini unfolds for work. In one tank, the system was used while suspended by the tether to cut and remove cables and steel pipes inside the tank. The manipulator arm is positioned so the elbow touches down first, allowing the vehicle to pivot on the elbow then the plow until the tracks touch, at which point they are driven forward slowly so the vehicle lands upright (DOE 1999a).

While the Houdini vehicle was designed to be completely submerged, to keep the cameras clean the operators create a shallow waste "landing spot" for the system, using retrieval tools held by the Modified Light-Duty Utility Arm. Different tools were deployed by the Houdini system depending on the retrieval work to be done:

- The Confined Sluicing End Effector was used to slurry and retrieve sludge. It was also used to wash tank walls and in-tank equipment.
- The plow blade was used to push the final 1 to 3 inches of waste to the Confined Sluicing End Effector for retrieval. The CSEE was deployed by the Modified Light-Duty Utility Arm.
- The robotic arm was used to pick up debris (such as tape, pipes, and hand tools) and move them to a consolidation basket for removal. It was also used to take waste samples and deploy the wall coring tool. Further, it was used to hold the Confined Sluicing End Effector in the correct position for the Modified Light-Duty Utility Arm to grasp.
- The Gunite Scarifying End Effector and the Linear Scarifying End Effector were used to remove contaminated gunite from the tank walls. The Houdini did not have problems handling the reaction

loads of the high-pressure waterjet system, which did present problems to the Modified Light-Duty Utility Arm.

Using the Houdini system, Confined Sluicing End Effector, Waste Dislodging and Conveyance System, and a Flygt mixer, the waste was transferred from Tanks W-3, W-4, W-6, W-7, W-8, and W-10 to Tank W-9.

Because of the gunite pieces in the Tank W-5 waste, Flygt Mixers were used for mobilizing the waste. The gunite pieces in the waste could have damaged the Houdini system; thus, it was not used. The Flygt Mixer was deployed into the tank. The angled blades on the propeller mixed the waste into a transportable slurry that was pumped to Tank W-9 (Roeder-Smith 2001).

There, the waste was conditioned using the pulsed-air mixer. This effectively suspends the light waste fraction from the heavier particles, maintaining the lighter portion near the waste surface. This lighter waste can then be safely pumped through waste transfer pipelines to the Melton Valley Storage Capacity Increase Tanks to await treatment, leaving a dense sludge layer at the bottom of W-9 (WPI 2000). With the Heavy Waste Retrieval System, the remaining sludge was mobilized and transferred out of W-9 (TFA 2001e).

In Tank TH-4, the Russian Pulsating Mixer Pump was operated in several 1-hour or more increments (up to 10 hours at a time in some instances) to mix sludge and supernate. Mixing was accomplished by lowering the pump and monitor into the tank. The system drew waste into a vertical cylindrical chamber near the tank floor. The waste was then expelled at the bottom of the tank, mobilizing and mixing the waste (as well as scouring the tank floor). Then, the waste was pumped out of TH-4 and into a holding tank (JCCEM 2001).

An initial sludge depth ranging from 2 to 3 feet deep at the beginning of pumping operations was reduced to an outer band ranging from 1 to 3 feet wide and about 1 foot deep at the end of pumping operations. The outer band of water sludge then "slumped" and spread across the tank floor. Sludge samples taken during transfer operations appear to have a high-water content (TFA 2001d).

Implementation: These new technologies and processes required the site safety and quality assurance staff to find ways to show that the intent of rules and safety requirements would be complied with during operations. A pilot operation "retrievability study" was used to demonstrate the technology and evaluate safety and regulatory concerns. This was less of a step than full-scale operations. Once the pilot-scale operations were shown to be acceptable, it was more manageable moving to full-scale operations.

Progress: In September 2000, 95% of the radiation sources and 99% of the sludge from seven tanks was removed (Lloyd et al. 2001; Roeder-Smith 2001).

The Russian Pulsating Mixer Pump removed approximately 25,000 gallons of waste from TH-4. U.S. Department of Energy and state regulators determined that additional sludge removal will not be necessary before the tank is closed (TFA 2001d).

Lessons learned:

- *Deploying and retracting MLDUA*: Operational efficiency and personnel radiation exposure levels were improved by leaving the arm inside the tank at the end of each shift (Unknown 2001).
- *Power systems and MLDUA*: To prevent the gripper tool from releasing (and thus dropping the tool it was holding), a separate hydraulic pump was added to maintain pressure to the gripper (Unknown 2001).
- *Operator Training on Houdini*: While the system does not require special qualifications, inexperienced operators can damage the system. Thus, sufficient lead time and a cold test facility are needed to train operators (DOE 1998b).
- *Ergonomics*: Designing systems to be easily operated is a critical issue. Several human interface occurred.
  - Reaching the Houdini vehicle in the containment system to perform maintenance is difficult because of limited glove port access and the extended distance between the glove ports.
  - Additional cameras could provide assist operators by providing more expansive views (Unknown 2001).
- *Separate Power Supplies*:

- A separate power supply could make the Houdini Tether Management and Deployment System (TMADS) more versatile as current national safety regulations require power in the TMADS to be shut off during maintenance and repair.
- The hoist inside the Houdini TMADS should have a separate power supply and all of the power supplies need to be accessible on the outside of the containment structure.

- *Sealing Bag-Out Port on Houdini System*: Water spray and splash from the decontamination spray ring made sealing the 20-inch bag-out port (located in the TMADS containment bezel) very difficult. Because of this poor seal, the port had to be cleaned before the polycarbonate material window could be placed in the port to provide additional light for workers (Vesco et al. 2001).
- *Tank access for CSEE*: Ensure tank risers are large enough to deploy the CSEE, the deployment system, and in-tank video cameras.
- *In-tank components*: Risers, in-tank equipment, and debris in the tank can hinder deployment of the CSEE. Ensure that in-tank components are mapped and their interference with the CSEE system is understood.
- *Tank dome loading*: Ensure that the tank dome can support the weight of the system. A load-bearing platform may be needed.
- *Tank atmosphere*: Ensure that the tank atmosphere, especially flammable a environment, is evaluated and impacts on the CSEE are understood.
- *Vehicle deployment*: Consider the value of providing a temporary holster or resting place for the CSEE when the vehicle arm is needed for short-term tasks.
- *CSEE seals*: Determine the impact of the nature of the waste on CSEE seals. The abrasive nature of the waste caused excessive seal wear. As the seal wore, the vacuum at the CSEE inlet was reduced and pumping efficiency dropped.
- *Water additions*: Coordinate activities and emphasize water conversation in waste retrieval.
- *Inlet screen and CSEE*: The inlet screen was easily plugged by waste and debris. Backflushing was not as efficient as operators hoped. In addition, it added significant water volume to the system.
- *Shock waves in pulsed-air mixer*: When a relatively high gas pressure is used, a considerable shock wave can be produced within the waste. This shock wave could damage mechanical and structural elements of the tank. Before pulsed-air mixing is used, the tank must be studied to ensure that the shock wave will not damage the tank (DOE 1999b).
- *Aerosol generation and pulsed-air mixer*: A fine mist of waste slurry is generated when the pulsed-air mixer is used. This mist could require higher capacity tank ventilation systems, although unlikely (DOE 1999b).
- *Stiff, cohesive sludge and pulsed-air mixer*: The pulsed-air mixer is not the correct choice for mobilizing stiff, cohesive sludge in large diameter, flat-bottomed tanks (DOE 1999b).

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Annex 2

Fluidic Pulse Jet Mixer
at the Bethel Valley Evaporated Waste Tanks
by Pete Gibbons and Darcy Short

Statement of Problem

At the Oak Ridge National Laboratory in Tennessee, evaporator-generated waste in the Bethel Valley Evaporator Service Tanks (BVESTs) needed to be removed to make room for newly generated waste.

Waste type: Approximately 129,000 gallons of liquid low-level waste (LLLW) was stored in the BVESTs. The five BVESTs (W-21, W-22, W-23, C-1, and C-2), held waste that contained approximately 22,000 Ci (TFA 2001b). Radiation levels detected in and around the tanks have been up to 27 Rads per hour (DOE 1998).

The waste in the tanks separated into two distinct layers: sludge and supernate. Because the supernate was acidic, sodium hydroxide was added periodically to neutralize it. The 3 to 5-inch sludge layer is primarily composed of metal nitrate, carbonate, and hydroxide precipitants (DOE 1998)[1]. The major metal components in W-21, W-22, and W-23 are calcium, sodium, magnesium, and potassium (Kent et al. 1998a). There are several metal components in tanks C-1 and C-2 including chromium, lead, and mercury (Keller and Giaquinto 1998). The sludge is considered remote handled (RH) because of high gamma radioactivity; it has also been classified as transuranic (TRU). Principle radioactive components are fission products such as cesium and strontium; activation products such as cobalt; and actinides such as thorium, uranium, and plutonium (Kent et al. 1998a).

Storage arrangements: All five tanks have 50,000-gallon capacities. The stainless steel tanks are held in underground concrete vaults located in the center of the Oak Ridge National Laboratory campus. The vaults have double containment and measure 12 feet in diameter and 61.5 feet in length (DOE 1998).
The concrete vault walls vary in thickness from to 2 to 3 feet. The roof is between 3 and 3.5 feet thick. The tanks are connected by about one mile of transfer pipelines to the Melton Valley Storage Tanks. There is limited access into the W-21, W-22, and W-23 tanks. These tanks have one 19-inch access hole located 17 feet from the north end. The tanks contain many obstructions located along their centerlines (Kent et al. 1998a).

Access holes were installed on the C-1 and C-2 tanks during the summer of 1997. The access holes are located on the east and west ends of the tanks. Before the installation of these access holes, there was no way to access these tanks (Keller and Giaquinto 1998).

Reasons for retrieval: This waste needs to be removed to free space in the tanks. The space is needed for the newly generated waste being produced by the Oak Ridge National Laboratory (TFA 2001a).

Objectives: The objectives for retrieving waste from the BVESTs were to 1) mix and remove waste in a cost-efficient manner, (2) reduce the amount of time required to perform these activities, 3) reduce risks, and 4) minimize the generation of secondary waste (DOE 1999a).

Retrieval Strategies

Sampling: Tanks W-21, W-22, and W-23 were sampled and characterized in the late summer and fall of 1996; tanks C-1 and C-2 in 1997. The waste was sampled to determine the appropriate retrieval strategy (Keller et al. 1997; Keller and Giaquinto 1998).

Sampling was done by means of manually operated grab samplers mounted on a long rod.

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[1] Sludge found in tanks C-1 and C-2 was described as light and dark tan and yellowish-green with a "mud-like" consistency. The C-1 tank had black particulates dispersed throughout the sludge (Keller and Giaquinto 1998). A detailed physical description of the waste in tanks W-21, W-22, and W-23 was not found.

Waste characterization: The waste was characterized using the U.S. Environmental Protection Agency methods. Some modifications were made to handle chemical matrix problems, high radiation levels, and waste content (Keller et al. 1997).

The following analyses were performed:

- Particle size
- Metal
- Anion
- Radiochemical
- Non-halogenated volatile organic
- Volatile organic
- Semi-volatile organic
- Polychlorinated biphenyls
- Settling tests
- Hydroxylamine (Keller et al. 1997; Keller and Giaquinto 1998).

More information on the characterization of the waste can be found in *Characterization of the BVEST Waste Tanks Located at ORNL*. ORNL/TM-13358. http://www.ornl.gov/rmal/tm-13358.pdf (Keller et al. 1997), and in *Characterization of the C1 and C2 Waste Tanks Located in the BVEST at ORNL*. ORNL/TM-13546. http://www.ornl.gov/rmal//tm13546.htm (Keller and Giaquinto 1998).

Infrastructure upgrade: Tanks W-21, W-22, and W-23 used existing tank penetrations and piping. The pulse jet mixer was fitted and plumbed into an existing service pit. To receive the jet mixer apparatus, tanks C-1 and C-2 required two additional 24-inch access risers to be installed near each end of the tank.

Downstream process: The material from these tanks was transferred to active storage tanks. The waste is planned for later retrieval and the waste will be immobilized for disposal.

Distribution of Retrieval Process

Technologies involved: *A fluidic pulse jet mixer, designed and fabricated by AEA Technology, was used in the* retrieval process for the BVEST. The Fluidic Pulse Jet Mixer is a unique technology because it has no moving parts except for solenoid valves which are easily replaceable (Kent et al. 1998a).

The pulse jet system is connected to six existing tank nozzles, each nozzle is 3-inches in diameter. The nozzles have a 90° bend towards the end and extend to approximately 8 inches above the tank bottom (DOE 1999a). They hang throughout the length of the tank in opposing pairs. Each nozzle is connected to a charge vessel. The jet pump is attached to the charge vessels to apply the necessary vacuum or pressure to the waste. The pressure, frequency, and sequence of pulsing are adjusted to achieve the best possible mixing action (Kent et al. 1998a).

The pulse jet system is composed of seven modules: two charge vessel skids, a jet pump skid, valve skid, off-gas skid, pipe bridge skid, and control cubicle.

The valve skid, jet pump skid, and charge vessel skids are constructed out of 304L stainless steel. The stainless steel prevents corrosion and is compatible with acidic cleaning solutions.

The Fluidic Pulse Jet Mixer was designed and fabricated by AEA Technology (Kent et al. 1998b).

Process: The existing nozzles of the pulse jet mixer were vertically mounted in the tank and immersed in tank fluid (Kent et al. 1998a). Nozzles were immersed in fluid to mix settled sludge with existing supernate in the tank. A small amount of water was added when needed (DOE 1999a). The pump then created a vacuum and drew liquid into the six charge vessels. The charge vessels were then pressurized, which forced the liquid back into the sludge. The waste and fluid was then mixed (DOE 1998). When the liquid waste contained 10% solids, it was pumped to the other tanks (TFA 2001a). Finally, the system was vented to depressurize the charge vessels. This process was repeated until no additional sludge could be suspended (DOE 1998).

Before the first waste transfer to the Melton Valley Service Tanks, the slurry in the tank was tested. Suspended solids in the slurry could plug the transfer line. Testing determined the amount of suspended solids to guard against (DOE 1998).

Progress: As of August 1999, 43,100, or 96.9% gallons of the waste had been removed from the five tanks (DOE 1999a).

Lessons learned:

- In the W-Tanks, the pulse jet mixer could mix sludge in multiple tanks when cross-connection nozzles existed (DOE 1999a).
- The modular design, quick connect couplings, and low maintenance requirements minimize radiation exposure (Kent et al. 1998b).
- The use of existing or recycled liquid waste minimized the generation of additional waste.
- Continuous monitoring of the slurry for solids (which could plug transfer lines) could shorten mixing times, reduce operating costs, and provide better assurance of sufficient mixing.
- The rapid installation process for the pulse jet mixer can reduce costs.
- The amount of waste removed was limited by the physical characteristics of the sludge and the configuration of the tank (DOE 1999a).
- The pulse jet mixer is suitable for tanks with interior structures.
- The pulse jet mixer is suitable for use in tanks with flammable gasses (DOE 1999b).

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Annex 3

Small Tanks and Waste Retrieval
at Oak Ridge National Laboratory
by Pete Gibbons and Kristin Manke

Statement of Problem

Waste retrieval in the United States is complicated by the various sizes and configurations of the tanks, especially small (less than 50,000 gallon tanks). The technologies that are capable of retrieving waste in one configuration are not necessarily adaptable to another. The Oak Ridge National Laboratory, in Tennessee, has small horizontal and small vertical tanks with different access configurations. A pulse jet mixer was successfully used in larger tanks, and Oak Ridge wanted to adapt it to smaller tanks because of the potential for portability and low requirements for water addition (secondary waste). This section describes the application of a small, mobile pulse jet system to Oak Ridge's Tank 3003-A, a small tank built in the early 1940s.

Waste type: The waste in Tank 3003-A was previously pumped, leaving less than 1 foot of sludge and approximately 5.5 feet of supernate (Bechtel 1993). Estimates regarding the actual volume of waste in gallons vary. During retrieval, the tank was found to contain a significant quantity of long pine needles placed in the tanks because of suspected contamination.

In the supernate, the following metals were detected: arsenic, barium, cadmium, calcium, nickel, and thorium. The following radionuclides were also detected: cesium, plutonium, and uranium. No volatile or semivolatile organic compounds were detected. The density, which is considered a suspicious measurement, was between 0.9575 and 0.96.08 g/mL. The pH was 8 (Bechtel 1993).

The sludge contained the following metals: lead, chromium, iron, calcium, zinc, magnesium, sodium, and cadmium. In addition, it contained the following radionuclides: cesium, plutonium, and uranium. No volatile organic compounds, pesticides, or polychlorinated biphenyls were detected. However, semivolatile organic compounds were detected, including 2-methylnaphthalene (Bechtel 1993).

Storage arrangements: Tank 3003-A is a 16,000-gallon-capacity concrete tank located partly aboveground. It is about 7 feet in diameter and 14 feet in height, and does not have secondary containment or level detection (Kuhaida and Parker 1997). The tank contains a 3-foot-diameter access port (Bechtel 1993). Built in 1943, it received liquid radioactive waste from three cells and a stack in Building 3003, which was the air-handling facility for the Oak Ridge graphite reactor (Kuhaida and Parker 1997).

Reasons for retrieval: There are two reasons for retrieving the waste from Tank 3003-A. First, according to the terms of the Federal Facility Agreement, the U.S. Department of Energy must remediate all of the tanks removed from service, such as Tank 3003-A (EPA et al. 2001). Second, the tank does not have secondary containment and as the tank ages the possibility of waste leaking increases.

Objectives: The objective of the retrieval activity was to remove enough sludge and supernate to allow stabilization of the tank in place with grout. This was evaluated after retrieval using visual and sample data. There were no pre-determined cleanliness criteria.

Retrieval Strategy

Sampling: Most of the liquid samples were collected using suction from a small vacuum pump to minimize radiation exposure to workers. This technology may have volatilized the lighter organic compounds in the liquid. The samples were collected into 250-mL glass sample jars with Teflon™-lined caps. Sludge was collected using an open-ended sample collection tube. After the sludge enters the tube, a flat, neoprene-coated pate is rotated over the opening to close it (Bechtel 1993).

Access to the tanks was limited because of the tank design and worker safety issues. This limited access restricted the number and heterogeneity of the samples taken. This sampling method did not show the large amount of pine needles in the tank.

For more information on waste sampling, see *Waste Characterization Data Manual for the Inactive Liquid Low-Level Waste Tank Systems at Oak Ridge National Laboratory, Oak Ridge, Tennessee.* DOE/OR/01-1159&D1 (Bechtel 1993).

Waste characterization: Liquid and sludge samples were characterized using U.S. Environmental Protection Agency or Contract Laboratory Program methods that were modified to incorporate radiological considerations. In some cases, changes to the procedures were required to incorporate additional safety measures.

The analyses performed included:

- Metal analyses
- pH determination
- Volatile organic studies
- Semivolatile organic studies
- Pesticides and polychlorinated biphenyls
- Anion determination
- Radioisotope determinations
- Densities (Bechtel 1993).

For more information on waste characterization, see *Waste Characterization Data Manual for the Inactive Liquid Low-Level Waste Tank Systems at Oak Ridge National Laboratory, Oak Ridge, Tennessee.* DOE/OR/01-1159&D1 (Bechtel 1993).

Infrastructure upgrade: The access to this tank was sufficient for retrieval and access to the transport truck. No tank-top modifications were required.

Downstream process: Following loading of the transport truck, the waste was moved to a Bethel Valley Evaporator Service Tank (BVEST). From there, the material was pumped via existing pipeline to the Melton Valley Storage Tanks for treatment and packaging for disposal (at the Nevada Test Site as solid waste).

Distribution of Retrieval Process

Technology involved: The Mobile Retrieval System (MRS) was used to remove supernate and sludge from Tank 3003-A. The MRS consists of 1) a charge vessel skid housing the operating pressure vessel, the jet pumps that control vacuum and pressure in the charge vessel, control sensors and valves, and piping directing the pressurized liquid either into the tanks to mobilize the waste or to a discharge path; and 2) a control skid containing a control computer and switchgear, trace heating controls, and compressed air valves that operate the jet pump. Both skids can be transported to the desired waste tank. A nozzle individually manufactured to suit the tank conditions is installed through the tank riser. The nozzle pipework is connected to the charge vessel/air piston by a flexible double-contained hose shielded by lead blankets as required (TMS 2001a). In addition to mixing and retrieving waste, the system can be designed to sample homogenized waste, transfer waste, and introduce grout into the tank and mix the heel with the grout to give a stable final waste form.

The system is considered mobile. The charge vessel skid is 6 feet, 6 inches high, by 6 feet wide, and 8 feet long; and weighs 4,000 pounds. The control skid is approximately 7 feet high, 6 feet wide, and 8 feet long; and weighs 2,200 pounds (AEA Unknown Year).

Operating Principle of Fluidic System

The pulse jet pump system mixes the sludge and supernate via a three phase mixing process:

- A suction phase. During the suction phase, the jet pump is used to create a partial vacuum in the charge vessel, which draws liquid up from the storage tank into the vessel
- A drive phase. Once the charge vessel has been filled with the liquor, the jet pump pressurizes the charge vessel, which drives the liquor back into the storage tank, agitating the contents of the tank and re-suspending settled solid particulates into the supernate.

- A vent phase. When the liquor levels have reached the bottom of the charge vessel, the drive phase is terminated and the charge vessel is depressurized through the jet pump in the vent phase.

The cycle is repeated until the sludge and the supernate have been mixed.

AEA Technology, Oak Ridge National Laboratory, and Bechtel Jacobs worked together to develop and deploy the technology (TFA 2001c).

Process: The Mobile Retrieval System nozzle is specifically designed for deployment through the tank riser. The nozzle is deployed inside the tank through standing liquid until it contacts the sludge layer of the waste.

Liquid is pulled in through the nozzle to the charge vessel using the jet pump to create a partial vacuum. Once the charge vessel is filled, the jet pump pressurizes the charge vessel, forcing the waste back into the storage tank, agitating the contents of the tank and re-suspending settled particulates into a slurry. The process gradually entrained more sludge into the liquid; the mixing cycle continued until the required suspended solid composition was reached. At this point, the mobilized sludge and entrained liquid slurry are drawn into the charge vessel and directed to the receiving vessel on the transfer truck (TFA 2001a).

After two days of operation, approximately 700 gallons of sludge and liquid were removed from Tank 3003-A. On the third day, the system's nozzle became plugged with pine needles that resided on the bottom of the tank. The suction lines were not flushed after operations concluded on day two; this may have exacerbated the situation. The pulse tube was disconnected and left in the tank (TFA 2001b). Had the presence of the pine needles been known, the nozzle could have easily been design to accommodate their bulk.

Progress: The Oak Ridge staff determined that enough material was removed from the tank to allow closure. The Oak Ridge staff have cancelled plans to use the Mobile Retrieval System in other tanks, citing concerns that the nozzle could become blocked above ground with waste that has a high plutonium content (TFA 2001b).

Lessons learned:

- Ensure the system is flushed every day to prevent the buildup of solid material.
- Sample the tank in a way that assures a representative sample.
- A generic, mobile system can empty a series of tanks without expensive infrastructure upgrades.
- The mixing nozzle design can be adapted for a specific tank geometry.
- The system design allows the skids to be quickly and efficiently decontaminated.
- The system is easily transported between tank locations and can be set up quickly without extensive training and requirements.

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Annex 4

Long-Shaft Mixer (Slurry) Pump Retrieval
at the Savannah River Site, South Carolina
by Pete Gibbons and Kristin Manke

Statement of Problem

Tank 8, at the Savannah River Site in South Carolina, contains radioactive sludge and supernate. While the tank is considered sound, it is approaching the end of its design life (approximately 50 years). The bulk of the tank waste needs to be removed to meet the site's schedule for waste vitrification.

Waste type: The waste in Tank 8 contained dried solid material. Water was added to the tank to re-hydrate this waste. The dried materials dissolved into the water, and segregated into two layers. The solids remained into a layer in the bottom of the tank. This layer is approximately 43 inches in depth. The supernate is approximately 32 inches in depth (TFA 2001a).

The waste in this tank was not characterized before retrieval.

Storage arrangements: Tank 8 (a Type I tank) has a carbon steel primary tank, a secondary pan, and a concrete support structure. The primary tank has a 750,000 gallon capacity, is 75 feet in diameter, and approximately 24.5 feet high. The pan is 5 feet deep and 5 feet larger in diameter than the primary tank. The tank and pan are set on a 30-inch-thick base concrete slab. They are enclosed by a cylindrical 22-inch-thick reinforced concrete wall and a flat concrete roof. Twelve 2-foot-diameter concrete columns support the roof; each column is encased in steel plate. The roof is covered with approximately 9 feet of earth. Access to the tank is provided through eight risers, averaging 2 feet in diameter (McNatt 1999).

Reasons for retrieval: The waste in Tank 8 needs to be removed before structural problems develop that allow the waste to leak into the soil and groundwater. In addition, the sludge must be removed to meet the site's schedule for waste vitrification.

Objectives: The sludge in Tank 8 was needed to provide feed to the Defense Waste Processing Facility (DWPF) glassification plant. The sludge was transferred to staging tanks for DWPF. A second objective was to remove as much waste as practical for eventual closure of the tank. A follow-on retrieval campaign (to be defined later) will take the tank to closure conditions.

Retrieval Strategy

Waste characterization: Recent characterization efforts were not done before the waste was retrieved. However, several characterization efforts were completed after the waste was retrieved (Conway 2000).

Sampling: Recent sampling efforts were not done before the waste was retrieved. However, several efforts were completed after the waste was retrieved, including samples in September 2000 (Conway 2000; Swingle et al. 2000).

Infrastructure upgrade: Significant infrastructure upgrades, including bearing water, electrical systems, and load support structures, were required to use the long-shaft mixers at Tank 8 (SRS 2001).

Downstream process: At the Savannah River Site, the tank waste is not homogenized during retrieval to meet the vitrification requirements. Instead, the waste is mixed with inhibited waster (0.01 M sodium hydroxide) to maintain the flow rate in the slurry line (Conway 2000; TFA 2001a; Wilmarth et al. 2001). Homogenizing and other activities to prepare the material for vitrification are conducted in the receipt tank, in this case, Tank 40 (Conway 2000; TFA 2001a).

Distribution of Retrieval Process

Technology involved: To remove the bulk of the sludge from the tank, four long-shaft vertical mixers were deployed into the tank. These 150-hp mixers use a dual jet and pump system to mix the waste. The pump, located

at the center of the shaft, pulls waste in. The waste is then forced out through two jets, located on opposite sides of the pump. This system rotates inside the tank, mixing solid waste with supernate.

In addition to the mixers, a telescoping transfer pump was also used. This pump, which can be lowered in increments, removed the mixed waste.

Process: The bulk of the supernate in Tank 8 evaporated. To retrieve the waste, water was added to the tank. This water combined with the dry solids to form a layer of supernate and a layer of hydrated sludge.

Four standard long-shaft mixers were positioned above the sludge level. The four mixers were used along with the telescoping transfer pump to cover the 75-foot diameter of the tank The mixers and pump were located on the periphery of the tank.

The mixers drew in supernate and forced it back out into the tank through two nozzles located on opposing sides of the vertical pump. The mixer was operated until a 12 weight percent solids level was reached in the waste. This is the maximum solids concentration that can be transferred. The mixed waste was pumped out using a telescoping transfer pump.

Sludge soundings were taken after 7 days of full-speed running to estimate the effective cleaning radius of the mixers. When the mixers had effectively removed the waste in a circle approximately 28 feet in diameter, the mixers and the telescoping pump were lowered 10 inches and resumed mixing. This generated another batch of mixed sludge and supernate that was pumped out of the tank. This process was repeated one more time (TFA 2001a). After this last batch was completed, operations were halted.

Progress: Approximately 1 foot of waste is left in the tank. Plans call for this waste to be removed using other technologies before the tank is closed.

Lessons learned:

- *Expense*: Because of the infrastructure upgrades required for long-shaft mixers, using this technology is expensive, with a cost ranging from $6 million to $11 million.
- *Efficiency*: This technology can be inefficient, depending on both the tank design and the operations plan. In some cases, it can leave as much as 40,000 gallons of waste in the tank.
- *Time*: This technology requires time-intensive upgrades to the tank infrastructure (SRS 2001).
- Long shaft (60 foot) mixers are prone to shaft vibration and bearing/seal failure.

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Annex 5

Waste Retrieval for Tank 19
at the Savannah River Site
by Pete Gibbons and Darcy Short

Statement of Problem

At the Savannah River Site (SRS), located near Aiken, South Carolina, high-level waste (HLW) in Tank 19 needed to be removed to allow tank closure.

Waste type: Approximately 283,000 gallons of supernate, salt, zeolite, and sludge were in Tank 19 (Keilers and Davis 2000). The waste was produced by separating uranium and plutonium from irradiated fuel (TFA 2001). Zeolite, an ion-exchange column resin, was used to remove cesium during nuclear processing. When the zeolite was spent, it was placed in Tank 19 where it settled to the bottom of the tank, forming a 2-3 inch layer (TFA 2001b). Zeolites are crystalline aluminosilicates of the group I (alkali) and group II (alkaline earth) elements (McFarlane et al. 1997) that physically resemble coarse sand. Other insoluble chemical constituents include: aluminum oxide (33 wt%), iron oxide (30 wt%), silicon oxide (6 wt%), and sodium nitrate/nitrite salts (6 wt%) (WSRC 1995).

The major elements found in the solid mound in the tank were sodium, aluminum, silicon, and iron. Assuming all of the silicon in the sample is due to zeolite, the sample contains approximately 30% zeolite by weight. This implies that the majority of the sample could be sodium aluminate that was never dissolved and removed from the tank in the early 1980s (WSRC 1997).

The tanks at the Savannah River Site hold highly radioactive waste, containing approximately 534,000,000 Ci. The primary radioactive constituents are cesium-137 and strontium-90 (WSRC 2000). The supernate in the SRS tanks is a highly concentrated solution of salt compounds in water (TFA 2001a). Soluble chemical constituents are primarily sodium salts such as sodium nitrate (49 wt%), sodium nitrite (12 wt%), sodium hydroxide (13 wt%), sodium-aluminum tetrahydroxide (11 wt%), sodium sulfate (6 wt%), and sodium carbonate (5 wt%) (WSRC 1995).

Storage arrangements: Tank 19, a Type IV tank, has a 1.3 million gallon capacity. It is a carbon steel tank built with a single layer steel wall and no active cooling system (DOE 2000). The tank was designed for waste storage that did not require auxiliary cooling. It is built in a concrete vault and the tank measures 85 feet in diameter and 33 feet in height (SRS 2001b). Access to the interior of the tank is achieved through risers located at the top of the tank. These round openings are less than 2 feet in diameter and approximately 6 feet long (WSRC 2000).

The equipment being used to close the tank was installed in many different areas and occupied many of the different riser locations, other risers contained tank monitoring equipment. This equipment occupied riser space and created obstructions along the tank interior and along the floor. Other miscellaneous obstacles occupied the tank floor as well (WSRC 2000).

Tank 19 has cracks in the tank walls (well above current waste levels), which are believed to have been caused by groundwater corrosion. A small amount of water has leaked into the tank, but there is no evidence of waste leaking out of the tank (DOE 2000).

Reasons for retrieval: This waste needed to be removed to begin the tank closure processes. SRS is currently on a mission to stabilize material, restore the environment, manage waste, and decontaminate facilities no longer needed. The tank closure will comply with the U.S. Department of Energy's responsibilities under the AEA and the South Carolina closure requirements (DOE 2000).

Objectives: The objectives of the waste retrieval process were to 1) leave no more than 1,000 gallons of waste in the tank (WSRC 2000) and 2) stabilize contamination (DOE 1999a).

Retrieval Strategies

Sampling: Tank 19 was sampled and characterized during the summer of 1996. The waste was sampled to determine the best possible retrieval method. Two cups were dropped into the tank to obtain samples. The samples

were taken from the top few inches of the mound that is in contact with a large volume of supernate. One of the sample cups was empty and the other contained about 50 g of solid material (WSRC 1997).

How representative the sample is of the entire mound of residual solids is uncertain. The sample contained moist, dark brown solids that were easily broken apart with light pressure from a spatula. It was more granular than typical sludge samples. A very small amount of liquid was drained from the sample.

More information on the sampling of the waste can be found in *Characterization of Tank 19F Samples in Support of Tank Closure.* WSRC-RP-97-074 (WSRC 1997).

Waste characterization: The analyses performed included

- Weight solids
- Aluminum
- Metallic
- Mercury
- Actinide
- Strontium
- Gamma emitting fission product tests
- Technetium(WSRC 1997).

More information on the characterization of the waste can be found in *Characterization of Tank 19F Samples in Support of Tank Closure.* WSRC-RP-97-074 (WSRC 1997).

Infrastructure upgrade: Tank 19 required upgraded services to operate the retrieval equipment. Existing mixers and transfer pumps had to be re arranged to provide access fro the new equipment. The transfer line to the destination tank (Tank 18) required installation of a diverter in tank 18 to allow the same existing pipe to carry slurry from Tank 19 to 18 and decanted liquid back to Tank 19.

Downstream process: At the Savannah River Site, the tank waste is not homogenized during retrieval. Instead, the waste is mixed with inhibited water (0.01 M sodium hydroxide) and supernate returned from Tank 18 to maintain the flow rate in the slurry line (Conway 2000; TFA 2001a; Wilmarth et al. 2001).

Tank 18 will be retrieved in the 2003 time frame. The waste will be sent for processing in the Defense Waste Processing Facility.(Conway 2000; TFA 2001a).

Distribution of Retrieval Process

Technologies involved: The three technologies used to retrieve waste out of Tank 19 were

- Three 50 HP Flygt mixers
- Submersible transfer pump (BIBO)
- Air-operated-type scavenging pump (Pitbull ™)

Flygt mixer: The Flygt mixer is used to suspend solids in the tank waste. The Flygt mixer's open propeller is configured to create long-range currents at a rate of 20,000 gallons per minute (TMS 2001a). The Flygt mixer's propeller is approximately 20 inches in diameter and runs at 860 rpm (Poirier et al. 1998).

The Flygt mixer was developed by Flygt, and Westinghouse Savannah River Company and tested by the Pacific Northwest National Laboratory (DOE 2001).

Submersible transfer pump (BIBO): The BIBO pump is a centrifugal pump designed to transfer 200 gallons per minute at 125 feet of total head (SRS 2001a) The light-weight pump is designed for use in difficult abrasive situations. The pump housing is made of deformation-resistant, durable, cast aluminum. The inspection screws in the main housing and oil housing are always accessible from the outside of the tank. The impeller is made of high-alloyed steel, wear-resistant material. Bolt connections are made of corrosion-proof material and designed for repeated use as well as to the size of the pump (ITT Flygt 2001).

The BIBO pump is a product of Flygt.

Air-operated-type scavenging pump (Pitbull ™): The submersible transfer pump (Pitbull ™) is an alternative to diaphragm pumps for retrieving residual tank waste. The pump is comprised of airlines, a pump chamber, and a control panel (TMS 2001b). The chamber is cylindrical to facilitate insertion of the pump through a tank riser. It is 14 inches in diameter and 49 inches tall. The inlet to the pump is through a 5-inch check valve located on the bottom of the pump. The check valve is horizontally orientated to prevent solids from settling inside the valve. A 2-inch discharge valve is located above the chamber (Hatchell et al 1998).

The pump is designed to sit on the bottom of the tank and vacuum sludge through a 1-inch gap between the tank bottom and the inlet. To operate the Pitbull ™ in Tank 19, a 40- foot equivalent discharge head was required (Hatchell et al. 1998).

The Pitbull ™ was developed by the Chicago Industry Pump Company and the Savannah River Site. The two groups collaborated to develop a unique version of the commercially available Pitbull through the Chicago Industry Pump Company (TMS 2001b).

Process: Three Flygt mixers were installed in August 2000 and retrieval processes began in September 2000. First, 87 inches of water were added. Then, to mobilize the settled solids, the mixers were operated in racetrack mode, then oscillated across the tank center. Racetrack mode allows waste to be pushed to the center of the tank, center mode then pushes the material to the periphery. During the mixing cycle, the tank was pumped to the 48-inch level as the waste was transferred to Tank 18. The 87-inch liquid level was reached again when the decanted liquid was returned to Tank 19. The process was repeated. Periodic full pump-downs to gauge progress were performed (TFA 2000a). In December 2001, the mixer in the southwest riser failed. Operations personnel began limiting long-term for the two remaining mixers to prevent premature failure (TFA 2001c).

The BIBO pump was then installed and deployed in August 2000 (SRS 2001a). It rested 30 inches from the tank floor on a zeolite mound. In November 2000, it eventually broke the mound and was lowered to within 10 inches of the floor through a hole in the zeolite crust (TFA 2000b; TFA 2001b). After breaking the zeolite mound, the pump was basically encased in the resulting hole, limiting its ability to pump liquid lower than 18 inches deep (TFA 2001b).

Progress: The Westinghouse Savannah River Company moved the waste to Tank 18. The tank is scheduled for complete closure in 2003 (Keilers and Davis 2000).

Operation of the Flygt mixers alone removed all but 7,000 gallons of waste. Further retrieval, if required will use clean waste sluicing to concentrate the waste at the transfer pump.

Lessons learned:

Flygt mixers

- Using an increased number of mixers in the tank, decreased the required mixer power needed to suspend the solids.
- Decreasing the size of the zeolite, from 0.7 mm to 0.3 mm decreased the required mixer power needed to suspend the particles (Poirier et al. 1998).
- Mechanical abnormalities as a result of extended use, age of hoists, and the lack of an internal maintenance/inspection program resulted in a hoist failure. Review of maintenance and inspection processes for these type hoists are recommended (DOE 1999b).

Pitbull ™

- Improvements on the check valve should be made to improve the ability to pump slurries containing hard solids.
- The original stainless steel exhaust valve (model EXVS75) should be replaced with a larger aluminum valve (EXV200) to reduce the likelihood of icing.

- Gaskets should be added between the valve body and mating flanges.
- The pump is likely to inject air into the discharge line when operated without surveillance for long time periods. This could result in water hammer defects. To prevent this and increase reliability, a low-level bubbler could be added to the pump.
- The vendor recommends aluminum sealing surfaces for pumping slurries containing harder materials. Nitrile was used specifically for SRS.
- To reduce solid accumulation in the pump chamber, the gap should be reduced between the discharge pipe and chamber bottom. The current gap is 6.35 cm. Air nozzles could be incorporated into the chamber to suspend solids (Hatchell et al. 1998).

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Annex 6

Waste Retrieval for Tank 17
at the Savannah River Site
by Pete Gibbons and Darcy Short

Statement of Problem

Tank 17 was the second high-level waste (HLW) tank closed at the Savannah River Site (SRS), near Aiken, South Carolina. Retrieval of the waste in the tank was needed to allow tank closure.

Waste type: Tank 17 had approximately 2,500 gallons of sludge and 300,000 gallons of tritiated water (Fortenberry and Sanders 1997).

The primary chemical constituents in Tank 17 included: aluminum, iron, manganese, nitrate, and uranium. The major radionuclides included: tritium and plutonium (DOE 1997). High levels of technetium were observed in the sludge heel. The sludge contains 4.6×10^{-1} μCi/g ^{99}Tc/mL, nearly 1,000 times more than the supernate's specific activity, 7.4×10^{-4} μ Ci/mL (DOE and RAS 1999).

The waste in the tanks at the SRS was produced by separating uranium and plutonium from irradiated fuel (TFA 2001a).

Storage arrangements: Tank 17 is a carbon steel tank with a single layer steel wall and no active cooling system (DOE 2000). The tank was designed for waste storage that did not require auxiliary cooling. It is built in a concrete vault, and the tank measures 85 feet in diameter and 33 feet in height (SRS 2001). The tank is located slightly above the water table (DOE 2000).

Tank 17 did not contain much internal equipment, which made it an ideal candidate for closure (DOE 1999). There are small cracks in the walls of Tank 17 but there is no evidence of leaks (TFA 1999).

Reasons for retrieval: Tanks 17 and 20 of SRS were the first HLW tanks to be scheduled for closing. Tank 17 had exceeded its design life and was scheduled for closure after Tank 20. The waste needed to be removed to allow closure. SRS no longer produces nuclear materials and is currently on a mission to stabilize material, restore the environment, manage waste, and decontaminate facilities no longer needed (DOE 1999; WSRC 2000). Closure will reduce the potential for environmental problems in the future (TFA 1999).

Objectives: The objectives of the waste retrieval process for Tank 17 were to 1) remove the bulk of the and stabilize residual contamination and 2) provide answers to many of the technical and institutional questions relating to HLW tank closure and to help baseline the tank closure process (DOE 1999).

Retrieval Strategies

Sampling: Sampling was accomplished by attaching a float to an electric sample pump and allowing the sample pump to float on the liquid surface. One end of a flexible hose was connected to the sample pump and the other end hung from the floating pump and rested on the bottom of the tank using a weight as a ballast. A filter and sample vial were attached to the sample pump discharge. A small air hose was attached to the float to act as a propulsion device. This allowed the float and sample pump assembly to collect samples from various areas in the tank. The suction hose was dragged across the floor. Two samples were taken. Once the samples were retrieved from the tank, they were shipped to Savannah River Technology Center for analysis (DOE 1997).

More information on sampling activities can be found in *Industrial Closure Module for the High-Level Waste Tank 17 System-Revision 2*. Savannah River Site, Aiken, South Carolina (DOE 1997).

Waste characterization: The Savannah River Technology Center used characterization methods previously developed by the Center for HLW. The following analyses were performed:

- Tritium

- Metals
- Mercury
- Silver
- Alpha-emitting radionuclides
- Gross beta
- Gamma-emitting radionuclides
- Radionuclides
- Specific ions
- Specific gravity (DOE 1997).

More information on the characterization of the waste can be found in *Industrial Closure Module for the High-Level Waste Tank 17 System-Revision 2*. Savannah River Site, Aiken, South Carolina (DOE 1997).

Infrastructure upgrades: The transfer path for the waste to move to Tank 18 had to be modified, tested, and certified. Electrical and air services were provided. Several new access ports were added to the top of the tank for the addition of closure grout. A grout plant and grout service/distribution were set up to fill Tanks 17 and 20 with grout following the completion of waste retrieval from Tank 20.

Downstream process: The air operated diaphragm pump transported the waste through an existing transfer line, to Tank 18. From there, the waste will be transferred to vitrification staging tanks for eventual vitrification.

Distribution of Retrieval Process

Technologies involved: The technologies involved were:

- Pan-and-tilt sluicer using clean water at 100 psi, 150 gpm
- Air operated double diaphragm scavenging transfer pump
- Water mouse waste spreader/leveler

Pan-and-tilt sluicer: A commercial pan-and-tilt sluicer was used for spray water washing using inhibited water for corrosion control. The sluicer was a commercial fire-fighting unit, inverted and inserted into the tank through a riser access port.

Air operated double diaphragm scavenging transfer pump: The pump was a simple, air-operated pump with a 40-foot head at 120 gallons per minute (DOE and RAS 1999). Although it has relatively slow pump rates, it can lift waste more than 60 feet. It is rugged and reliable but susceptible to fouling from heavy solids (sand and gravel).

Water mouse: An adaptation of a water mouse, an off-the-shelf, commercial technology designed for pipe cleaning. The water mouse, consists of a rectangular, hollow steel cleaning head measuring 12 inches wide, 13 inches long, and 6 inches tall, it weighs about 50 pounds. It also has 10 rear-facing thruster jets to propel the water mouse up a pipe, and two forward-facing jets to clean or cut (TFA 2001; TTG 2001). For this application the mouse was mounted on a small base plate with light steel cables on either side that run to a central mast and up through the tank top. Pulling one or the other cable turns the plate and causes the main jets to slew the mouse to one side. Water is supplied to the unit at approximately 60 per minute and 2000 psi from an external source. The water mouse was used to redistribute sand-like solids from drifts resulting from sluicing to a level, thin layer, more conducive to grout entrainment. (TTG 2001).

Process: Due to limited space for water additions, an air operated double diaphragm scavenging transfer pump was used. The pump was installed in North East Riser. A pan-and-tilt sluicer was installed through tank risers. The sluicer used inhibited water to move the waste towards the pump (DOE 1997). After washing with sluicing stream, video cameras were used to survey the tank and identify areas that needed further cleaning. The sluicer was used to sweep heavy solids toward the diaphragm pump. Collector arms with their vertex at the pump suction concentrated the solids there. Small water jets on the arms helped move the solids to the pump suction (DOE 2000).

The water mouse was deployed in the last stage before proceeding with tank closure. The system was deployed through a 22-inch riser. It was then maneuvered through the tank to spread out the solids accessible drifts to make

the solids more accessible for grout entrainment. The water mouse was left in the tank rather than removed and decontaminated (TTG 2001).

To finish the tank closure process, sludge-entraining reducing grout, which inhibits the spread of soluble radionuclides, was added before the risers and other pipes were sealed (TFA 1997).

Progress: Tank 17 was officially closed on December 15, 1997, three months after the process began (DOE 1999). There was 2,000-3,000 gallons of waste left in the tank.

Lessons learned:

- Sluicing or spray washing was effective on lighter residual material; however, the remaining rapid settling, heavier solids were more difficult to remove (SRS 2000).
- Proper isolation of the tank following closure safely relaxes long-term administrative burden of tank monitoring.
- Ventilation requirements need to be considered carefully (DOE 1999).
- Running a caustic liquid through an aluminum sluicer degrades the sluicer over time and reduces spray acuity. This is a cost trade. For Tank 17 the sluicer life was adequate.

Water mouse:

- Improvements to directional control should be made.
- Wide high-pressure spray was effective at mobilizing material and has the potential for many tank and vessel floor cleaning applications.

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Annex 7

Retrieval at Idaho National Engineering and Environmental Laboratory
by Pete Gibbons and Kristin Manke

Statement of Problem

A sludge heel and deposits adhering to tank walls were discovered in Idaho National Engineering and Environmental Laboratory (INEEL) tanks. Previously, no solids were assumed to exist in the highly acidic waste in these tanks. A spray ball sluicer, steerable sluicing jets, and a steam-jet removal/transfer pump are being tested to remove waste heels from tanks with cooling coils on the walls and floor space and to clean the tank walls.

Waste type: Plans call for the system to be used initially in Tanks WM-182 and WM-183. These tanks contain stronium-90 and cesium-137. The primary chemicals in the waste are nitrates, sodium, aluminum, zirconium, and fluorides. The high-level waste is acidic, with a pH of less than 1 (TFA 2001a). The solid residuals are stable at this low pH.

Storage arrangements: Tanks WM-182 and WM-183 are located in concrete vaults of pillar and panel construction. These stainless steel tanks are free standing in those vaults. The 300,000-gallon-capacity tanks have a 50-foot diameter and the walls are 21 feet high. The tanks contain cooling coils on the walls and floor (TFA 2001a). The cooling coils inhibit movement of sludge across the tank floor to the retrieval pump. The highly adherent residue on the tank walls also presents waste removal challenges.

Reasons for retrieval: Previously, researchers believed the acidity of the tank waste prevented solids from forming. However, sampling in three of INEEL's tanks discovered a layer on the bottom of the tanks and dry deposits adhering to the cooling coils and the tank walls. This waste needs to be removed to meet regulatory agreements (Gibbons 2000).

Objectives: The objective of this retrieval activity is to remove enough radioactive sludge from the tank floor and deposits from the walls for safe closure of the tanks (INEEL 2001).

Retrieval strategy: The steam-jet transfer pump will be replaced with one that has its suction at one-half inch from the tank floor (versus 6-12 inches of original pumps). The rotating spray ball will agitate the heel sludge in the residual 6 to 12 inches of liquid in the tank into slurry and wash the tank walls. The steam jet should pump out most of the heel and cleaned wall deposits. The directional sluicer will target stubborn wall deposits and push material on the floor of the tank toward the jet transfer pump for removal. When this process is complete, concrete grout will be added in a pattern that will force more of the residual slurry to the transfer pump and entomb the remainder.

Waste characterization: Waste samples were taken from Tanks WM-182 and WM-183. Analyses performed included the following:

- Settling rate
- Particle size distribution
- Yield stress (INEEL 2001).
- Radioactive and chemical analysis for closure calculations.

Sampling: Heel samples were taken from Tanks WM-182 and WM-183 with the Light-Duty Utility Arm along with video footage.

Infrastructure upgrades: The spray ball and sluicers require very little infrastructure changes above the tank. A pad has been installed for water and air supplies and a control room. Existing transfer lines will be used. The major infrastructure expense lies in removal of existing in-tank equipment to make room in the access riser for the new steam-jet pump and the spray-ball and sluicers.

Downstream processes: The downstream processing of this waste would include additional water. The retrieved waste will be transferred to another waste tank for consolidation of solids. The disposition of these solids will have to be developed, but it is not required to get out of these early tanks.

Distribution of Retrieval Process

Technologies involved: The waste retrieval system for the tanks at INEEL included the following:

- Video camera system
- Spray ball system
- Controlled directional nozzles
- Steam jet pump.

Video camera: Video cameras provide the operators with information on the tank waste retrieval process. Video camera systems are positioned above the spray ball and located directly on the directional sluicer nozzles

The camera will include the following features:

- pan and tilt movement
- manual and automatic focus
- lighting
- water tight integrity
- lens protection (INEEL 2001)
- lens cleaning system (water spray).

Spray ball system: This is a stainless steel rotating two-nozzle washing system. A clockwork driven by an internal water wheel rotates the nozzles around two nozzles to cover the entire tank interior. The system is lowered into the tank through a central tank riser. This type of system is used commercially in the shipping and petroleum industries to clean storage tanks (INEEL 2001).

Directional nozzles: These are custom stainless steel (for acid resistance) nozzles with piggyback cameras mounted directly on the nozzle that can be pointed directly at "trouble areas" are used to remove accumulated waste solids (INEEL 2001).

Steam-jet pump: The commercially available steam-jet pump, similar to the two already in INEEL Tanks WM-182 and WM-183, was used. The steam-jet eductor's high specific drive energy results in minimum net water addition during pumping. A steam-jet eductor requires a separation tank to vent off gasses (INEEL 2001).

Process: On September 13 and 14, 2000, testing was conducted using a test bed with a tank mockup (approximately 25 feet in diameter and 16 feet in height--half the size of an actual INEEL pillar and panel tank). Solid simulant and water were placed in the test bed to a depth of 11 inches, with 8 inches of settled solids. The solids at INEEL have a slow settling rate and will stay in suspension several minutes after agitation (INEEL 2001).

The rotating spray ball was placed in a shroud that caught the jets as they pointed away from the mockup (Gibbons 2000). The spray ball washed solids from the cooling coils and walls. However, it did not move the solids on the floor well, except near the steam pump. A "wave action" from the spray ball caused larger and heavier solids to move towards the tank perimeter (INEEL 2001). The system was not effective at accessing or mobilizing this waste; however, overall, the spray ball sluicer removed 90-95% of the solid material, leaving an approximately 3/4-inch-deep slurry layer (Gibbons 2000; INEEL 2001).

Because using the spray ball to remove this waste would have added significant volumes of water, two directional spray nozzles were deployed near the tank walls to remove the remaining waste (INEEL 2001). The nozzles directed a liquid stream at the waste near the tank walls. The nozzles easily moved the waste towards the pump, where it was drawn out of the tank (Gibbons 2000; INEEL 2001).

Implementation: The retrieval strategy describe above is scheduled for implementation in 2001 and 2002.

Progress: The system proved reliable and effective, removing 99.2% of the solid waste (INEEL 2001). A 1/16-inch-thick layer was left on the tank floor. A hot demonstration is planned for 2001 (Gibbons 2000).

Lessons learned:

- *Video camera system effectiveness*: Recording capability, that is, the clarity under full magnification using the digital and optical zoom, was acceptable.
- *Video camera operation*: The operators should complete training and practice exercises with the camera, video recording, and lighting system before actual deployment.
- *Video camera positioning*: The location of the camera relative to the spray ball should be optimized to reduce liquid spray.
- *Spray ball system effectiveness*: After approximately 8 hours of washing with the spray ball and pumping with the steam jet, 85% of the solid material was removed.
- *Spray ball nozzle size*: The 10-millimeter nozzle is recommended with water supplied at a pressure of 80 to 100 psi. The smaller nozzles were not as effective for washing. The larger nozzles added excessive amounts of water and were no more effective than the 10-millimeter nozzle.
- *Spray ball configuration*: The two nozzle configuration for the spray ball is recommended. The four nozzle configuration adds additional liquid and poses deployment problems because of the larger size.
- *Wave movement*: The spray ball system created waves of waste on the floor of the tank and underneath the cooling coils. The waves pushed waste toward the tank walls, away from the pump. The cooling coils on the floor prevented the water and solids from moving or settling back towards the center of the tank. This left waste in a 1-inch layer near the tank walls.
- *Water use*: To minimize the amount of water added, the usage of the spray ball and the directional nozzles should be optimized.
- *Steam-jet pump*: Being able to adjust the height of the pump proved effective in waste removal. The primary concern is in lowering the pump too close to the tank floor and cutting off the flow to the pump. This occurred if the pump was located lower than 1/4 inch from the tank bottom. However, this may be due to the jet support system and may not cause problems in an actual tank.
- *Steam jet effectiveness*: The steam jet is not capable of removing water as fast at it is added by the spray ball; thus, the spray ball must be stopped on occasion to allow the steam jet to "catch up." This allows the solids to settle quickly. However, the spray ball does not effectively contact the solids with the excess liquid in the tank, so the liquid must be removed.
- *Transfers*: The steam jet and piping system can transfer surrogate slurries as high as 165 g/L.
- *Use of vendor facility*: The mockup tank was located at a private vendor facility. This allowed for rapid construction and testing (that is, 4 to 6 weeks for construction, equipment setup, and initiation of the first test) (INEEL 2001).

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Annex 8

Waste Retrieval Sluicing System
at the Hanford Site, Washington State
by Pete Gibbons and Kristin Manke

Statement of Problem

Tank C-106 at the Hanford Site contained 5,000,000 curies of strontium-90; this strontium produced high levels of heat, capable of damaging the tank's structure (DOE 1998a). The temperature inside the tank reached as high as approximately 235 degrees Fahrenheit (DOE 1999). To dissipate the heat by evaporation at the waste surface, about 6,000 gallons of water were added to the tank every month (DOE 1998a; Bamberger 2000).

Waste type: The waste volume was estimated at 229,000 gallons (or 72 inches), including 192,000 gallons of sludge (Hanlon 1998; Schreiber et al. 1996; DOE 1998a; DOE 1999; Sanders 2000).

The supernate includes the following metals: phosphorous, silver, sodium, sulfur, and uranium. It also includes the anions: nitrate, nitrite, oxalate, phosphate, and sulfate. The supernate includes the following radionuclides: cesium, plutonium, uranium, and strontium. Finally, it includes organic and inorganic carbon (Schreiber et al. 1996).

The sludge includes the following metals: aluminum, calcium, chromium, iron, phosphorous, silicon, silver, sodium, and sulfur. It also includes the following anions: nitrate, nitrite, oxalate, phosphate, and sulfate. The sludge includes the following radionuclides: cesium, plutonium, uranium, and strontium. Finally, it includes organic and inorganic carbon (Schreiber et al. 1996).

Storage arrangements: The underground tank, built in the early 1940s, is constructed of a single layer of mild steel (ASTM A283 Grade C) within a concrete vault and dome (Schreiber et al. 1996; DOE 1998b). The tank is 75 feet in diameter, with a dish-shaped bottom (DOE 1998b; Schreiber et al. 1996). It has a 530,000-gallon capacity (HTI 1999). The top of the tank dome is located approximately 7 feet underground (Schreiber et al. 1996). For access, the tank has 10 risers (openings between the tank and the surface) ranging in diameter from 4 inches to 36 inches.

Reasons for retrieval: Regulatory and other agencies were concerned about this tank because sufficiently high temperatures could cause a structural failure, which could result in highly toxic and highly radioactive waste leaking to the environment (DOE 1998a; DOE 2001). If the tank leaked, the water additions would have to be continued or the resulting high temperatures could lead to a dome collapse (Schreiber et al. 1997). Thus, the waste needed to be removed from this tank to prevent possible damage to the environment.

Objectives: The waste retrieval sluicing system for Tank C-106 has three goals: 1) remove enough sludge from the tank to eliminate the need to add water to the tank, 2) demonstrate that waste can be removed safely, and 3) provide high-level waste feed to the privatization contractor for vitrification (DOE 1998a).

Retrieval Strategies

Sampling: Grab sampling was performed during February and March 1996. Vapor samples were collected in February 1994 and March 1996. As the tank was deactivated in 1979, the sampling results are considered valid (Schreiber et al. 1996).

During the 1996 grab sampling event, samples of the supernate and upper 60 percent of the sludge were taken from two locations. The lower 40 percent of the sludge was not sampled, and this may have biased the characterization data (Schreiber et al. 1996).

All of the grab samples were collected in glass bottles and were a nominal 125 mL in volume. The samples were taken at various depths within the supernate and upper 60 percent of the sludge. Duplicate samples were taken (Schreiber et al. 1996).

For more information on the sampling of Tank C-106 waste, see *Tank Characterization Report for Single-Shell Tank 241-C-106*. WHC-SD-WM-ER-615, Revision 0 (Schreiber et al. 1996).

Waste characterization: The samples were analyzed according to the safety screening data quality objectives.

The analyses performed included

- Energetics
- Specific gravity
- Water content
- Total alpha activity
- pH determination
- Particle size
- Viscosity
- Anions
- Metals
- Total organic and inorganic carbon
- Radionuclides
- Semivolatile organic compounds
- Normal paraffin hydrocarbons and tributyl phosphate
- Flammability of tank headspace (Schreiber et al. 1996).

In addition, studies were performed on the compatibility of the waste in Tank C-106 with the waste in Tank AY-102, the receiving tank (Schreiber et al. 1996).

For more information on the characteristics of Tank C-106 waste, see *Tank Characterization Report for Single-Shell Tank 241-C-106*. WHC-SD-WM-ER-615, Revision 0 (Schreiber et al. 1996).

Infrastructure upgrade: This includes installation of the dual 4-in. transfer lines. One carried supernate from the receipt tank to the sluicing nozzle. The other carried waste to the receipt tank. This required modifications to the highly radioactive sluicing and pump pits, located on top of the tank. It cost $4 million to modify these pits because of the high levels of radiation. These pits collected any waste leaking from jumper connections and drained it back into Tank C-106. The ventilation system was upgraded to a Safety Class HEPA filtration system, large enough to handle the mist generated during sluicing operations. The cooling system in the receipt tank was upgraded to handle the high heat waste. Power was brought in to run the equipment. An old transfer pump was removed. A crew facility and change room was installed with a remote control capability for the retrieval equipment. Extensive operating procedures and safety evaluation were prepared and defended. All his contributed to the more than $100 million cost of retrieving the waste in Tank C-106.

Downstream process: The waste was transferred to double-shell Tank AY-102, which has a 1,000,000-gallon capacity. The temperature, flammable gas levels, solids settling, and density profile were monitored in this tank (Sanders 1999a). Chemical compatibility with future vitrification of the Tank AY-102 contents was assessed.

Distribution of Retrieval Process

Technology involved: The waste retrieval sluicing system consists of a sluicer, a submersible transfer pump in Tank C-106, a booster pump in the pit above Tank C-106, two double-encased underground pipelines running between the tanks, an in-tank camera system, and extensive instrumentation to measure and monitor temperature, flammable gas generation, and leak detection (DOE 1998a). The waste retrieval system is a departure from past practice sluicing, which uses sluicing jets on opposite sides of the tank and a pump in the center (Erian et al. 1997).

Process: The sluicer was installed in a 12-in.-diameter riser in Tank C-106 at one edge of the tank, approximately 5 ft from the internal wall (Erian et al. 1997). The sluicer system has a 1-in.-diameter nozzle with two degrees of motion control (rotation 194 degrees) and nozzle elevation. The nozzle pivots and rotates at a fixed elevation in the tank and can be aimed with a dedicated hydraulic system. The sluicer is approximately 11.5 in. in diameter. It can produce pressures up to 300 psi (Bamberger 2000).

An adjustable height submersible pump was installed at the other end of the tank, approximately 65 feet from the sluicing nozzle (Erian et al. 1997; DOE 1998a; Bamberger 2000). The pump was a centrifugal, direct-drive, end suction, 40 horsepower pump with a 0.25-in. mesh intake screen (Bamberger 2000).

Supernate was pumped from Tank AY-102 to a booster pump at Tank C-106 that pumped the waste to the sluicer nozzle in the tank. The supernate, which contained less than 10 percent solids loading, greatly reduced the amount of additional water needed for sluicing (Bamberger 2000). The sluicer was operated in a specific circular pattern, creating a cleared area, or pit, around the pump and using the sluicer to push more waste into the pit. The submersible pump moved the waste from the tank to the transfer line where the waste was forced along the 4-in.-diameter double-encased underground pipe to Tank AY-102. Each pipe was approximately 1800 ft long (Erian et al. 1997). The pipe terminated into a pump pit, where it was instrumented to monitor for percentage of solids and other characteristics. Then, the waste was pumped into Tank AY-102 (Bamberger 2000). Water was provided for flushing and other activities to ensure that the transfer lines and pumps did not become clogged (Bamberger 2000).

Implementation: After several years of preparations, sluicing was accomplished in 1999. The system worked as designed, removing 95 to 97 percent of the sludge (Bailey 2000). Hard pan sludge remained; it broke up and formed a drift across the tank from the sluicer jet. The lack of a heel pump at the bottom of the dish (in the tank center) prevented dewatering the tank completely. A second sluicing nozzle or a longer campaign would have removed more waste. A crawler-based system was proposed to complete retrieval, but was diverted to another tank containing more waste for the demonstration.

Progress: Approximately 186,000 to 187,000 gallons of an estimated total of 192,000 gallons of radioactive sludge was removed from the tank and transferred to a double-shell tank better equipped to handle the high heat levels (DOE 1999; Bailey 2000; Sanders 2000). However, approximately 55,000 gallons of liquid waste was left in the tank. This waste will evaporate in the next 1.5 to 2 years. These transfers occurred in 21 batches (Bailey 2000). The temperature in Tank C-106 was reduced from approximately 200 degrees Fahrenheit to less than 120 degrees Fahrenheit, ending the safety concern about the tank (Sanders 1999b).

Lessons learned:

- *Improve hose management:* In lowering the pump into Tank C-106, the pump hose often became twisted or kinked. This caused difficulties in placing and using the pump. Reducing the length of the hose, using stiffer material for hose construction, or using a spiral wound wire spring may resolve this issue (Sanders 1999b; Bailey 2000).
- *Operate continuously:* Because of safety concerns, sluicing was done in batches, removing 12 in. of sludge at a time. Continuous sluicing would significantly reduce costs. Even if facility or system modification is required, cost-benefit analysis should be conducted (Sanders 1999b).
- *Maintaining key personnel continuity:* Retaining key project personnel from the design through the operational phase helped ensure that critical in-depth systems knowledge was not lost due to personnel transition (Bailey 2000).
- *Provide additional sluicing efficiency:* The single sluicer lacked sufficient power to mobilize the sludge mounds next to the in-tank slurry pump, which was on the other side of the tank (Sanders 1999b). This forced sluicing to continue with excess supernate in the tank. A second sluicer added adjacent to the pump is one option; however, it would result in increased complexity and costs. Another option is to investigate alternative sluicing options such as adding a sluicing feature to the pump, which would be less complex and costly (Bailey 2000).
- *Reduce dispersion from sluicer nozzle*: A new sluicer straightening vein tube design should be substituted for the current design to reduce the dispersion of the sluicing stream. This would enhance the ability of the sluicing stream to mobilize waste at greater distances.
- *Cooling needed for hydraulic system:* The hydraulic system for the sluicer overheated during the hot summer months (the tanks are located in a semi-arid region of the United States). A cooling system should be considered.
- *Shorten and decrease flexibility in slurry pump hose:* The slurry pump discharge hose was more flexible than anticipated and longer than needed. In addition, the mechanical rotary piping joins were more resistant to rotation than planned. These factors resulted in the formation of a loop in the hose

reaching below the level of the pump inlet screen. After water flushing the transfer line and pump/winch assembly, the hose never completely drained. When the pump was lowered back into the waste, the looped hose configuration produced a liquid seal in the discharge hose. The seal prevented air trapped in the pump impeller casing from moving up the transfer line, preventing pump priming. This problem was solved at the site by blowing air through the line for several hours after the transfer line flush. This significantly extended the time required for sluicing. Adding a small vent hole at the high point of the pipe elbows on the submersible pump discharge line, immediately before the first rotary joint, would be another alternative that would not require extensive waiting periods.

- *Reduce gas from boost pump seals:* The gas seals selected for the sluice and slurry booster pumps, selected to avoid adding water or organic materials to the tank, added volumes of seal gas into the process stream. This interfered with the mass flow meter, causing erroneous estimates for the mass of solids transferred to Tank AY-102. These seals required continual adjustments during the early phases of the project. These seals or the control system should be modified to reduce this problem.
- *Add heel pump:* A heel pump, located in the center riser of the tank, could reduce any potential for a leak from the tank by reducing the hydrostatic head over a potential leak site. In addition, it would simplify the evaluation of sluicing progress by allowing more waste to be pumped from the tank, increasing the visibility, and thus volume estimates, of the sludge.
- *Resolve booster pump intake issues:* When the sluicing stream was directed near the intake of the operating slurry pump, inadequate booster pump intake pressure problems were encountered. The reduced pump intake caused the booster pump to be shutdown. A solution was not discovered for this problem; it should be studied before continued sluicing operations are conducted.
- *Simplify flushing capabilities:* Flushing the slurry transfer line should use supernate to flush the lines where possible. It should also be designed to consider placement issues, such as the use of cranes or heavy equipment that can increase costs.
- *Simplify maintenance for in-tank imaging:* The in-tank image slowly degraded during sluicing; this, in part, was the result of the inability to wash the camera and lights independently. One alternative is to wash the camera lens and lights independently. Another is to use an infrared imaging system that does not require lights. Finally, portable systems could be used to provide additional views of the tank interior (Bailey 2000).

For more information on lessons learned during the waste retrieval from Hanford Site Tank C-106, see *Waste Retrieval Sluicing System and Project W-320, Tank C-106 Sluicing, Lessons Learned* (RPP-5687, Rev. 0) (Bailey 2000).

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Annex 9

Retrieval at Zheleznogorsk, Russia
by Pete Gibbons and Kristin Manke

Statement of Problem

The radioactive waste in Tank 8301/3 needed to be removed for decommissioning plans to continue at the Mining and Chemical Combine in the Zheleznogorsk complex (also known as Krasnoyarsk-26). The tank is located inside the Zheleznogorsk complex, which was built inside a mountain, placing the complex 250 to 300 meters underground (Bellona 2001). The plutonium-uranium extraction process used at the reprocessing facilities at the site produced the radioactive tank waste.

Waste type: Some time ago, the supernate was removed from Tank 8301/3, leaving sludge and solid materials. This sludge separated into three layers. The top layer could be stirred and had a solid phase concentration of 60 grams per liter. The second layer was more dense and viscous, having the consistency of fruit jam. The solid phase concentration was 120 grams per liter. The final layer was strongly dehydrated and structured, with a solid phase concentration of 600 to 800 grams per liter (RFMAE 2000).

Studies indicated the uppermost phase contained hydroxides. The solid phase of the sludge contained metal hydroxides (steel corrosion products, aluminum), polymerized forms of silicic acid, niobium and magnesium oxides, nickel and cerium ferrocyanides, and ion-exchange resins. In addition, the sludge contained significant concentrations of uranium and plutonium. However, because of changes in the processing of the nuclear materials, the waste characterization information on the sludge was not comprehensive (RFMAE 2000). The waste had a pH of 12 (DOE 2000).

The temperature at the solid-liquid interface was 75 to 108°C, depending on the depth of the upper layer of sludge (RFMAE 2000).

Storage arrangements: Tank 8301/3 is a vertical tank, approximately 30 meters in height and 12 meters in diameter, with a capacity of approximately 3,000 cubic meters. Carved out of the rock floor of the complex, the tank was reinforced with concrete and lined with stainless steel. Retrieving the waste was not an issue when the tank was built. It was built with a single 159-millimeter-diameter access port (called a backup well) to place equipment (RFMAE 2000). Because the tank is inside the complex, retrieval and characterization equipment can be used without regard for the weather; however, large-scale equipment cannot be used because of the height of the complex's ceiling (RFMAE 2000).

Reasons for retrieval: Plans at the Zheleznogorsk complex call for the waste to be removed to 5 milliRoentgen/hour, also known as maintenance levels (DOE 1997). Once the waste is removed, the tank could be dismantled and the rock cavity used for store materials generated by other activities (RFMAE 2000).

Objectives: There were two objectives for removing the waste from Tank 8301/3. The first objective was to demonstrate the effectiveness of several waste retrieval technologies in a vertical tank configuration. The second was to remove enough waste to reach maintenance levels for the tank.

Retrieval Strategies

Sampling: The waste was sampled and provided for characterization. Information is not available on the sampling campaign.

Waste characterization: The waste was characterized before it was retrieved. The characterization analyses included:

- Metal analyses
- Radionuclide analyses
- Beta activity
- Mercury analyses
- Solids concentration (RFMAE 2000).

Infrastructure upgrade: Shielded access ports, each 10 cm in diameter, were added to the top of the tank. In addition, shielded transfer lines were arranged on the hall floor. In addition, a video camera, an eductor to provide rarefaction, an air distributor with slide valve, pipelines, armature, and filters to clean discharge air were installed (DOE 2000b).

Downstream process: Once the sludge was removed from the tank, it was chemically treated to extract uranium and plutonium. Plans call for the treated sludge to be immobilized as borosilicate glass, although grout or deep well injection could be used (DOE 1997; RFMAE 2000).

Distribution of Retrieval Process

Technology involved: Hydro monitors and hydro elevators were used to remove waste in Tank 8301/3. The hydro monitors, which are similar to some sluicing jet systems used in the United States, uses two sluicing jets mounted on opposite sides of a vertical shaft. The lower jet is designed for immersion in the waste. The upper jet is not. Sluicing is powered by a pulsating pump. Supernate can be used as the motive fluid (DOE 2000b). The hydro elevator is similar to a conventional axial jet pump, used in the United States (Enderlin et al. 1997). The pump consists of a vessel; intake and discharge check valves, a working air supply pipe, and discharge pipe. Intellectual property issues prevent a full description of the equipment used (DOE 1997).

Process: Ten hydro monitors and four hydro elevators were installed near the center of the tank. To remove the waste, supernate from an adjacent tank was forced through the immersed jet and agitated the waste in a circle approximately 4 meters in diameter. Periodically, the waste was pumped out using the hydro elevators. When the cleared area reached 2 meters in depth, the lower jets were closed and the upper, non-immersed jets were used to create a pressurized stream of liquid. This method effectively mobilized waste at a 16 to 24 meter radius. This process mobilized the uppermost layer of sludge (DOE 2000b).

After the upper layer was removed, one of the hydro monitors was removed and replaced with a hydro monitor with four horizontal jets at the lower end. The jets were effective near the hydro monitor but left thick sludge several feet deep in the tank.

Next, 30 grams per liter or 0.5 molar nitric acid was added to the tank through a hydro monitor at 5 to 6 atmospheres. The nitric acid reacted with sludge, and acidified sludge was pumped out of the tank and separated. The solids were transferred to another location; the liquid was returned to the tank with additional acid. This process was repeated over the course of a year or more.

Implementation: A pulsating mixer pump is being developed to have better effect on the hard sludge. The unit consists of an integral pulsating pump that discharges either through lower nozzles, under liquid directly at the sludge, or a steerable sluicing nozzle in the air above the waste. The through air nozzle has a greater effective range than the submerged nozzles. It will be tested in the next tank to be retrieved.

Progress: Approximately 75 % of the 380 cubic meters of sludge was removed from the tank by this retrieval process. This did not meet the objective of reducing the radioactive contamination to maintenance levels. However, it did show that the sluicing and pumping equipment used was effective at removing hydrated sludge.

Lessons learned:

- *Closure requirements*: It is not technically possible to remove all of the heavy residues from the tank bottom with the current retrieval technologies.
- *Dehydrated sediments*: Chemical treatment removed some of the dehydrated sediments at the bottom of the tank. These sediments need to be removed before the rest of the waste because the waste, which has temperature readings in excess of 100°C, could boil if the more hydrated materials are removed first (RFMAE 2000).
- *Sluicers*: Liquid can be replaced with supernate, water, or peptizing agents, based on chemistry concerns (DOE 2000b).

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Annex 10

Waste Transfer Issues

by Pete Gibbons and Kristin Manke

Statement of Problem

In the United States, at high-level waste sites, radioactive waste retrieved from underground tanks is transferred through pipelines to another storage tank or to a processing facility. These pipelines can be up to 7 miles long. With the dilution factors currently planned for waste removal, millions of gallons of waste will be pumped through pipelines (Gephart and Lundgren 1998). Typically, these pipelines are 2 to 3 inches in diameter and are buried or mostly buried underground (TFA 2001a). When radioactive waste is transferred, solids can settle during an inadvertent shut-down of pumping to form blockages in the pipeline, or saturated salt precipitation and other chemical reactions can occur that cause gel-like solids to form. Water pressure-flushing was used to remove pipeline plugs in most cases. However, this method is not always effective. Several lines have been abandoned as a result of plugging. This annex describes research to understand the chemistry of precipitation/solids formation plugs and to develop better methods to remove both settled and precipitated plugs when they occur.

Plugged pipelines present severe financial and scheduling problems for the radioactive waste site (Hunt et al. 2000). In addition, because of the high radiation levels in the buried pipes and insufficient knowledge about the location or nature of the plug, it is often not possible to cut into the pipeline and remove the plug. When it is possible to remove the plug, for example, at the evaporator transfer line at the Savannah River Site, the cost is extremely high (Hunt 1999). Often, waste plugs require the project to find another way to transfer the waste, increasing the time required to complete the project and the associated costs.

Chemistry of Precipitated Waste Plugs

The radioactive tank waste in the United States varies in complexity. The Hanford Site (Washington, United States) contains very complex waste because of the different nuclear processing methods used. As a result, operators are concerned about the possibility of plugs developing when the waste is transferred. Five of seven waste cross-site transfer lines at the site are plugged (Gephart and Lundgren 1998). Waste transfer criteria are based on physical properties such as viscosity, specific gravity, and percent solids and the chemistry of the waste solutions. Studies performed on waste plugging and saltcake dissolution (Hunt et al. 1999) are helping form the basis for future transfers.

Background: Waste plugs develop for one of two reasons: 1) precipitation or a chemical reaction or 2) solid settling. There are two likely scenarios for precipitation of solids in a transfer line. The first is chemicals used in the waste retrieval process (water or waste supernate) react with the tank waste to form solids. The second is a saturated liquid retrieved waste cools in the transfer lines and precipitates solids. The lines are underground, thus cooler than the tanks. A sufficient volume of solid material can precipitate to block the line. For example, a Hanford pipeline was plugged when the pipe temperature decreased and small sodium-fluoride-phosphate crystals formed. In Russia, pipeline plugs are often the result of salt formation/crystallization (see http://www.hcet.fiu.edu/r&d/tfa/unplugging/ares.asp). Other chemical reactions can also occur. For example, the waste may contain chemicals that react and form gelatinous mixtures. At the Hanford Site, a 3.5-inch-diameter transfer line was plugged because of a chemical reaction between aluminum and phosphate in the waste. The combination of these elements resulted in a blockage described as "green gunk" (Gephart and Lundgren 1998).

Solids settling during sludge transfer can occur when the motive force is slow enough to allow particles trapped in the motive liquid to settle onto the bottom of the pipeline. When enough of these solids settle, a plug can form (TMS 2001).

New information: While the general causes of waste plugs are known--precipitation and solids settling--detailed information on the specific chemical components and physical properties is needed. Starting in the late 1990s, tests were conducted on Hanford Site waste. These studies include 1) prediction of solids formation from ionic waste solutions, 2) measurement and prediction of the viscosity of waste solutions and slurries, 3) measurement of the kinetics of precipitation and measurement of precipitate properties, 4) pilot-scale tests of slurry transfers, 5) development of slurry transport models, 6) measurement of the properties of settling sludge suspensions, and 7) lab

dissolution testing with actual saltcake. Sources of more information on these studies include *Prevention of solids formation: Results of FY 1999 studies* (Hunt et al. 1999), *FY2000 saltcake dissolution and feed stability workshop* (Hunt et al. 2000), *Saltcake dissolution FY 1999 status report* (Herting et al. 1999), and the Tanks Focus Area Web site (http://www.pnl.gov/tfa/).

Technologies for Unplugging Blocked Pipelines

The configuration of the tank systems makes accessing plugged pipelines difficult. Because of the radioactivity of the materials, the pipelines were built underground with few access ports. This makes accessing, not to mention locating, the plug difficult. The high radiation levels require remote technologies.

Four technologies for removing pipeline plugs were tested at the Hemispheric Center for Environmental Technology at Florida International University. These technologies were tested to determine performance basis. The radioactivity of the waste will be considered in final technology selection. The technologies were

1. Ridgid snake® by Roto-Rooter®
2. High-pressure water jets on a flexible hose by A-to-Z Environmental Services, Inc.
3. Hydrokinetics™ sonic resonance technology by the Atlantic Group
4. Fluidic wave action technology by AEA Technology.

Ridgid snake®: This technology is a long, slightly flexible cable that is used similar to an auger to drill through and push out plugs. It is the pipe snake used to remove materials from residential sewer lines in the United States (HCET 2001c). This technology removed simulated clay-like waste but is limited to 2-300 feet insertion length including three to five elbows (HCET 2001c; TFA 2001c). Of the technologies evaluated in this annex, this is one of the least costly systems to buy, but it would be very costly to implement in a remote application. For more information, see http://www.hcet.fiu.edu/r&d/tfa/unplugging/testbeds/roto_demo.asp.

High pressure water jets: A high pressure water jet was also tested (TFA 2001c). A hose was propelled by water into the line under 2-3000 pounds per square inch pressure. The pipeline was cleaned by powerful forward and reverse jets of water, which washed waste and other materials back to the insertion point (Roto-Rooter 2001). This technology was effective against the clay-like waste, but it is limited to 500 feet insertion including three to five elbows (HCET 2001c; TFA 2001c). Of the technologies evaluated in this annex, this is one of the least expensive to purchase. Development of remote application configuration appears feasible.

Hydrokinetics™ sonic resonance technology: The Atlantic Group is the distributor for AIMM Technologies, Inc. Hydrokinetics™ technology for cleaning fouled and even completely blocked pipes, heat exchanger tubes, and furnaces. This technology is based on creating sonic resonance with the liquid-filled pipe. The sonic resonance travels through the liquid between the plug and the transfer source. The resonance vibrates both the pipe and the plug. Because the pipe wall and the plug are made of different materials, they vibrate at different frequencies. These different frequencies break the cohesive bond between the plug and the pipe, allowing the plug to be expelled, usually in large pieces (HCET 2001b; TFA 2001b). The pipe is exposed to the sonic wave for only a fraction of the process time, well below the number of cycles required to cause metal fatigue, even in soft metals (TFA 2001b). The Hydrokinetics™ technology can be used with "pigs," small torpedo-shaped devices that can be inserted into the pipeline. The pig is forced through the pipeline where it dislodges material (HCET 2001b).

The technology requires the pipe to be full of liquid up to the point of application. As most waste transfer lines are sloped, this technology can be applied above the location of the blockage. Distance to the blockage and number of elbows in line was not a consideration. It has a potentially short mobilization, demobilization, and unplugging times. For more information, see http://www.hcet.fiu.edu/r&d/tfa/unplugging/testbeds/atlantic_demo.asp or *Fiscal year 2001 semi-annual technical progress report for the November 2000 to April 2001 period: Plugging prevention and unplugging of waste transfer pipelines* (Ebadian et al. 2001).

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Fluidic wave action technology: This technology is designed on the suction/drive principals used on AEA Technology's pulsed mixers (see Annex ___). The system is connected to the end of the blocked pipe that is at a lower elevation than the blockage and, therefore, is empty of liquid below the blockage. A vacuum is drawn on the

pipe. The pipe is then back-filled with water or other solvent to about 95% capacity. The charge vessel is pressurized to 40-100 pounds per square inch, generating a wave at the air-water interface. The wave washes under the bubble at the end of the clear pipe area and breaks against the blockage. Waves are continually generated; this erodes and/or dissolves the plug until it loosens and can be flushed from the pipe. The continued waves erode the blockage much as waves erode jetties in the ocean (TFA 2001b). This is the only technology available that can work on a blocked pipe from the dry end and the only technology that can deliver a solvent of choice to the blockage area. Tests to date have been effective at 1750 feet, the extent of the existing test pipeline. For more information, see http://www.hcet.fiu.edu/r&d/tfa/unplugging/testbeds/AEAT_demo.asp.

Lessons learned:

- *Hydrokinetics*™: A powerful and available technology that can work from the upper/flooded end of a pipeline and is not greatly affected by pipe length or number of elbows. This technology should be coupled with a flushing source.
- *AEAT Pulse system*: This technology is a combination of solvent application, wave action erosion, and cyclical pressure and vacuum acting to form a bypass or leak in the blockage. Once the leak is formed, the surging liquid quickly opens the blockage restoring flow. This technology can only be applied at an elevation below the blockage.
- *Transfer lines*: Three inch transfer lines at the Savannah River Site typically have short radius elbows for ease of seismic and thermal stress calculations. These add difficulty to any mechanical intrusion system. It is commonly assumed that weep elbows would have been used for ease of cleanout. This may not be the case and needs to be verified on a case-by-case basis.
- *Considerations*: A remote system for adapting unplugging technology to a pipeline has to consider confinement, shielding, and the path to a destination for residual liquid in the pipe after the blockage is removed.

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Annex 11

Chemical Retrieval Testing
for Savannah River Site
by Pete Gibbons and Kristin Manke

Statement of Problem

The mechanical retrieval systems (long-shaft centrifugal, dual-jet slurry-mixers with transfer pumps) used on underground tanks at the Savannah River Site (SRS) (South Carolina, United States) can leave up to 40,000 gallons of radioactive waste in a tank that contains support columns and cooling coils (TFA 2001a). This waste contains contaminants that, if they leached to the groundwater, could harm the environment, workers, and nearby residents. To remove the residual waste, chemical cleaning methods that break down solids until they can be pumped out are being studied.

Waste type: The plutonium-uranium extraction sludge in the SRS tanks, which is the primary component of residual waste, contains aluminum, iron, manganese hydroxide precipitates, mercury, and sodium nitrate/nitrite/hydroxide salts. Organic constituents may be present in low to trace concentrations (DOE and KRI 2000). The primary radioactive constituents are strontium-90; cesium-137; plutonium-238, and -239; and lesser amounts of other transuranic elements (TFA 2001c). The fissile isotopes are neutron poisoned by iron and manganese from fission products (DOE and KRI 2000).

Storage arrangements: Types I and II tanks at SRS contain support columns that obstruct mechanical retrieval technologies. The Type I tanks each contain 12 concrete columns to support the flat concrete roof. Cooling coils are both vertical on 4-foot centers and horizontal across the tank floor. The columns are 2 feet in diameter and encased in carbon steel plate. The tank walls are composed of carbon steel. The tanks are 75 feet in diameter and 24.5 feet in height; they each have a capacity of 750,000 gallons. Additional containment is provided by a secondary carbon-steel pan. The 1,030,000-gallon-capacity Type II tanks each have a single central roof-supported column. The walls are composed of carbon steel. The tanks have a diameter of 85 feet and a height of 27 feet. Additional containment is provided by a secondary carbon steel pan (TFA 2001c).

Reasons for retrieval: Mechanical radioactive waste retrieval methods at SRS can leave as much as 40,000 gallons of waste in an obstructed tank (TFA 2001a). This waste can contain technetium-99 and other contaminants of concern that are radioactive and highly mobile in groundwater (TFA 2001b). If the tank is "closed" with the waste inside the tank, a possibility exists that the contaminants could leach to the soil and groundwater. Thus, retrieving the residual waste, and reducing the volume of technetium, would reduce the risk the tanks pose to the environment.

Objectives: The objectives are to find a chemical cleaning process that effectively mobilizes hard-to-retrieve sludge. The process must maintain criticality safety, prevent disintegration of tank walls and floors, and minimize impacts on downstream treatment processes (TFA 2001d).

Retrieval Strategy

Following normal retrieval operations, when it is determined that more waste needs to be removed to meet radioactive source-term limits, acid reduction of sludge will be considered. The SRS baseline for this is oxalic acid. This was used to remove waste from Tank 16 in the 1980s. It has been determined that oxalic acid alone tends to concentrate plutonium relative to iron and manganese. This negated a key assumption of the Site criticality safety basis. Alternate chemistry is being sought that will work on compounds containing these three elements at an equal rate.

Sampling: Waste samples will be obtained from SRS tanks.

Waste characterization: When chemical cleaning is performed on actual tank waste samples, the waste will be characterized before and after the cleaning.

Infrastructure upgrade: Depending on the chemical cleaning process used, infrastructure upgrades, such as chemical tanks, delivery systems, and offgas recovery and processing systems could be required at the tank site.

Downstream process: Because retrieval is only one part of the remediation of tank waste, downstream impacts must be carefully considered. Downstream processing issues will include metal concentrations, chemical concentrations, and waste volume and their impact on cesium separation and immobilization in glass.

Development of Chemical Cleaning Retrieval Process

Process: Research on simulated SRS tank waste showed that oxalic acid effectively dissolved the majority of the components in waste, except for manganese dioxide and mercury oxide. However, regulatory agencies are concerned because pure oxalic acid does not dissolve plutonium and the neutron poisons at the same rate and this could lead to a criticality incident (that is, enough nuclear material could be in the right configuration to cause an energetic nuclear chain reaction). This concern forced researchers to look at other chemical cleaning agents.

A mixture of oxalic acid (0.06 M) and citric acid (0.026 M), neutralized by sodium hydroxide to a pH of 4 to 4.2, effectively dissolved the sludge, except for aluminum. The presence of aluminum considerably decreased the dissolution rate of the sludge. Thus, the following process was created to remove the aluminum and dissolve the remaining waste:

- Leach the aluminum from the sludge using 2M sodium hydroxide solution heated to 60 °C. The sludge is leached seven times.
- Rinse the sludge with water to remove excess sodium hydroxide.
- Treat the sludge with 5 g/L oxalic acid and 5 g/L citric acid heated to 60 °C. The sludge to solution volume ratio is 1:2.

This process effectively dissolved the sludge. The solution from this process did not pose a criticality issue, because the concentration of plutonium was exceedingly low (1/10 g/L). The solid phase could be a criticality issue, because of the higher concentration of plutonium and the lower levels of neutron poisons; however, extremely uneven distribution of plutonium would be required to produce a criticality event. Because of the possibility of a criticality, experiments were conducted on adding a neutron poison to the sludge. Crystalline boron carbide was selected for the following reasons: 1) it will readily settle out of the sludge, 2) at concentrations up to 10% by mass, it does not impact the dissolution rate or the completeness of dissolution, and 3) it is not cost prohibitive. However, intensive stirring is required. The pH of the oxalic and citric acid combination and the temperature increase (to 60 °C) lead to a small increase in the corrosion rate of the carbon steel. The corrosion rate of the combined acids in simulated sludge (that is, there is a solid phase to the waste) did not exceed 0.09 millimeters per year. In conclusion, the oxalic acid and citric acid combination effectively dissolved simulated SRS waste (Popik 2000).

Implementation: Following validation testing, a positive recommendation the Site authorization basis will be updated, and candidate tanks will be evaluated for field demonstration.

Progress: Simulated waste tests were conducted. Actual waste tests will be conducted before further consideration is given to using the process (Popik 2000).

Lessons learned:

- *Simulated waste vs. real waste*: Experiments with simulated waste in controlled laboratory conditions are not identical to actual plutonium-uranium extraction waste containing fission products. Further testing, with actual waste, is needed before final consideration can be given to a process.
- *Plutonium*: Use of oxalic acid to partially dissolve plutonium-uranium extraction sludge can preferentially dissolve iron and manganese compounds resulting in relative concentration of plutonium compounds.

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Annex 12

Waste Retrieval at the West Valley Demonstration Project
by Pete Gibbons and Darcy Short

Statement of Problem

High-level waste in Tanks 8D-1 and 8D-2 at the West Valley Demonstration Project (WVDP) near West Valley, New York, needed to be removed and transferred to the Vitrification Facility (Hamel and Meess 1999). Removal was necessary to allow the HLW to undergo vitrification (Hamel and Meess 1999).

Waste type: Tank 8D-1 was considered a "spare" tank at the site. It stored 144,000 pounds (65,300 kilograms) of spent zeolite under an alkaline liquid. Zeolites are crystalline aluminosilicates of the group I (alkali) and group II (alkaline earth) elements used in ion-exchange processes (McFarlane et al. 1997). Ion exchange columns located in the top of the tank were used to strip cesium and strontium from liquid wastes before evaporation or grouting. When the columns were saturated, the zeolite was dumped into Tank 8D-1. In addition, Tank 8D-1 contained 137,000 gallons (520,000 liters) of excess liquid from pretreatment and zeolite transfer operations. The liquid had a pH of approximately 10.5 (Hamel and Meess 1999).

Tank 8D-2 contained a mixture of washed plutonium-uranium extraction sludge solids, zeolite, and supernate. The sludge included the following chemical constituents: iron oxide (35.5 wt%), silicon dioxide (20.8 wt%), sodium oxide (14.4 wt%), thorium oxide (10.4 wt%), and aluminum oxide (7.1 wt%). The sludge was estimated at 220,500 pounds (100,000 kilograms), with a specific gravity of 3.35. The primary radionuclides in the sludge were strontium-90 and thorium and uranium isotopes. The strontium-90 activity was estimated at 5.81 million curies. Approximately 125,700 pounds (57,000 kilograms) of zeolite contained approximately 5.5 million curies of cesium-137 (Hamel and Meess 1999).

Storage arrangements: Tank 8D-1 and 8D-2 are 740,000-gallon (2.8 million liter), carbon steel tanks contained in separate underground concrete vaults with secondary containment pans. The tanks measure 69 feet (21 meters) in diameter and 27 feet (8.2 meters) in height. The tank bottoms are reinforced by complex internal gridwork structures, which support the tank roof and floor. The tanks also contain four inactive air circulators, thermowells, a heat exchanger, and level/density probes. The internal gridwork and structures make the waste retrieval process difficult by blocking sluicing jets and limiting physical equipment access (Hamel and Meess 1999; Hamel et al. 2000).

Reasons for retrieval: The West Valley site is required to remove the waste by federal law, that is, the West Valley Demonstration Project Act of October 1, 1980. This act mandated the U.S. Department of Energy (DOE) remove and solidify the HLW into a form suitable for transportation to the federal repository for final disposal.

Objectives: The objectives of the waste retrieval process are to remove waste from the tanks to prepare the tanks and the removed waste for final disposition and storage.

Retrieval Strategies

Sampling: Tank 8D-2 was sampled and characterized extensively. Supernate sampling was done through the only available riser using a Penberthy air jet eductor. The device is lowered into the tank using a winch. Supernate samples were taken at 0.3 and 1.5 meters below the vapor/solution interface at one depth setting, and at 4.6 and 5.8 meters below the interface at a second setting (DOE 1986). In addition, as waste was removed from 8D-1 and 8D-2, it was directed to a vitrification staging tank where it was well mixed and sampled. This provided an accurate assessment of the waste removed and sent to vitrification. More information on the sampling of the waste can be found in *High-level waste characterization at West Valley: Progress report for the period 1982-1985* (DOE 1986).

Waste characterization: Tank 8D-2 waste was extensively characterized. Tests performed included the following:

- Chemical analyses

- Radiological analyses
- Specific gravity
- Density
- Leachability
- Temperature (DOE 1986).

More information on the characterization of the waste can be found in *High-level waste characterization at West Valley: Progress report for the period 1982-1985* (DOE 1986).

Downstream process: Liquid waste was polished through a zeolite ion exchange column and then grouted into rectangular metal containers with the form factor of a standard 55-gallon drum. Solid waste, including the loaded zeolite resin, was transferred to the vitrification facility for immobilization in borosilicate glass, sealed into stainless steel containers.

Distribution of Retrieval Process

Technologies involved: The technologies used in the waste retrieval process were as follows:

- Mast-mounted tool delivery system with various tools
- Transfer pump
- Long-shaft vertical mixer pumps

Mast-mounted tool delivery system: The mast-mounted tool delivery system is a remotely operated mast with tools mounted on carriages that can be raised and lowered along the mast. Tools include an arm-mounted sluicer, arm-mounted wall sampler, lights and cameras. The system is comprised of a 49-foot steel beam, deployed through a 25.75-inch riser that extends to within 1 foot of the tank bottom. The top of the beam extends out of the riser and is mounted to a rotary bearing connected to an electric gear motor. A series of eight hydraulic winches and actuators are mounted to the mast, above the rotary bearing. Each winch can lift a maximum of 1,000 pounds (TTG 2001).

Transfer pump: The transfer pump is a 13-stage, 36.37-foot (12 meter) slurry transfer pump. It has a radial inlet suction that extends approximately 2.75 to 3.5 inches (7 to 9 centimeters) above the tank bottom. Two concentric strainers prevent large debris from entering the pump. It has a 20-horsepower motor located in a concrete shielded pump pit directly over the pump column. The pump has the capacity to pump 100 gallons (380 liters) per minute with a 197-foot (60-meter) head (Hamel and Meess 1999).

Long-shaft vertical mixer pumps: A long-shaft vertical mixer pump is a centrifugal pump 50 feet (15.3 meters) long powered by a 150-horsepower motor. The pump has one impeller that draws material into the pump suction. The pump suction is fitted with a strainer to prevent large debris from entering the pump. The suction is positioned 1 to 4 inches (2.5 to 10 centimeters) above the bottom of the tank. Two tangential, 1.5-inch- (3.8-centimeter-) diameter nozzles discharge the pumped waste from the volute about 7 to 10 inches (18 to 25 centimeters) above the bottom of the tank. Each nozzle distributes 515 gallons (2270 liters) per minute at the 100%-rated pump speed of 1800 rpm (Hamel and Meess 1999).

Process: Between June 1996 and September 1998, WVDP performed 102 waste transfers from the tanks to the Vitrification Facility. Six mobilization pumps were used to mix the solids that settled on the tank bottom. A long-shaft vertical transfer pump transferred the waste from the tank to the Vitrification Facility.

Implementation: Eight additional risers were remotely installed on the top of the tank to provide for pump installations (and subsequently, other retrieval equipment), and three trusses were constructed over the tank to support the pumps and distribute the weight (Hamel and Meess 1999).

Progress: Most of the waste was removed from the two tanks. In Tank 8D-1, approximately 96% of the cesium-137, strontium-90, and sludge was removed (Hamel et al. 2000). In Tank 8D-2, greater than 99% of the long-lived radioactivity was removed, only a few small areas of settled cesium-137-laden zeolite remain (DOE OFO 2001; TFA 2001).

Lessons learned:

- A mobilization pump trial failed. The impeller key sheared. Pump designs were then modified, so the easily accessible motor coupling key would fail before the inaccessible coupling key was sheared.
- Mobilization pump suctions lowered from 4 inches (10 centimeters) above the tank bottom to 1.5 inches (4 centimeters) provided additional clearance between the jet centerlines and the tank structural gridwork. This improved the effective solids mobilization radius, and it allowed for the pumps to be operated at lower tank levels.
- Installing transfer pump motors, a pump tachometer, and valve position switches inside the pump pits proved easy and cost-effective.
- Positioning equipment outside the pump pit so it can be easily serviced eliminated the need for personnel to enter a highly contaminated area and it kept the equipment cleaner.

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