USE OF MULTIPLE INNOVATIVE TECHNOLOGIES FOR THE RETRIEVAL AND HANDLING OF LOW-LEVEL RADIOACTIVE TANK WASTES AT OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

The U.S. Department of Energy (DOE) successfully implemented an integrated tank waste management plan at Oak Ridge National Laboratory (ORNL) (1), which resulted in the cleanup, removal, or stabilization of 37 inactive underground storage tanks (USTs) since 1998, and the reduction of risk to human health and the environment. The integrated plan helped accelerate the development and deployment of innovative technologies for the retrieval of radioactive sludge and liquid waste from inactive USTs. It also accelerated the pretreatment of the retrieved waste and newly generated waste from ORNL research and development activities to provide for volume and contamination reduction of the liquid waste. The integrated plan included:

1. retrieval of radioactive sludge, contaminated material, and other debris from USTs at ORNL using a variety of robotic and remotely operated equipment;
2. waste conditioning and transfer of retrieved waste to pretreatment facilities and interim, double-contained storage tanks;
3. the development and deployment of technologies for pretreating newly generated and retrieved waste transferred to interim storage tanks;
4. waste treatment and packaging for final off-site disposal;
5. stabilization of the inactive USTs that did not meet the regulatory requirements of the Federal Facilities Agreement between the DOE, the Environmental Protection Agency (EPA), and the Tennessee Department of Environment and Conservation (TDEC); and
6. the continued monitoring of the active USTs that remain in long-term service.

This paper summarizes the successful waste retrieval and tank stabilization operations conducted during two ORNL tank remediation projects (The Gunite Tanks Remediation Project and the Old Hydrofracture

Facility Tanks Remediation Project), the sludge retrieval operations from the active Bethel Valley Evaporator Service Tanks, and pretreatment operations conducted for the tank waste. This paper also provides the status of ongoing activities conducted in preparation of treating the retrieved tank waste for final disposition, and the efforts to improve monitoring capabilities for waste collection and storage tanks that will remain in long-term service at ORNL.

INTRODUCTION

Since its establishment in 1943, ORNL has performed nuclear research and development activities. ORNL initially served as a model for plutonium production facilities constructed during the Manhattan Project of World War II. Later, ORNL provided major leadership and scientific contributions to the development of nuclear technology and processes, and continues to be a leader in nuclear research and development. During the initial construction and during subsequent upgrades of ORNL, a liquid low-level waste (LLLW) system was built to manage radioactive and chemical wastes resulting from research activities. The LLLW system initially included several single-shelled UST's that were used for the collection, treatment, and storage of LLLW, and underground pipelines that connected the research facilities with the USTs. Additional USTs and piping were added as the mission of ORNL grew. By the early 1990s the ORNL LLLW system had changed considerably, with the single-shelled tanks placed in an inactive status and newer double-contained steel tanks installed and integrated into the LLLW system. An evaporator was constructed at ORNL in Bethel Valley to provide LLLW volume reduction. Five stainless steel tanks, known as the Bethel Valley Evaporator Service Tanks (BVESTs), were positioned in underground vaults. The BVESTs serve as feed tanks for the Bethel Valley evaporator and storage tanks for the evaporator concentrate. Two tank farms consisting of double-contained, stainless steel tanks were constructed at ORNL in Melton Valley to store concentrated waste. The Melton Valley Storage Tanks (MVSTs) include eight 189-m^3 (50,000 gal) tanks located in two steel-lined underground vaults that provide secondary containment. The Melton Valley Capacity Increase Tanks (MVCITs) include six 378.5-m^3 (100,000 gal) tanks located in an above ground vault.

DOE and ORNL implemented an integrated tank waste management plan to coordinate the retrieval of residual wastes from the inactive single-shell tanks, and the waste transfers and consolidation of the retrieved waste to the active tanks in the ORNL LLLW system. The plan also addressed the pretreatment of the consolidated waste slurry by evaporation to ensure that the MVSTs were not filled over capacity. The integrated tank waste management plan included interim storage for the retrieved/consolidated sludge waste in the MVSTs prior to final treatment and packaging at the new ORNL TRU Waste Treatment Facility, which is currently under construction. Following treatment at the new facility, the tank waste will be transported for final disposition at the Waste Isolation Pilot Plant (WIPP) and/or the Nevada Test Site (NTS); depending on the characteristics of the treated waste. The major unit operations performed as part of the ORNL integrated tank waste management plan are described in the following sections. The operations were overseen and performed by a number of organizations. The DOE was responsible for oversight and management of the program. Bechtel Jacobs Company LLC is the DOE management and integrating contractor for DOE Oak Ridge Operations, and was responsible for waste management and remediation of the tanks and sites. ORNL [Lockheed Martin Energy Research (previous prime contractor) and U.T. Battelle LLC (current prime contractor)], TPG Applied Technology, Advanced Integrated Management Services, Inc., and other subcontractors provided research and development support and technical support. Figure 1 shows a conceptual drawing of the ORNL integrated tank waste management plan and the flow of waste between the tanks and treatment facilities.

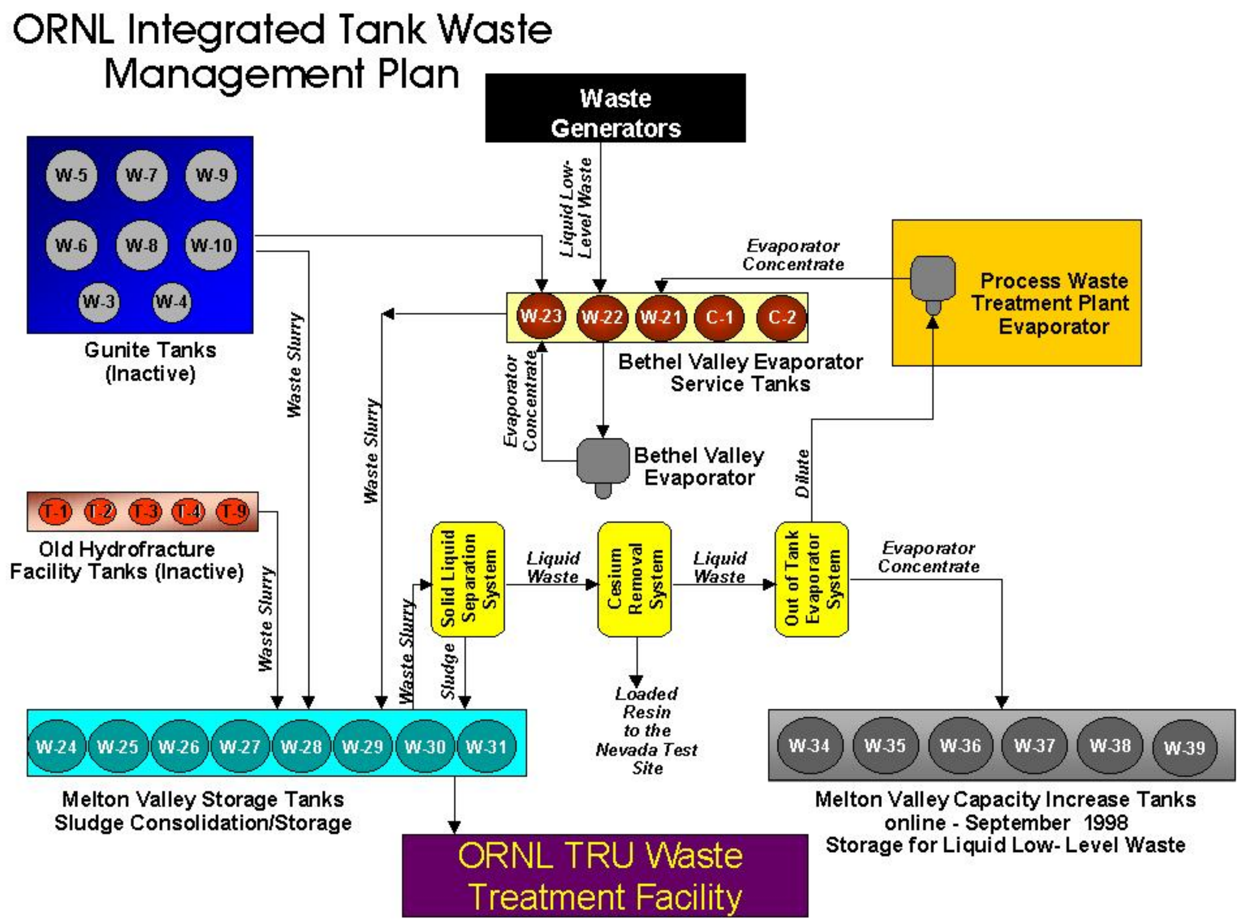

Fig. 1. Conceptual Drawing of the ORNL Integrated Tank Waste Management Plan.

WASTE RETRIEVAL OPERATIONS

Waste retrieval operations were performed in most inactive USTs and some active USTs as part of the ORNL integrated tank waste management plan. The following sections focus on two major tank remediation projects that were conducted as part of the plan, and the sludge retrieval operations conducted in the five tanks that service the Bethel Valley Evaporator. Each section provides an overview of the waste retrieval processes and technologies that were used to successfully retrieve the waste from these tanks.

The Gunite Tanks Remediation Project

Eight large USTs were built during the original construction of ORNL as part of the Manhattan Project in 1943 and 1944. The tanks were constructed to serve as temporary LLLW storage tanks, and were built with the gunite process, where a portland cement and sand mixture was sprayed over a wire mesh and reinforcing rod frame. The eight single-shelled, domed tanks were constructed in the North and South Tank Farms in the center of ORNL, and had storage capacities of up to 643.5 m^3 (170,000 gallons). Throughout their years of service (up until the early 1970s), the tanks were used to treat and store LLLW. After they were placed in an inactive status, the tanks continued to store LLLW and a thick layer of radioactive sludge, which was the result of precipitants settling out of the LLLW. Initial waste retrieval operations were conducted in the six largest gunite tanks (located in the South Tank Farm) from 1982 through January 1984. Operators used conventional single-point sluicing and significant quantities of water to dislodge and retrieve approximately 90% of the sludge volume present in these tanks. Following the initial waste retrieval operations, it was estimated that more than 341 m^3 (90,000 gal) of sludge remained in the tanks, with inleakage from rain and groundwater contributing to the volume of LLLW remaining in the tanks.

The DOE, EPA, and TDEC agreed to perform a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial Investigation/Baseline Risk Assessment (RI/BRA) and Feasibility Study. The RI/BRA helped determine the physical and radiological characteristics of the tanks and residual waste and the risk they presented to the public and environment. The Feasibility Study provided information that was used to select a remediation method that could meet the cleanup goals established in an addendum to the RI/BRA, which concluded that at least 90% of the residual sludge and contamination needed to be removed from the tanks in order to reduce the risk of the public developing cancer to less than 1×10^{-4}, or 1 in 10,000 people. A CERCLA Treatability Study provided the opportunity to select, integrate, and test new and off-the-shelf robotic and remotely operated technologies that were used during the waste retrieval operations in the eight largest gunite tanks.

The integrated waste retrieval system, used during the Gunite Tanks Remediation Project, became known as the Radioactive Tank Cleaning System (RTCS). The RTCS included technologies and equipment that performed specialized functions. Over 40 different advanced technologies/equipment were deployed during the Gunite Tanks Remediation Project (2). Key in-tank components of the RTCS included:

- remote video camera and lighting systems, which served as the eyes of the equipment operators;
- the Waste Dislodging and Conveyance (WD&C) system;
- remotely operated vehicles (ROVs), known as Houdini I and Houdini II; and
- a robotic arm known as the Modified Light Duty Utility Arm (MLDUA).

Waste mixers were also deployed in two tanks during the Gunite Tanks Remediation Project. Two Flygt mixers were deployed to help retrieve sludge waste in tank W-5, which exhibited signs of interior wall deterioration. Three Pulsair mixers (and later a Flygt mixer) were deployed in tank W-9 (the project’s waste consolidation and batch transfer tank), in order to keep the sludge in suspension following waste retrieval and consolidation in the tank. The Balance of Plant System provided the electrical, air, and process water requirements for the RTCS, and above ground conditioning systems assured and verified that the retrieved waste met waste transfer criteria before it was transferred to the BVESTs or MVSTs.

The WD&C system used the confined sluicing process to retrieve sludge waste and minimize the addition of water to the tanks. Significant amounts of sluice water were required throughout the project’s tank waste retrieval operations. Recycled LLLW was used whenever possible to minimize the addition of clean water. Tank W-8 served as the LLLW consolidation/supply tank and stored decanted LLLW from various sources that was reused during confined sluicing operations in the gunite tanks. The WD&C system included a confined sluicing end-effector with rotating water cutting jets for breaking up sludge, and a gunite scarifying end-effector that was used to clean the tank walls. The WD&C system also included a hose management arm that reduced the load on the MLDUA and ROVs and helped to position the waste transfer hose inside the tanks. The hose management arm was integrated with the power and water supply lines for the confined sluicing end-effector. The WD&C system’s axial flow jet pump, located in the mast of the hose management arm, provided the suction power to retrieve the waste slurry from the tanks.

The MLDUA was an eight-degree-of-freedom robotic arm that was used to deploy tank characterization equipment, tank modification tools, and waste retrieval and wall cleaning end-effectors. The MLDUA was integrated with a gripper end-effector and two cameras, which were used to assist in grasping equipment and monitoring operations. The MLDUA had a reach of about 4.6-m (15-ft) and a payload capacity of about 12.7 kg (200 lbs). Waste retrieval operations in the largest 15-m (50-ft) diameter gunite tanks typically required deployment of the MLDUA through four different access ports when tank wall cleaning was required. Operators controlled the MLDUA via a console installed in the equipment control room. The MLDUA could be operated remotely or programmed to perform robotic operations, such as wall cleaning operations, which created low visibility in the tanks.

The Houdini ROVs provided versatility during in-tank operations. Each vehicle weighed about 454 kg (1,000 lbs) and had a rectangular-shaped footprint measuring approximately 1.2 m x 1.5 m (4 ft x 5 ft). The Houdini I and II ROVs were tethered vehicles with two tracks located on the longer sides of the frame that provided mobility. The Houdini ROV frames folded to a parallelogram-shape for deployment and retraction through 0.6-m (24-in) diameter tank access risers. Each ROV came equipped with an integrated manipulator arm and grasping end-effector. The six-degree-of-freedom arms had payload capacities of about 109 kg (240 lbs) at full extension. The manipulator arms were used to pick up and organize debris so that it could be retrieved from the tanks. The arms were also capable of deploying a variety of tools and end-effectors, which were used to modify the interiors of the tanks, sample the tank waste, and retrieve the waste. Cameras mounted on the manipulator arm and rear panel of the vehicles, near the tracks, provided a video feed to monitors mounted at the vehicle's control console, which was located in the equipment control room. Operators controlled the vehicles via the control console and could adjust the camera views to help them grasp tools and perform intricate operations. The ROVs were also equipped with a plow blade on the front of their frames. The plow blades were useful for breaking-up sludge heels at the junction of the tank wall and floor, and pushing sludge toward the MLDUA deployed confined sluicing end-effector.

During the Gunite Tanks Remediation Project, waste retrieval operations were performed in eight tanks located in the North and South Tank Farms beginning in June 1996. Waste retrieval operations conducted in tanks W-3 and W-4 were considered hot tests for the waste retrieval equipment. South Tank Farm waste retrieval operations began in April 1998 after the waste retrieval equipment was moved from the North Tank Farm and installed on tank W-6. Figure 2 shows the waste retrieval equipment installed on the tank W-6 equipment platform during waste retrieval operations in that tank.

Fig. 2. Waste retrieval equipment installed in the South Tank Farm at ORNL during the Gunite Tanks Remediation Project. Note the RTSC equipment installed on the equipment platform over tank W-6, which was undergoing waste retrieval operations at the time of this photo. Two Flygt mixers were installed in tank W-5 and the Pulsair mixers were installed in tank W-9, which served as the waste consolidation tank.

Waste retrieval operations were completed in the South Tank Farm in September 2000, resulting in the retrieval of more than 336 m^3 of remote-handled transuranic sludge from the eight largest gunite tanks. The project exceeded the waste retrieval goals established in the RI/BRA addendum (remove at least 90% of the residual waste/contamination) by successfully removing over 99% of the waste and 95% of the contamination from the eight largest gunite tanks (3). Table I summarizes the contamination and waste retrieval performance for the Gunite Tanks Remediation Project. Following the waste retrieval operations, the North and South Farms were cleaned up. The equipment was demobilized, and the equipment platforms that supported the waste retrieval equipment were torn down and recycled. The gunite tanks were successfully stabilized in-place during the summer of 2001, and the South Tank Farm was leveled and paved to provide additional parking in "downtown" ORNL.

Table I. Gunite Tanks Remediation Project contamination and waste retrieval performance summary.

	Tank Number								
	W-3	**W-4**	**W-5**	**W-6**	**W-7**	**W-8**	**W-9**	**W-10**	**Total**
Initial liquid volume (m^3)	59.4	112.6	150.8	157.0	13.5	244.4	172.7	400.7	1311.1
Initial sludge volume (m^3)	20.8	51.1	25.0	48.8	38.2	39.3	35.2	106.4	364.8
Final sludge and liquid volume (m^3)	0.4	0.4	9.9	5.9	1.8	2.1	5.3	3.0	28.8
Initial contamination (bq)	1.3E+13	3.7E+13	9.7E+12	1.6E+14	1.8E+14	3.0E+14	2.3E+14	2.2E+15	3.2E+15
Final contamination (bq)	4.4E+11	4.1E+11	3.1E+12	2.1E+13	7.7E+12	3.1E+13	4.2E+13	3.9E+13	1.5E+14
Waste removed (%)**	99.7	99.7	98.5	99.1	99.7	99.7	99.3	99.7	99.4
Contamination removed (%)	96.5	98.9	68.2	87.3	95.6	89.6	82.2	98.2	95.2
Amount of retrieval water used (m^3)	158.2	349.4	0	196.8	234.7	159.6	246.0	247.1	1591.8

* Includes sludge waste consolidated from tank W-3.
** Based on the total tank capacity(ies)

The Old Hydrofracture Facility (OHF) Tanks Remediation Project

The OHF tanks are located in Melton Valley and served as feed tanks for the hydrofracture process, which was conducted from 1964 through 1979. The OHF tanks stored LLLW that was mixed with grout during the hydrofracture process and injected into shale formations over 305 m (1,000 ft) underground. The tanks remained in active service until 1980. The five inactive OHF tanks (T-1, T-2, T-3, T-4, and T-9) are cylindrical single-shelled carbon steel tanks that are positioned horizontally about 1.8 m (6 ft) underground. Two of the tanks (T-3 and T-4) were rubber-lined tanks. The tanks range from 2.4-m (8-ft) to 3.2-m (10.5-ft) in diameter and from 7.3-m (24-ft) to 13.4-m (44-ft) in length. Tank modifications were performed during the summer of 1997. Workers installed 0.7-m diameter access ports/risers at each end of the tanks to provide access for submersible pumps and monitoring equipment. Tank access ports/risers measuring 0.5-m in diameter were installed in the center of the tanks to support the installation of a mobile waste retrieval technology, known as the Borehole Miner extendable nozzle.

Waste retrieval operations were performed in the OHF tanks over a 3-week period in the summer of 1998. Waste retrieval operations were conducted as a technology demonstration project of the Borehole Miner extendable nozzle technology, in coordination with the DOE Tanks Focus Area. This mobile technology, previously used in the mining industry, included an articulated, extendible nozzle that could be remotely positioned/rotated in the tank to avoid in-tank obstacles. The single high-pressure jet nozzle could achieve operating pressures of 3.4 to 20.7 MPa (500 to 3,000 psi), with a flow rate of 75.7- to 757-L/min (20- to 200-gal/min). The Borehole Miner extendable nozzle system used recycled LLLW and about 31 m^3 of additional water to dislodge/breakup the sludge and provide a mixing action in the tanks. Submersible pumps were successful used to transfer 230.8 m^3 of waste slurry containing 36.7 m^3 of sludge to the MVSTs. The Borehole Miner extendible nozzle technology was successful at retrieving over 98% of the of initial 37.1 m^3 of sludge contained in the OHF tanks (4). Following the waste retrieval operations, the equipment was demobilized, the site was cleaned up, and the tanks were stabilized in place in 1999.

The Bethel Valley Evaporator Service Tanks (BVESTs) Sludge Retrieval Project

The five BVESTs provide surge and storage capacity for an evaporator system that processes LLLW collected from facilities throughout ORNL via an underground collection and transfer system. Each 189-m^3 (50,000-gal) stainless steel, cylindrical tank is about 3.5 m (12 ft) in diameter and 18.5 m (61 ft) long. The BVESTs are located in the main plant area of ORNL in underground reinforced concrete vaults that are lined with 16-gauge stainless steel to provide secondary containment. Sludge retrieval was performed in the BVESTs using two fluidic pulsed jet mixing systems. Modifications were made to the tanks W-21, W-22, and W-23 to provide larger access ports at one end of the tanks for the installation of a remote video camera and lighting system. Tanks C-1 and C-2 were modified to include larger tank access ports at each end of the tanks in order to accommodate a mobile pulsed jet mixing system, since these tanks were not equipped with pulse/mixing nozzles. At the start of waste retrieval operations nearly 170 m^3 of remote-handled transuranic sludge was contained in the BVESTs (4).

A modular fluidic pulsed jet mixing system (designed, manufactured, and operated by AEA Technology) was installed in and around the common pump and valve pit for three of the BVESTs (W-21, W-22, and W-23) during the summer of 1997. The modular system was connected to six existing 7.6-cm (3-in) mixing nozzles located in each tank through connections in the pump and valve pit. The nozzles enter the tanks from the top and extend to about 20.3 cm (8 in) from the bottom of the tank. Each nozzle has a 90-degree elbow at the bottom, and the nozzles are positioned in opposing pairs along the length of the tanks. The pulsed jet mixing system used an above ground jet pump to create a vacuum and pulse action through the nozzles located in the tanks. During the vacuum phase, liquid waste was pulled via the nozzles into charge vessels installed in the pump and valve pit. During the pulse phase the liquid was pulsed back into the tank through the nozzles, creating a mixing action that mobilized the sludge into a waste slurry.

A modified pulsed jet mixing system was used to retrieve sludge from tanks C-1 and C-2. These tanks historically served as LLLW concentrate tanks. Since these tanks were not equipped with mixing nozzles, charge vessels were inserted through the tank access risers located at the ends of the tanks. The charge vessels included two opposing discharge nozzles to provide adequate mixing action in these tanks. Waste slurry from the C-tanks was transferred to tank W-23, which served as the interim consolidation tank during sludge retrieval operations. During the sludge retrieval/consolidation operations, the original pulsed jet mixing system was operated in tank W-23 to maintain the sludge in suspension before it waste transferred to the MVSTs.

The pulsed jet mixing systems were operated over several waste mixing campaigns in each tank. Acid was added to some of the tanks to help dissolve the residual sludge heel and increase the amount of waste retrieved. Waste slurry was transferred from the BVESTs to the MVSTs after the waste samples were analyzed to confirm that an adequate amount of sludge was suspended in the slurry, and that the slurry met the waste acceptance criteria for transfer into the MVSTs. Due to successful waste mixing operations with the fluidic pulse jet mixing systems, over 95% of the radioactive sludge was safely removed from the BVESTs during waste retrieval campaigns conducted during 1997, 1998, and 1999 (4). Figure 3 shows the mobile fluidic pulsed jet mixing system installed over the pump and valve pit that services tanks W-21, W-22, and W-23.

Fig. 3. Above ground view of the fluidic pulse jet mixing system installed at ORNL over the pump and valve pit servicing Bethel Valley Evaporator Service Tanks W-21, W-22, and W-23.

WASTE PRETREATMENT

In order to balance ORNL's waste storage needs with the available waste storage capacity, the ORNL integrated tank waste management plan called on technologies for treating newly generated wastes and the wastes transferred to the interim storage tanks. Several complimentary pretreatment technologies provided the ability to

1. separate the solids (containing the bulk of the radioactive contamination) from the LLLW,
2. remove selected contaminants from the bulk liquid waste stream, and
3. concentrate the bulk liquid waste.

DOE conducted a Wastewater Triad Project at ORNL to provide pretreatment for the wastes consolidated in the MVSTs. The Wastewater Triad Project demonstrated and deployed three modular operational systems: the Solid/Liquid Separation (SLS) system, the Cesium Removal (CsR) system, and the Out-of-Tank Evaporator (OTE) system. These modular, skid-mounted pretreatment systems were designed to reduce the volume and radioactivity of the LLLW stored in the MVSTs. The systems could be operated independently, or in series to accomplish pretreatment goals. The systems and process were successfully deployed from December 1997 though April 2000.

Fourteen operational campaigns were completed over the course of the Wastewater Triad Project (four demonstrations and ten full-scale deployments). The deployments of the SLS, CsR, and OTE systems resulted in the pretreatment of approximately 1,014.5 m^3 (268,000 gallons) of LLLW. The CsR system removed more than 98% of the cesium from the LLLW, and achieved an average decontamination factor (C_0/C) of approximately 6E+6 was for cesium-137 (10). About 2.85E+14 Bq (7,700 curies) of cesium-137 was removed from the LLLW and concentrated on the crystalline silicotitanate ion exchange sorbent. The combined use of the SLS system and the OTE system allowed the continuation of the waste retrieval operations at ORNL. Using the OTE, approximately 44 m^3 (117,000 gal) of distillate was evaporated from the LLLW, which was then treated at the ORNL Process Waste Treatment Plant (PWTP) and discharged to the environment. The OTE process freed up critically needed capacity in the MVSTs, which serve as the interim storage tanks for all the consolidated ORNL tank waste/sludge. In most cases, the performance of the systems met the expectations and requirements defined in the Wastewater Triad Project plans.

Solid Liquid Separation (SLS) System

A modular SLS system was based on cross-flow filtration technology and used to provide solids-free feed liquid to the CsR and OTE systems for processing. The SLS system was designed to provide clarified supernatant at a much faster rate than the existing gravity settling system, and to allow the flexibility of processing waste from any of the eight MVSTs. The SLS waste feed system was located in the MVSTs pump and valve vault and integrated with all eight of the MVSTs. The SLS system's cross-flow filters, backpulse reservoir, and chemical feed system were located in a fully contained and shielded skid that has a footprint of 6.25 m (20.5 ft) in length, 3.2 m (10.5 ft) in width, and a height of 3.81 m (12.5 ft). The shielded skid was positioned near the MVSTs on the east side of the vault cover (5). The SLS system used 0.5-µm stainless steel sintered-metal filter units with a total filter surface of 4.6 m^2 (50 ft^2). The SLS system included a backpulse system to minimize the fouling of the filters. A pressurized pulse of fluid (~ 690 kPa), in the reverse direction of the flow rate, was effective at pushing the collected solids away from the filters. If the backpulse system was ineffective at clearing the filters, then chemical cleaning could be performed using dilute nitric acid.

The SLS system was designed to provide filtrate at a rate of 3.8- to 18.9-L/min (1- to 5-gal/min) [flux range of 0.8- to 4.1-L/min/m^2 (0.02- to 0.1-gal/min/ft^2)]. The actual filtrate production during four SLS campaigns ranged between 2.3- to 30.3-L/min (0.6- and 8.0-gal/min) [flux range of 0.5- to 6.6-L/min/m^2 (0.012- to 0.16-gal/min/ft^2)] (6). The filtrate was collected in a 454.5-L (120-gal) holding tank and then sent to either the CsR or OTE systems, to the MVCITs, or back to the MVSTs. The performance of the system was excellent and the quality of filtrate consistently met the feed requirements for the downstream CsR and OTE systems.

Two Coriolis meters were used simultaneously to create a suspended solids monitoring system that was used during two of the SLS runs in fiscal year (FY) 2000. One Coriolis meter was used to measure the density of the incoming slurry. The other meter was used to measure the density of the outgoing filtrate after the solids were removed. Grab samples of the dry solids particles were also collected and analyzed to verify the results obtained with the dual Coriolis meter system. The dry solids density was determined by laboratory analysis of the grab samples, and was assumed to be constant throughout the periods that grab samples were collected. The suspended solids concentration was calculated from the density relationships between the slurry and the filtrate, and then compared to the density of dry solid particles established through laboratory analysis. The results showed that the concentrations of suspended solids as reported by the dual Coriolis meter system tended to be slightly higher than those obtained from laboratory analysis. However, it should be noted that a linear relationship existed between the methods, which indicates that the bias was proportional to the concentration of the suspended solids (7). The standard deviation of the suspended solids concentration determined with the dual instruments was 0.08 %. The precision for the Coriolis meters was very good. The meter measuring the slurry density had a standard deviation of plus or minus 0.0005 g/mL, while the meter measuring the filtrate density had a standard deviation of plus or minus 0.0002 g/mL (7). These results are quite good when one considers that the densities of the waste slurries were 0.01 to 0.05 g/mL greater than the densities of the filtrates.

The Cesium Removal (CsR) System

The CsR ion-exchange system used a crystalline silicotitanate-based sorbent (Ionsiv IE-911, manufactured by UOP Molecular Sieves, Inc.) to remove cesium from the LLLW. The CsR system is a modular and mobile system that was installed at ORNL in Building 7877 (Figure 3), which provided secondary containment and a high efficiency particulate air (HEPA) ventilation system. The CsR system consists of three separate skids, including:

- a feed tank skid,
- an ion-exchange skid, and
- a sorbent sluicing/drying skid.

The feed tank skid contains a 1.89-m^3 (500-gal) feed tank that was shielded on four sides by 6.35-cm (2.5-in) of lead shot encased between 6.35-mm (¼-in) plates. Two progressive cavity pumps control the flow in and out of the feed tank, with one of the pumps controlling the flow to the ion-exchange columns at flows up to 19-L/min (5-gal/min). The shielded ion exchange skid includes a 25-µm stainless steel back-washable filter and two stainless steel ion exchange columns. The ion exchange columns are about 97 cm (38 in) tall with an inner diameter of 30.5 cm (12 in). The ion exchange columns could operate independently, in series (with either column leading), and in parallel due to the arrangement of the associated piping and controls. The sorbent sluicing/drying skid includes a stainless steel sorbent loading tank. The skid is used to load the sorbent into the ion exchange columns and also contains equipment to dewater the sorbent after it is removed from the columns.

The CsR system successfully removed more than 90% of the cesium from the feed liquid and concentrated it on 2 m^3 (540 gal) of crystalline silicotitanate-based sorbent (8). The crystalline silicotitanate-based sorbent was successfully dewatered and packaged to meet the waste acceptance criteria for the NTS. A portion of the cesium-loaded crystalline silicotitanate-based sorbent was shipped to the Savannah River Technology Center (SRTC) in Aiken, South Carolina, where it was unloaded into a hot cell facility and used in vitrification demonstrations. The SRTC developed a glass formulation for the crystalline silicotitanate-based sorbent that could incorporate up to 65-wt% of the cesium-loaded sorbent into the glass matrix without crystal formation. Ion-exchange with the crystalline silicotitanate-based sorbent is one of the alternative technologies being pursued at both Savannah River and Hanford for treatment of their tank wastes.

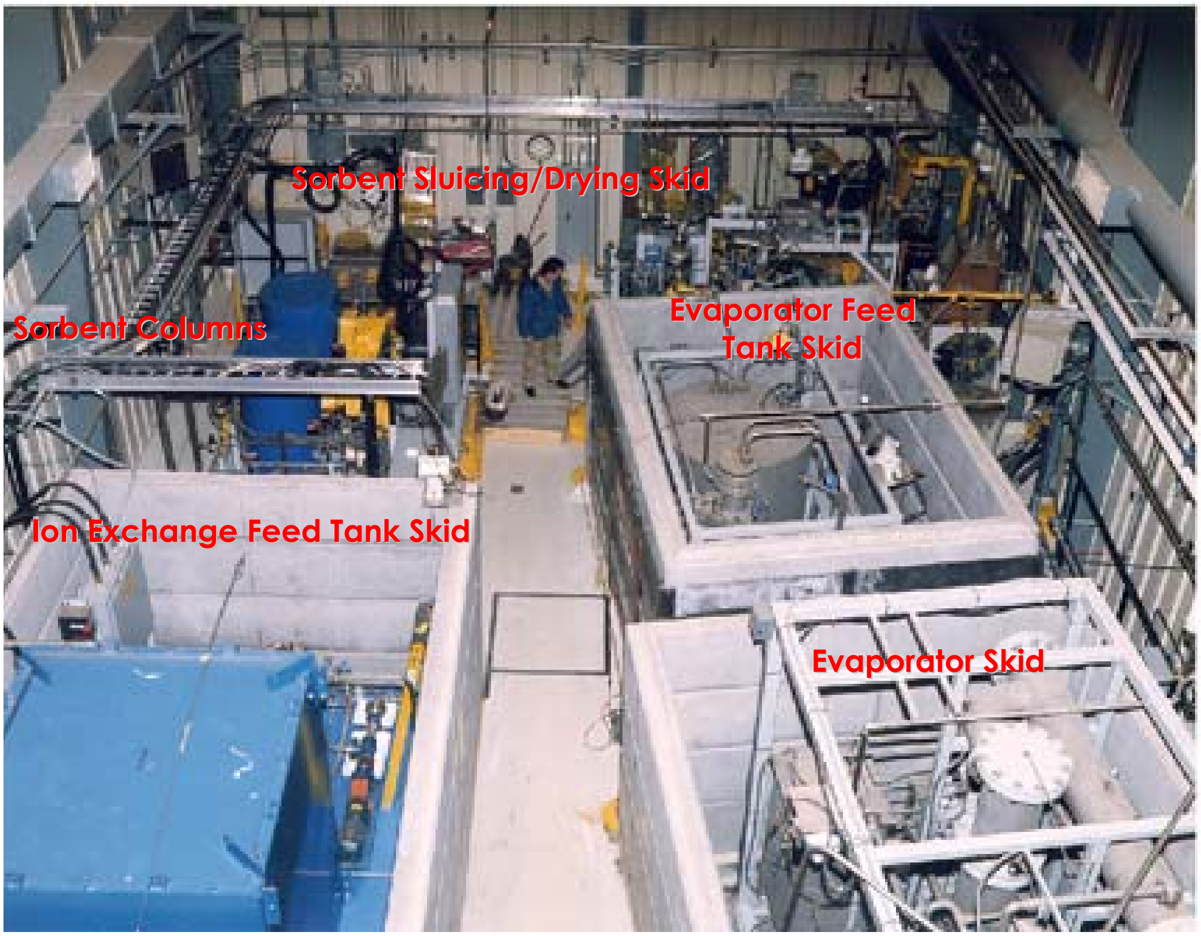

Fig. 4. Overview of components of the CsR and OTE systems at ORNL in Building 7877 after the installation of shielding around the modular skids, which are identified in the photo.

The Out-of-Tank Evaporator (OTE) System

The OTE system used a subatmospheric evaporator for LLLW volume reduction in the MVSTs. Subatmospheric evaporation is designed for energy efficiency and reduced scaling of heat transfer surfaces because of lower boiling temperatures. The use of the OTE system at ORNL resulted in additional UST storage capacity, and allowed effective waste management of the large quantity of sluice water required for tank waste retrieval activities, and the newly generated waste from ongoing research and reactor operations at ORNL. On two occasions in the early 1990s, it was necessary for ORNL Waste Operations to conduct very expensive liquid waste solidification campaigns to solidify tank supernatant in grout for disposal at the NTS. The OTE was designed to deal with this problem by evaporating the excess water from the MVSTs.

The OTE system consisted of five modular skids. The feed skid contained the feed holding tank and concentrate recirculation tank. The distillate skid included a distillate holding tank and a transfer pump. The heating skid held the electric heat exchanger and an ethylene glycol recirculation system. The cooling skid included two fin-fan heat exchangers and an ethylene glycol recirculation system. The main evaporator skid contained the evaporator heat exchanger, the vapor separation unit, the condenser, and feed circulation pumps. The OTE system was designed to produce about 340-L/hr (90-gal/hr) of distillate with purity that met the waste acceptance criteria for on-site wastewater treatment and discharge. The OTE system usually produced 113.5- to 227-L/hr (30- to 60-gal/hr) of distillate that met the criteria for treatment at the ORNL PWTP and discharge to the environment (9). The performance results of the CsR and OTE systems during the ten deployment runs conducted during the Water Triad Project are summarized in Table II.

Table II. The OTE and CsR systems performance during the Wastewater Triad Project.

Run #	Waste Processed (m^3)	Out of Tank Evaporator (OTE) Performance: Waste Evaporated (m^3)	Out of Tank Evaporator (OTE) Performance: Waste Evaporated (%)	Cesium Removal (CsR) System Performance: Cesium-137 Removed (Bq)
1	72	OTE Not Used	0	7.4E+13
2	72	19	26	3.7E+13
3	106	42	40	7.4E+13
4	80	38	48	CsR System Not Used
5	53	30	57	1.5E+13
6	76	34	45	6.7E+13
7	80	34	43	CsR System Not Used
8	64	38	59	1.9E+13
9	45	23	50	CsR System Not Used
10	49	26	54	CsR System Not Used
Total	**696**	**284**	**40 (average)**	**2.8E+14**

TANK MONITORING AND INSPECTION

The ORNL legacy radioactive sludge and LLLW was successfully consolidated in the MVSTs and the MVCITs. The MVSTs will be turned over to the ORNL TRU Waste Treatment Facility (constructed and operated by the Foster Wheeler Environmental Corporation) when it becomes operational, so that the sludge and LLLW contained in the tanks can be treated and packaged for final disposition at the WIPP and/or NTS. Waste treatment is scheduled to begin at the ORNL TRU Waste Treatment Facility in January 2003. After waste/sludge retrieval operations are completed in the MVSTs, these tanks, along with the MVCITs and the BVESTs, will remain in long-term service to collect and store waste generated from ongoing ORNL research activities. Innovative UST monitoring and inspection techniques are being investigated for the active ORNL USTs, including the BVESTs, the MVSTs, and the MVCITs.

Corrosion Monitoring System

An electrochemical noise (EN)-based system that is capable of detecting and monitoring corrosion in stainless steel tanks was deployed at ORNL in the summer of 2001. The Corrosion Monitoring System was fabricated by HiLine Engineering and Fabrication and then sent to ORNL, where it was cold tested with surrogate waste before it was installed in tank W-23 (one of the BVESTs). The corrosion probe, which is the main part of the system, is fabricated from 304/304L stainless steel and was designed to fit through a 10.16-cm (4-in) diameter tank access port. The probe includes two channels of C-ring type electrodes and two channels of bullet type electrodes, which are capable of withstanding temperatures less than 100º C, pH levels from 7 to 14, and exposure levels up to 1,000 R/ hr. The waste in tank W-23 is typically high pH, with high concentrations of nitrates and nitrites.

Testing data for tank W-23 indicated that the system is performing as expected and shows low rates of uniform corrosion. There were occasional transients in the data consistent with minor pit initiation, but laboratory data indicates no gross surface damage and pitting corrosion The system will continue to collect EN forensic data in tank W-23 in FY 2002. The probe will be retrieved from the tank in the future and the electrodes will be inspected for corrosion damage.

Remote Tank Inspection System

A remote tank inspection system was developed by ORNL and deployed in the MVSTs during July and August 2001. The inspection system includes integrated remote-controlled video and lighting capabilities, and is capable of fitting through a 7.62 cm (3 in) sampling port located on top of the tanks. The system was required to have sufficient flexibility due to internal obstructions located along the centerline of the MVSTs. Articulation was required so that the camera could be positioned far enough to the left and right of the center of the tanks in order to see around the row of central obstructions. Modifications to the system's lighting features were performed at ORNL by U.T. Battelle to optimize the lighting capabilities of the system.

An evaluation of the video inspection system deployment results is being performed in FY 2002. The video data collected during the system's deployment in the MVSTs is being used to assess the general condition of the tank interiors. Video data will also help define the sludge configurations and estimate the sludge quantities in each tank. Data will be used to support the upcoming MVSTs sludge retrieval and treatment operations.

SUMMARY

The implementation of the ORNL integrated tank waste management plan resulted in the cleanup and stabilization of nearly all of ORNL's inactive tanks. Advanced technologies were sought out and implemented through the ORNL integrated tank waste management plan in an effort to reduce the costs and schedule for tank waste retrieval, waste consolidation, and waste pretreatment. A joint effort between the DOE Environmental Management, Office of Science and Technology and ORNL resulted in the implementation of over 40 new or modified technologies during the tank waste retrieval and pretreatment activities at ORNL. The plan resulted in the stabilization of the gunite tanks more than 10 years ahead of schedule, with cost savings of $120 Million compared to the baseline schedule and budget estimate. In addition, the stabilization of the inactive tanks at ORNL will save about $400,000 annually in tank surveillance and maintenance costs. The retrieved tank waste was consolidated in the MVSTs. Approximately 3,563 m^3 (941,500 gal) of radioactive waste slurry containing 535 m^3 of remote-handled transuranic sludge was safely transferred and consolidated in the MVSTs during the implementation of the ORNL integrated tank waste management plan. Pretreatment of the consolidated tank waste provided additional volume and contamination reduction. The Wastewater Triad Project pretreated 1014.5 m^3 (268,000 gallons) of LLLW, resulting in the removal of about 2.85E+14 Bq (7,700 curies) of cesium-137, and the evaporation of approximately 44 m^3 (117,000 gal) of LLLW from the MVSTs. Final tank waste treatment will be performed at the ORNL TRU Waste Treatment Facility, where the treated waste will be packaged for final disposal and transported to the NTS and/or WIPP.

The tank waste retrieval and pretreatment projects conducted as part of the ORNL integrated tank waste management plan have helped ORNL meet its tank waste management objectives. Similar to it's mission in the early 1940 of serving as a model for plutonium production, the ORNL Inactive Tanks Program and integrated tank waste management plan has served as a model for tank waste retrieval plans and operations at other sites in the DOE complex. The ORNL Inactive Tanks Program shared information with other DOE sites on all of the retrieval and pretreatment technologies, and the results of the tank waste retrieval activities at ORNL have been published in Remedial Action Reports and Final Removal Action Reports as indicated in the references of this paper. Additional information about the Gunite Tanks Remediation Project can be found at www.aimsicorp.com/GAAT. The DOE Office of Science and Technology published several Innovative Technology Summary Reports on the tank waste retrieval technologies deployed at ORNL, which can be found at http://apps.apps.em.doe.gov/ost/itsrtfa.html.

The information gained and lessons learned from the tank waste retrieval and pretreatment projects and technology deployments at ORNL are being shared with other DOE sites that face similar tank remediation challenges. This information and expertise will be extremely valuable as other DOE sites plan and prepare for similar projects and deployments. The technologies used during the ORNL tank remediation projects are applicable to tank remediation projects at other sites. Several pieces of equipment from the Gunite Tanks Remediation Project have been transferred to other sites. All three of the technologies used in the Wastewater Triad Project are in the baseline planning flowsheets for the treatment of tank waste at DOE's Hanford, Savannah River, and Idaho sites. These sites are also considering using many of the ORNL tank waste retrieval technologies, and the equipment is being transferred to interested parties. If you would like additional information on the available technologies or are interested in obtaining any of the available equipment for use at another DOE site, please contact Jacquie Noble-Dial via email at nobledialjr@oro.doe.gov.

REFERENCES

1. K. M. Billingsley, C. Mims, and S. M. Robinson, *Integrated Tank Waste Management Plan at Oak Ridge National Laboratory*, Proceedings of Spectrum '98, vol 2, p 1376, American Nuclear Society, LaGrange Park, Ill., 1998.
2. B. E. Lewis, et al., *Tank Waste Retrieval Performance and Lessons Learned for the Gunite and Associated Tanks Remediation at the Oak Ridge National Laboratory*, ORNL/TM-2001/142, in preparation.
3. *Remedial Action Report on the Gunite and Associated Tanks Interim Remedial Action Project at the Oak Ridge National Laboratory, Oak Ridge, Tennessee,* DOE/OR/01-1955&D1, June 2001
4. B. D. Oakley, K. M. Billingsley, K. P. Guay, G. L. Riner, *Remote Handled Transuranic (RH-TRU) Sludge Consolidation Activities at Oak Ridge National Laboratory*, Proceedings from WM01, February 2001.
5. T. E. Kent, J. H. Wilson, and J. R. Farmer, *Development and Deployment of a Full-Scale Cross-Flow Filtrations System for Treatment of Liquid Low-Level Waste at Oak Ridge National Laboratory,* ORNL/TM-2000/186, November 2000.
6. J. F. Walker, Jr and T. E. Kent, *Wastwater Triad Project: Solid-Liquid Separator FY 2000 Deployment,* ORNL/TM-2000/186, November 2000.
7. T. D. Hylton, *An Evaluation of a Dual Coriolis Meter System for In-Line Monitoring of Suspended Solids Concentrations in Radioactive Slurries,* ORNL/TM-2000/184, September 2000.
8. J. F. Walker et al., *Cesium Removal Demonstration Utilizing Crystalline Silicotitanate Sorbent for Processing Melton Valley Storage Tank Supernate: Final Report,* Oak Ridge National Laboratory, Oak Ridge, TN, March 1998.
9. J. Lucero et al., *Out-of-Tank Evaporator Demonstration: Final Report,* ORNL/TM-13501, February 1998.
10. J. F. Walker Jr. and T. E. Kent, *Wastewater Triad Project (WTP): Final Summary Report,* ORNL/TM-2001/129, September 2001.