THE GUNITE TANKS REMEDIATION PROJECT AT OAK RIDGE NATIONAL LABORATORY; SUCCESSFUL INTEGRATION & DEPLOYMENT OF TECHNOLOGIES RESULTS IN REMEDIATED UNDERGROUND STORAGE TANKS

Karen Billingsley
Advanced Integrated Management Services, Inc.
702 S. Illinois Ave, Suite B-203, Oak Ridge, TN 37830

David Bolling
Bechtel Jacobs Company LLC
P.O. Box 2008, M.S. 6402, Oak Ridge, TN 37830

ABSTRACT

This paper presents an overview of the underground technologies deployed during the cleanup of nine large underground storage tanks (USTs) that contained residual radioactive sludge, liquid low-level waste (LLLW), and other debris. The Gunite Tanks Remediation Project at Oak Ridge National Laboratory (ORNL) was successfully completed in 2001, ending with the stabilization of the USTs and the cleanup of the South Tank Farm. This U.S. Department of Energy (DOE) project was the first of its kind completed in the United States of America. The Project integrated robotic and remotely operated technologies into an effective tank waste retrieval system that safely retrieved more than 348 m^3 (92,000 gal) of radioactive sludge and 3.15E+15 Bq (85,000 Ci) of radioactive contamination from the tanks. The Project successfully transferred over 2,385 m^3 (630,000 gal) of waste slurry to ORNL's active tank waste management system. The project team avoided over $120 Million in costs and shortened the original baseline schedule by over 10 years. Completing the Gunite Tanks Remediation Project eliminated the risks posed by the aging USTs and the waste they contained, and avoid the $400,000 annual costs associated with maintaining and monitoring the tanks.

INTRODUCTION

Remediating underground storage tanks (USTs) that contain radioactive waste is challenging. The safety of workers, the public, and the environment are primary concerns. The remediation of the gunite tanks at Oak Ridge National Laboratory (ORNL) presented unique challenges, since these tanks were aging, single-shell tanks constructed of gunite; a Portland cement and sand mixture sprayed over a steel reinforcing rod and wire mesh frame. Deterioration on the inner tank walls was evident in some of the tanks, and inleakage from rain and groundwater continued to add to the volume of liquid waste in the tanks. In addition, the tanks were located across the street from the ORNL cafeteria in the middle of a pedestrian traffic area. Many types of operations and underground technologies were required to safely complete the remediation of the gunite tanks. This paper discusses the underground equipment and technologies used to perform:

1. tank inspections and sampling activities,
2. tank modifications,
3. waste retrieval operations, and
4. waste mixing and transfer operations.

BACKGROUND INFORMATION

The eight largest gunite tanks were built in 1943 and 1944 during the initial construction of ORNL. ORNL served as a model plutonium production facility during the Manhattan Project of World War II. The gunite tanks were built to collect, neutralize, and store liquid radioactive and/or hazardous waste from ORNL nuclear research and development operations. The vertically oriented, domed tanks included concave/dished bottoms constructed of poured concrete and cylindrical sidewalls and domes constructed with steel reinforcing rod and wire mesh frames that were covered with layers of gunite. The tanks were primarily located in two tank farms in central ORNL. Table I indicates the location, size, and capacity of the nine USTs remediated during the Gunite Tanks Remediation Project.

Table I. Location and size of the gunite tanks included in the Gunite Tanks Remediation Project.

Tank Number	**Location**	**Inside Tank Diameter (m)**	**Sidewall Height (m)**	**Dome Height (m)**	**Nominal Capacity (m^3)**
TH-4	Southwest of Building 3500 under a maximum of 6-ft of soil cover.	6.1	2.0	0.8	53
W-3 and W-4	North Tank Farm, northeast corner of Central Ave. and Third St. under a maximum of 6 ft of soil cover.	7.6	3.7	0.8	161
W-5 through W-10	South Tank Farm, southeast corner of Central Ave. and Third St. under a maximum of 6 ft of soil cover.	15.2	3.7	1.8	644

The gunite tanks were an important part of ORNL's liquid waste management system up until the early 1970's when they were designated as inactive tanks. Although the status of the tanks changed, they continued to store LLLW and radioactive sludge waste. Waste retrieval operations in the mid 1980s, using traditional sluicing, removed a majority of the sludge and liquid waste from the tanks. However, residual sludge and other debris remained in the tanks, and inleakage from rain and groundwater contributed to the volume of LLLW in the tanks.

Regulatory Approach

The Gunite Tanks Remediation Project was regulated by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Federal Facilities Agreement (FFA) between the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Tennessee Department of Environment and Conservation (TDEC). Preliminary tank and waste characterization results were compiled in a combined CERCLA Remedial Investigation/ Baseline Risk Assessment (RI/BRA) published in 1994 (1). The RI/BRA identified significant uncertainties in the risks associated with remediating the gunite tanks, such as the degree to which the tanks could be cleaned, and the cost and schedule for potential cleanup options. The DOE, EPA, and TDEC agreed to perform additional sampling and characterization activities to resolve these uncertainties. The results were published as an addendum to the RI/BRA (2). A CERCLA Feasibility Study (3) assessed the feasibility of the remedial alternatives identified in the RI/BRA. In addition, a CERCLA Treatability Study was conducted in order to develop a tank remediation plan that would meet the risk criteria identified in the RI/BRA Addendum. The RI/BRA Addendum indicated that at least 90% of the radioactive sludge waste needed to be removed from the tanks to achieve the CERCLA threshold risk target for developing cancer in a lifetime of 1E-4 (1 in 10,000 individuals). The Treatability Study also provided an opportunity for the project team to select, develop, integrate, and test robotic and remotely operated waste retrieval equipment that would be used to safely retrieve the residual radioactive sludge and other debris from the tanks. During the Treatability Study additional sampling activities and tank inspections were performed to clarify the condition of the tank walls and the types and amount of waste and contamination in the tanks. Cold tests of the integrated robotic and remotely operated equipment were performed during the Treatability Study to establish safe operating procedures and maintenance schedules. The Treatability Study included a hot demonstration of the integrated waste retrieval system, which was conducted in the North Tank Farm in tanks W-3 and W-4. The hot demonstration helped establish the efficiency of the waste retrieval equipment and the degree to which the tanks could be cleaned. Based on the results of the Treatability Study, a CERCLA Interim Record of Decision established the criteria for waste retrieval operations in the six largest gunite tanks in the South Tank Farm.

UNDERGROUND TECHNOLOGIES USED FOR TANK INSPECTIONS AND SAMPLING ACTIVITIES

Understanding the characteristics of USTs and the waste they contain is an important first step toward completing a successful tank remediation project. Characterization activities included tank inspections and waste sampling/analysis campaigns, which provided important information for the development of cleanup criteria and waste retrieval strategies in the gunite tanks. Initially, the project team performed tank inspections and waste sampling campaigns to establish the volume and physical characteristics of the waste, and to determine the condition of the tanks so that cleanup goals could be established. Later, sampling campaigns and tank inspections helped the team identify special requirements for the waste retrieval technologies, such as the ability to retrieve thick sludge, waste crystals, and chunks of debris, or the ability to remove or work around obstructions in the tanks. During waste retrieval operations, it was important for the equipment operators to have the ability to clearly observe and monitor the waste retrieval operations and equipment so they could safely retrieve the waste. Tank inspections and sampling operations conducted during and after the waste retrieval operations confirmed that established waste retrieval goals were met.

Tank Inspection Technologies

Remote-controlled video cameras and lighting systems were crucial to the waste retrieval operations in the gunite tanks. Camera systems should be radiation hardened to prolong their life during radioactive waste retrieval operations, and should be easy to install and replace. Cameras should also be equipped with adequate zoom and manual capabilities to allow close-up views. In-tank waste retrieval operations required at least two camera views. A single camera does not provide equipment operators with adequate depth perception to reliably operate in-tank systems. Adequate lighting, with the ability to adjust the illumination helps provide views with adequate depth-of-field. A variety of remote controlled video cameras and lighting systems were used to perform tank inspections and monitor sampling and waste retrieval operations. Remote cameras and lighting features were also integrated into various components of the waste retrieval system to increase the visual capability of the equipment operators.

For preliminary tank inspections, a remote-controlled and integrated video camera and lighting system was inserted through a tank access riser. The system's video and remote-control cables ran through the center of a vertical extension pole (for contamination control) to a cable box mounted at the end of the extension pole. An extension cable connected the cable box to a remote control unit. A video cable from the remote control unit connected to a video tape recorder, and monitor in series. Camera operators used the system to perform and record tank inspections in the gunite tanks. Pan and tilt switches on the remote control unit allowed camera operators to adjust the pan and tilt of the camera nearly 360° in any direction. The remote control unit contained rotating knobs to adjust the camera's illumination and zoom. The camera's focus could be set to adjust automatically or manually. A manual focus feature was an important feature that allowed operators to focus in on specific objects. The remote control unit was programmable to display the time, and degree of pan and tilt on the video monitor. A text generator allowed the operators to label important information, such as the tank number and date of the tank inspection. Methodical inspections of the tank's interiors provided important information on the interior condition of the tanks. These preliminary inspections showed wall deterioration in some of the tanks, and gave an indication of the size and position of sludge banks and other debris in the tanks.

Before waste retrieval operations began in the gunite tanks, four remote-controlled and integrated video camera and lighting systems were installed in the tanks through 10.16-cm (4-in) tank access ports. These access ports were specially installed in various locations of the tank domes to provide access the video monitoring system. Instead of the two factory standard 35-W lights, the camera housings were modified to include a single 250-W lamp with a polished aluminum reflector shield. A heat shield between the 250-W lamp and the camera prevented overheating problems with the camera. Video and remote control cables ran through the center of a vertical extension tube up to a cable box. The systems were designed so that a long extension cable could be used to connect the camera and light systems to a multiplexed pan, tilt, zoom and illumination remote-control unit installed in the equipment control room. Video cables were also connected to video tape recorders and monitors so that operators could perform and monitor waste retrieval operations in the tanks. By using the remote-control unit, equipment operators were able to conveniently and rapidly select and control the cameras and lights during waste retrieval operations. When the cameras and lights were not in use, they were turned off, or operated with reduced lighting to avoid overheating the cameras.

Waste Sampling Technologies

The sampling team performed preliminary waste sampling campaigns with various types of equipment that provided them with specialized capabilities. Sampling equipment was manually inserted through existing tank access risers. The sampling team dressed in personal protective equipment and followed a sampling plan to collect waste sampled from the gunite tanks. Waste samples were also collected during waste retrieval operations using remotely operated equipment. After the samples were collected, they were sent to an onsite analytical laboratory for waste characterization and analysis.

During preliminary sampling activities, the sampling team used cylindrical push tube samplers that were mounted on vertical extension poles to collect core samples of the sludge waste. Operators manually deployed the push tube samplers through tank access risers and pushed the sampler down through the sludge. When resistance was met, the operator manually triggered a stainless steel disk on the bottom of the sampler to close off the tube and collect the sample. The sampling team used the ponar sampler to collect larger sludge samples and other debris from the tanks. The ponar sampler was a clamshell-type grasping device that was deployed from a simple hoisting rig. When the ponar sampler was lowered into the tank and encountered the sludge waste it automatically closed to collect the sample. These sampling tools worked well, but were only capable of collecting samples directly above a tank access riser. A floating boom was developed so that waste samples and data could be collected from other areas of the tank. The floating boom was fabricated out of lightweight material that linked together to form a long chain (approximately 15 m) that could bend and float on the liquid waste. The ponar sampler and depth-finding device were deployed with the floating boom to collect additional information about the distribution of the sludge over the bottom of the gunite tanks. Operators lengthened or shortened the boom extension in the tank via a platform that mounted over a tank riser. The platform rotated 360° so that the boom could be positioned in various locations to collect samples and sludge depth information.

During waste retrieval operations, waste samples were collected with the help of the Houdini I and Houdini II remotely operated vehicles (ROVs). The ROV's manipulator arm and grasping end-effector were instrumental in collecting the samples, and the mobility of the ROVs allowed samples to be collected anywhere in the lower portion of the tanks. During some in-tank sampling operations, a simple sampling tool, similar to a spatula, was held by the grasping end-effector and positioned by the manipulator arm to collect sludge samples in desired areas of the tanks. During other in-tank sampling operations, the ROV's grasping end-effector was used to pick up chunks of waste material or gunite for analysis. The samples were collected in a container inserted through one of the tank access risers and suspended on a line. This sampling process was effective since the remote video cameras integrated on the ROV's manipulator arm and near the ROV's tracks provided close-up views of the sampling operations and allowed the operators to select specific samples.

Fig**. 1**. The Houdini I ROV collects samples of the thick sludge during waste retrieval operations in tank W-3.

Waste samples were also collected from the waste slurry after it was retrieved from the tanks. In-line samplers were strategically placed extract samples from the waste stream as it was retrieved and transferred from the gunite tanks. The Flow Control Equipment Containment Box that was part of the Waste Dislodging and Conveyance System included an in-line sampler. The Sludge Conditioning System and the Solids Monitoring Test Loop also contained in-line samplers.

Tank Sampling and Characterization Technologies

The project team sampled and characterized the walls of the gunite tanks so that they could determine the amount of contamination on/in the tank walls, and the depth to which the contamination had penetrated. Some of the tank walls showed signs of deterioration, and most displayed what appeared to be a scale on the tank walls. Sampling and characterization tools were developed and deployed in the tanks to collect samples and data from the tank walls to establish cleanup criteria and confirm that cleanup goals were met. Various tools were deployed inside the tanks to help assess the levels of radioactive contamination in the tank walls.

Initially, the Gunite Isotope Mapping Probe (GIMP) was used to characterize the tank walls. The GIMP was deployed by a crane and inserted into the tanks through a tank access riser. The GIMP included beta and gamma radiation detectors in a box-like assembly that was mounted on a vertical extension pole. The GIMP's mobile control room was position near the tank being assessed. The control room contained monitoring equipment that received radiological information via feed cables from the GIMP. Later, the characterization end-effector (CEE) and the collimated analyzing radiation probe (CARP) (a component of the CEE) were deployed in the tanks by the Modified Light Duty Utility Arm (MLDUA). Problems identified during the initial CEE deployment lead to the cannibalization and exclusive use of the CARP to collect wall contamination data prior to waste retrieval and wall cleaning operations. The MLDUA deployed the CARP in vertical and radial sweeps of the tank walls to collect radiation data. A video camera integrated into the MLDUA mast provided a real-time video signal of the CARP's data display in the equipment control room. The Topographical Mapping System was deployed in some of the tanks and helped determine the location and depth of sludge deposits by providing 3-dimensional, variable resolution mapping in the tanks. This laser-based, self-contained system was designed and developed to operate in radioactive environments.

Simple tools such as a wall scraping tool and feeler gauge were also deployed by either the MLDUA or a vertical extension pole to collect additional tank wall data. The feeler gauge was swept vertically up and down the tank walls to determine if there were variations in the gunite. The wall-scraping tool was a simple flat metal bar that had a series of cavities machined on one side to collect wall scale. When the surface of a tank wall was scraped with the tool, the wall scale and a small portion of the tank wall collected in the cavities. The collected material was sent to an on site laboratory for analysis so that the amount of contamination adhering to the tank walls could be estimated. A modified electric drill and collection system became known as the Wall-Coring Tool. This tool was deployed by the Houdini I and Houdini II ROVs, and used to collect core samples of the tank walls before and after wall cleaning operations. The Wall-Coring Tool collected 2.54-cm (1-in) diameter, by 5.08-cm (2-in) thick samples from various tank wall locations. The core samples were released into a collection container suspended from a tank access riser. The samples were analyzed to determine the types of contamination contained in the tank walls, and the depth to which the contamination was found. These core samples helped the project team plan wall cleaning operations and helped prove that cleanup goals were met after the wall cleaning operation were completed.

TECHNOLOGIES USED FOR TANK MODIFICATIONS

Modifications to the gunite tanks were required so that waste retrieval operations could be successfully performed in these USTs. Although many modifications were required both above and below ground, this section focuses on modifications to the tank domes and interiors. The gunite tanks were excavated to expose their domes and additional tank access risers were added to accommodate tank inspection and waste retrieval equipment. Hole saws ranging in size from 10.16-cm (4-in) in diameter to 0.9-m (36-in) in diameter were used to cut holes in the tank domes. Steel risers were installed over the holes and sealed in place. The tanks were backfilled with the excavated soil after the installation of the tank access risers and then covered with compacted gravel to provide a stable surface for the waste retrieval equipment, platforms, and tank remediation activities.

Modifications to the tank interiors included removing obstructions that could hinder the deployment of waste retrieval equipment or operations. Operators used the Houdini I ROV manipulator arm and grasping end-effector to deploy a hydraulic shear to cut a pipe that obstructed the ROV's access to it's landing area in one of the tanks (Figure 2). The ROV was partially inserted into the tank so that the manipulator arm could reach the small diameter pipe (less than 2.54 cm). Overview cameras in the tank and on the ROV's manipulator arm allowed operators to position the hydraulic shear and cut the pipe. A modified electric band saw was also deployed by both the Houdini ROV and MLDUA to cut away small pipes (greater than 2.54 cm) that obstructed waste retrieval equipment on other tanks.

Fig. 2. A hydraulic shear, deployed by the manipulator arm of the Houdini ROV through a tank access riser, successfully cuts a pipe obstructing the landing area of the ROV in this photo captured during operations in tank W-3.

A disposable pipe-plugging tool was deployed by the MLDUA in tanks W-6 and W-8. Pipes that protruded into these tanks were plugged to isolate them from the environment. The tool consisted of a stainless steel cup that was slightly larger than the diameter of the pipes. The cup was mounted on a grab bar that was grasped by the MLDUA's grasping end-effector during deployment. A steel cone that protruded from the interior of the cup helped position the cup over the pipe. Epoxy was placed in the cup to provide a good seal when the tool was positioned over the pipe. After the epoxy had a few minutes to harden, the MLDUA released the grab bar, leaving the disposable tool in position over the pipe and effectively plugging it.

UNDERGROUND TECHNOLOGIES USED DURING WASTE RETRIEVAL OPERATIONS

Waste retrieval operations were performed in the eight largest gunite tanks using robotic and remotely operated equipment. The primary waste retrieval operations included dewatering the tanks, sludge retrieval, wall cleaning, and debris retrieval. The project team developed and used the integrated Radioactive Tank Cleaning System (RTCS) to remotely perform underground waste retrieval and wall cleaning operations in the tanks. Several subsystems provided specialized capabilities to the RTCS. The team used the Waste Disloding and Conveyance (WD&C) System to dewater the tanks and perform confined sluicing to breakup and retrieve the massive sludge heels that remained in the gunite tanks. The robotic MLDUA and Houdini I and Houdini II ROVs were instrumental to the successful waste retrieval operations. These systems worked together to deploy tools and end-effectors in the gunite tanks. The unique capabilities of each system allowed operators to perform complimentary operations in unison, which helped speed up waste retrieval operations. The RTCS subsystems and their unique capabilities are described in the following sections and shown in Figure 3.

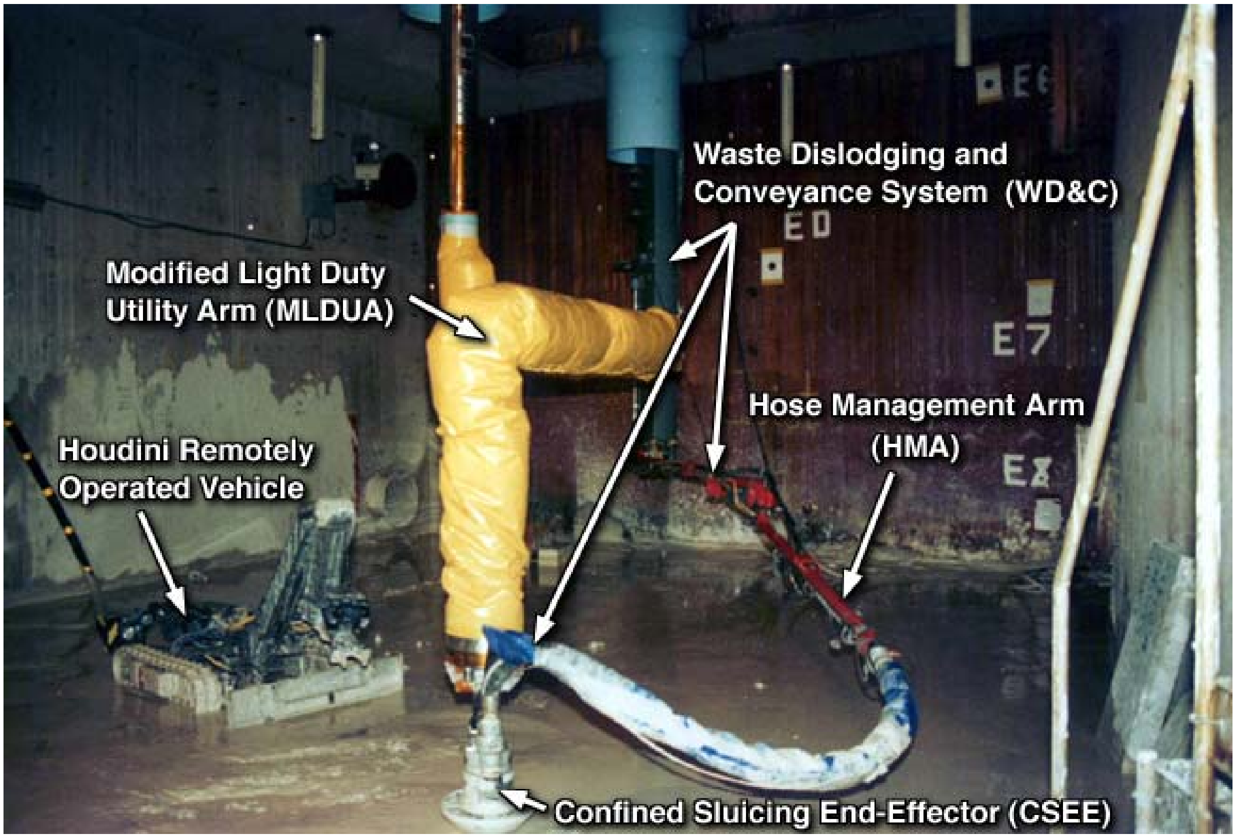

Fig. 3. The primary in-tank components of the Radioactive Tank Cleaning System (RTCS) used during the Gunite Tanks remediation project are identified in the photo above, which was taken during cold tests/demonstration of the technologies.

Waste Dislodging & Conveyance (WD&C) System Equipment & End-Effectors

The WD&C system included several components that were used to dewater the tanks, break up the sludge waste, clean the tank walls, and convey the resulting waste slurry from the tanks. Each component contributed to the waste retrieval operations and performed specific functions. WD&C System components included:

- the flow control equipment containment box (FCECB),
- the water powered, axial-flow jet pump and waste conveyance line,
- the hose management arm (HMA),
- the confined sluicing end-effector (CSEE), and
- the gunite scarifying end-effector (GSEE),

The FCECB served as the interface between the tanks and the waste transfer lines to tank W-9, which served as the waste consolidation tank for the Project. The FCECB housing contained the WD&C system control hardware and was located on the equipment platform above the tanks. The FCECB also contained sampling equipment that was used to monitor the characteristics of the waste slurry removed from the tanks.

The axial flow jet pump generated the vacuum power required to retrieve the waste from the tanks. The jet pump's venturi nozzle was constructed with hardened stainless steel. The three motive jet nozzles were hardened stainless steel inserts, with a short, steeply tapered inlet set in hex-socket inserts. The jet pump was installed near the bottom the HMA mast and discharged through a pipe that ran straight to the top of the HMA mast. The discharge pipe connected to the FCECB via a hose jumper. Sludge retrieval rates as high as 30.3 L/min (8 gal/min) were achieved. The pump was typically operated at a motive water pressure of 48.3 MPa (7,000 psi), and consumed about 37.9 L/min (10 gal/min) of filtered process water for the motive jets. The waste conveyance line was integrated with the HMA and connected the jet pump and CSEE, providing a conduit for the waste slurry. The conveyance line connected to the HMA's intermediate, rigid, pipe links, which doubled as structural sections and conveyance conduit. The conveyance line continued inside the HMA mast to the jet pump, then up to the platform to the FCECB.

The HMA containment structure housed the jet pump and served as a four-degree-of-freedom positioning arm that minimized the load on the MLDUA and Houdini ROVs when they deployed the CSEE during waste retrieval operations. The base link of the HMA was a heavy vertical mast that rotated on a turntable above the tank riser. The HMA's intermediate links were two rigid pipes that folded up against the mast in the deployment position, and extended to a horizontal working position with motorized swivel joints. The distal link to the CSEE was a short umbilical hose and cable bundle. Using the HMA's integral hoist, the HMA could be retracted into its containment housing, which was located above the turntable enclosure. The HMA retracted from the tank through a decontamination spray ring into its containment structure located on the equipment platform. The HMA containment structure included eight glove ports that provided access for maintenance operations and to electrical power controls and hose connections. The HMA containment structure was used to isolate the system from workers and the environment. The HMA was retracted and secured in its containment structure before it was moved to the next tank scheduled for remediation.

The CSEE and GSEE were made of aluminum, stainless steel, and polymers. They included a rotating array of three water jets capable of achieving water pressures of 1.8- to 48.3-MPa (200 to 7,000 psi). The GSEE was used to clean the tank walls. The GSEE did not include a vacuum head, which allowed it to operate at a minimum standoff distance from the walls during cleaning/scarifying operations. The GSEE spray jets diverged from the axis to cover a wider swath than was possible with the CSEE, and were capable of removing a 0.635- to 0.8382-cm (0.25- to 0.33-in) layer of gunite when operated at 152- to 207- MPa (to 22- to 30-ksi) using a high pressure pump that was installed for wall scarifying operations. The GSEE was powered by a separate umbilical that bundled motor control and power cables and a medium pressure supply hose. The CSEE was used to dewater the tanks and performed confined sluicing operations to break up the large sludge banks in the tanks. The CSEE motor could achieve rotational rates of 0-600 rpm, with 300 rpm being adequate for normal confined sluicing operations. The rotating cutting jets on the CSEE surrounded a vacuum head that connected to the waste transfer hose. The CSEE umbilical included the motor power and control cables and a supply line for the rotating water cutting jets. The CSEE umbilical was routed along the HMA's intermediate rigid pipe links, up conduits in the HMA mast, and then to jumper connections leading to the Balance of Plant system at the platform, which supplied the process water and power to the CSEE.

Modified Light Duty Utility Arm (MLDUA)

The MLDUA was an important component of the RTCS that performed many types of operations, including tank characterization, tank modifications, dewatering, sludge retrieval, and wall cleaning. This eight-degree-of-freedom robotic arm provided reach and mobility during operations in the gunite tanks. The MLDUA had a reach of 4.6-m (15-feet) and a payload capacity of about 90-kg (200-lbs). Integral to the MLDUA was a gripper end-effector (GEE) that was used to grasp and hold the various tools required for in-tank operations. Video cameras were integrated into the wrist and mast of the MLDUA and provided a remote video feed to monitors positioned in the MLDUA's control console, which was located in the equipment control room. The video feed provided by the integrated cameras helped operators grasp tools and end-effectors and monitor the waste retrieval operations. The robotic arm could be programmed to perform specific operations, such as wall cleaning operations, or could be operated remotely from the control room.

The MLDUA deployed and retracted through 0.6-m (24-in) tank access risers that were outfitted with decon spray rings. The MLDUA's containment structure was mounted on the equipment platform above the tank access risers and helped control the spread of contamination. Gloveports in the containment structure provided operators with access to the equipment for maintenance and repair activities. A spray wand mounted inside the containment structure was used to decontaminate the MLDUA. The MLDUA containment structure housed the MLDUA when it was moved. Waste retrieval operations in the largest 15.24-m (50-ft) diameter gunite tanks typically required deployment of the MLDUA through four different access ports when tank wall cleaning was required.

Houdini I and II Remotely Operated Vehicles (ROVs)

The Houdini I and II ROVs were tethered vehicles that performed a variety of operations in the gunite tanks. The vehicles provided mobility in the tanks and their abilities complemented the MLDUA during waste retrieval operations. Each vehicle weighed about 453.6 kg (1,000 lbs.) and had a parallelogram-shaped footprint measuring approximately 1.2 m x 1.5 m (4 ft x 5 ft). Two tracks located on the longer sides of the frame provided mobility. The frames folded for deployment and retraction through 0.6-m (24-in) diameter tank access risers. Each Houdini vehicle was equipped with an integrated manipulator arm and grasping end-effector. The six-degree-of-freedom arm had a payload capacity of 109-kg (240-lbs) at full extension. The manipulator arm was used to pick up and organize debris so that it could be retrieved from the tanks by steel debris baskets that were lowered into the tanks on a line. The arm was 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 plows were useful for breaking up sludge heels at the junction of the tank wall and floor. Operators were able to accelerate waste retrieval operations by using the Houdini's plow to push sludge towards the MLDUA deployed CSEE. The Houdini ROVs versatility and mobility allowed operators to remotely perform a many types of in-tank operations. The Houdini ROVs were housed in containment structures that were positioned on the equipment platform above a tank access riser. The containment structure included gloveports, which provided operators with vehicle access during maintenance or repair activities.

TECHNOLOGIES USED DURING WASTE MIXING AND CONDITIONING OPERATIONS

Waste mixing and conditioning operations were performed during the Gunite Tanks Remediation Project. Waste mixing operations were performed in three of the gunite tanks (TH-4, W-5, and W-9). Specialized waste conditioning and transfer equipment were integrated and used to prepare retrieved waste slurry for safe transfer to the ORNL LLLW system. The equipment was stationed in the South Tank Farm near tank W-9, and was used in conjunction with the Pulsair and Flygt mixers. The following sections describe the equipment used in mixing and conditioning operations in the gunite tanks.

Pulseair Mixers

Tank W-9 in the South Tank Farm served as the consolidation tank for the waste slurry retrieved during the Gunite Tanks Remediation Project. This tank was outfitted with three Pulseair mixers that were used to mix the consolidated waste slurry. The Pulseair mixers use a pulsed-air mixing technique, where discrete pulses of air produce large bubbles near the tank floor and induce mixing as the bubbles rise to the surface of the liquid. The mixers helped control the solids content of the slurry prior to its transfer to the MVSTs. The Pulseair mixer system operated in conjunction with the Solids Monitoring Test Loop, which contained in-line solids monitoring instrumentation to provide real-time solids data for the tank W-9 mixed waste slurry.

The Pulseair mixers fold up for installation and demobilization, and are capable of fitting through the 0.61-m (24-in) tank access risers. Once inside the tanks, the mixers are released from their installation configuration so that the pulse air supply pipes are positioned a few centimeters from the tank floor in a mixing configuration. The mixing assemblies included an array of circular accumulator plates located at the ends of the folding air supply pipes. The circular plates are positioned horizontally along the bottom of pipes that supply air for the system. Pulses of air are supplied to the underside of each plate to create the mixing action in the tank. A total of 13 pulse plates, approximately 0.3-m (1-ft) in diameter were positioned around the bottom of tank W-9 to agitate the waste slurry and maintain suspension of the solids using pressurized air. The Pulseair mixer's control equipment and pulsing valves control the pulse frequency, duration, pressure, and sequencing to create optimal mixing conditions within the tank.

The Pulseair mixer is relatively self-operating and reduces potential risk to workers. The Pulseair mixers should be operated continuously for improved results, as it was determined during operations that the Pulseair mixers were better at maintaining solids in suspension, rather than in agitating and suspending settled solids. The best results were obtained when the system was operated during waste consolidation operations. The system also performed well during waste transfers, which were completed near the end of the waste consolidation operations in tank W-9.

Flygt Mixers

Two Flygt mixers were deployed in tank W-5 to assist in removing the sludge waste. The walls in tank W-5 exhibited signs of deterioration, and there were concerns that the RTCS could be damaged by falling gunite if it was deployed in this tank. The Flygt mixers were used in tank W-5 to mobilize the sludge into the liquid waste for transfer out of the tank. One Flygt mixer was later deployed in tank W-9 to assist with sludge mobilization in this tank.

The Flygt mixers included a mast-mounted 11.2 kW (15-hp) submersible electric motor, with a three-blade, direct-drive, axial-flow propeller, which agitated the waste in the tank. Hardened aluminum alloy blades were originally installed on the Flygt mixers, however two of the blades broke. One blade was broken during the installation of the system into the tank, and the other blade was broken by in-tank debris. The broken blades were replaced with stainless steel props and no further problems were experienced. Each mixer attached to a mast assembly, which supported all mixer loads from a structural steel platform that was located above the tank over the tank access riser. The length of the mast was adjustable to allow the depth of the mixer to be changed according to the sludge depth beneath each mixer. The mixer was rotated 90º from its vertical stowed position and locked into place after it was lowered into the tank. The Flygt mixers were able to develop high axial flows in the surrounding liquid/sludge wastes, which mobilized the sludge into a waste slurry that was pumped from the tanks.

Pulsating Mixer Pump (PMP)

Tank TH-4 is one of the smaller gunite tanks located outside of the North and South Tank Farms. Waste retrieval was accomplished in this tank using a Russian engineered and fabricated PMP. The PMP system included a pressure vessel that was inserted into the tank and waste via a tank access riser installed in the top of the tank. A suction inlet port, which included a ball-check valve, was located at the bottom of the pressure vessel. An opposed pair of discharge jet ports were also located at the bottom of the pressure vessel and arranged parallel to the tank floor. The PMP's pressure/vacuum source, air distributor system, and control system were located on a steel equipment platform constructed over the UST. These systems supplied the cycling pressure and vacuum to the headspace of the pressure vessel; alternately drawing slurry or liquid waste into the vessel via the suction inlet and then discharging it through the jets ports. The PMP system eliminates the need to add process water to a tank as it requires no additional working fluids unless fluids are needed to achieve a specified dilution. The PMP was deployed in tank TH-4 in January 2001 and used to mobilize the 0.6- to 0.9-m (2 - 3 ft) layer of sludge present in the bottom of the tank.

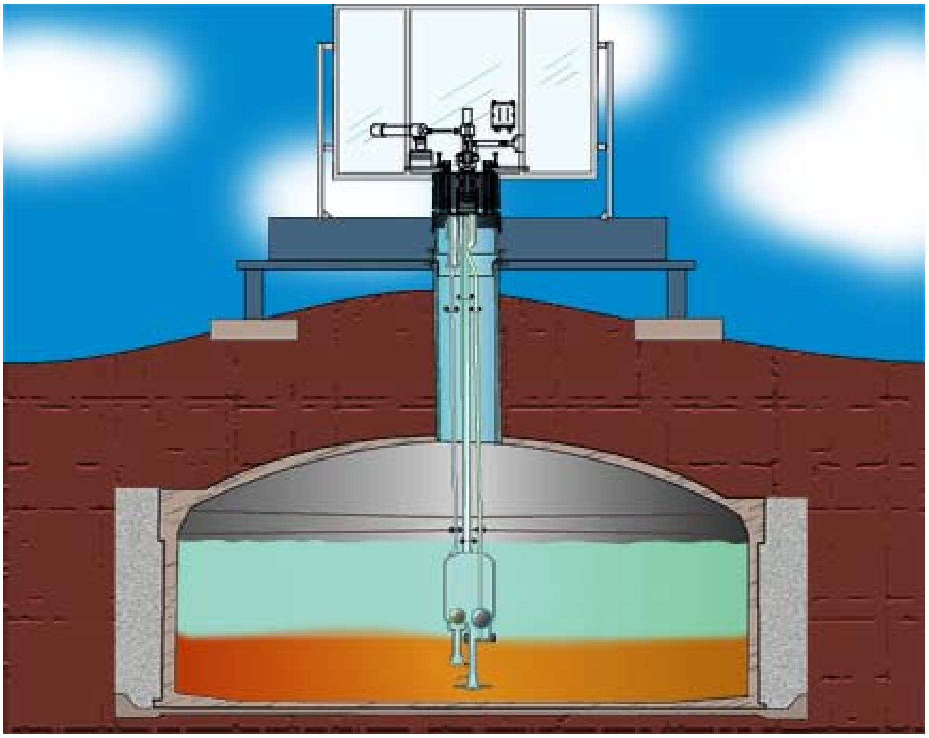

Fig. 4. Schematic of the PMP equipment and equipment platform during operations in an UST.

Sludge Conditioning System (SCS)

The SCS was stationed aboveground near waste consolidation tank W-9 in the South Tank Farm. The SCS was used to mobilize, retrieve, condition, and characterize the retrieved/consolidated waste slurry before it was transferred to the to the Melton Valley Storage Tanks (MVSTs) at ORNL. The MVSTs serve as the waste consolidation tanks for the tank waste retrieval operations at ORNL. The SCS included integrated equipment that performed specific operations. The waste slurry consolidated in tank W-9 was conveyed through SCS components before it was transferred in batches to the MVSTs.

SCS components included a submersible pump, the primary conditioning system, and the slurry monitoring test loop. The submersible pump was used to transfer waste slurry from tank W-9 across ORNL through a 61-cm (2-in) diameter double-contained stainless steel waste transfer line to the MVSTs. The submersible pump was mounted on a vertical mast that could be raised or lowered in the tanks, depending on the waste depths in the tanks. The pump included a 93-kW (125-hp) electric motor with an integrated Discflo™ low-shear pump head. The pump was capable of generating discharge pressures in excess of 2.1 MPa (300 psi). The primary conditioning system integrated parallel roughing filters, three sample ports, and a high-efficiency particulate air (HEPA) filter air inlet within a containment box that was located in the South Tank Farm. Waste pumped from tank W-9 was routed to the primary conditioning system, which filtered the waste slurry and allowed sampling of the waste slurry. The solids monitoring test loop included in-line instrumentation for measuring the solids content of the waste slurry, and the particle-size distribution and count. The loop also included a sample port and HEPA filter air inlet, which were incorporated into a containment box that was located in the South Tank Farm. Other process instrumentation included in the loop provided a method for taking measurements, such as pressure, temperature, flow rate, etc.

CONCLUSION

The underground technologies deployed during the Gunite Tanks Remediation Project were essential to the success of the project. The integration and use of simple and complex technologies enabled workers to remotely perform underground sampling, characterization, tank modification, waste retrieval, and waste mixing operations. Robotic, remotely operated, and manual equipment were successfully integrated into an underground tank waste retrieval system that allowed the project team to safely perform the underground operations that were required to safely remediate the gunite tanks.

The selected underground equipment was cold tested with simulated sludge at ORNL, which provided on-the-job training for equipment operators. Actual tank waste retrieval operations were performed from April 1997 to January 2001. Waste retrieval operations in the North Tank Farm were considered hot tests. Data from the hot tests proved the waste retrieval equipment could perform tank clean up operations and meet the cleanup requirements established in the RI/BRA (retrieve more than 90% of the residual contaminants in the tanks). Waste retrieval operations in the South Tank Farm were successfully performed with the RTCS in tanks W-6 through W-10, and with the Flygt Mixers in tank W-5, which showed signed of interior deterioration. Waste retrieval efforts resulted in the transfer of approximately 2,385 m^3 (630,000 gal) of waste slurry containing about 348 m^3 (92,000 gal) of radioactive sludge and 3.15E+15 Bq (85,000 Ci) of radioactive contamination. Twenty-seven waste transfers were made to the active ORNL LLLW system during the project. These transfers were coordinated with other tank remediation projects through the implementation of the ORNL Integrated Tank Waste Management Plan. The Gunite Tanks Remediation Project was completed more than 10 years ahead of the original baseline schedule and with a cost avoidance of over $120 Million. The technologies and processes used during the Gunite Tanks Remediation Project have application for other large UST remediation projects. The integration and use of the robotic and remotely operated equipment decreased the risk to workers, speeded up the tank cleanup operations, and increased the efficiency of the waste retrieval process. Additional information about the Gunite Tanks Remediation Project can be found at www.aimsicorp.com/GAAT.

FOOTNOTES

1 Jacobs Environmental Restoration Team, *Remedial Investigation/Baseline Risk Assessment for the Gunite and Associated Tanks Operable Unit at Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, DOE/OR/02-1275&D1, Jacobs Engineering Group, Inc., Oak Ridge, Tennessee, May 1994.

2 *Addendum to the Remedial Investigation/Baseline Risk Assessment for the Gunite and Associated Tanks Operable Unit at Waste Area Grouping 1 at the Oak Ridge National Laboratory, Oak Ridge, Tennessee,* DOE/OR/02-1275&D2/A1, March 1996, Prepared by Jacobs ER Team and Lockheed Martin Energy Systems, Oak Ridge, Tennessee.

3 Jacobs Environmental Restoration Team, *Feasibility Study/Proposed Plan for Sludge Removal from the Gunite and Associated Tanks Operable Unit, Waste Area Grouping 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee*, DOE/OR/02-1509/V1&D2, Jacobs Engineering Group, Inc., Oak Ridge, Tennessee May 1996.