INNOVATIVE TECHNOLOGY

Summary Report

DOE/EM-0595

Heavy Waste Retrieval System

Robotics Crosscutting Program
Tanks Focus Area

Prepared for
U.S. Department of Energy
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INNOVATIVE TECHNOLOGY
Summary Report

Heavy Waste Retrieval System

OST/TMS ID 2194

Robotics Crosscutting Program
Tanks Focus Area

Demonstrated at
Gunite and Associated Tanks Operable Unit
Oak Ridge National Laboratory
Oak Ridge, Tennessee

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports (ITSRS) are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from the U. S. Department of Energy's (DOE's) Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST web site at www.em.doe.gov/ost under "Publications."

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SECTION 1
SUMMARY

Technology Summary

Problem
The U.S. Department of Energy (DOE) is responsible for the cleanup and closure of 273 large, aging, underground storage tanks (USTs), which have been used to store tens of millions of gallons of high- and low-level radioactive and mixed waste. The nature of the waste precludes humans from working in the tanks. Therefore, remote-controlled retrieval methods must be used.

One such system, the Tank Waste Retrieval System (TWRS),[1] described in Burks et al. 1997, was developed for cleanup of the Gunite and Associated Tanks (GAAT) Operable Unit (OU) at the Oak Ridge National Laboratory (ORNL). The TWRS was proven to be effective in dislodging and removing about 88,000 gal of radioactive sludge and solids and about 250,000 gal of liquid from seven tanks and consolidating the waste into a single tank. In all cases, the consolidation tank was no more than 150 ft from the source tank, and there was no significant elevation head to overcome. As a result, the Waste Dislodging and Conveyance System's[2] (WD&C's) jet pump (Randolph et al. 1997) and Confined Sluicing End Effector (CSEE) (U.S. DOE-OST 1998a) were effective in dislodging the waste and pumping it from the source tank to the consolidation tank. The WD&C's Hose Management Arm (HMA) and CSEE were able to access all of the tank and when operated in conjunction with the Modified Light Duty Utility Arm (MLDUA) (U.S. DOE-OST 1998b) and the Remotely Operated Vehicle (ROV), Houdini™-II (U.S. DOE-OST 1999), were able to motivate all of the sludge in the underground storage tank in which the system was deployed.

Two primary factors, however, prevented the use of the existing TWRS alone for the final cleanup of the consolidation tank. The intermittent nature of the waste stream from the jet pump and the limited discharge pressure precluded the use of the existing jet pump to move the waste over the distance required to remove it from the site. In addition, because the TWRS was not designed to control the solids content of its discharge (i.e., particle size and density), it could not, alone, meet the Waste Acceptance Criteria (WAC) of the destination storage facility, the Melton Valley Storage Tanks (MVSTs).

The Sludge Conditioning System (SCS), subsequently developed for use in the GAAT OU, was used between May 1999 and March 2000 to mix and transfer about 483,000 gal of sludge and supernatant from the consolidation tank to a remote processing tank ~ 1 mile distant (Lewis et al. 2000). The SCS provided an effective and efficient means to mix, characterize, classify, and pump a significant portion of the waste to more distant processing and storage facilities. The SCS, however, was not designed to access all parts of the tank, nor was it intended to retrieve the heavier sludge and solids.

Options and recommendations for a Heavy Waste Retrieval System[3] (HWRS) for the GAAT Project are provided in ORNL/TM-2000/251 (Lewis et al. 2000). Functions and requirements for the HWRS were defined in an ORNL internal report (Lloyd et al. 2000).

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[1] The TWRS is alternately referred to as the Sludge Removal System in some GAAT project documentation.
[2] The WD&C is one of several major systems that collectively comprise the TWRS.
[3] Other GAAT Project documents refer to the HWRS as the Waste Removal and Transfer System (WaRTS).

How It Works
A schematic of the HWRS, which is shown as Figure 1, was developed as an enabling technology to address the shortfalls of the existing waste-removal (TWRS) and -transfer (SCS) systems, which are already in service at the GAAT OU. The HWRS takes advantage of the existing capabilities of the TWRS and the SCS. In addition, it provides:

- a Waste Stream Consolidation System (WSCS) comprised of;
  - a surge tank, T1
  - a remote-viewing camera and adjustable lighting,
  - secondary containment, and
  - associated piping and valving;
- a Supernatant Pumping System (SPS), which consists of;
  - a supernatant reservoir, T2
  - a positive displacement pump, P2,
  - secondary containment, and
  - associated piping and valving;
- a positive displacement pump, P1, in the Primary Conditioning Module[4] (PCM) of the SCS; and
- a control system, which provides for safe, efficient remote operation of the additional hardware and features
  - a distributed network architecture,
  - interlocks with existing systems, and
  - a graphical user interface (GUI).

The HWRS was designed to meet requirements of the GAAT OU for transferring wastes from tank W-9 in the ORNL South Tank Farm (STF) to the Bethel Valley Evaporator Service Tank (BVEST) W-23, which is part of ORNL's Active Low-Level Liquid Waste (LLLW) System. The HWRS consists of the previously existing, TWRS, and SCS, and the additional subsystems and equipment described previously.[5]

Several publications (Burks et al. 1997, Randolph et al. 1997, and Blank et al. 1998) provide good descriptions of the operation of the TWRS and its components. A thorough description of the SCS Slurry Monitoring Test Loop (SMTL) is provided in Hylton and Bayne 1999. The design, operation, and fabrication cost and schedule information for the SCS is described in Randolph et al. 2000.

During operations, waste is pumped from the source tank, W-9, by the TWRS into the surge tank, T1, where the heavier particles of sludge and debris are allowed to settle out. The screen on the CSEE intake allows objects up to a diam of ~ 0.5 in to be pumped into the surge tank. In addition to settling, the consolidation tank provides a surge volume between the WD&C's jet pump and the HWRS's pump, P1, an air-operated, double-diaphragm, positive-displacement pump. Because of the distance between tanks W-9 and W-23 (~ 500 ft), the positive static head that must be overcome (~ 5 ft), and a pipe configuration known to have several sharp turns and local low points, it is important to ensure full-pipe and constant flow in the transfer line to prevent solids buildup. As long as sufficient supply is available at the inlet to P1, the pump is capable of maintaining the flow in the transfer line to W-23 at a rate sufficient such as to ensure that solids do not settle in the line. The surge capability of T1 was designed to meet this requirement.

[4] The PCM is alternately referred to as the Sludge Conditioning Module (SCM) in some GAAT project documentation.
[5] Many GAAT Project documents alternately refer to this collection of additional equipment as the WaRTS.

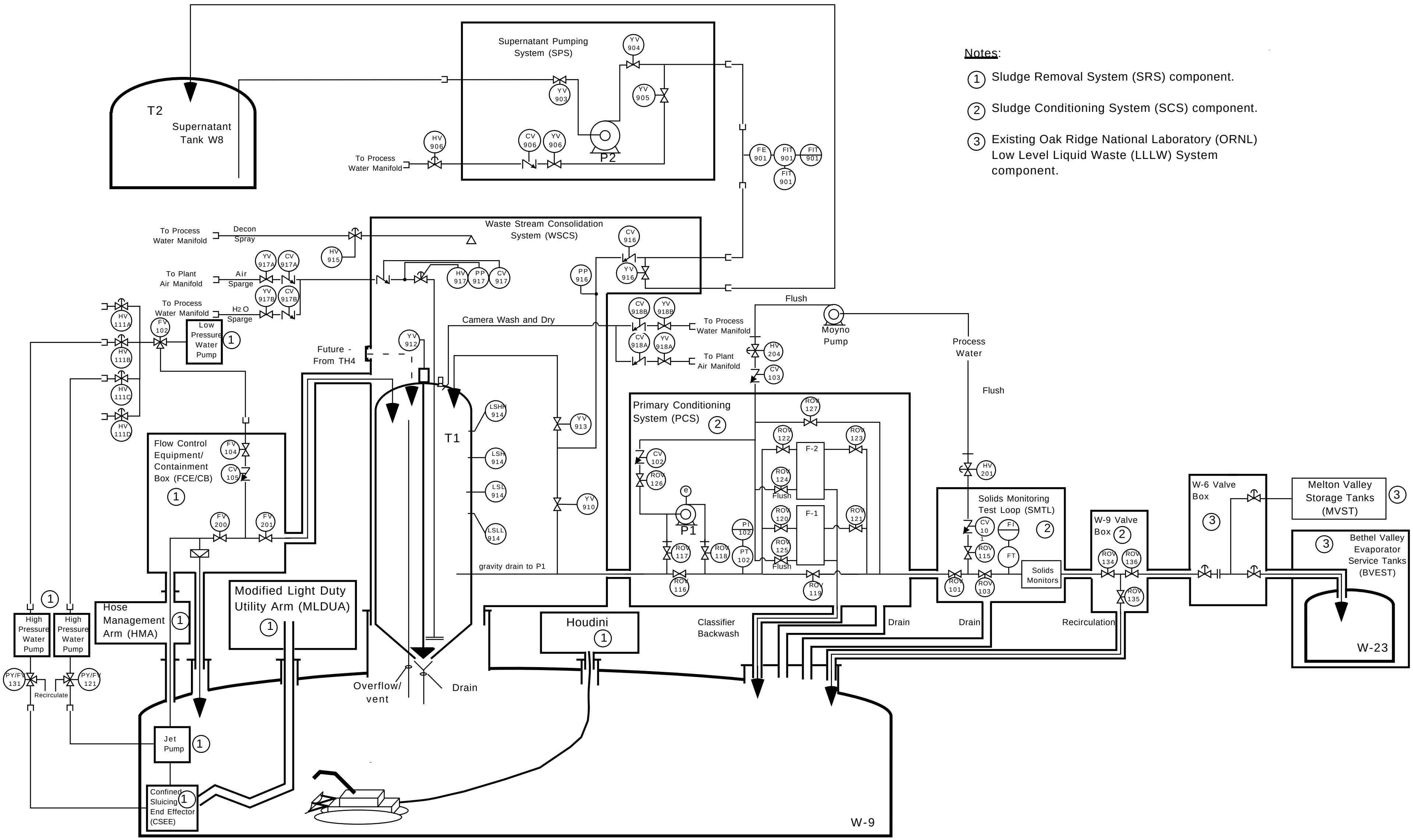

Figure 1. Heavy Waste Retrieval System flow diagram.

However, because of the nature of the waste-removal operations, it was anticipated that the surge volume provided by T1 would be inadequate during certain portions of the waste removal when sludge delivery from the WD&C jet pump is extremely intermittent (e.g., when cleaning the final few inches of sludge from the tank floor). In addition, concern existed about the capability of the TWRS to meet the WAC for transfer of the waste to the MVSTs, and it was commonly accepted that there would likely be some requirement to dilute the slurry in order to meet the density requirements. As a result, a supernatant pumping system was added to provide "makeup" supply to P1 when the level in T1 reaches a preset lower limit. The supernatant pump, P2, is identical to P1. The HWRS took advantage of a previously cleaned adjacent storage tank for use as the supernatant reservoir, T2.

Additional detail on design considerations for the HWRS is provided in Lewis et al. 2000.

Potential Markets

The HWRS was designed to meet the specific needs of the GAAT OU for removing and transferring dense mixed-waste sludge from a consolidation tank to a distant processing facility. Similar problems are likely to exist throughout the DOE complex, including Fernald, Hanford, Idaho National Engineering and Environmental Laboratory (INEEL), the Savannah River Site (SRS), and other sites at the ORNL.

Advantages over the Baseline

The baseline approach for cleaning the GAAT is the use of the TWRS and the SCS to feed the effluent waste to a large consolidation tank for mixing and subsequent transfer to the ORNL active waste system. The HWRS allowed ORNL to clean out tank W-9 using the existing TWRS and SCS without the need for a large, local consolidation and mixing facility. Such a facility would have required a capacity of about 10,000 to 30,000 gal. Above-ground construction of such a facility, with all of the required shielding, secondary containment, etc., would have been prohibitively expensive. Additional costs would have been incurred for the cleanup and disposal of the temporary facility. The HWRS's 350-gal surge tank combined with its supernatant pumping system provided the functionality of a much larger and more expensive tank waste-storage, -mixing, and -transfer facility. Specifically, it combined and enhanced the capability of the existing TWRS and SCS to facilitate removal of dense, mixed-waste sludge; transfer of the dense waste to a processing facility; and final cleanup of the large UST.

Demonstration Summary

Previous waste-removal campaigns in the ORNL GAAT OU (Weeren 1984, Blank et al. 1998, and Lewis et al. 2000) were effective in removing nearly all of the legacy waste from the USTs. The remaining waste (~ 40,000 gal of dense sludge and supernatant) was consolidated in the GAAT OU tank W-9. In order to complete the remediation effort, the remaining waste required mobilization and transfer to the active waste system. This final waste retrieval was the objective of the HWRS.

Between July and September 2000, the HWRS was used effectively to efficiently transfer the remaining waste from tank W-9 to BVEST W-23. Transfer beyond tank W-23 is outside the scope of this report.

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Licensing and Permitting

The HWRS was developed by the ORNL. This technology is available for licensing and reuse by contacting the Office of Technology Transfer, UT-Battelle, (865) 576-2577.

Other

All published Innovative Technology Summary Reports are available on the OST web site at www.em.doe.gov/ost under "Publications." The Technology Management System (TMS), also available through the OST web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for the Heavy Waste Retrieval System is 2194.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Goals and Objectives
The HWRS was designed to meet requirements (Lloyd et al. 2000) of the GAAT OU for retrieval and transfer of wastes from tank W-9 in the GAAT OU STF to BVEST tank W-23, which is part of ORNL's LLLW System.

Description of the Technology
Figure 1 provides a schematic of the HWRS, which consists of the following major components:

- TWRS;
  - WD&C,
  - MLDUA,
  - Houdini™/Houdini-II, and
  - Balance of Plant (BOP);

- SCS;
  - PCM with waste-transfer pump P1 added,
  - SMTL,
  - Moyno® pump, and
  - Interconnecting piping and valving;

- WSCS;
  - surge tank, T1,
  - secondary containment, and
  - associated piping and valving;

- SPS;
  - a positive-displacement pump, P2,
  - secondary containment, and
  - associated piping and valving.

In addition, a control system, which provided for remote operation of the newly added hardware was developed. The control system was built around a distributed network architecture and provided interlocks with existing systems. A GUI provided the operator with a convenient method of pump and valve control, monitoring system status, and display of error and alarm conditions.

Before the development of the HWRS, the TWRS and SCS were operated independently to perform cleanup of several large USTs in the GAAT OU at ORNL. The TWRS provided a means of dislodging and removing waste from the tanks, while the SCS provided a means of mixing, classifying, characterizing, and pumping the wastes to a distant treatment site. While effective, these steps had to be taken separately and required an intermediate holding tank. In order to clean the final tank, which had served as the holding tank, these actions had to be performed concurrently. The addition of the WSCS and the SPS, and the addition of P1 to the PCM maximized the use of existing equipment capabilities and enabled the additional requirements for cleanup of the final tank to be effectively and efficiently satisfied.

Basic Principle of Operation
The reader is again referred to Figure 1.

The HWRS takes advantage of functionality already available from systems in service at the GAAT OU (i.e., the TWRS, SCS, existing transfer lines, and valves). The TWRS is used to dislodge and remove the sludge from the source tank, W-9. The SCS is used to characterize (i.e., verify density and particle size) and sample the sludge. The submersible Discflo pump, Pulsair®, and Flygt Mixer systems, previously part of the SCS (Lewis et al. 2000), are not used with the HWRS. Two separate, but already existing, 2-in. diam surface/subsurface transfer lines were tied together to connect the discharge of the SMTL and the inlet to tank W-23, which is ~ 500 ft west of and 5 ft in elevation above, W-9.

During operations, waste is removed from the UST by the TWRS (Burks et al. 1997) and pumped by the WD&C jet pump into the surge tank, T1, where the heavier particles of sludge may be allowed to settle out. Settling is an important feature of the surge tank since subsequent processing facilities limit the particle size and density of the sludge that they will accept (Lloyd et al. 2000). However, since the objective of the cleanup is to remove the waste as efficiently as possible, settling needs to be limited when particle size and density are already below maximum thresholds. In addition, the dense and adhesive nature of the sludge (Lloyd et al. 2000) suggests the likelihood of blockages at the tank drain valve, YV912, if too much settling is allowed to take place. An air and water sparger in the bottom of the surge tank is provided to permit agitation and mixing of the tank contents, thus reducing settling and the likelihood of valve blockage. Another method to preclude blockage of the drain valve is to periodically drain the surge tank by opening the drain valve. Although effective, this second method reduces the efficiency of the process, and it is not used as long as the sparger is operational and effective in preventing blockages.

The discharge pressure required to overcome the combination of distance, elevation gain, and classifier differential pressure,[6] and the requirement to maintain uninterrupted turbulent flow through the transfer line, precluded the use of the HMA jet pump alone for making the transfer from W-9 to W-23. Therefore, a positive displacement air-operated, double-diaphragm pump, P1, was added to the PCM for this purpose. As long as sufficient supply is available at the inlet to P1, the pump is capable of maintaining the required flow rate through the transfer line to W-23. Although not required, a gravity drain from the surge tank through the feed line to P1 helps ensure that the inlet to P1 is never starved as long as the level in T1 is maintained above the discharge port.

An array of conductivity-type level instruments and a camera mounted inside the surge tank provide the operator with sludge level information necessary for operation.

In addition to settling, a second and equally important function of T1 is to provide a surge volume between the WD&C System's jet pump and P1. During sludge-removal operations, the MLDUA or the Houdini moves the CSEE over and through sludge piles in the bottom of the tank. The cutting jets on the end effector dislodge the waste and create a slurry, which is vacuumed up by the jet pump and delivered to the surge tank inlet. Past experience with the TWRS suggests that as long as the sludge piles and slurry are easily motivated, the jet pump is capable of delivering ~ 70 gal/min, a rate well above the minimum required flow rate for P1 of 40 gal/min.[7] At other times, when the sludge piles and slurry become more difficult to motivate and pump, the flow rate into T1 can drop to as low as 10 gal/min. The surge tank provides ~ 250 gal of surge capability, which can be used to give the WD&C operators an opportunity to "catch up."

Past experience with the WD&C suggested that the surge volume provided by T1 would be inadequate during certain portions of the waste removal. Depending on the nature of the sludge, delivery from the WD&C jet pump can be extremely intermittent (e.g., when cleaning the final few inches of sludge from the tank floor). As a result, a supernatant pumping system was added to provide makeup supply to P1 when the level in T1 reaches a preset value. The supernatant pump, P2, is identical to P1, but P2 is independently controlled. During transfer operations, P2 is started and left running with remotely controlled valves, YV910 and YV916, positioned so that the supernatant recirculates to the supernatant reservoir, T2, a previously cleaned adjacent storage tank. The operation of these valves is interlocked with the level instruments in the surge tank so that supernatant is delivered to P1 when the level in T1 falls below a preset level. Unless reset by the operator, the position of the valves remains unchanged until a second, higher, preset level is reached. At that point, valves YV910 and YV916 change state so that the supernatant is again recirculated. A remote manual control capability was added to the control system so that the operator could dilute the slurry in the event that the solids content was above the WAC for the destination tank.

The positive displacement nature of the pumps, P1 and P2, suggests a risk of significant pressures in the event of a deadheaded line downstream from the pump. However, the downstream pressure from the air diaphragm pumps selected for this application is limited to the air pressure in the supply airline (in this case, less than 120 psi).

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[6] The classifiers are part of the SCS and are installed in the PCM.
[7] A 40-gal/min flow rate ensures turbulent flow through the 2-in. diam transfer line, thus reducing the likelihood of settling.

An emergency stop switch at the operator console provides a rapid, safe, and effective means to shut down all related equipment in the event of an emergency or off-normal condition.

All of the remotely operated valves are solenoid controlled and air operated. The air operators rely on conditioned (filtered and dry) plant air at less than 120 psi and are controlled by 120-VAC solenoids. In the event of a power failure or loss of air pressure, valves YV910, YV913, YV906, and YV905 fail closed; valves YV916, YV903, and YV904 fail open; and pumps P1 and P2 cease pumping.

Major Element Description

Development of the HWRS took maximum advantage of waste-retrieval and -transfer tools (i.e., the TWRS and SCS), which were previously developed for use at ORNL's GAAT OU. A brief description of these systems and some of the associated tools is given below.

- TWRS—Figure 2 is a photograph of the major TWRS components, the MLDUA, Houdini, and WD&C, during cold testing.

Figure 2. Modified Light Duty Utility Arm holding the Confined Sluicing End Effector and operating with Houdini and the Waste Dislodging and Conveyance System in the Cold Test Facility.

– MLDUA—An 8 degree of freedom (dof) robotic arm with a 200-lb payload and a 15-ft horizontal reach, capable of deployment through a 12-in. diam riser. The MLDUA is a modified version of the Light Duty Utility Arm (LDUA). Both the LDUA and the MLDUA are manufactured by SPAR Aerospace. A summary of the LDUA and MLDUA capabilities is given in U.S. DOE-OST 1998b.

– Houdini-II—A remotely operated, tethered vehicle, which weighs ~ 1000 lb and which is capable of entering through a 24-in. diam riser. Houdini-II is a second-generation vehicle, which is manufactured by RedZone Robotics, Inc. It has an integral 6-dof manipulator arm with a 240-lb capacity at full extension, on-board camera system, and a plow blade. A summary of the Houdini-II capabilities is given in U.S. DOE-OST 1999.

– WD&C System—A suite of subsystems, which is capable of deployment through a 24-in diam riser, which can be used to dislodge, mobilize, and remove waste to above-ground treatment or transportation systems. The WD&C System consists of the CSEE, HMA, jet pump, and associated high-pressure water pumps, valves, and piping. (See Randolph et al. 1997.)

- CSEE—Rotating water-jet cutter and vacuum head, which is used to dislodge and mobilize the waste. Cutting jets are supplied with water at 200–7,000 psi and rotated at 0–500 rpm to break up the sludge and create a slurry, which is then vacuumed from the tank. A summary of the CSEE capabilities is provided in U.S. DOE, OST 1998A.
- HMA—A 4-dof arm with a hose distal section. Deployable through a 24-in diam riser and capable of remote teleoperation or passive positioning by the MLDUA or Houdini™-II. Provides cable and hose management for the CSEE and serves as the discharge conduit for the waste from the CSEE. Also provides the mounting mechanism for the jet pump.
- Jet Pump—An axial-flow, water-powered eductor, which uses 7,000-psi motive water to vacuum the waste from the tank. Design and testing of the jet pump are described in Mann 1998.

– Gunite Scarifying End Effector (GSEE)—Rotating water-jet cutter with a form factor similar to that of the CSEE that is used to scarify the contaminated gunite and scale from the tank walls using high-pressure water. May be positioned in the tank by the MLDUA or the Houdini-II. Capable of operating at pressures of up to 22,000 psi.

– Linear Scarifying End Effector (LSEE)—Two-headed water-jet cutter, which is used to scarify the contaminated gunite and scale from the tank walls using high-pressure water. The two spray heads travel back and forth along a linear rail, which is positioned parallel to the tank wall by the Houdini-II. Capable of operating at pressures of up to 7,000 psi. (See Fitzgerald et al. 2001.)

– Wall-Coring Tool—A modified electric drill and collection system, which is used to remove core samples from the tank walls. Samples are analyzed to determine the degree of migration of radioactive contaminants. Positioned by the MLDUA or Houdini-II.

– Wall-Scraping Tool—A scraping tool, which is used by the MLDUA to collect scale samples from the tank walls.

– Pipe-Cutting Tool—A modified electric band saw used by the MLDUA to cut pipe obstructions inside the tanks. (See Chesser and Lewis 2000 and Glassell and Lewis 1999.)

– Pipe-Plugging Tool—A device, which is used by the MLDUA to seal pipe openings that appear in the tank. Once positioned by the MLDUA, epoxy cement is injected into the exposed end of the pipe and permitted to cure. (See Chesser and Lewis 2000 and Glassell and Lewis 1999.)

- SCS—Located in the vicinity of the source tank (W-9), the SCS is used to classify, characterize, monitor, and sample the waste stream before the waste is transferred to the destination tank (W-23). Before its integration with the TWRS, the SCS had its own mobilization and retrieval systems (i.e., the Pulsair Mixers, Flygt Mixer, and a large submersible DiscFlo pump). These systems are not used in the HWRS configuration.

  – PCM—The PCM (See Figure 3) provides for classification and sampling the waste slurry. It includes an in-line classifier to remove oversized particles from the waste stream, three sample ports, a high efficiency particulate air (HEPA) filter air inlet, flushing capability, and secondary containment enclosure.

Figure 3. Primary Conditioning Module.

Figure 4. Slurry Monitoring Test Loop Module.

- SMTL—The SMTL (See Figure 4) provides in-line instrumentation for measuring and displaying flow rate, density, temperature, pressure, solids content, particle-size distribution, and solids content of the waste stream. Display is provided in real-time to a remote display. The SMTL also includes a single sample port, HEPA filter air inlet, flushing capability, and secondary containment enclosure. A description of the slurry monitoring instrumentation in the SMTL is given in Hylton and Bayne 1999.
- Piping and Valving—Interconnecting piping and valving for the GAAT site and the interface to the ORNL active LLLW System.

In addition, the following equipment and systems were integrated with the existing systems to form the HWRS.

- WSCS—The WSCS is comprised of a surge tank, secondary containment, associated piping and valving.
  Figure 5 is a photograph of the WSCS during installation on Tank W9. Check valves were added to prevent any slurry from entering the supernatant supply. Provisions for clean process water flush of the system and containment system decontamination were also made. Figure 6 shows a top view of the WSCS with the lid to the secondary containment removed.
  - Surge Tank, T1—The surge tank was designed for installation above an existing 24-in diam riser in the source tank. It serves as the destination for waste removed by the WD&C from the source tank and provides a working volume of ~ 200 gal, a settling volume of ~ 75 gal, and ~ 50 gal of capacity above the working high level. The tank which is constructed of carbon steel pipe and 0.25 in plate features:
    - a 4-in diam drain line, which empties back into the source tank;
    - a remotely operable drain valve in the bottom of the tank which is designed to fail open;
    - level instruments, which provide the operator with process information and are used by the control system to automatically control the process;
    - a camera with remotely controllable light and camera wash and rinse;
    - a remotely operable air and water sparger in the bottom of the tank; and
    - a 4-in. diam overflow vent, which prevents pressurization or overfilling of the tank.

Figure 5. Waste Stream Consolidation System – surge tank during installation at Gunite and Associated Tanks Operable Unit, Tank W-9.

Figure 6. Waste Stream Consolidation System – surge tank top view, inside secondary containment.

- – Secondary Containment—The secondary containment is also constructed of 0.25-in. carbon steel. It sits on the platform above a 34-in. diam riser, to which it is sealed. It provides secondary containment for the surge tank and the associated piping and valving. Any leakage drains back into the tank.
- – Associated piping and valving—There are three remotely operable, air-operated, solenoid-controlled valves and a check valve housed in the WSCS secondary containment. These valves control the flow of supernatant and may be positioned such that the supernatant is recirculated to the supernatant supply tank, added to the waste stream, or added directly to T1. Check valves were added to prevent any slurry from entering the supernatant supply. Provisions for clean process water flush of the system and containment system decontamination were also made.

- SPS—The SPS is comprised of a supernatant reservoir, T2; a pump, P2; secondary containment; and associated piping and valving. Supernatant is used to dilute the slurry as required to meet transfer requirements and as makeup when the flow rate of waste slurry from the WD&C falls below the flow rate required to ensure that settling does not occur. Use of supernatant instead of clean process water reduces the volume of waste generated during the cleanup operation. Figure 7 is a photo of the inside of the SPS secondary containment. The pump, the four remotely operable valves, and some of the piping are visible in the photo. The SPS is made up of the following components:
  - – Supernatant Reservoir, T2—The supernatant reservoir provides storage for the supernatant. In the GAAT application, one of the previously cleaned USTs in the STF was used as the supernatant reservoir.
  - – Supernatant Pump, P2—The supernatant pump is a Warren Rupp SandPIPER®, model SB2-A. It is an air-powered, double-diaphragm, self-priming, positive-displacement pump with ball-type check valves. It has 2-in. suction and discharge ports and flow passages, which are capable of handling suspended solids up to 3/8 in. The pump is capable of delivering ≥70 gal/min at 115 ft of total dynamic head. The pump is capable of pumping a viscosity of 1.0—1.2 Seconds Saybolt Universal (SSU), with ≤80 scfm of air consumption at an inlet pressure of ≤90 psi. The pump is self-priming and capable of running dry without damage. It is capable of variable-speed operation and can be controlled either locally or remotely.
  - – Secondary Containment—The secondary containment is constructed of 0.25-in. carbon steel. It sits on the surface adjacent to a 12-in. riser in the supernatant reservoir, to which it is sealed. It provides secondary containment for the supernatant pump and the associated piping and valving. Any leakage drains back into the supernatant reservoir.
  - – Associated Piping and Valving—There are four remotely operable, air operated, solenoid-controlled valves and a check valve housed in the WSCS secondary containment. These valves control the flow of supernatant and process water and may be positioned such that either supernatant from the reservoir or clean process water is delivered to the rest of the system.

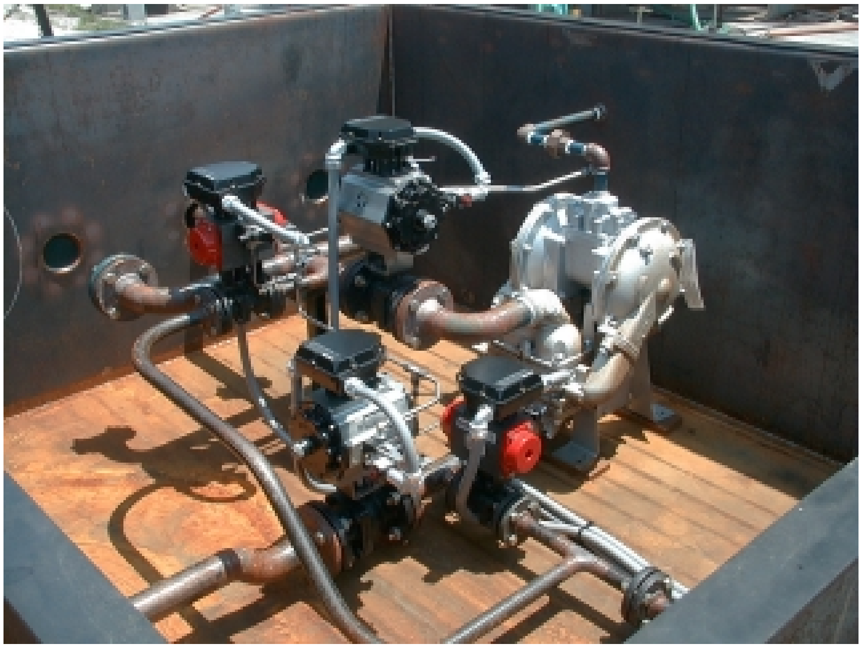

Figure 7. Supernatant Pumping System–P2, piping, and valves, inside secondary containment.

- PCM Pump, P1—Pump P1 was added to the PCM to provide the means of pumping the waste slurry from the discharge of the WSCS surge tank, T1, to the destination tank. It is identical to the supernatant pump, P2, except that in addition to the features described above, P1 is also outfitted with an electronic leak detector, which is designed to alert operators if either of the two air diaphragms develops a leak.

- Control System—A control system for operation of the additional hardware was also developed. The control system combines hardware software logic to provide safe, efficient, remote operation of the system. The control system was built around Opto-22's Snap® I/O (input/output) and FactoryFloor® suite of control software. Development of the control strategy was done using Opto 22's OptoControl™. The controller runs on a soft-logic controller, OptoRuntimePC™, under WindowsNT™ on a Compaq 486™. A GUI (see Figure 8) was developed using Opto 22's OptoDisplay and runs on the same computer as the controller using the OptoDisplay Runtime application. A distributed I/O architecture used three Opto 22 SNAP-I/O racks and an assortment of analog and discrete input/output I/O modules to interface with the hardware.

System Operation

Once installed, most of the HWRS operations are performed remotely from a control room, which is outside the radiation area. Samples can be taken remotely but removal of the sample require that the operator enter the radiological control area. In addition, system walk-downs, which require accessing radiological and contamination areas, are performed daily.

Preoperational checks can be performed in about 30 min. Although the remote-control nature of the system reduces operational dependency on weather, a GAAT Remediation Project administrative requirement to monitor the above-ground portion of the system for leaks during transfer operations limits its use at the GAAT OU during wet weather. During cold weather, winterization procedures (i.e., draining all exposed process lines) are performed at the end of each transfer operation and require about 30 min to execute.

The unique nature of the HWRS requires that operators receive specialized training. Operators developed, verified, and practiced operating procedures during cold testing. System-specific training is also required for service personnel who provide installation assistance, preventative, and corrective maintenance.

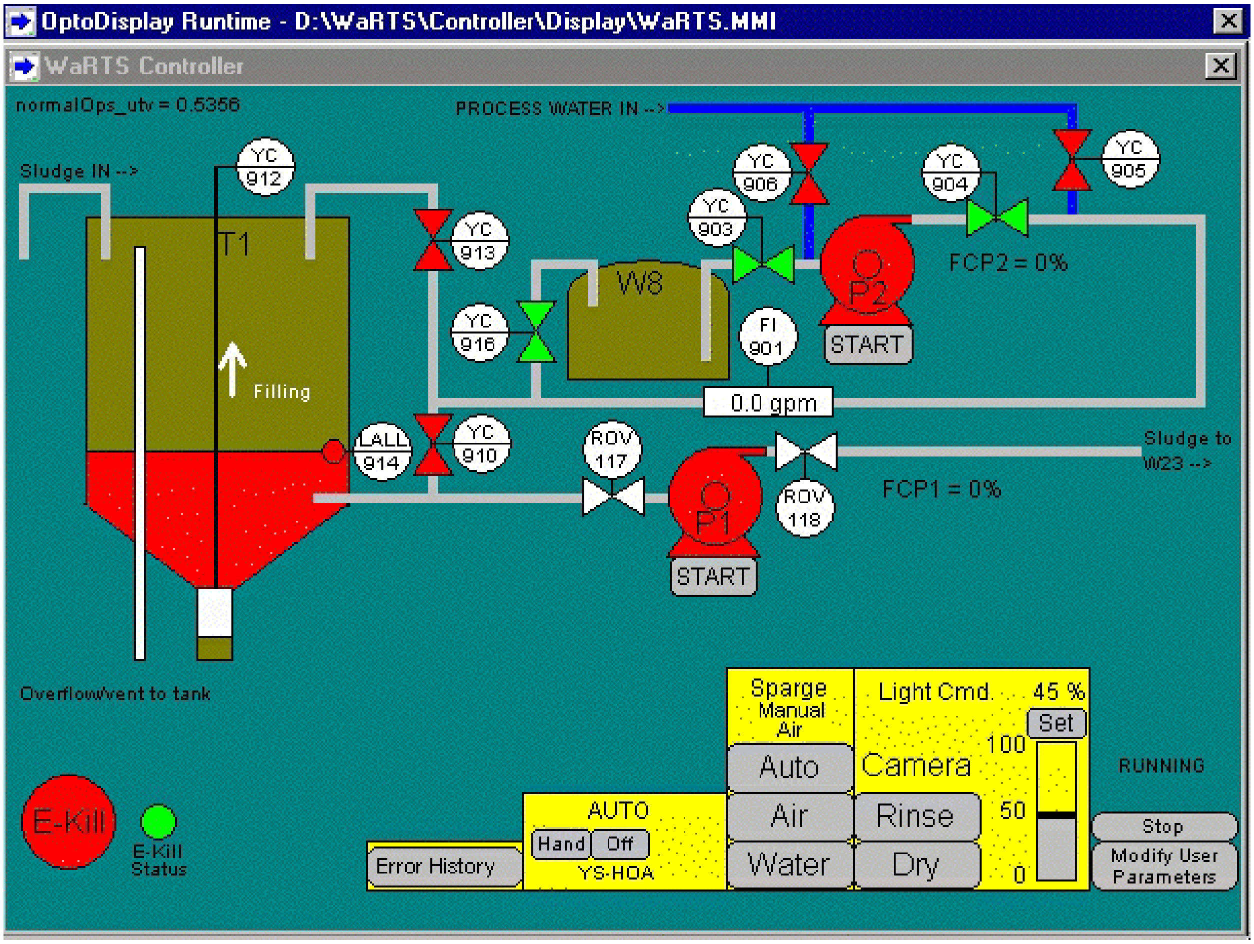

Figure 8. Screen dump of the graphical user interface for the Waste Stream Conditioning System and Supernatant Pumping System.

Operation of the HWRS requires the following personnel:

- Shift Supervisor,
- BOP Operator,
- WSCS, SPS, and SCS (WaRTS) Operator,
- WD&C Operator, and
- MLDUA Operator, and/or
- Houdini-II Operator.

Installation and maintenance activities require additional operators, technicians, and service personnel. Maintenance of contaminated equipment creates some unique challenges. Personal Protective Equipment (PPE), such as protective clothing and respirators, are typically required for this type of activity. Often maintenance of contaminated equipment can be performed in a glove box, but generally when larger pieces of contaminated equipment require maintenance, a dedicated maintenance facility is required. At the GAAT OU, a large maintenance tent was constructed for this purpose.

Retrieval operations create additional waste, mostly in the form of water added during sluicing, decontamination, and flushing. In addition, expended PPE, and system components replaced during preventative and corrective maintenance create a secondary waste stream.

The principle operational concern while moving waste from one storage facility to another is the risk of a leak from the equipment or transfer line and subsequent release to the environment. Quality control in the design and fabrication of the equipment, preoperational checks, leak-detection hardware in the SCS and ORNL LLLW System, process monitoring, and secondary containment are the key elements in guarding against such a problem. Another significant operational concern is the avoidance of radiation exposure for both the operators and other nearby personnel. The fact that the GAAT OU is located adjacent to a main vehicular and pedestrian thoroughfare at ORNL (with office buildings, research facilities, and the cafeteria nearby) mandated special attention to this issue (see Figure 9). Proper zoning, access control, radiation monitoring and shielding, work authorization, decontamination, and flushing procedures were all used to minimize personnel exposure during the operation of the HWRS.

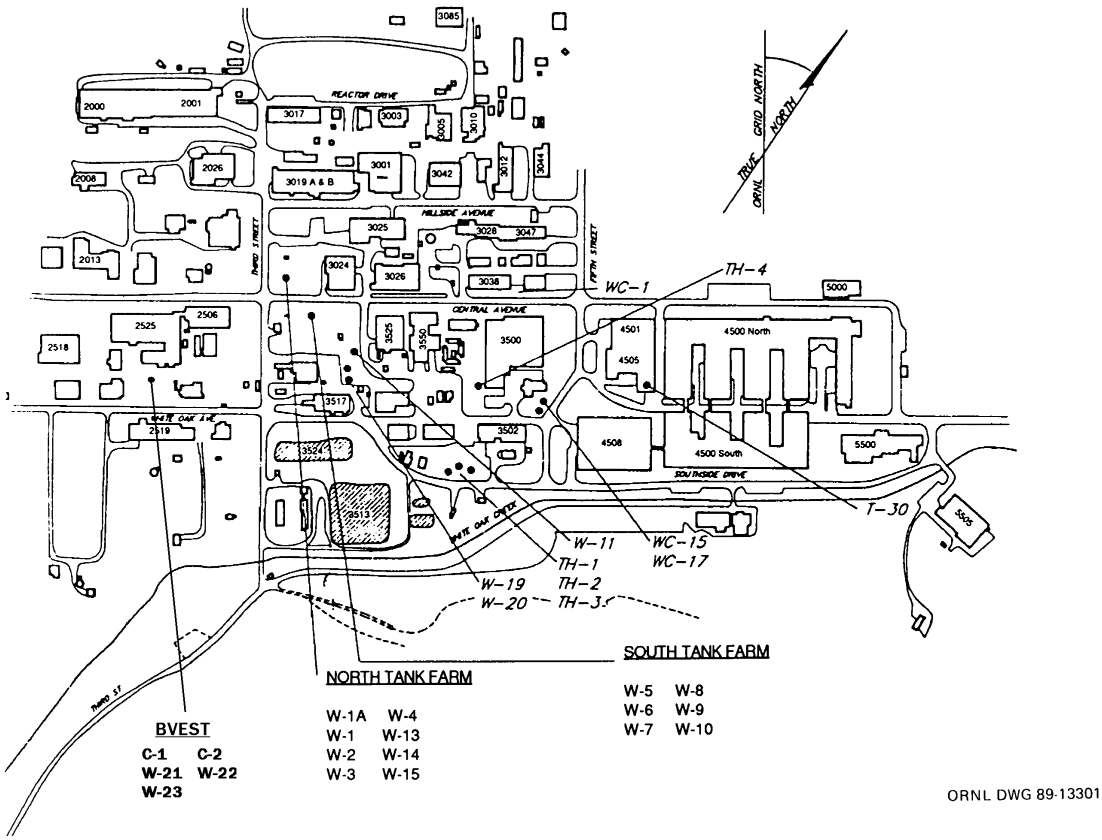

Figure 9. Location of the Gunite and Associated Tanks Operable Unit and the Bethel Valley Evaporator Storage Tanks at the Oak Ridge National Laboratory.

SECTION 3
PERFORMANCE

Demonstration Plan

Site Description and Background

The GAAT OU is a collection of USTs and associated equipment, which is located at ORNL and is part of Waste Area Grouping (WAG) 1. The tanks were constructed between 1943 and 1951 and were designed to contain the radioactive and chemical wastes generated by ORNL operations. A total of 12 gunite tanks and four stainless-steel (SS) tanks (W-1A, W-13, W-14, and W-15) comprise the GAAT OU, which is situated in a high traffic area in the middle of the ORNL site adjacent to a central vehicular and pedestrian thoroughfare. Over 90% of the sludge present in the six large gunite tanks, which form the STF (W-5, W-6, W-7, W-8, W-9, and W-10), was retrieved during an 18-month sluicing operation from 1982 through January 1984 (Weeren 1984). At the conclusion of this retrieval effort, a waste heel of ~ 88,000 gal of mixed-waste sludge remained in the six gunite tanks in the STF and the two gunite tanks (W-3 and W-4) in the North Tank Farm (NTF). As a result of in-leakage during subsequent years, an additional volume of ~ 250,000 gal of wastewater was created.

In 1994, the GAAT Remediation Project began retrieval of the remaining wastes from these tanks. Because of uncertainties surrounding remediation technologies, ORNL conducted a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) treatability study (TS) in the NTF of the GAAT OU. The TS provided data for evaluating potential alternatives for waste removal while transferring the material contents out of the tanks and consolidating them for future remedial action. Jacobs Environmental Restoration (ER) Team 1995 and Jacobs ER Team 1996 provide regulatory background on the GAAT-TS. Rule et al. 1998 provide results from the TS.

Early on, it was decided that tank W-9 would function as a waste-consolidation tank for the batch transfers to the MVSTs, which are located ~ 1 mile from W-9. Tank W-9 was used to hold the waste retrieved from the other tanks in the GAAT OU by the TWRS and served as a batch-processing tank for the transfers to the MVSTs by the SCS.

Demonstration Objective

A total of 18 waste transfers from W-9 occurred between May 25, 1999, and March 30, 2000. These transfers were accomplished using the Pulsair and Flygt mixers to mobilize and mix the slurry and a submersible DiscFlo retrieval-transfer pump to transfer the slurry through the PCM, SMTL, and the waste-transfer line (~ 1 mile long and 2-in. diameter) to the MVSTs. The transfers from W-9 were comprised of dilute slurries with solids contents ranging from ~ 2.8×10^4 to 6.8×10^4 mg/L at ~ 3 to 5 wt %. Of the initial 88,000 gal of sludge estimated in the GAAT, >60 wt % was removed. Once the transfers from the other GAAT OU tanks to W-9 were completed, the approximately 40,000 gal of remaining sludge and supernatant in W-9 required mobilization and transfer to the active LLLW system, BVEST W-23. This final waste retrieval was the demonstration objective of the HWRS.

Results

Waste Volume Treated

Between July and September 2000, the HWRS was used to transfer ~ 147,000 gal and 75,000 curies (Ci) of liquid and sludge solids from tank W-9 to the BVEST W-23. In addition, the walls of tank W-9 were washed using the CSEE and LSEE. Table 1 provides detailed information regarding the waste volume transferred from W-9 by the HWRS. Table 2 is a summary of the radioactivity data for the tanks in the GAAT OU.

Table 1. Sludge transfers from W-9 to W-23 by the Gunite and Associated Tanks Project.

Transfer No.	Transfer Date(s)	Volume (gal)	Density (g/mL)	Tot Solids (mg/L)	TSS[a] (mg/L)	Calc. wt % solids	Est. sludge (gal)
1	7/13/00	8,850	1.06	67,900	60,600	5.7	1,372
2	7/18/00	10,500	1.05	68,700	57,700	5.5	1,550
3	7/22/00	17,450	1.05	62,400	56,300	5.4	2,514
4	7/26–7/27	24,100	1.09	93,800	85,900	7.9	5,297
5	7/31–8/2	18,900	1.06	71,200	68,100	6.4	3,293
6	8/15–8/16	19,450	1.07	119,000	109,000	10.2	5,425
7	8/19–8/21	19,200	1.09	118,000	106,000	9.7	5,208
8	8/29–8/30	17,950	1.06	66,200	61,300	5.8	2,816
9	9/6–9/7	10,500	1.03	34,100	29,300	2.8	787
	Totals	**146,900**				**Total**	**28,262**

[a] TSS = Total Suspended Solids.

Table 2. Gunite and Associated Tanks Project radiation removal (W-9 to W-23) efficiency summary.

	Radioactivity (10^3 Ci)		
	Initial	Removed	Remaining
Sludge	78	+70	5-8
Supernatant	3	3	0
Walls	4	2	2
Totals	**85**	**+75**	**7–10**

Efficiency

Table 3 provides a summary of efficiency data for the HWRS operations in W-9. The complete retrieval effort required the addition of 12,550 gal of supernatant. By using supernatant, already classified as waste, the requirement for process water was reduced by ~ 16%.

The addition of the WSCS and SPS to the existing systems had no adverse impact on overall system efficiency. The limiting factor was the removal rate of the TWRS, described in Blank et al. 1998, and the rate at which the waste could be processed for transfer from the BVEST W-23 to the MVSTs.

Table 3. Gunite and Associated Tanks Project waste removal (W-9 to W-23) efficiency summary.

	Transferred volumes (gal)				Efficiencies		
Transfer No.	Total volume transferred[a]	Estimated sludge removed	Process water (PW) added	Supernatant added	Ratio—gal PW:sludge[b]	Operate time h:min	Removal rate gal/h[c]
1	8,850	1,400	2,800	750	2.0 : 1	3:20	1,606
2	10,500	1,550	4,500	1,400	2.9 : 1	6:00	767
3	17,450	2,500	7,900	4,400	3.2 : 1	10:30	490
4	24,100	5,300	10,400	1,400	2.0 : 1	11:20	1,086
5	18,900	3,300	10,850	0	3.3 : 1	13:00	619
6	19,450	5,400	7,850	650	1.5 : 1	11:40	938
7	19,200	5,200	7,200	2,000	1.4 : 1	15:00	667
8	17,950	2,800	8,600	1,650	3.1 : 1	14:50	519
9	10,500	800	5,650	300	7.1 : 1	13:10	345
Totals	146,900	28,250	65,750	12,550	2.3 : 1	98:50	694

[a] Total volume includes W-9 supernatant plus PW added and material removed during wall cleaning.
[b] Volume ratios do not include water added during wall cleaning. (PW added):(Estimated sludge removed).
[c] ((Total volume transferred – (PW added + Supernatant added))/(Operating time).

Comparison to Baseline

The baseline technology is the use of a consolidation tank for sludge storage, mixing, and transfer. The HWRS enabled tank W-9 to be cleaned out without construction of a large consolidation tank and the follow-on cleanup of that tank as well. Transfers to tank W-23 were typically between 5 and 10% by weight solids. Since the waste-operations limit for transfers to the MVSTs from W-23 is ≤5 wt % solids, the supernatant and water addition from use of the TWRS and the SPS have not diluted the sludge more than necessary for the 1-mile transfer to the MVSTs. The HWRS has successfully separated larger-particle-size material from the sludge as is also required by the waste-operations group at ORNL. Several cubic feet, ~ 200 gal (estimated), of sand-like material was separated from the waste stream and consolidated in tank W-9 under the surge-tank drain line.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Baseline Technologies
As previously stated, the HWRS is an enabling technology, which provides cost and performance benefits over the baseline approach of using a large consolidation tank. Specifically, it combined and enhanced the capability of the TWRS and SCS, already in operation at ORNL by the GAAT Remediation Project team, to facilitate removal of dense, mixed-waste sludge; transfer of the dense waste to a processing facility; and final cleaning of the large UST.

Other Competing Technologies and Comparisons
A number of general approaches were preliminarily considered as options for the removal and transfer of waste from W-9 to the MVSTs. These general approaches included the following concepts:

- enhancement to existing GAAT TWRS and SCS to pump the waste to BVEST, followed by use of Atomic Energy Authority Technology's (AEAT's) Pulsed Jet Fluidic Mixing Technology and existing transfer pumps and piping to transfer the waste to the MVSTs;
- construction of an accumulator tank in one of the previously cleaned GAAT OU tanks to facilitate transfer directly to the MVSTs;
- inclusion of additional mixers [e.g., Flygt Mixer, Pulsair (see Randolph et al. 2000, Harper 1999a, and Harper 1999b, for a description of these systems)] to the existing SCS to assist in mobilization of waste for direct transfer to the MVSTs;
- use of waste containers and casks to truck waste overland to the MVSTs;
- deployment of a tracked, remotely operable vehicle with an on-board pump (i.e., Environmental Specialties Group (ESG) Manufacturing Technology's TracPump™ (see Berglin 1997 and ESG 1997);
- deployment of a chopper pump (PIT HOG™) to break up large-diameter solids and subsequent transfer to BVEST for further processing before transfer to the MVSTs; and
- deployment of a centrifugal pump used to pump the sludge to BVEST W-23 for further processing before transfer to the MVSTs.

After a review and consideration of the basic concepts, the first option, enhancement of existing GAAT TWRS and SCS to facilitate transfer to BVEST for further processing prior to transfer to the MVSTs, was selected for further evaluation. A detailed description of the concepts is provided in Lewis et al. 2000. Table 4, which is taken from that report, summarizes the advantages and disadvantages of each concept.

Table 4. Advantages and disadvantages of the heavy waste retrieval concepts

Option	Advantages	Disadvantages
1. Tank in-Tank	• Ability to control "batch" characteristics • No LLLW impacts • Allows use of other GAAT for secondary containment	• Need design-No FY 1999 funds available • $0.5-$1 M Capital investment • Winter construction–Need spring FY 2000 • Schedule impacts • New system-Startup challenges • Waste in clean tank • Smaller batches to MVSTs based on operating characteristics of TWRS and tank size • Possible removal of tank dome • Additional D&D[a]
2. Use additional existing mixers (Russian, Flygt, Pulsair)	• Equipment and/or equipment design in hand • Low capital investment	• Uncertain performance • Likely to leave significant residual • More equipment moves • Operating schedule–slower removal rate may not meet goal
3. Cask/Bucket Truck	• Minimize waste volume • Eliminate need for conditioning • Potential for direct shipment to NTS[b]	• Transportation • Cask unloading at the MVSTs • Potential impact to sludge removal from the MVSTs • Safety & environmental documentation • Cask cost
4. ESG TracPump	• May eliminate the need for a booster pump • Equipment available from another DOE program	• Requires additional development and testing • Flooded suction line results in incomplete cleaning and inefficient operation
5. PIT HOG chopper pump	• May eliminate the need for a booster pump • Low cost	• Flooded suction line results in incomplete and inefficient operation • Requires additional design, development, and testing
6. ESG centrifugal pump	• No booster pump required if SCS used • Low cost	• Requires modifications • Too heavy for MLDUA • May require intermediate storage tank • Flooded suction line results in incomplete cleaning and inefficient operation
7. Use TWRS to pump Tank W-9 to W-23. Use AEAT Technology to mix and pump waste to the MVSTs	• TWRS, SCS, and AEAT proven technology • TWRS, SCS, and AEAT equipment in-hand • Minimal capital investment • Minimum schedule impact • May eliminate need for grinders	• Requires booster pump • Difficult valve box modification • Potential water balance–LLLW operations impact • Put waste in 'clean' but active tank • Potential need for WAC waiver • May use previously cleaned inactive GAAT tank for supernatant recycle

[a] D&D = deactivation and decommissioning.
[b] NTS = Nevada Test Site.

Once the basic concept was determined, a number of variations were developed and considered. These variations included the following:

- TWRS with two jet pumps and overhead transfer line for gravity feed to BVEST;
- TWRS with two jet pumps, SCS, and overhead transfer line for gravity feed to BVEST;
- TWRS with one jet pump, slurry consolidation tank, DiscFlo pump, SCS, and overhead transfer line for gravity feed to BVEST;
- TWRS with one jet pump, slurry consolidation tank, DiscFlo pump, SCS, and grade-level transfer line to BVEST; and

- TWRS with one jet pump, slurry consolidation tank, booster pump, SCS, and grade-level transfer line to BVEST.

Again, Lewis et al. 2000 provide a detailed description of these options and outlines the decision-making process. Table 5, taken from that report, summarizes the advantages and disadvantages of each option.

Table 5. Advantages and disadvantages of the alternatives to using the Tank Waste Retrieval System and Sludge Conditioning System for the Heavy Waste Retrieval System

Alternative	Advantages	Disadvantages
1. TWRS with two jet pumps and overhead transfer line for gravity feed to BVEST	• No excavation for transfer line • Low-pressure transfer • Low probability of clogging • Lowest cost	• Overhead radioactive waste transfer line • Transfer line protection, shielding, design considerations • Two-stage transfer • No control of particle size to BVEST
2. TWRS with two jet pumps, SCS, and overhead transfer line for gravity feed to BVEST	• No excavation for transfer line • Low-pressure transfer • Control of particles size to BVEST • Low probability of clogging • Small incremental cost	• Overhead radioactive waste transfer line • Transfer line protection, shielding, design considerations • Two-stage transfer • Uncertainty over pumping requirements for flow through SCS
3. TWRS with one jet pump, slurry consolidation tank, DiscFlo pump, SCS, and overhead transfer line for gravity feed to BVEST	• No excavation for transfer line • Reduced waste inventory in transfer line • Control of particles size to BVEST • Low probability of clogging	• Overhead radioactive waste transfer line • Possible transfer line pressurization by DiscFlo pump • Transfer line protection, shielding, and design considerations • Requires consolidation tank • DiscFlo pump reliability • Increased complexity and cost • Requires in-tank or large-capacity consolidation tank for large submersible pump
4. TWRS with one jet pump, slurry consolidation tank, DiscFlo pump, SCS, and grade level transfer line to BVEST	• Protected transfer line • Control of particles size to BVEST • Maximum use of existing system configuration	• Excavation for transfer line to BVEST • Requires consolidation tank • DiscFlo pump reliability • Increased complexity and cost • Requires in-tank or large-capacity consolidation tank for large submersible pump
5. TWRS with one jet pump, slurry consolidation tank, booster pump, SCS, and grade level transfer line to BVEST	• Protected transfer line • Control of particles size to BVEST • Improved reliability	• Excavation for transfer line to BVEST • Requires consolidation tank • Requires modification to SCS • Requires supernatant pumping system or additional process water

Technology Applicability

Other Potential Applications

The HWRS was designed to meet the specific needs of the GAAT OU for removal and transfer of dense, mixed-waste sludge from a consolidation tank to a distant processing facility. Similar problems are likely to exist throughout the DOE complex, including Fernald, Hanford, INEEL, the SRS, and other sites at the ORNL.

Other Application Considerations

Applicability of the HWRS technology to other, similar, problems will depend on a number of factors. Among the factors that should be considered are:

- Tank geometry—diameter, depth, location with respect to surface;
- Tank access—number, size and relative location of tank risers;
- In-tank environment—obstacles, sludge depth, explosive atmospheres;
- Waste properties—density, contaminants, corrosiveness, presence of non-pumpable waste; and
- Existing systems—tank superstructures, transfer piping, and valving.

Patents/Commercialization/Sponsor

Patent/Licensing Issues

The HWRS was developed by the ORNL. This technology is available for licensing/reuse by contacting the Office of Technology Transfer, UT-Battelle, (865) 576-2577.

The Hose Management Arm—A patent application entitled “Apparatus with Teleoperated Arm” was filed with the U.S. Patent Office in July 1998.

Commercial Involvement

Several participants in the development of the HWRS are subcontractors to UT-Battelle, which manages the ORNL for DOE. These subcontractors included, The Providence Group, Inc., Tetra-Tech NUS, Inc., and XL Associates.

Sponsors

The Robotics Crosscutting Program and Tanks Focus Area sponsored the development of the HWRS and its various components (listed below). The ORNL Environmental Management Program, which is managed by Bechtel Jacobs Company LLC for DOE, also provided oversight of the system deployment and operation.

- WaRTS
  - WSCS
  - SPS
  - Control System
- WD&C
  - CSEE
  - HMA
- Houdini/Houdini-II
- MLDUA
- SCS
  - SCM
  - SMTL

In addition, the Houdini and Houdini-II also received funding from the National Energy Technology Laboratory (NETL) (formerly Federal Energy Technology Center [FETC]), EM-50 Industry Program.

SECTION 5
COST

Methodology

Development and operation of the HWRS were less expensive than the baseline approach, installation and operation of a large (~20,000 gal), above-ground, batch mixing tank. A cost comparison between the two approaches is provided, and cost savings are estimated from the difference. Capital, operating, and deactivation and decommissioning (D&D) costs for the baseline are estimates. Actual capital and operating expenses associated with the HWRS are combined with estimated D&D costs for analysis purposes.

Cost Analysis

- HWRS Actual Costs
  - Cost for design, fabrication, test, and installation of HWRS — $492K
  - Cost for operation at tank W-9 — $64K
  - D&D cost estimate — 15K
  - Total cost for HWRS — $571K

- Baseline (Large Above-ground Batch Tank) Estimated Costs
  - Cost for design, fabrication and installation of a 20,000-gal batch tank (includes foundation, above-ground shielding, pipe lines, level monitors) — $900K
  - Mixing and transfer systems — $250K
  - Operating costs — $64K
  - D&D cost estimate — 50K
  - Total cost for batch tank — $1264K

Cost Conclusions

Development and operation of the HWRS cost less than half the estimated cost for installing a temporary batch tank for storage, mixing, and transferring the waste from tank W-9 to the ORNL active waste system. Because of the contaminated soil in the tank farm area, installation of an underground batch tank was not feasible. Reuse of an existing tank at the STF was not practicable because tank W-9 was the last tank to be cleaned; all others were already clean and could not have sludge waste reintroduced into them. There has been no attempt to install a waste-storage tank like this batch tank in the main ORNL area in the past few decades. Given the applicable safety and regulatory issues, the actual cost for this approach could be much larger than the estimate given above. The HWRS provided a means of cleaning out the last tank in the STF without the complexity of creating a large above-ground liquid-waste storage and processing facility. A cost saving in excess of $600K was realized.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

Waste removal from the GAAT OU tanks was performed in accordance with requirements and plans contained in the approved Interim Record of Decision (IROD) for the GAAT OU, Jacobs Engineering 1997.

No special permits are required to operate the HWRS. Environmental studies and permits required by CERCLA and/or the Resource Conservation and Recovery Act (RCRA) may be required depending on the specific application of the HWRS.

System components replaced during preventative and corrective maintenance and expended tools and PPE generate a secondary waste stream. Contaminated system components will also be added to the secondary waste stream upon completion of the cleanup task.

Regulatory issues related to the type of hydraulic fluid used on the MLDUA and Houdini-II are briefly outlined in U.S. DOE-OST 1998b and U.S. DOE-OST 1999, respectively.

Safety, Risks, Benefits, and Community Reaction

Remote operation of the HWRS during waste–removal and –transfer operations significantly reduces the risk to workers involved in the cleanup operation. Out-of-tank equipment does require manual operation or adjustment; however, the majority of that work is performed during non-transfer shifts when the risk of exposure is also reduced. Work in glove boxes follows standard practices, such as negative pressure, glove checks, proper bag-in and bag-out procedure, and other radiological controls and surveillance measures.

In addition to the radiological and contamination hazards associated with this system, standard industrial hazards associated with process operations, hoisting and rigging, and operation of large machines also exist. Good industrial hygiene and safety programs have proven adequate, and no extraordinary precautions have been required.

Development, deployment, and demonstration of the HWRS was guided by GAAT project documentation, specifically, the IROD for the GAAT OU, Jacobs Engineering 1997. Because the HWRS has contributed only to the overall remediation of the GAAT OU, the nine specific CERCLA criteria were not addressed separately from the GAAT Remediation Project.

Overall public and community response to the GAAT Project has been favorable. There has been no specific public response to the development, deployment, or operation of the HWRS. The most likely potential for negative publicity would come from an unexpected loss of containment and leaking a portion of the mixed waste into or onto uncontaminated areas. Pre- and post-operational checks, equipment inspections, careful process, and strict adherence to operational procedures reduce the likelihood of this type of event.

SECTION 7
LESSONS LEARNED

Implementation Considerations

For the most part, the HWRS performed as intended during final cleanup of GAAT OU tank W-9. As with the deployment of any new system; however, there was an opportunity to note deficiencies and make recommendations for improvements.

Implementation considerations and lessons learned from deployment of the TWRS and SCS are well documented in the references and will not be detailed here. Documents U.S. DOE-OST 1998b and U.S. DOE-OST 1998a provide implementation considerations for the MLDUA and CSEE, respectively. The performance of these two systems during the first part of the GAAT TS is described in Blank et al. 1998. Implementation considerations for the Houdini are outlined in U.S. DOE-OST 1999. The performance of the WD&C during the GAAT Remediation Project is provided in Depew et al. 2001.

Comments from WSCS and SPS operators suggested some additional improvements that should be considered in future deployments of similar systems. Recommendations include:

- Secondary containment windows or viewing ports—The addition of viewing ports or windows in the covers for the WSCS and SPS would have been useful in monitoring and troubleshooting the systems.

- SPS secondary containment leak detector—While no leaks in the SPS were experienced, a leak detector in the bottom of the secondary containment would provide valuable advance notice in the event of such a leak.

- Greater margin in self-priming head for air diaphragm pumps—The installation of the air diaphragm pump used to draw supernatant out of the supernatant reservoir attempted to take full advantage of the advertised suction lift of 22 ft. When difficulty was experienced in priming and maintaining prime on the suction side of the pump, additional supernatant had to be added to the supernatant reservoir to reduce the suction lift at the pump inlet.

- Seal sparge line against sludge migration—Initial design of the air-water sparge at the bottom of the surge tank called for an o-ring seal to prevent the migration of sludge into the sparge line. Subsequent “refinement” of the design eliminated the o-ring seal. Cold testing did not reveal a problem with the refined design. However, following deployment in the STF, sludge is suspected to have migrated into the sparge line, causing partial blockage of the sparger. This reduced the effectiveness of the sparger, but it did not significantly hinder operations. Periodic (approximately once each hour) opening of the T1 drain valve was required to prevent the heavier sludge in the surge tank from clogging the drain.

- Flow totalizer in the waste stream—Instrumentation in the SMTL provided the operators with information on the instantaneous flow rate. By monitoring the flow rate and estimating the nominal flow rate, the operator could estimate the total volume of waste delivered during a given period of time. The addition of a re-settable, remotely indicating flow totalizer would be useful in maintaining accurate waste-transfer balances.

- Surge-tank volume—The volume of the surge tank will be bounded by physical limitations, such as installation location and operational issues, such as shielding, accident analysis, etc., but, as a general rule, larger surge tanks will provide increased operational efficiency and operator flexibility. Batch type transfers (such as those required during the final portion of the W-9 waste removal campaign) are most efficient with large waste volumes.

Technology Limitations and Needs for Future Development

The HWRS was designed to meet specific requirements of the GAAT OU waste-removal and waste-remediation effort. Schedule, cost, and operational constraints precluded the development of a "universal solution." The approach selected was appropriate for the problem at hand and attempted to take maximum advantage of systems already deployed or constructed in the GAAT STF. As such, it may not be applicable or appropriate for similar subsequent efforts, and additional development will be required. For example, the system, as installed at the GAAT OU, did not require and therefore did not include hardware for solids size reduction (e.g., a grinder[8]). Depending on waste properties and waste-transfer requirements, subsequent systems may require this type of functionality.

Technology Selection Considerations

The HWRS approach (i.e., using a surge tank and supernatant pumping system to maintain flow during sludge waste transfer) was selected based on cost, reliability, and schedule considerations. Tables 3 and 4 provide details about the trade-offs for the various options considered.

[8] The loop originally provided in the PCM for a grinder was used for the installation of the waste-transfer pump, P1.

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APPENDIX B

ACRONYMS AND ABBREVIATIONS

AEAT	Atomic Energy Authority Technology
BOP	Balance of Plant
BVEST	Bethel Valley Evaporator Service Tanks
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
Ci	curies
CSEE	Confined Sluicing End Effector
D&D	deactivation and decommissioning
diam	diameter
DOE	Department of Energy
dof	degree of freedom
EM-50	DOE, Office of Science and Technology
ER	Environmental Restoration
ESG	Environmental Specialties Group
FCE/CB	Flow Control Equipment/Containment Box
FETC	Federal Energy Technology Center
ft	Feet
GAAT	Gunite and Associated Tanks
gal	gallon(s)
gal/min	gallons per minute
GSEE	Gunite Scarifying End Effector
GUI	Graphical User Interface
HEPA	High Efficiency Particulate Air
HMA	Hose Management Arm
h	hour
HWRS	Heavy Waste Retrieval System
in.	inch
INEEL	Idaho National Engineering and Environmental Laboratory
I/O	Input/Output
IROD	Interim Record of Decision
ITSR	Innovative Technology Summary Report
lb	pounds
LDUA	Light Duty Utility Arm
LLLW	Low Level Liquid Waste
LSEE	Linear Scarifying End Effector
min	minute
MLDUA	Modified Light Duty Utility Arm
MVST(s)	Melton Valley Storage Tank(s)
NETL	National Energy Technology Laboratory
NTF	North Tank Farm
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
OU	Operable Unit
P1	HWRS waste stream pump
P2	HWRS supernatant pump
PCM	Primary Conditioning Module
PPE	Personal Protective Equipment
psi	pounds per square inch
PW	process water
RCRA	Resource Conservation and Recovery Act
ROV	Remotely Operated Vehicle

rpm	revolutions per minute
sfcm	Standard Cubic Feet per Minute (measured at Standard Atmosphere)
SCM	Sludge Conditioning Module (pseudonym for PCM)
SCS	Sludge Conditioning System
SMTL	Slurry Monitoring Test Loop
SPS	Supernatant Pumping System
SRS	Savannah River Site
SS	stainless-steel
SSU	Seconds Saybolt Universal (a measure of viscosity used for low to medium viscosity fluids)
STF	South Tank Farm
T1	HWRS surge tank
T2	HWRS supernatant reservoir
TMS	Technology Management System
TS	Treatability Study
TWRS	Tank Waste Retrieval System
UST	Underground Storage Tank
VAC	Volts, Alternating Current
WAC	Waste Acceptance Criteria
WAG	Waste Area Grouping
WaRTS	Waste Removal and Transfer System (pseudonym for the combination of the WSCS, SPS, P1 pump and associated controls)
WD&C	Waste Dislodging and Conveyance System
WSCS	Waste Stream Consolidation System
wt %	weight percent