INNOVATIVE TECHNOLOGY
Summary Report

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Gunite Scarifying End Effector

Tanks Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Gunite Scarifying End Effector

Tech ID 2384

Tanks Focus Area

Demonstrated at
Oak Ridge Reservation
Oak Ridge, Tennessee

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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. Reports are also designed for readers who may recommend that prospective users consider a specific technology.

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 the technology's advantages to the DOE cleanup effort in terms of system performance, cost, and effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. They also include information about the technology's commercial availability and its readiness for implementation. ITSRs are intended to provide summary information. More detailed information is available from references listed in an appendix.

DOE has made an effort to provide key data describing the performance, cost, and regulatory acceptance of the technology. Any omissions of information not available at the time of publication are noted in the text.

All published ITSRs are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1
SUMMARY

Technology Summary

Overview
The U.S. Department of Energy (DOE) field-tested and deployed the Gunite Scarifying End Effector (GSEE) during the remediation of the Gunite and Associated Tanks (GAATs) at the Oak Ridge Reservation (ORR). Contamination stored for decades had penetrated into GAAT walls and could not be effectively removed with lower pressure water jets. By reconfiguring the water jets of the Confined Sluicing End Effector (CSEE) and adding an ultrahigh-pressure pump (UHPP), the GSEE, deployed on the Modified Light Duty Arm (MLDUA), was able to remove contamination embedded in the surface of GAAT walls. This technology has the potential for substantial cost savings in cleaning DOE's underground storage tanks.

History of Gunite Tanks
Gunite tanks were built between 1943 and 1951 to store radioactive and hazardous chemical waste from weapons material processing at the Oak Ridge National Laboratory (ORNL). Later, ORNL used these tanks to collect radiochemical and hazardous wastes from nuclear energy research and development. The tank walls were constructed by spraying a concrete mixture (gunite) over a steel reinforcement mesh, similar to the process used in fabricating some swimming pool walls. Waste retrieval operations revealed that 90% of wall contamination was embedded in the first 1/8 inch of the gunite, but existing technologies were unable to dislodge the contaminants. To help attain tank closure, innovative technologies were needed that would complement existing technologies developed to conduct waste retrieval and tank cleaning operations.

How It Works
The GSEE uses three powerful high-pressure water jets capable of both scaling and scarifying gunite tank walls (see Figure 1). Jet pressures of 6,000–10,000 pounds per square inch (psi) were used to remove surface scales. Jet pressures up to 22,000 psi were used to scarify gunite walls. Jet pressure was supplied by a UHPP with a 40,000-psi capability; however, water jet pressure was limited to 22,000 psi to avoid unacceptable lateral stress to the MLDUA and to avoid excessive removal of gunite.

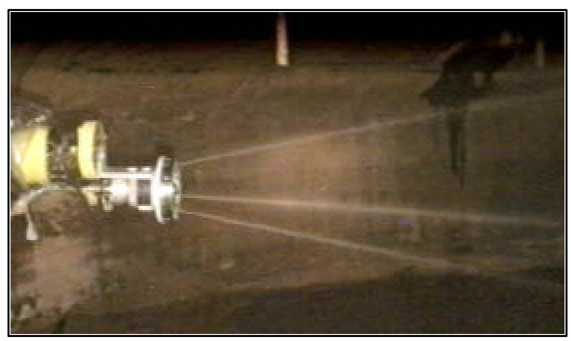

Figure 1. The GSEE scarifying waste inside a GAAT tank.

Potential Markets
The GSEE can be used to clean interior tank surfaces at the following DOE sites:

- Savannah River Site (SRS)
- Idaho National Engineering and Environmental Laboratory (INEEL)
- Hanford Site
- West Valley Demonstration Project (WVDP)

Advantages over Baseline
The baseline technology for cleaning tank walls is past-practice sluicing, which is traditionally performed by lowering a nozzle into a riser opening and directing a stream of water 10–40 ft at solids on the floor of a tank or on tank walls. Large volumes of water are used to suspend solids in a slurry, which is immediately pumped out. Because of the large distance between the nozzle and the solids, the impact force of the water is only about 200 psi (DOE 1998a). Obstructions within tanks can prevent some locations from receiving the direct impact of the water.

Tests with the CSEE showed that its maximum pressure of 6,500 psi was sufficient to remove loose scale but was insufficient to remove contamination embedded in the tank walls. With a changed configuration of water jets and pressure increased to as high as 22,000 psi, the CSEE evolved into the GSEE, which had adequate pressure to remove the surface of gunite tank walls.

Demonstrated advantages of the GSEE include the following:

- more efficient removal of contamination from tank walls,
- faster completion of tank scarifying and cleaning operations, and
- lower overall deployment costs.

Demonstration Summary

The GAAT Remediation Project, closely coordinated with the Tanks Focus Area and the Robotics Crosscutting Program, developed and deployed a suite of technologies to successfully retrieve waste and clean the GAATs. The GSEE was adapted from the CSEE to clean the GAAT walls at ORNL. The GSEE is part of an integrated retrieval and cleaning system that includes the UHPP, Tank Riser Interface and Containment (TRIC), MLDUA, a Hose Management Arm and tether, and the Collimated Analyzing Radiation Probe (CARP). Other technologies deployed as part of the GAAT Remediation Project include Houdini, Waste Dislodging and Conveyance System, CSEE, and Hose Management Arm. The entire suite of technologies was used to achieve tank cleaning in preparation for closure.

The GSEE was first used in Tank W-6 between April and August 1998. Between September 1998 and March 1999, the GSEE was used in Tank W-7. The most recent deployment was in Tank W-10 between May and October 1999 (Glassell, Burks, and Glover 2001).

Key Results
Initial deployments in Tank W-6 provided operational experience at low pressures. Key results from the deployment of the GSEE and associated high-pressure technologies in Tanks W-7 and W-10 include the following:

- Overall radiation levels of walls in Tank W-7 were reduced by 50–60% in about one-fourth of the time observed in trials using the CSEE.
- Overall radiation dose rate was reduced by 59–66% in Tank W-10.
- Radioactive contamination associated with wall scale was reduced by 98% in Tank W-10.

Parties Involved in the Demonstration
The following organizations were closely involved in the demonstrations described in this report:

- Pacific Northwest National Laboratory (PNNL)
- ORNL
- Waterjet Technology, Inc.
- NLB Corporation

Commercial Availability and Readiness
The GSEE was designed and fabricated for the ORR GAAT Remediation Project by Waterjet Technology Inc. based on the CSEE design from the University of Missouri–Rolla and collaboration with PNNL. The UHPP is commercially available. For the cleaning of GAATs, the UHPP was fabricated by NLB Corporation and shipped to ORNL.

Contacts

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Licensing

Dan Alberts, Waterjet Technology, Inc. (WTI), Kent, Washington, (253) 872-1366. WTI main office, (253) 872-1925. WTI is the subcontractor to PNNL that designed and manufactured waste retrieval end effectors. WTI can build the GSEE or can modify the design for individual client applications.

Other

All published Innovative Technology Summary Reports are available on the Office of Science and Technology (OST) Web site at http://ost.em.doe.gov under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The Tech ID for the Gunite Scarifying End Effector is 2384.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Demonstration Goals and Objectives
The goal was to remove the 1/8-inch of the gunite surface containing 90% of wall contamination without affecting the integrity of the tank wall.

Description of the Technology
The design of the GSEE was based on the CSEE (Tech ID 812) using the same main chassis and motor (Mullen 1997a). The GSEE has a similar array of water jets, but they are aimed outward instead of inward. A large standoff hub (Figure 2) replaces the conveyance inlet on the CSEE. The UHPP can generate pressures up to 40,000 psi; however, GSEE pressures were limited to 22,000 psi to avoid excessive lateral stress to the MLDUA. At 22,000 psi the GSEE was able to scarify gunite tank surfaces. It can remove more than 1/4-inch of fine aggregate concrete at a rate of 9 square inches per second when fitted with 0.022-inch nozzles. At 22,000 psi the GSEE used 5.25 gallons per minute (gpm) of process water.

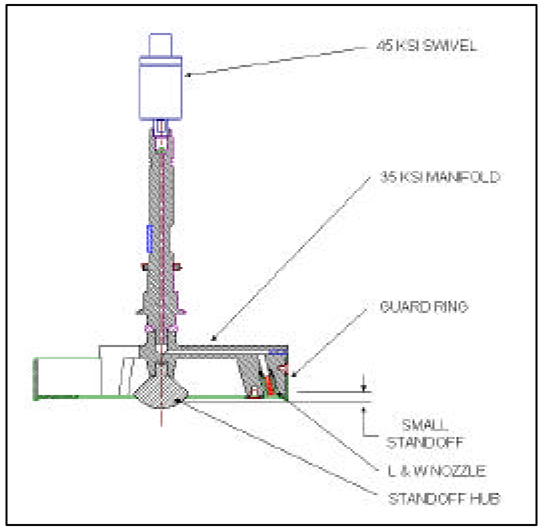

Figure 2. GSEE manifold assembly.

Relationship to Other Scarifier Technologies
Development of scarifier technology and design has evolved since fiscal year 1992 when the Multi-Function Scarifier/Conveyor Project (Tech ID 861) first started as the seed project for scarifiers under OST's Underground Storage Tanks Integrated Demonstration (Bamberger et al. 1994). Figure 3 shows the timeline and evolution of scarifier technologies developed under OST sponsorship.

The GSEE tool is based on the High Pressure Scarifier (HPS, also referred to as the "Ultra High Pressure Scarifier"), which employs pressures up to 40,000 psi. The HPS was originally designed as a process test for the now-abandoned Long Reach Arm developed for single-shell tank retrieval at Hanford (Hatchell 1997b). The Lightweight Scarifier was a small version of the HPS developed for use with the Light Duty Utility Arm (Hatchell 1997a). The CSEE was developed as a similar cleaning and retrieval system, but with maximum water jet pressures of 10,000 psi (DOE 1998a). This system was selected for sludge removal in the ORR gunite tanks in part to avoid penetration of the tank walls (Mullen 1997b). Later, when a major portion of contamination was discovered as both a surface scale and embedded in a 1/8-inch surface layer of the interior gunite tank wall, ORNL attempted to use the CSEE to scarify tank walls (Billingsley et al. 1998). The converging jets of the CSEE cleaned too small an area, and the water pressure was insufficient to dislodge wall surface materials. The CSEE design was then modified, resulting in the GSEE. The main differences include operating at pressures up to 22,000 psi, water jet nozzles that are divergent and shoot water outwards, and the absence of a suction for removing waste materials. Although the GSEE is an offshoot of the CSEE, it is not considered a retrieval tool.

Major Elements of the Technology and Support Equipment
Major elements of the equipment that support the operation of the GSEE include the following:

- UHPP shown in Figure 4
- TRIC enclosure
- MLDUA shown in Figure 5
- A tether-handling system attached to the TRIC enclosure
- CARP to measure contamination before and after scarification

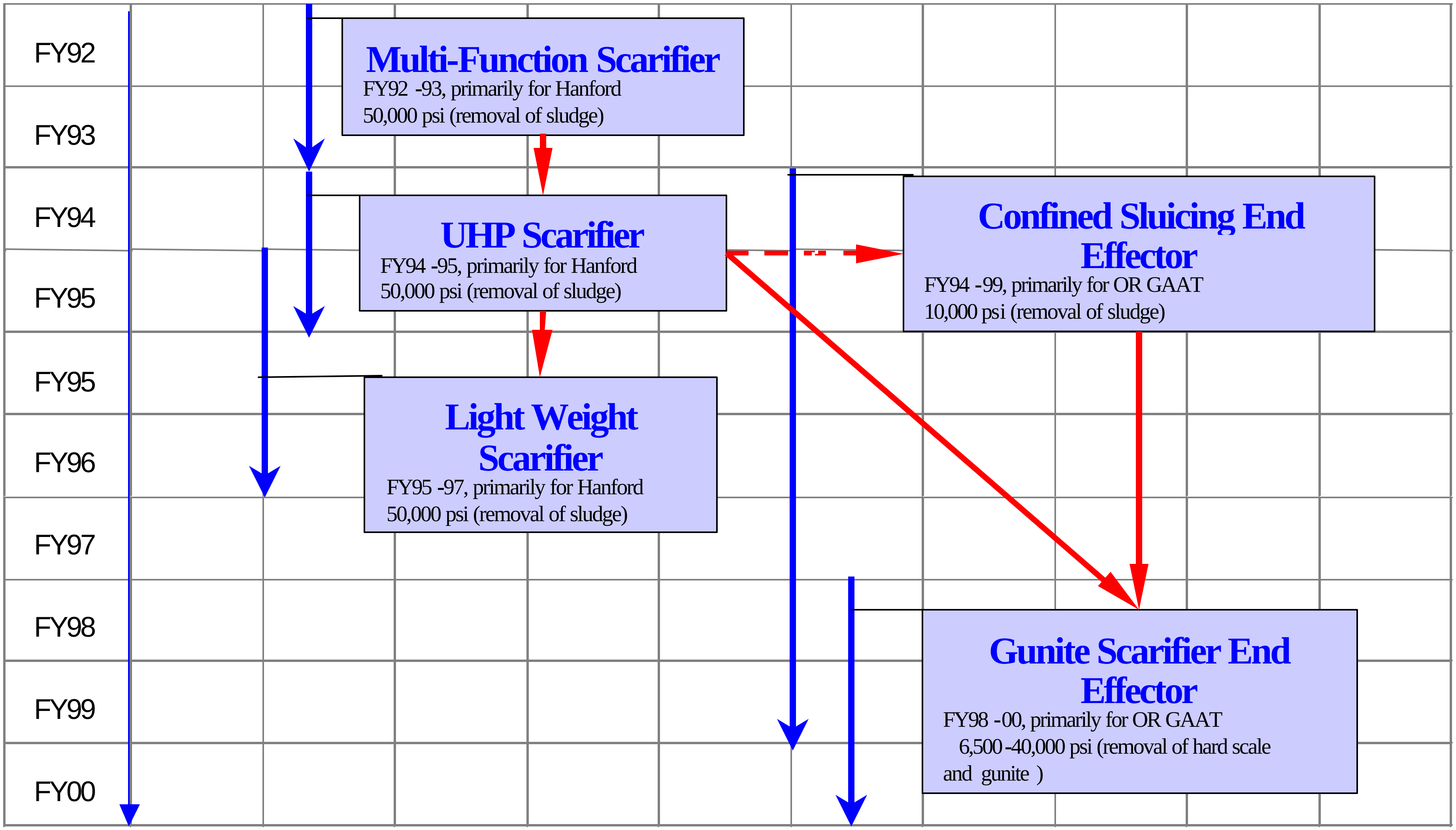

Figure 3. Timeline and Evolution of Scarifier Technologies under OST Sponsorship

Figure 4. Ultrahigh-pressure pump skid.

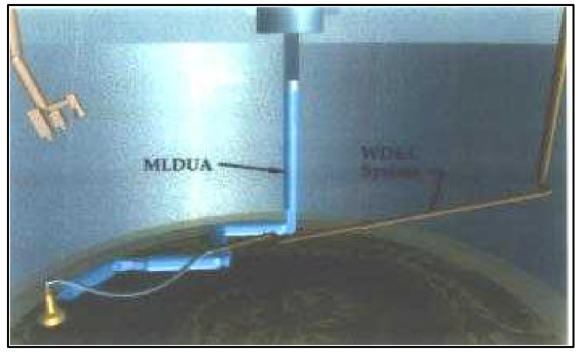

Figure 5. Modified Light Duty Utility Arm deploying a tank cleaning tool.

The UHPP is a skid-mounted pumping system that can provide process water to the GSEE at pressures up to 40,000 psi but which was limited at ORR to 22,000 psi. The system consists of a pump assembly, diesel engine, high-pressure hose, pump and engine controls, and local and remote control panels.

The MLDUA is a robotic manipulator arm used for deployment of tank characterization and waste retrieval tools. The features of the MLDUA include a 45-ft vertical extension, 15-ft horizontal reach, and a payload of 200 pounds. It can be deployed through a 12-inch diameter riser.

The tether-handling system is attached to the TRIC enclosure, allowing simple and fast positioning in the tank.

System Operation

Operating Parameters and Conditions

The GSEE is attached to the MLDUA and deployed through a 12-inch diameter tank riser. Power and process water are provided to the GSEE through an umbilical cord arrangement controlled by a tether. Process water is delivered by the UHPP through a high-pressure hose. Pictures of the operation are taken by cameras located in the tank and fed to video monitors located in a control trailer outside the tank farm radiation area. The tank fogs up when the water spray is turned on (Billingsley et al. 1998).

The GSEE has a modular design developed to facilitate maintenance and allow interchange with components used in the CSEE. The manifold assemblies are also interchangeable. The GSEE motor is housed in a sealed canister that can be readily exchanged as a unit. The direct current motor rotates the jets at various speeds from 60 to 600 revolutions per minute. Table 1 shows major operating parameters.

Table 1. GSEE operating parameters

Parameter	Operational range
Working pressure	500–22,000 psi
Water jet rotation speed	60–600 rpm
Nozzle size	0.022–0.024 inches
Traverse speed	0.5–5 inches/sec

Materials, Energy, and other Consumables

The GSEE uses approximately 5.25 gpm of process water at the maximum 22,000-psi pressure. The UHPP used by ORNL was powered by a diesel engine, but other configurations can be employed.

Manpower Skills and Training Requirements
Special training is required to operate the GSEE due to the complexity and uniqueness of the various components. System operators are trained for approximately 5 months in a "cold-test" facility, where they perform activities similar to those expected in the actual waste tank.

Secondary Waste Stream Considerations
Because the scarifying fluid is water in small amounts, there are no special considerations for secondary waste designation, storage, and disposal. The added scarifying water is retrieved with the removed solids and processed as tank waste.

Potential Operational Concerns and Risks
GSEE pressures must be limited to 22,000 psi to avoid lateral stress on the MLDUA. If dynamic reaction forces exerted by the GSEE generate a vibration frequency near 1 hertz, severe vibration problems with the MLDUA could occur (Hatchell et al.1997). Prolonged scarification in one location can result in excessive GAAT wall deterioration. The MLDUA can be programmed to automatically move the GSEE along tank walls at a fixed distance. Manual control of the setback distance is not possible because the GSEE generates a mist that obscures visibility inside the tank (Billingsley et al. 1998).

Removal of the GSEE from the tank requires a decontamination ring to wash contamination back into the tank riser. During decontamination and maintenance, appropriate precautions for handling contaminated equipment must be observed to minimize worker radiation exposure.

SECTION 3
PERFORMANCE

Demonstration Plan

Several deployments of the GSEE took place since early 1998 in conjunction with the GAAT remediation project. The GSEE was first used in Tank W-6 between May and August 1998. Between October 1998 and March 1999, the GSEE was used in Tank W-7. The most recent deployment was in Tank W-10 between May and October 1999 (Glassell, Burks, and Glover 2001).

Major Objectives

State of Tennessee regulatory requirements for cleanup of the GAATs at ORR mandate radionuclide contamination removal efficiency to be at least 90%. This requirement was the driving factor in deciding to conduct wall-cleaning operations in addition to supernatant and sludge retrieval.

After the GAATs were originally cleaned by past-practice sluicing, characterization indicated that 90% of radioactive contamination in tank walls was embedded in the first 1/8-inch of the interior wall surface. In addition, it was found that the tank walls often contained a scale layer that accounted for a large portion of the contamination.

The CSEE was used during the initial wall-cleaning attempts in the GAATs, but it had inadequate water pressure and jet characteristics to effectively dislodge embedded contamination from the gunite walls. In Tank W-3, the CSEE reduced the radiation level on the walls by only 20% (Blank et al. 1998). For the GAAT applications, the GSEE was used at pressures up to 22,000 psi using diverging water jets (Lewis et al. 2000). This design allows for larger and faster coverage than that of the CSEE. In all the deployments of the GSEE, a major objective was to remove the scale layer of contamination and scarify the outermost layer of gunite.

Demonstration Results

The ORNL demonstrations of the GSEE were limited to maximum pressures of 22,000 psi. Limitations were imposed by the amount of thrust that could be sustained by the MLDUA, which held the GSEE. In certain tanks the pressure was limited by concern for the integrity of the gunite walls.

Wall Cleaning Tests in Tank W-6

A new movable platform was installed over the top of Tank W-6 in early 1998 to support the weight of the remediation equipment (DOE 1998b). Remediation equipment was moved from Tank W-4 to W-6 in February 1998. Measurement of background radiation began in April 1998 (Glassell, Burks, and Glover 2001). Prior to 1990, video cameras revealed serious deterioration of portions of the W-6 inside wall (Fricke and Chung 1995). Tank W-6 had been used to store acid waste, and pieces of gunite had fallen off the screening (Billingsley et al. 1998). The decision was made not to clean the tank wall using high-pressure water in the GSEE for fear of causing more wall damage. The entire tank was washed with a low-pressure rinse with the GSEE. A follow-up measurement of radiation showed that sufficient cleaning had been achieved. The MLDUA equipment was shut down on August 24, 1998 to prepare for the move to Tank W-7.

Wall Cleaning Tests in Tank W-7

MLDUA operations began in the Tank W-7 south riser on September 15, 1998 with an initial radiation survey. The walls showed no damage from contact with the waste material stored for years. The wall surface was cleaned with the GSEE at pressures in the range of 6,500-22,000 psi. The walls were surveyed to establish radiation levels both before and after the cleaning.

MLDUA operations and tank wall cleaning with the GSEE at the W-7 west riser occurred between November 17 and December 3, 1998. Cleaning through the north riser occurred between December 15, 1998 and February 11, 1999. Cleaning through the east riser occurred between March 2 and March 26, 1999 (Glassell, Burks, and Glover 2001).

The UHPP was fabricated by NLB Corporation and shipped to ORNL in September 1998. The UHPP system hardware was installed at the South Tank Farm during October and November 1998. The system was hydrostatically tested with the GSEE connected and the nozzles blanked off. Initial “hot” operations in Tank W-7 were intended to test the effectiveness of various combinations of UHPP operating parameters and to determine optimal UHPP/GSEE operating configurations.

During the tank cleaning process, the UHPP/GSEE was shown to be very effective, reducing radiation levels of tank walls by 50–60% in about one-fourth of the time required by the CSEE-based scarifying system (Harper 2000). In April 1999 the UHPP/GSEE equipment was relocated to Tank W-10.

Wall Cleaning in Tank W-10

W-10 tank cleaning efforts were initiated in May 1999 from the northwest riser location. Based on extensive experience in the previous GAAT, a regimen of sluicing, wall cleaning, and pumping of waste material from Tank W-10 to Tank W-9 (the designated waste consolidation tank) was followed. For tank wall cleaning, the UHPP was operated at pressures ranging 6,000–10,000 psi. This range was appropriate based on observed wall conditions.

The GSEE was positioned by the MLDUA at approximately 10–12 inches from the tank wall. It was moved across the wall at a traverse speed of approximately 1/2-inch per second until the scale layer was removed from all accessible wall areas. Baseline radiation dose rates were measured prior to the commencement of cleaning operations using the CARP, a characterization probe deployed by the MLDUA. Upon completion of UHPP/GSEE tank cleaning in the northern quadrants in June 1999, CARP measurements were conducted to determine the effectiveness of the GSEE. Postcleaning radiation dose rates from the northwest riser ranged 29–64 rads per hour (R/h). An overall dose rate reduction of approximately 66% was achieved in the northern quadrants of the tank (Harper 2000, see Table 2).

Table 2. Dose rate reduction in Tank W-10 walls

Tank walls	Precleaning dose rates (R/h)	Postcleaning dose rates (R/h)	Overall dose rate reduction (%)
Northern quadrants	72–144	29–64	66
Southern quadrants	48–162	29–60	59

With tank cleaning from the northwest riser completed, cleaning equipment was relocated to the Tank W-10 southwest riser in late summer of 1999. Precleaning dose rates at the tank walls in the southern quadrants were measured with the CARP and found to range 48–162 R/h. Wall cleaning from the southwest riser started in mid-September 1999. Operating parameters of the UHPP/GSEE were essentially identical to those used previously in the northwest riser. Postcleaning radiation dose rates varied 29–60 R/h, corresponding to a reduction of overall tank wall dose rates of approximately 59% in the southern quadrants of the tank (Harper 2000). Table 2 shows dose rate reductions achieved after GSEE wall scarification.

Pre- and postcleaning estimates of the curie (Ci) content in the tank wall scale were also made in the southern portion of the tank. Based on analysis of wall scale scrapings, approximately 1146 Ci was removed from the tank wall as a result of scarification by the UHPP/GSEE, leaving a residual of 17 Ci in the walls, corresponding to a removal efficiency of about 98%. Core analysis of the gunite material itself indicated that approximately 245 Ci of residual contamination remained in the 1/8-inch surface layer of the interior tank wall, for a total (scale + gunite) residual wall contamination of 262 Ci (Harper 2000).

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

The GSEE technology has been used for the cleanup of the GAATs at ORR. The GSEE and other high-pressure scarifier configurations have been considered for use at Hanford, SRS, and INEEL. The technology has applicability for cleaning industrial tanks requiring high-pressure surface cleaning, material removal from the surface of tank walls, or remote access and operations. The primary need is to remove hard waste deposits such as hardpan or saltcake radioactive waste found in DOE underground storage tanks or other contaminated surfaces.

In assessing the applicability of the GSEE technology for use in underground storage tanks or other waste removal operations, the following aspects should be considered and properly evaluated.

- Load on MLDUA—The payload of the MLDUA is limited to 200 pounds. This restriction requires consideration of the weight of the hose, gripper device, and the GSEE.
- Lateral forces on MLDUA—The pressure to be used for cleaning is limited by the lateral force limits on the MLDUA (Mullen 1997a). The MLDUA was limited to 22,000 psi.
- Fundamental frequency of the MLDUA—The first fundamental frequency of the MLDUA is approximately 1 hertz. Any frequency generated near 1 hertz is likely to pose severe vibration problems with the arm. This constraint drove the need to characterize the dynamic reaction forces exerted by the GSEE in all its modes of operation (Hatchell et al. 1997).
- Visibility—Substantial misting and occlusion of visibility occur while operating the GSEE against tank walls. The use of a computer-programmed MLDUA is required to maintain a constant distance from the tank wall.
- Automatic control—Given that water jet energy dissipates rapidly with jet length, aggressive high-pressure scarifying may need to be conducted using robotic control to maintain close tolerances for the standoff distance. This procedure requires careful surface mapping and planning of a scarifying path that can be programmed for automated control. Fogging of cameras prevents manual control.
- Tank access—In waste tank applications, access risers must be large enough to allow easy deployment and maneuverability of equipment. Separate risers are needed for each piece of equipment to be installed inside the tank. The MLDUA is deployed inside the tank through a 12-inch riser. Risers up to 24 inches in diameter could be needed to deploy waste removal equipment.
- In-tank obstructions—The ability of the GSEE and supporting equipment to access all tank areas may be hindered by obstructing objects such as pipes, risers, pumps, and gratings. Other technologies may be needed to remove the blocking objects before commencing tank wall cleaning.
- Tank loading—During a tank waste retrieval operation, the addition of heavy equipment loading on the tank dome must be considered. This concern has been successfully addressed by constructing a platform that bridges the tank and transfers the weight of required equipment to the soil around the outside diameter of the tank (Figure 6).
- Tank environment—Special tank atmospheres such as flammable environments must be considered.

Figure 6. Load-bearing platform bridging underground storage tanks at Oak Ridge.

Competing Technologies

Equipment that uses pressurized water for cleaning ship hulls, brick buildings, and heat exchanger tubes has been commercially available for years. WVDP demonstrated an ultrahigh-pressure (UHP) system for cutting and cleaning radioactive equipment using commercial technology (Wiedemann and Standish 1986). The UHP system expelled water pressurized up to 35,000 psi through an orifice to form a high-energy jet stream for cleaning concrete and steel. When garnet grit was added to the stream of water exiting the orifice, the UHP system was used for wet grit blasting and for cutting concrete and steel. The power unit was contained in a skid-mounted steel frame with an attachment to allow lifting by a crane or transport by a forklift. WVDP added a heated weather shelter to keep the water systems from freezing during winter weather (WVNSC 2000). The flexible hoses that transport the high-pressure water are available in a variety of lengths, making it possible to operate the working tools inside contaminated facilities several hundred feet from the power unit. The power unit can be located in a distant, uncontaminated area.

The Oak Ridge GAAT Remediation Project used a competing technology to scarify the walls of the final two GAATs, Tanks W-8 and W-9. The competing technology was a Linear Scarifying End-Effector (LSEE) held by a mechanical crawler positioned on the floor of the tank. The mechanical device was on a tether, which allowed the LSEE to be used on all portions of the tank walls from just one riser location (Fitzgerald, Falter, and Depew 2001). This was a cost-saving, timesaving approach compared to the MLDUA/GSEE system, which required a setup period of 2–4 weeks for each of four quadrants to reach all portions of the tank wall.

The LSEE had not undergone rigorous cold testing to define operating parameters. Initial operations required a period of adjustment to learn which operating pressures tipped the mechanical crawler (and the LSEE) over into the layer of highly caustic sludge on the floor of the tank. There was no capability to water-wash the caustic sludge that coated the LSEE and the crawler. In Tank W-8 the electrical controls of the LSEE corroded and shorted out, rendering the cleaning system inoperable. In Tank W-9 the sludge eventually jammed the drive screws of the crawler and rendered the cleaning system inoperable. These experiences are expected to yield a more robust system after appropriate design modifications (Fitzgerald, Falter, and Depew 2001).

Scarifying the walls produced a dense mist that made it extremely difficult for the teleoperated vehicle to maneuver around the tank while maintaining a constant standoff distance with the scarifying end effector. The MLDUA could have the cleaning paths preprogrammed and then essentially “fly blindly” while executing the required wall-cleaning operations.

Demonstrated advantages of the GSEE include the following:

- more efficient removal of contamination from tank walls than that achieved by the CSEE,
- faster completion of tank scarifying when attached to a preprogrammed MLDUA, and
- lower overall deployment costs.

Patents/Commercialization/Sponsor

The GSEE was designed and fabricated for ORNL by Waterjet Technology, Inc. with the collaboration of PNNL. The GSEE design is based on the CSEE design from the University of Missouri–Rolla. The UHPP is commercially available and was fabricated for ORNL by the NLB Corporation.

SECTION 5
COST

Cost Savings Considerations

The GSEE is one component of a suite of technologies used in radioactive waste retrieval and tank cleanout. The baseline technology for the GSEE is past-practice sluicing. Assessment of waste retrieval equipment using the GSEE showed the following cost savings aspects:

- The GSEE achieves a level of tank cleaning that complies with regulatory requirements for closure. Clean tanks do not require costly tank monitoring and maintenance activities (DOE 1998b).
- The added volume of water is much smaller than with past-practice sluicing, thereby reducing the cost of treating the retrieved waste.
- The time required to complete tank cleaning is much shorter, resulting in sizeable cost reduction.

Earlier attempts at cleaning contaminants embedded in tank walls using the CSEE did not result in satisfactory cleanup levels. Further, the inherent design of the CSEE limited the speed at which wall cleanup could progress. The GSEE was developed based on the CSEE design with modifications to eliminate the drawbacks observed in using the CSEE as a wall scarifier. As a result, the use of the GSEE improved the performance of the CSEE-equipped tank retrieval and cleaning system. It provided a higher level of tank cleanup through the effective removal of contaminated wall scale and scarification of the outer layer of wall materials. These aspects increased the likelihood of accelerated tank closure and contributed to the cost savings.

Cost Analysis

The use of past-practice sluicing for cleaning tanks resulted in a baseline schedule of 2013 with a baseline cost estimate of $196 million (DOE 1998a). The cost of developing the GSEE included the development costs of the CSEE, plus the modifications to the CSEE that resulted in the GSEE. The costs associated with the development and operations of the CSEE are presented here as a comparative cost basis. Table 3 shows the CSEE development costs but does not include the costs of research and development of the precursor scarifying concepts, as presented in Figure 3.

Table 3. Comparative costs from the development of the CSEE

Step	Cost ($K)
Conceptual development (University of Missouri–Rolla)	63
Functional requirements and system conceptualization	63
Prototype testing at PNNL Hydraulic Test Bed	100
Conceptual design at Waterjet Technologies, Inc.	100
Fabrication of first CSEE and controller at Waterjet Technologies, Inc.	100
Project management and other costs	105
Total	**531**

Operating costs depend largely on the cleanup site and the equipment used to deploy the CSEE. The overall cost to operate the waste retrieval equipment previously used at Tank W-3 at ORNL was approximately $25,000 per day (DOE 1998a), including operating crew labor, project management, and consumable items.

Cost Conclusions

Following the deployment of the GAAT waste retrieval equipment at several ORNL tanks, the improved efficiency of tank cleaning provided a basis to estimate potential cost savings. Two major components of cost savings are based on the following estimates:

- The GAAT remediation project was completed 12 years ahead of schedule (2001 instead of 2013), resulting in $120 million of reduced costs, from an estimated $196 million to $76 million.
- The elimination of tank monitoring and maintenance activities resulted in a costs savings of $0.4 million annually (DOE 1998b).

Past-practice sluicing requires less hardware and lower equipment costs than the installation/operation of the MLDUA/GSEE system. However, given the speed at which the MLDUA/GSEE performs, overall costs and cleanup times are greatly reduced, resulting in significant overall savings. Furthermore, past-practice sluicing simply cannot be used in leaking tanks because of the large amount of water added. Past-practice sluicing does not have sufficient pressure to deal with harder waste layers left in tanks after the soft material has been sluiced away.

The use of the GSEE increases the likelihood of tank closure as a result of removing contamination embedded in tank walls, meaning that GSEE deployment can yield potential cost savings as discussed above.

SECTION 6
REGULATORY AND POLICY ISSUES

The use of any technology for environmental remediation and waste management is constrained by state, federal, and local regulations, which differ at each DOE site. State and local regulations can vary widely, despite some efforts by the U.S. Environmental Protection Agency (EPA) and states to encourage regulatory reciprocity, i.e., acceptance of testing from one state or region to another. The regulatory approval and permitting of the GSEE will likely be integrated with the entire tank cleaning and retrieval system. No regulatory or permitting issues have been identified with the GSEE and the tank cleaning and associated retrieval system. It does not appear to be controversial in terms of public acceptance.

Regulatory Considerations

The GSEE is a component of a tank cleaning and retrieval system that was the central feature of the GAAT Remediation Project. The Federal Facility Agreement (FFA) among DOE, the EPA, and the Tennessee Department of Environment and Conservation (TDEC) integrates all regulatory requirements applied to the cleanup efforts conducted on ORR. The GAAT Remediation Project complied with the FFA (Billingsley et al. 1998).

Characterization activities and studies on potential remediation approaches were performed from the late 1980s through early 1994 (Billingsley et al. 1998). The results were compiled in a combined remedial investigation/feasibility study, which identified significant uncertainties in the risks presented by the gunite tanks. To resolve the uncertainties, DOE, EPA, and TDEC agreed to perform a treatability study under the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act.

Two and a half years after the start of the GAAT Treatability Study, the tank cleaning system was assembled and undergoing performance testing. DOE, EPA, and TDEC developed a two-phased strategy to complete the gunite tank remediation (DOE 1998b).

An interim remedial action was conducted to remove the sludge and liquid waste from eight gunite tanks and clean the tank shells with the CSEE and GSEE. Waste removal from the GAATs was performed in accordance with requirements and plans contained in the approved “Record of Decision for Interim Action: Sludge Removal from the Gunite and Associated Tanks Operable Unit, Waste Area Grouping One, Oak Ridge National Laboratory, Oak Ridge, Tennessee,” DOE/OR/02-1591 & D3 (Harper 2000).

A final remedial action will be conducted to close the tank farm sites in concert with the ORNL main plant closure process resulting from the Bethel Valley Record of Decision (DOE 1998b).

Safety, Risks, Benefits, and Community Reaction

Because of the decreased risk associated with remote operation of the GSEE, the tank cleaning and retrieval process complies with “as-low-as-reasonably-achievable” principles. The normal procedures for working with radioactive material are applicable. Training of tank farm operators is required to teach how to install, operate, remove and decontaminate the tank cleaning system.

Worker Safety and Risks

Safety and risk issues associated with the deployment of the GSEE as part of the tank cleaning and retrieval system are minimal. Because the main components of the tank cleaning and retrieval system, including the GSEE, are operated remotely, no major worker safety issues arise through using this equipment. Because the support systems are located above the tank, mostly on the platform, and require hands-on operation, worker exposure is limited. Contact maintenance must be performed using appropriate contaminated-equipment precautions. Equipment operators are required to undergo specialized training in a cold-test facility.

The primary contamination control activity is the operation of a decontamination spray ring that washes contamination of the GSEE as it is removed from a riser. Operators use a handheld spray nozzle to remove contamination from locations on the GSEE that cannot be reached by the spray ring water.

Community Safety

GSEE technology has no history of accidents. Community safety was ensured by a safety analysis that established controls on the GAAT Remediation Project (Platfoot 1998). DOE requires similar safety analyses wherever GSEE may be used in the future. Future applications must comply with safety guidelines of DOE, EPA, and other applicable regulatory agencies.

Benefits

The use of the GSEE increases the likelihood of tank closure as a result of removing contamination embedded in tank walls, meaning that GSEE deployment increases the potential cost savings related to monitoring and maintenance, as discussed earlier.

Community Reaction

Community reaction has been positive to the tank cleaning and retrieval system, including its components such as the GSEE. The public has supported DOE efforts to reduce public risk by removing waste from older tanks.

SECTION 7
LESSONS LEARNED

Implementation Considerations

When considering use of the GSEE, the most important issue is to assess whether the process will compromise the integrity of tank walls. The GSEE should not be used in cases where the jet pressure would damage wall materials beyond the desired effect and degrade the strength of the wall. Other issues to be carefully evaluated before using the GSEE in tank cleaning operations include the following:

- state and characterization of tank wall surfaces,
- depth of contamination embedded in tank walls,
- jet pressure and GSEE standoff distance for removing wall scale,
- jet pressure and standoff distance for scarifying wall materials, and
- use of MLDUA to automatically control standoff distance.

Technology Limitations and Needs for Future Development

The GSEE is being considered for use in other applications at other DOE sites. The Lightweight Scarifier (Bamberger 2000), a variation of the GSEE, is also under consideration for use in Hanford waste tanks. The GSEE is ready for implementation without further major development effort. Scarifier technology employed in waste tank cleaning operations in the future—whether for use in gunite walls, saltcake, or hardpan waste—may require only engineering design modification or scale-up.

Some of the limitations of this technology include the following:

- Obtaining the training to use the integrated retrieval and cleaning system equipment.
- Adequate number and size of risers for the MLDUA/GSEE technology to work efficiently.
- The number of obstacles in the tank may make other parts of the integrated retrieval and cleaning system, such as the MLDUA, less maneuverable.

APPENDIX A
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APPENDIX B
ACRONYMS

CARP	Collimated Analyzing Radiation Probe
Ci	curie
CSEE	Confined Sluicing End Effector
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FFA	Federal Facility Agreement
GAAT	Gunite and Associated Tank
gpm	gallons per minute
GSEE	Gunite Scarifying End Effector
HPS	High Pressure Scarifier
INEEL	Idaho National Engineering and Environmental Laboratory
ITSR	Innovative Technology Summary Report
LSEE	Linear Scarifying End Effector
MLDUA	Modified Light Duty Utility Arm
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OST	Office of Science and Technology
PNNL	Pacific Northwest National Laboratory
psi	pounds per square inch
RI/FS	remedial investigation/feasibility study
R/h	rads per hour
SRS	Savannah River Site
TDEC	Tennessee Department of Environment and Conservation
TMS	Technology Management System
TRIC	Tank Riser Interface and Containment
UHP	ultrahigh-pressure
UHPP	ultrahigh-pressure pump
WTI	Waterjet Technology, Inc.
WVDP	West Valley Demonstration Project