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INNOVATIVE TECHNOLOGY
Summary Report

Confined Sluicing End Effector

Tanks Focus Area

Prepared for
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Office of Environmental Management
Office of Science and Technology

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Summary Report

Confined Sluicing End Effector

OST Reference #812

Tanks Focus Area

Demonstrated at
U.S. Department of Energy
Oak Ridge Reservation
Oak Ridge, Tennessee

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if 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 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 online at http://em-50.em.doe.gov under "Publications".

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SECTION 1

SUMMARY

Technology Summary

A Confined Sluicing End-Effector (CSEE) was field tested during the summer of 1997 in Tank W-3, one of the Gunite and Associated Tanks (GAAT) at the Oak Ridge Reservation (ORR). It should be noted that the specific device used at the Oak Ridge Reservation demonstration was the Sludge Retrieval End-Effector (SREE), although in common usage it is referred to as the CSEE (see Figure 1). Deployed by the Modified Light-Duty Utility Arm (MLDUA) and the Houdini remotely operated vehicle (ROV), the CSEE was used to mobilize and retrieve waste from the tank. After removing the waste, the CSEE was used to scarify the gunite walls of Tank W-3, removing approximately 0.1 in of material.

Figure 1. The Confined Sluicing End-Effector (also called the Sludge Retrieval End-Effector) in a service stand.

The CSEE uses three rotating water-jets to direct a short-range pressurized jet of water to effectively mobilize the waste. Simultaneously, the water and dislodged tank waste, or scarified materials, are aspirated using a water-jet pump-driven conveyance system. The material is then pumped outside of the tank, where it can be stored for treatment.

There are several advantages in using the CSEE over past-practice sluicing (the current baseline technology for tank waste retrieval). These advantages include the following:

- Short standoff distance for sluicing provides greater control of sluicing operations.
- Less water is used to remove the waste.
- CSEE can retrieve a greater portion of the waste heels that resist mobilization by long-range sluicing jets.

The following potential disadvantages may affect the selection of the CSEE for waste retrieval operations:

- Small amounts of water must be added to the tanks in order to operate the CSEE.
- Operating the CSEE on an arm or a remotely operated vehicle is expensive and requires specialized training.

This technology has the potential for use at other DOE sites for tank cleaning. The CSEE-equipped retrieval system used in Tank W-3 can be used in tanks constructed from different materials (e.g., gunite, carbon steel) with access ports large enough to deploy the equipment. Additionally, the CSEE may be modified for specific mission requirements (e.g., a larger unit may be needed for retrieval of waste in large tanks.)

Demonstration Summary

The CSEE was demonstrated in Tank W-3, which is located in the North Tank Farm at the Oak Ridge National Laboratory (ORNL), part of the ORR. The North Tank Farm is located in Bethel Valley, roughly in the center of ORNL. Equipment was first deployed in Tank W-3 in June 1997. The Tank W-3 waste retrieval and wall scarifying was completed in September 1997.

The gunite tanks vary in size from 8 ft to 50 ft in diameter and in curie content from zero to several thousand. Tank W-3 (see Figure 2) is moderate in size, with a diameter of 25 feet and fairly low curie content. This tank provided an excellent opportunity to retrieve waste from a tank with only moderate risk.

Key results of the GAAT retrieval work included removal of the following:

- approximately 7,200 gal of supernate above the sludge,
- 5,500 gal of sludge at the bottom of the tank, and
- 0.1 in of scale from the tank walls.

The retrieval of the waste and scarifying of the walls resulted in

- removal of approximately 354 Curies (about 97% of the contamination originally in the tank) and
- less than 0.5% of the total tank volume left as final residual waste.

The DOE's Office of Science and Technology (OST) and the Oak Ridge Environmental Management Program worked together to develop the GAAT retrieval system, including the MLDUA, the Hose Management Arm (HMA), Houdini, and the CSEE.

The plan at ORNL is to use the retrieval equipment in the GAAT to clean several of the gunite tanks and transfer the waste to Melton Valley Storage Tanks (MVST). Tank W-9 will be used for staging the transfer of supernate and sludge to the MVST. Tank W-9 itself will be the final tank to undergo retrieval. Waste will be treated, packaged, and then shipped to the Waste Isolation Pilot Plant for disposal.

Figure 2. Location of gunite tanks.

Contacts

Technical
O. Dennis Mullen - Cognizant Engineer, PNNL, Richland WA (509) 375-2395
Peter Gibbons - TFA Technology Integration Manager, NHC, Richland WA (509) 372-0095

Management
Jeff Frey - DOE's Tanks Focus Area Lead, DOE-Richland, Richland, WA (509) 372-4546
Kurt Gerdes, Program Manager, Tanks Focus Area, DOE EM-50 Gaithersburg, MD (301) 903-7289

Other
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TECHNOLOGY DESCRIPTION

Overall Process Definition

OST programs, technologies, and problems. The OST Reference # for the CSEE is 812.

The goals of the demonstration at GAAT were to retrieve all visible waste and to scarify the walls with 7,000-psi jets.

The CSEE is the portion of Waste Dislodging & Conveyance System (WD&C) used to dislodge waste and introduce the waste into the jet pump conveyance system. A schematic of the CSEE is presented in Figure 3. Figure 4 illustrates the fielded system, including the CSEE and the deployment package.

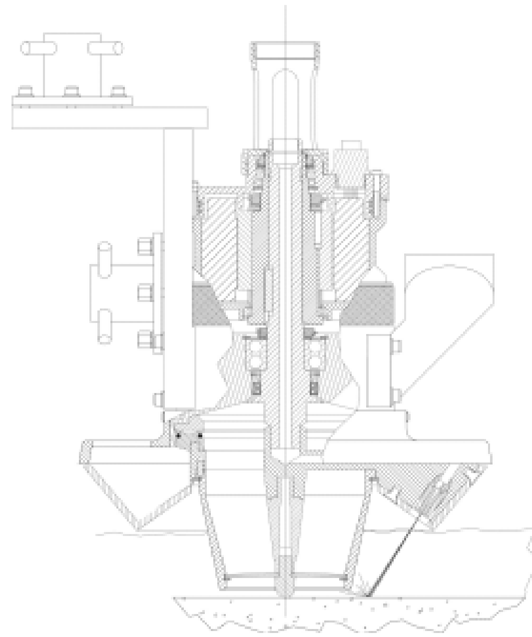

Figure 3. Schematic of the CSEE.

The CSEE uses three rotating water-jets to direct a short-range pressurized jet of water to effectively mobilize the waste. The jets are positioned around the circumference of an intake port to direct the waste towards a suction line. Inside the inlet ports, the jets collide, which tends to cancel the energy of the jets and confine the water at lower pressures. A direct current (DC) motor rotates the jets at various speeds, from 60 to 600 rpm.

A remote control module is used to control the CSEE motor. The

Figure 4. GAAT retrieval equipment.

module provides feedback on motor speed, current, and fault conditions.
The sluicing/scarifier mechanism is coupled to a jet pump conveyance system to remove waste from the tank as the process dislodges it. The dislodged waste is aspirated into a central inlet conveyance port through a screen. The WD&C uses a jet pump located on the HMA to draw a vacuum and convey material from the central inlet of the CSEE, through a short flexible hose, and into the jet pump that pushes the material to the surface. The jet pump conveyance system can handle gas, liquid, divided solids, and multiphase flows; the predominant mode for waste retrieval is dilute multiphase flow. Significant operating parameters are detailed in Table 1.

Table 1. CSEE operating parameters.

Parameter	Range
Working Pressure of Jets	200-10,000 psi
Rotational Speed	60-200 rpm
Nozzle Size	0.032 in.
Effector Traverse Speed	0-2 in./sec

The jet pump operates by injecting high-pressure water into a venturi mixing section in the pump. The jet pump can be used to pump supernate, dry materials, or sludge. By mixing and diluting the sludge, the jet pump facilitates transport of the sludge.

Except when the inlet is submerged, air is entrained with the material being conveyed. The contaminated air is sent into a receiving tank with the rest of the retrieved material, where it is filtered and vented with the existing tank systems.

System Operation

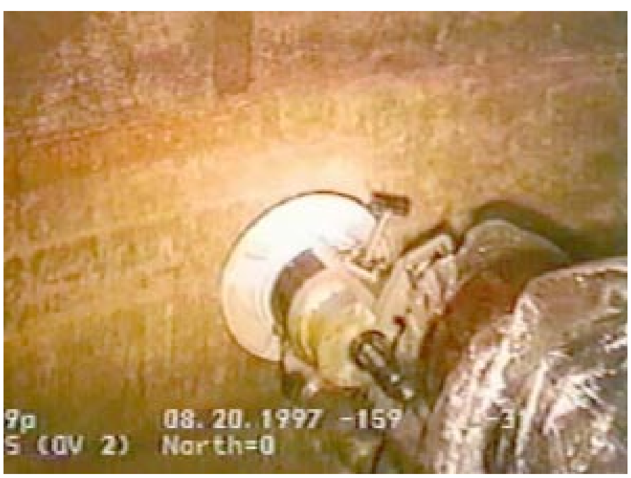

Figure 5. CSEE in position for wall scarifying.

The CSEE is deployed through a tank riser by the HMA. This arm tracks the movement of the CSEE and supports the load from the conveyance line and the high-pressure hose. The MLDUA or Houdini is deployed through a separate riser. A gripper on the MLDUA or Houdini grasps the CSEE.

Operation of the retrieval system is performed remotely from the control trailer outside the tank farm radiation area. From the control room, the CSEE-equipped MLDUA or Houdini can be operated with the assistance of video monitors serving several in-tank cameras. Figures 5 and 6 show the CSEE in operation.

Figure 6. CSEE removing sludge.

Because the equipment is deployed inside an underground tank, local weather is not usually a concern. If the winds are high, the MLDUA mast can be lowered from the vertical position.

The retrieval system does create additional waste. Most of the secondary waste is from water added for sluicing, equipment decontamination, and flushing operations. In addition, a small amount of hydraulic fluid leaked from the deployment equipment. The type of fluid and the small amount added do not require any special considerations for waste designation or storage/disposal.

The CSEE is remotely deployed and operated, limiting worker exposure. During operation, contact maintenance must be performed with appropriate contaminated-equipment handling precautions.

Special training is required to operate the retrieval system. Because the deployment systems are unique, the system operators trained for approximately 5 months in a cold test facility. Activities similar to those expected in the actual waste tank were performed with teams of operators.

SECTION 3

PERFORMANCE

Demonstration Plan

The North GAAT tank farm includes Tanks W-3 and W-4. Tanks W-3 and W-4 had a limited number of access risers. To allow the deployment of the retrieval equipment into Tanks W-3 and W-4, additional risers were added to the tanks. These risers allowed access from above ground into the tank.

A large, load-bearing platform was constructed over the top of Tanks W-3 and W-4 to direct the loads from the retrieval equipment (MLDUA, retrieval pumps, Houdini support system, etc.) away from the tank domes and to the surrounding soil. The platform also supported electrical and high-efficiency particulate air (HEPA) filtered exhaust equipment (see Figure 7).

Figure 7. Load-bearing platform over Tanks W-3 and W-4.

Treatment Performance

The specific retrieval goals agreed to by the regulators for this demonstration were to retrieve all visible waste and to scarify the walls with at least 7,000-psi jets.

Over the course of 3 months, the CSEE-equipped GAAT retrieval system

- retrieved approximately 7,200 gal of supernate above the sludge,
- retrieved 5,500 gal of sludge at the bottom of the tank, and
- scarified the tank walls (scale and approximately 0.1 in of gunite were removed from the surface).

The complete Tank W-3 retrieval project resulted in 41,800 gal of water added to the waste stream, a 3.3:1 ratio of water added to waste retrieved. This volume of water added included water used for the CSEE, the jet pump, flushing operations, and equipment decontamination. Of the retrieval activities, approximately

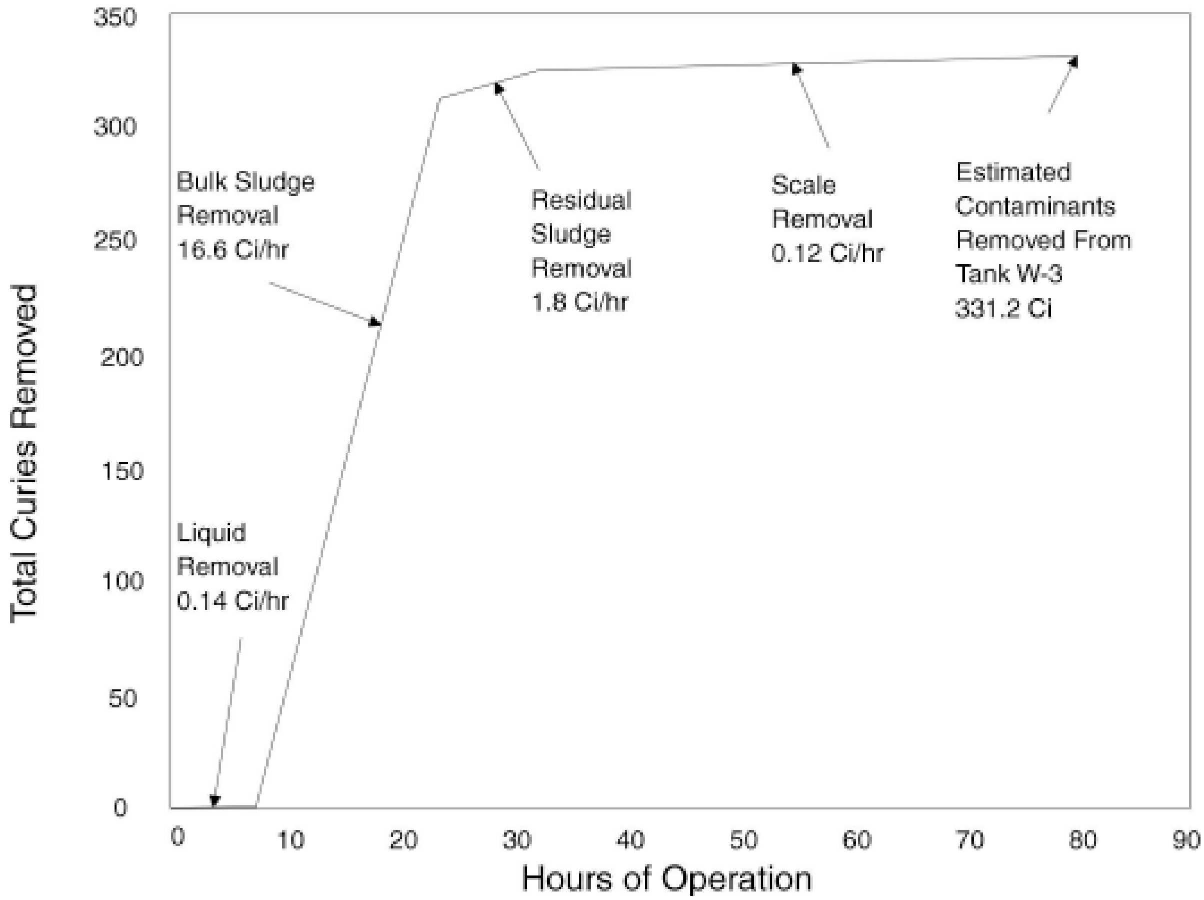

Figure 8. Summary of Tank W-3 cleaning efficiency.

one-third of the water used was for scarifying operations and two-thirds was from jet pump operations. Smaller water additions are expected for future operations.

The time required to remove the supernatant was 7.4 hours for an average rate of 973 gal/h. The 5,200 gal of bulk sludge (not including 300 gal that made up the last inch of material) was removed in 19 h of operation, yielding an average rate of 274 gal/h. Scarification of the walls lasted approximately 54 h (see Figure 8).

Approximately 354 curies were removed from Tank W-3 during the 80 hours of CSEE operation. Although most of the curie removal was achieved by retrieving the sludge, retrieval of the supernate and wall scarifying contributed as well.

The overall cleaning of Tank W-3 was very thorough. After completion of retrieval activities:

- Approximately 97% of the contamination originally in the tank had been removed.
- Less than 0.5% of the total tank volume was left as residual waste.

In conjunction with the other GAAT retrieval equipment, the CSEE has shown to be much more efficient for final cleanout than the baseline of past-practice sluicing for several reasons, including:

- The system is capable of removing virtually all of the tank waste, including a hard sludge heel and debris versus only bulk supernate and soft sludge.
- Less water is added, substantially reducing the increase in waste volume.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

The key problem with the GAAT was that it was unknown how the tanks were going to be cleaned, since earlier sluicing activities had failed to fully clean the tank. The characteristics of the waste were not well understood, and it was unknown how advanced technologies would clean the tank. The retrieval work in Tank W-3 resulted in a better understanding of the waste and included the complete cleaning of the tank.

The CSEE (or its derivative) deployed by the other GAAT retrieval equipment could be used to retrieve waste from other vertical tanks. The CSEE has proven to be effective in the removal of waste forms that include liquids, thick sludges, and concrete. MLDUA can be used to deploy the CSEE for automated work. Additionally, the Houdini can also be used to push waste to a location accessible with the MLDUA and the CSEE.

A system similar to the one used in the GAAT could be used in the high-level waste tanks at the Idaho National Environmental Eengineering Laboratory. These stainless steel tanks are overlaid by a series of pipes, which are supported by infrastructure; leaving a small space between the walls and the pipes. The light duty arm used to deploy this end effector supports a considerably smaller load capacity, and a more compact, lightweight CSEE system is being considered. The CSEE is also being considered for heel retrieval in tank C-106 as part of the Hanford Tanks Initiative.

In determining the applicability of the technology for other tanks, parameters that should be considered include the following:

- Tank access – access risers must be large enough to deploy the equipment. In this demonstration, the riser diameters required by the deployment systems were the limiting factor (i.e., 24 in for Houdini, 12 in for MLDUA).
- In-tank components – obstructions within the tank may hinder the equipment's ability to access all parts of the tank.
- Tank dome loading – equipment may need to be supported by a load-bearing platform.
- Tank atmosphere – special tank atmospheres such as flammable environments must be considered.

Competing Technologies

Past-practice sluicing is the baseline for retrieval of tank waste. Table 2 presents a comparison of the two technologies. Key disadvantages of past-practice sluicing include the following:

- proved incapable of removing the hard sludge heel
- would not remove wastes that were too large to enter the transfer pump
- excessive amounts of water (as much as 10 times the original waste volume) were added, increasing the resulting waste volume
- the large water additions necessary for this technology limits the usefulness of past-practice sluicing in a leaking tank

In tanks where hard heel removal is required, past-practice sluicing is not a viable option for preparing a DOE waste tank for closure.

Key benefits to using a system equipped with the CSEE include

- removal of supernatant,
- removal of the hard heel, and
- substantial reduction in the amount of water added .

Table 2 Water-jet-based retrieval technology comparison.

Criteria	Past Practice Sluicing	Confined Sluicing End Effector
Jet Pressure	200 psi	200 to10,000 psi
Retrieve salt cake wastes	Yes, those fractured by 200 psi liquid jets	Yes, those fractured by 10,000 psi liquid jets
Retreives sludge wastes	Yes	Yes
Retreives solid heels	No	Yes
Liquid accumulation in tank	~100,000 gallons	<~100 gallons
Suitable for leaking tanks	No	Yes
Waste retreival rates	0.2-8 gpm	In Tank W-3: Sludge: 4.5 gpm Supernate: 16.2 gpm
Deployment	Riser mast	Arm or vehicle
Remotely Operated	Yes	Yes
Maintainability	Pumps may be contaminated based on the source of the sluicer fluid	Pumps not contaminated
Removal	System removed through riser	System removed through riser

Patents/Commercialization/Sponsors

The demonstration of the CSEE-equipped GAAT retrieval system was a joint effort with many contributors. The CSEE design, fabrication and testing team included

- Pacific Northwest National Laboratory
- Water Jet Technology, Inc.
- University of Missouri-Rolla

SECTION 5

COST

Introduction

The CSEE-equipped GAAT retrieval activities save money in several ways, including

- completely cleaning tanks, eliminating the cost required to maintain them (monitoring liquid levels, performing site maintenance, etc.) and
- reducing the costs required to deal with added waste by eliminating waste storage or evaporating costs associated with the extra volume of water added to the tank during past-practice sluicing.

Cost Analysis

Table 3 reports the costs for the development, design, fabrication and testing of the CSEE.

Table 3. CSEE development costs.

CSEE Development Breakdown	Cost
FY95 conceptual development at Univeristy of Missouri-Rolla	$63K
FY95 functional requirements/system conceptualization	$63K
FY96 prototype testing at the Pacific Northwest National Laboratories Hydraulic Test Bed	$100K
FY96 CSEE conceptual design at Waterjet Technologies, Inc.	$100K
FY96 fabrication of the first CSEE and controller at Waterjet Technologies, Inc.	$100K
FY95-96 project management and miscellaneous costs	$105K

Operating costs will vary greatly depending on the deployment site and the equipment used to field the CSEE. The cost to operate the retrieval equipment at Tank W-3 was approximately $25,000 per day. This cost covers labor for the operating crews, project management, and consumable items.

Cost Savings versus Alternative Technologies

Using the CSEE-equipped GAAT retrieval system at ORNL will result in

- the GAAT remediation project being completed 11 years ahead of schedule (from 2013 to 2002) and $120 million under initial estimates ($196 million to $76 million) and
- approximately $400,000 annual savings by eliminating the need for tank ventilation, monitoring of tank liquid levels, periodically removing liquids, and performing site maintenance and access control.

The less extensive hardware requirements for past-practice sluicing result in lower equipment costs than the CSEE-equipped GAAT system. However, a direct cost comparision between past-practice sluicing and the GAAT system cannot be performed because of the increased capabilities of the GAAT system.

In very large tanks, a larger CSEE might be fielded in order to be cost-effective. Another alternative would be to use past-practice sluicing for bulk retrieval, and the CSEE would be fielded later to remove the heel. In conclusion, The CSEE is most cost-effective when deployed in smaller tanks or when past-practice sluicing cannot be used (such as in a leaking tank or when a hard heel is present).

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

In general, waste in storage tanks at DOE sites are subject to a number of different regulations and regulatory authorities.

Most of the waste is high-level waste derived from reprocessing of nuclear fuel, the disposal of which is governed by the U.S. Nuclear Regulatory Commission (NRC) as required by the Nuclear Waste Policy Act of 1982. DOE is responsible for safe storage and treatment of the waste.

Certain materials used in reprocessing may be designated incidental waste and may be treated and disposed of onsite as low-level waste (LLW). The final waste form must meet NRC LLW disposal requirements. A performance assessment of the disposal site must demonstrate adequate protection of the public from radiation exposure.

The hazardous constituents of the waste are subject to regulation under the Resource Conservation and Recovery Act (RCRA). Most states are authorized to implement RCRA, including permitting of hazardous waste treatment, storage, and disposal facilities.

Some of the tanks within the DOE complex were retired many years ago and contain legacy wastes. These may be subject to remediation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Waste storage and treatment facilities are also required to meet Clean Air Act and Clean Water Act requirements for airborne and liquid effluents. Requirements are typically implemented at the state or even local level for these statutes.

Treatment technologies are sometimes specified within compliance orders, such as Hanford's Federal Facility Agreement and Consent Order. These compliance orders are often limited to immobilization technologies (waste forms) or emission control technologies. There are several examples where compliance orders allow separate decision processes to occur, such as evaluation of alternatives in an environmental impact statement, through which a technical baseline is identified. Finally, engineering trade studies are used to select a specific technology to meet the baseline. These trade studies are performed at a level far more detailed than that which regulatory authorities typically address.

Safety, Risks, Benefits, and Community Reaction

Because the main components of the GAAT retrieval system are operated remotely, there are no major worker safety issues posed by using this equipment. The support systems are located above the tank, mostly on the platform, and do require hands-on operation. However, these systems do not present any special safety concerns for the workers.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The CSEE proved to be a useful tool for retrieval of a limited variety of waste forms and to be compatible with two significantly different deployment platforms (Houdini and the MLDUA). As the first such device to be deployed in actual waste, it represents an important first step, from which a great deal may be learned.

Further critique of the equipment is expected from the GAAT Treatability Study. Depending on the type of waste to be retrieved, the operational parameters and possibly the CSEE design may need to be “tuned” for the most efficient operation.

The planned operating mode of incrementally milling away the waste was not deemed the most productive or practical by the operators. Given the manipulator dexterity required to work freehand, operators will prefer to do so, and in some cases this may be the most productive mode.

An inlet-cleaning jet may be evaluated in the next design iteration. The idea incorporates a narrow fan-shaped cleaning jet to cover one side of the inlet/manifold interior, sweeping the entire interior as it rotates. This cleaning jet could be fed independently from a pump at the surface operating at whatever pressure is found effective.

The addition of a holster to the Houdini ROV would be useful for temporary parking of the CSEE when the ROV’s arm is needed for brief tasks.

Careful coordination of activities with more emphasis on water conservation could reduce the dilution ratio achieved in the Tank W-3 deployment.

The conveyance inlet screen is easily plugged and sometimes difficult to clear. Back-flushing with low-pressure process water may not be the most efficient method of clearing it since the expansion of the flow passage at the end effector makes it impossible to maintain much pressure or velocity against some of the troublesome areas. Each time the system is back-flushed, the water volume used is significant.

APPENDIX A

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APPENDIX B

LIST OF ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSEE	Confined Sluicing End-Effector
GAAT	Gunite and Associated Tanks
HEPA	high efficiency particulate air
HMA	Hose Management Arm
LLW	low-level waste
MLDUA	Modified Light-Duty Utility Arm
MVST	Melton Valley Storage Tanks
NRC	United States Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OST	Office of Science and Technology
psi	pounds per square inch
RCRA	Resource Recovery and Conservation Act
ROV	Remotely Operated Vehicle
SREE	Sludge Retrieval End-Effector
WD&C	Waste Dislodging and Conveyance