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Innovative Technology
Summary Report

Light Duty Utility Arm

Tanks Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Light Duty Utility Arm

OST Reference #85

Tanks Focus Area

Demonstrated at
Oak Ridge National Laboratory
and
Hanford Site Tank 241-T-106

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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 on the OST Web site at http://ost.em.doe.gov under "Publications".

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SECTION 1

SUMMARY

Technology Summary

The Light-Duty Utility Arm (LDUA) System is a mobile, multi-axis positioning system capable of deploying tools and sensors (end effectors) inside radioactive waste tanks for tank wall inspection, waste characterization, and waste retrieval. The LDUA robotic manipulator enters a tank through existing openings (risers) in the tank dome of the underground tanks. Using various end effectors, the LDUA System is a versatile system for high-level waste tank remediation. The LDUA System provides a means to deploy tools, while increasing the technology resources available to the U.S. Department of Energy (DOE). Ongoing end effector development will provide additional capabilities to remediate the waste tanks.

The LDUA has a seven degree-of-freedom design that allows the arm to reach around obstacles and position end effectors for in-tank operations. The LDUA provides the capability to perform in-tank operations by allowing off-riser access (areas other than directly below the riser). The system reduces worker exposure through remote operations, and reduces secondary waste generation through in situ operations.

Figure 1. Hanford truck-mounted LDUA

A modified version of the LDUA (MLDUA) has been developed for the Oak Ridge National Laboratory (ORNL). The MLDUA has the same capabilities as the LDUA with a slightly longer horizontal reach and greater payload capacity. The MLDUA is skid mounted as opposed to the truck-mounted LDUA. Because of the similar design and capabilities, the MLDUA will be implicitly included in the discussion of the LDUA, unless only the ORNL unit is being referred to.

Within the DOE complex, Hanford, ORNL, and Idaho National Engineering and Environmental Laboratory (INEEL) are the current users of the LDUA. Spar Aerospace Ltd, of Brampton, Ontario, Canada, under a subcontract to Westinghouse Hanford Company, designed and manufactured four arm and deployment systems. Technology development was performed under the guidance of the Tanks Focus Area (TFA). The Hanford unit (Figure 1) was demonstrated in a radioactive tank and is scheduled to support sampling and inspection for the Hanford Tanks Initiative. The MLDUA was deployed in FY97 to perform retrieval activities in ORNL's gunite tanks. Through February 1998, the MLDUA retrieved waste from two tanks. The INEEL unit was delivered and is being integrated with other balance-of-plant systems. Qualification testing and operator training are being conducted at a cold-test facility. The INEEL system will be used to sample tank heels to validate performance data supporting closure of high-level waste tanks at the Idaho Chemical Processing Plant. The fourth unit has been used in Hanford's cold-test facility to support field operations, application development, and operator training.

Demonstration Summary

In September 1996, Hanford's LDUA System was successfully demonstrated in Tank 241-T-106. The remote stereo viewing systems and gripper end effector were demonstrated in the tank.

At ORNL, the MLDUA was used to remove the waste from two gunite tanks, W-3 and W-4, from June 1997 through February 1998. The MLDUA, with the Houdini remotely-operated vehicle, deployed several tools required to remove the supernate, sludge, and debris as well as to clean the walls. The MLDUA is planned for retrieval activities in several more of ORNL's gunite tanks.

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Other

All published Innovative Technology Summary Reports are available at http://em-50.em.doe.gov under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference Number for Light-Duty Utility Arm is 85.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

Technology Schematic

The LDUA system was designed to meet current user requirements while maintaining flexibility for future needs. The deployed LDUA and support equipment are represented in Figure 2.

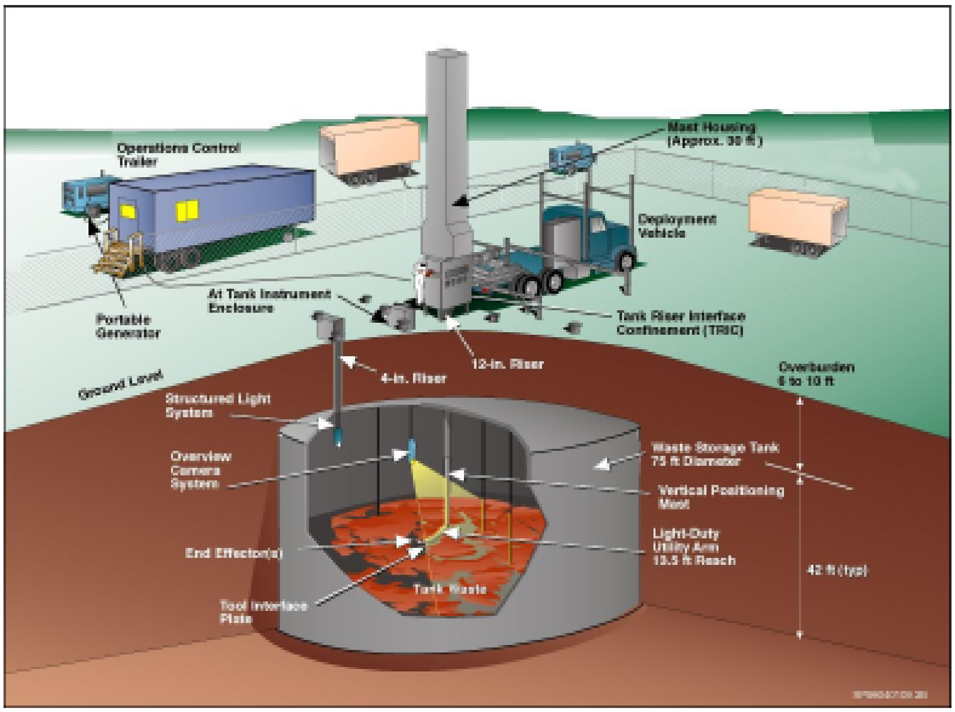

Figure 2. Schematic of deployed LDUA and supporting systems.

The LDUA arm with the seven degrees of freedom is shown in Figure 3.

The LDUA's features include the following:

- Designed to resist radioactive, corrosive chemical, and flammable gas environment.
- Seven degree-of-freedom arm attached to a two degree-of-freedom mast.
- 50-lb payload (200-lb for MLDUA).
- Vertical reach of 50 ft below grade.
- Horizontal reach of 13.5 ft (15 ft for MLDUA).
- Fits through a 12-in. diameter or larger riser.
- Programmable for automated sequences.
- Remotely operated from outside radiation areas.
- Tool interface plate provides the utilities and communications needed for many types of end effectors.

The system is functionally divided into major equipment subsystems and additional ancillary and support equipment. The subsystems include the following:

- Arm and deployment system.

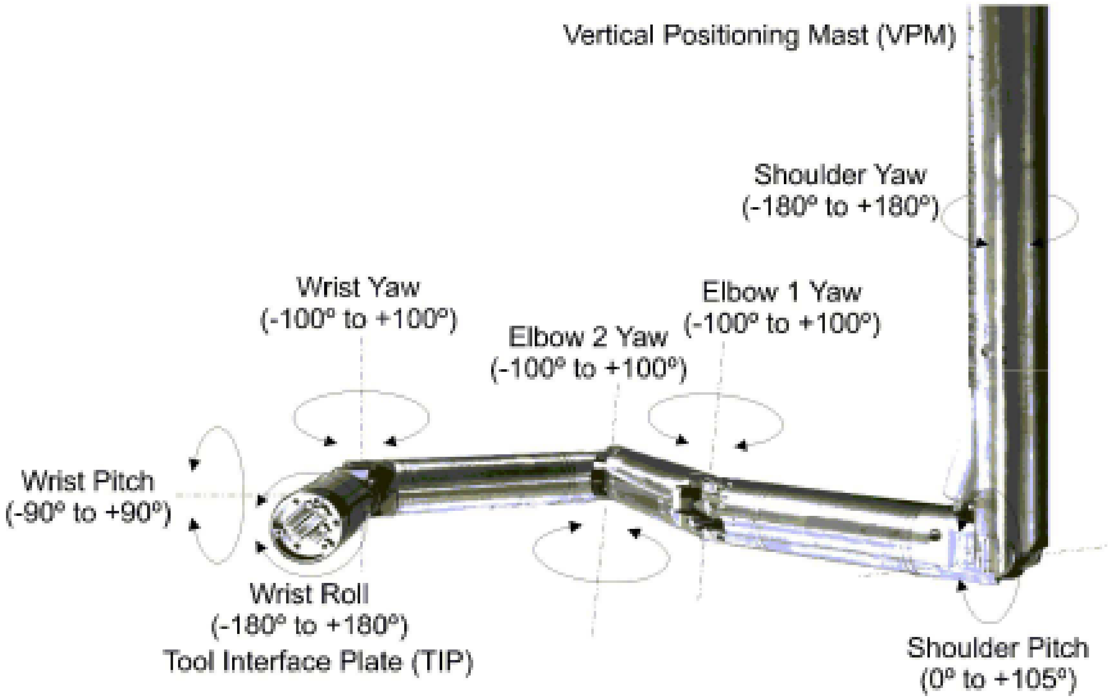

Figure 3. The LDUA (depicting all seven degrees of freedom).

- Tank riser interface and confinement system.
- Operations control center.
- Utilities and support systems.
- End effectors.

Cold-test facilities have been set up at Hanford, ORNL, and INEEL to train operations personnel and to test and qualify the systems for hot operations in the waste tanks at each site. These facilities have also been used for troubleshooting field equipment, planning operational campaigns, and continued applications development.

System Configuration

Arm and Deployment Subsystem

The arm and deployment subsystem consists of the robotic manipulator arm, the vertical positioning mast and mast housing, the deployment vehicle, and alignment positioning mechanisms.

The robotic manipulator has a seven degree-of-freedom kinematic design that provides dexterity for reaching around obstacles and orienting end effectors to perform in-tank operations (Figure 4). The maximum reach of the arm is 13.5 ft (15 ft for MLDUA) as measured from the shoulder to the wrist. The system is designed to allow deployment into tanks with very limited head space, allowing as little as 6 ft of clearance between the bottom of the tank riser (top of waste tank) and the waste surface. The arm provides a lifting capacity of at least 50 lb at maximum extension with high-precision accuracy and repeatability.

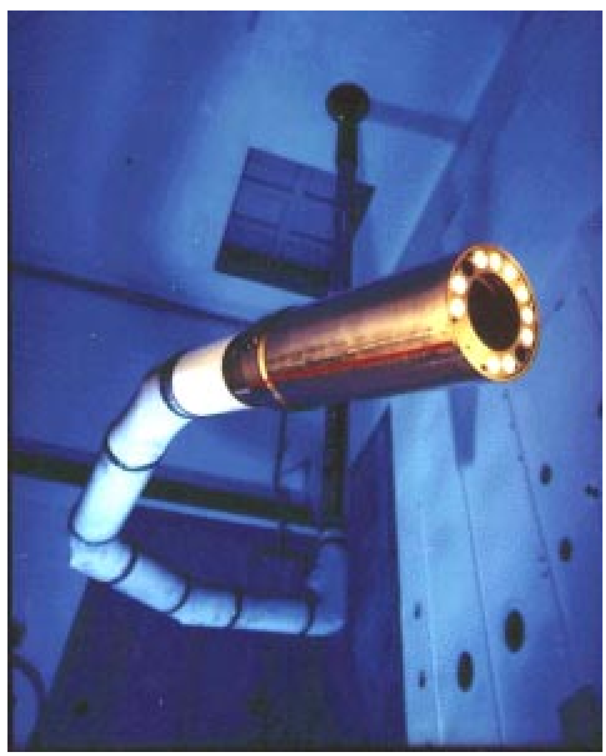

Figure 4. LDUA arm in Hanford's cold-test facility.

The extended capability to lift end effectors is up to 75 lb, with some compromise to positioning accuracy performance. To perform retrieval operations, the MLDUA has a lifting capacity of 200 lb.

The arm is mounted on the vertical positioning mast (VPM), which lowers the system into the tank. The VPM consists of nested telescoping tubes mounted in a confinement housing that provides a contamination control. The VPM extends to deploy the arm as far as 50 ft below grade. During transportation and storage, the mast housing (containing the retracted arm and mast) is lowered over the deployment truck or skid. An alternative trailer-mounted deployment platform was developed to reduce weight.

Tank Riser Interface and Confinement Subsystem

The tank riser interface and confinement (TRIC) subsystem (Figure 5) provides an interface between the tank riser and the VPM housing. It provides the systems needed to isolate the tank atmosphere, install or remove end effectors, and decontaminate the mast, arm, and end effectors as they are removed from the tank. Glove ports allow operators to perform the tasks within the TRIC without risk of contamination. A remotely operated end effector exchange and sample retrieval mechanism is being developed by INEEL to accommodate the anticipated high radiation levels of the waste samples.

Figure 5. The tank riser interface and confinement subsystem.

Operations Control Center

The operations control center can be located outside the tank farm perimeter fence. The control center includes instrumentation and control systems to remotely operate and control all aspects of the LDUA system. Video monitors display views from in-tank cameras allowing the operators to "see" inside the tank. A data acquisition system is provided to collect, analyze, report, and archive information obtained by various end effectors.

The at-tank instrument enclosure is located near the tank riser and integrates various electrical and instrumentation feeds from the system installed at the tank. The required signal conditioning and conversion hardware to allow multiple feeds to communicate with the remote trailer via fiber optic link are also provided by the at-tank instrument enclosure.

Utilities and Support Systems

Ancillary systems are required to support operation of the LDUA subsystems. These include power, communications, cabling, instrumentation, purge gas supply, and special tools and fixtures. The system is powered from either a large portable generator or site power. A power distribution skid receives power from the main feed and conditions it to the proper requirements for each of the downstream loads. The purge gas supply allows the LDUA system to be fully purged to meet stringent requirements for deployment in flammable gas environments.

End Effectors

End effectors are used to perform various tasks in the tank. Primary applications support surveillance and inspection, in-tank waste analysis and sampling, retrieval, and operations monitoring and recovery. Several tools and sensors have been developed for the LDUA system that allow it to meet user needs in these areas.

Two examples of end effectors are shown in Figures 6 and 7. The confined sluicing end effector uses a high-pressure (up to 10,000-psi) rotating water jet and a jet pump to dislodge, mobilize, and remove waste sludge and to clean tank walls. The extended reach end effector increases the LDUA's reach by almost 7 ft and has a detachable sampler with a clamping force up to 300 lb.

Figure 6. confined sluicing end effector used for retrieval operations.

Figure 7. The extended reach end effector increases the reach and includes a sampler.

System Operation

Most of the LDUA operations are performed remotely from the operations control center that can be located outside the tank farm radiation area to reduce worker exposure. Because the equipment is deployed inside an underground tank, local weather is not a concern unless it affects access for glove port operations. If winds are high, the LDUA mast can be lowered from the vertical position to prevent damage to the system.

The complete setup of the LDUA system onto a tank riser can be accomplished in two 8-hour shifts. During operation, two operators are needed to operate the LDUA system from within the operations control center. One operator controls the LDUA, and the other controls the installed end effector and the video displays and recorders. Two additional operators are needed at the TRIC to perform end effector changes and to decontaminate the LDUA and end effectors during removal from the tank. Takedown of the system also takes two 8-hour shifts.

The LDUA system does not pose any significant risks to workers, the public, or the environment. Some tasks, such as end effector exchange, require operator activities above the tank but do not pose significant risks to the workers.

Because the LDUA system is unique, special training is required to operate it. The system operators developed, verified, and practiced using operating procedures in the cold test facilities. Key craft personnel were also trained to support setup, takedown, and maintenance of the equipment.

SECTION 3

PERFORMANCE

Demonstration Plan

The LDUA System was demonstrated at Hanford, and the MLDUA was deployed at ORNL. These tank installations demonstrated surveillance and inspection, in-tank waste analysis, sampling, and waste heel retrieval applications. The LDUA System was successfully demonstrated in Hanford Tank 241-T-106 in September 1996. The MLDUA is currently being used for waste retrieval from Gunite and Associated Tanks (GAAT) at ORNL.

System Performance

The LDUA was developed to deploy end effectors to perform remotely operated tasks in unique environments such as a underground tank. Since this technology deploys other technologies that actually execute the in-tank operations, it is difficult to obtain quantitative performance data for LDUA operations. As a result, this section presents an overall discussion of LDUA performance.

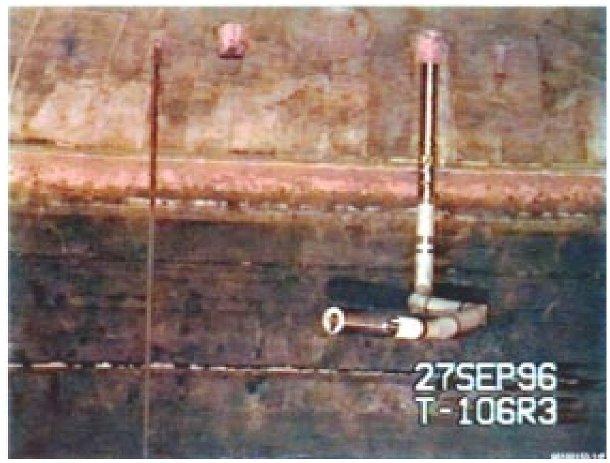

Figure 8. LDUA inside Hanford Tank 241-T-106.

Hanford Site Demonstration

The first LDUA System delivered to the Hanford Site underwent a rigorous testing and qualification program at the Hanford cold-test facility before receiving approval to use in a single-shell waste tank. This rigorous testing identified system modifications that were incorporated into the ORNL and INEEL systems prior to fabrication and assembly. Following the signing of a technology transfer agreement between the Hanford Tank Waste Remediation System (TWRS) and the TFA, the LDUA was transferred to the site. The LDUA System was demonstrated in Tank 241-T-106 in September 1996 (Figure 8), where it demonstrated its performance in a radioactive environment. During this demonstration, the remote stereo viewing system allowed examination of the tank dome, a riser (Figure 9), and welds in the tank wall from only a few inches away. The gripper end effector demonstrated the ability to grasp and reposition debris on the surface of the waste (Figure 10).

Figure 9. LDUA with viewing system examining a riser at the tank dome.

Figure 10. LDUA with gripper grasping debris in a tank.

ORNL Deployment

Many LDUA support systems developed for the Hanford Site were adapted to meet ORNL needs. The MLDUA System, the Houdini vehicle, and confined sluicing end effector were evaluated for waste retrieval in the gunite tanks at ORNL (Figures 11 and 12) during the initial Tank W-3 deployment. As a result of successful performance, a decision was made to continue use of the equipment to complete the waste retrieval operations in the remaining gunite tanks. Integrating these systems is an efficient retrieval method drawing on the unique strengths of each technology. Performance data from the GAAT retrieval work will be used to support a Record of Decision on closing the gunite tanks.

Figure 11. MLDUA being used to deploy the confined sluicing end effector in an ORNL gunite tank.

The ORNL gunite tanks offer a relatively low-hazard environment, as compared with Hanford and INEEL tanks, which have much higher radiation levels. This project provides valuable tank waste retrieval data that can be used to support planning for future retrieval activities at other tank sites. Retrieval performance data gathered in this deployment provides valuable insight into the performance of arm- and vehicle-based retrieval systems to other DOE sites and potential privatization contractors.

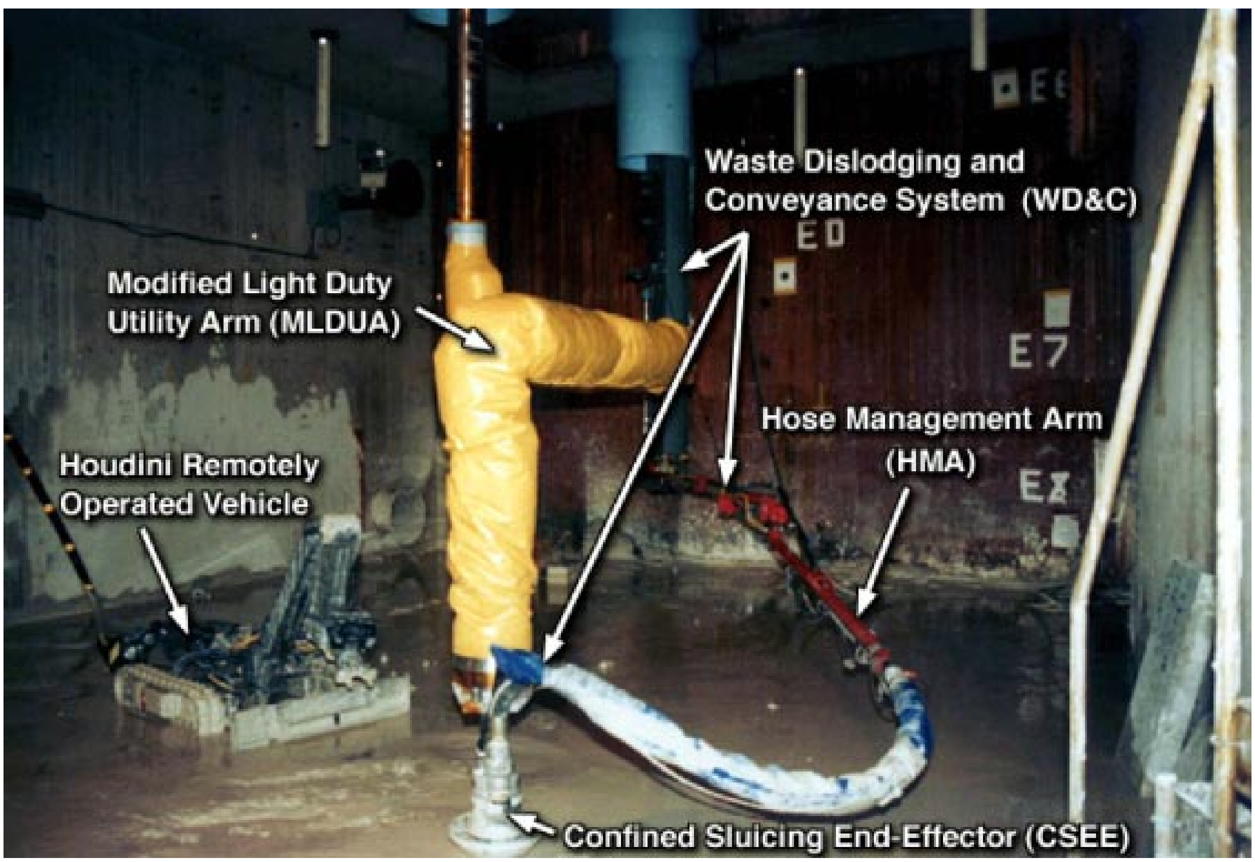

Figure 12. GAAT retrieval equipment in the ORNL Tanks Technology Cold-Test Facility.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

The LDUA has been used at both Oak Ridge and Hanford. The LDUA will be deployed at INEEL in FY99. The following section discusses the application of the LDUA at each of these sites.

Hanford

The TWRS Safety Program is interested in the LDUA's capabilities to monitor waste conditions, such as moisture levels, to support safe storage of wastes. The TWRS Characterization Program may use the system in the single-shell waste tanks. Other tank farm programs may use the system to support a variety of operational needs, including remote operations in highly contaminated valve boxes and pump pits above the tanks.

ORNL

The ORNL GAAT Operable Unit investigated the potential technologies that could be used to remediate tanks, as specified in a Federal Facility Agreement signed by the DOE and the State of Tennessee in 1992. A treatability study was performed according to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provisions. As the result of the GAAT Treatability Study, the MLDUA system was selected as one of the technologies for remediation of gunite tanks. This activity is retrieving waste and providing cost and performance data that are critical to evaluating risks and making informed decisions on future remediation actions.

INEEL

INEEL identified a need to deploy an LDUA system in the Idaho Chemical Processing Plant high-level liquid waste tanks. The tanks are constructed of stainless steel, and most are lined with cooling coils along the walls and floor. The cooling coils on the tank bottom are mounted on supports that elevate the coils above the tank floor. The coils prevent all the liquids from being successfully pumped out to INEEL's calcining facility, leaving a waste heel in the bottom of the tanks. The LDUA system will be used to gather samples of waste heel materials to plan for eventual heel removal or in-tank grouting.

INEEL is also planning to use the LDUA to deploy end effectors to inspect the tank walls to determine their structural integrity. Current video inspection methods have identified areas of the tank wall where small anomalies appear. The LDUA will allow the walls to be inspected using high-resolution video techniques and nondestructive evaluation methods. INEEL would like to inspect tank weld areas below the liquid level for corrosion or cracking. Several corrosion coupons will be retrieved with the gripper end effector in support of their corrosion monitoring program.

Competing Technologies

The LDUA system can be used for a variety of tasks including tank and waste inspections, waste characterization, and waste retrieval. In addition to the LDUA's ability to perform all of these tasks, it has the following advantages over the associated baseline technologies:

- For tank inspections, in-tank cameras can be used. Although vertical positioning, pan, and tilt are available with these cameras, they lack the advanced positioning capabilities offered by the LDUA.

- For waste sampling, baseline technologies can sample only directly below the riser. The LDUA provides off-riser access to sample from otherwise nonaccessible locations.

- For waste retrieval, past-practice sluicing is the baseline method. Past-practice sluicing only removes bulk supernate and soft sludge. The MLDUA (working with the Houdini vehicle and confined sluicing end effector) removes virtually all of the in-tank waste, including hard sludge heel and debris. Past-practice sluicing adds a significant volume of water to the tank, increasing the volume of the secondary waste; the MLDUA system adds significantly less water. The MLDUA system also deployed a scarifying end effector to remove embedded contamination in the gunite walls. Past-practice sluicing does not have this capability.

SECTION 5

COST

Methodology

The LDUA is an arm-based platform designed to deploy other tools to execute remote, in-tank operations. Operations performed in conjunction with an LDUA may include several other technologies, such as remotely operated vehicles, various end-effectors, pumps, and visualization systems. An in-depth, accurate cost analysis would be extremely complex. This level of detail would not be appropriate for this document.

Rather than performing a cost analysis between an example LDUA-equipped mission and a comparable baseline technology, this section will discuss the costs incurred for a “typical” deployment of an LDUA.

Capital Cost

The cost for an LDUA system is approximately $1.9 million, and about $2.0 million for an MLDUA system. End effectors are an additional cost, with the development, fabrication, and testing totaling approximately $200,000. Costs for ancillary support equipment for operations stations, power, and instrumentation vary depending on the site-specific requirements.

Operational Costs

The estimate for the cost of LDUA deployment in this report is based on actual data derived from the ORNL GAAT deployment of the MLDUA in FY97. The costs common to all tank deployment campaigns are excluded from this estimate. Excluded costs include

- operation procedures
- unit transfer
- health physics personnel
- general administrative documents
- safety assessment
- operational readiness review.

Table 1 shows the costs for a single day of LDUA operation. Note that costs for decontamination, personal protection equipment, and consumable supplies are comparable to most other deployment activities.

Table 1. LDUA operation costs

Task	Workers required	Cost/hour/ person	Daily subtotal	Comments
Arm operators	2	$100	$1600	Depending on the mission and use of various end effectors, an additional operator may be required
Additional support operators	2.25	$100	$400	Decon crew
Craft support			$500	
Personal protection equipment			$500	Common to all deployment devices
Consumables			$500	
Total			$3,500	

For LDUA operation, the personnel support required is similar to the support needed for the operation of most in-tank systems, making the operation costs of the LDUA system comparable to those of other in-tank equipment.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

No regulatory issues or special permits were required with the use of the LDUA at Hanford or the MLDUA at ORNL. The main regulatory concern was the selection of hydraulic fluid used, because small amounts leak into the tank during operation. Because standard petroleum-based hydraulic fluid could cause regulatory problems if enough leaked into the tank, both systems use a mineral oil-based fluid that does not present regulatory difficulties.

Secondary wastes generated by the retrieval equipment include used parts and decontamination supplies. Except for reusable equipment, items used in the tank are considered contaminated equipment and are disposed of as waste.

Safety, Risks, Benefits, and Community Reaction

Because the main components of the retrieval are operated remotely, no significant worker safety issues are posed by using this equipment. The support systems are above the tank and require hands-on operation but do not present any special safety concerns for the workers beyond routine waste tank operations.

Worker exposure during maintenance and operations that require access to contaminated in-tank equipment can be an issue for worker safety. To mitigate this, decontamination spray rings are used to remove waste during equipment removal, and all “hands on” work is done through glove ports in containment devices.

SECTION 7

LESSONS LEARNED

Implementation Considerations

At Hanford, the LDUA performed well in the field. Issues discovered during the demonstration that resulted in suggestions for future deployments, include the following:

- Riser alignment was not performed with the optical alignment scope end effector due to flexibility of the VPM and the fact that the inner tube was not exactly concentric with the outer tube. Instead, a simpler device was used successfully.
- The fact that the sequence of the VPM inner tube and the outer tube (which moves first) can be made only in the fully stowed position caused some operational difficulties and limitations.
- Improvements to the graphic user interfaces and to the ergonomics of some of the components were suggested.

The MLDUA performed well for the deployments at ORNL. The MLDUA proved to be especially useful for tasks that required repeatability. Several design and implementation issues were discovered during the MLDUA's use;

- The dynamic effects of the decontamination spray ring impinging on the MLDUA mast resulted in using the spray ring below the maximum available pressure to avoid inducing position errors in the arm controller.
- The primary and secondary contamination-prevention boots both required replacement. The primary boot was replaced because of tears in the boot. The secondary boot was replaced several times due to tears, significant contamination, and when oil leaks had sufficiently dirtied the boot.
- An O-ring seal in the wrist pitch joint failed twice causing significant downtime.
- The VPM encoder cable was separated from the guide pulley due to interference with a camera cable.

These issues were resolved, often incorporating improvements that allowed the MLDUA to complete the retrieval activities and prevent future failures.

Technology Limitations and Need for Future Development

The MLDUA, with the Houdini, has demonstrated the capabilities of arm- and vehicle-based retrieval systems. This information will be valuable in determining retrieval options in other waste tanks. The LDUA may be used instead of current baseline technologies to perform tasks that currently cannot be completed.

In the future, additional end effectors for other applications will be developed, increasing the capabilities of the LDUA. The ongoing development of end effectors will allow the LDUA to support a variety of future tasks within waste tanks.

APPENDIX A

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APPENDIX B

LIST OF ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	Department of Energy
GAAT	Gunite and Associated Tanks
INEEL	Idaho National Engineering and Environmental Laboratory
LDUA	Light-Duty Utility Arm
MLDUA	Modified Light-Duty Utility Arm
ORNL	Oak Ridge National Laboratory
TFA	Tanks Focus Area
TRIC	tank riser interface and confinement
TWRS	Tanks Waste Remediation System
VPM	vertical positioning mast