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Scarab III
Remotely Operated Vehicle System

Robotics Crosscutting Program
Tank Focus Area

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Scarab III

Remotely Operated Vehicle System

OST Reference # 2086

Robotics Crosscutting Program
Tank Focus Area

Deployed at
Tank T-14
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Purpose of this document

Innovative Technology Summary Reports (ITSRs) 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. These reports are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from the U.S. Department of Energy's (DOE) 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 effectiveness. Most reports include comparisons to baseline technologies and other competing technologies. Information about commercial availability and technology readiness for implementationis also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in Section 8.

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.

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SECTION 1

SUMMARY

Technology Summary

Problem
The U.S. Department of Energy (DOE) is responsible for cleaning and closing over 300 small and large underground tanks across the DOE complex that are used for storing over 1-million gal of high- and low-level radioactive and mixed waste (HLW, LLW, and MLLW). The contents of these aging tanksmust be sampled to analyze for contaminants to determine final disposition of the tank and its contents. Access to these tanks is limited to small-diameter risers that allow for sample collection at only one discrete point below this opening. To collect a more representative sample without exposing workers to tank interiors, a remote-controlled retrieval method must be used. Many of the storage tanks have access penetrations that are 18 in. in diameter and, therefore, are not suitable for deployment of large vehicle systems like the Houdini™ (DOE/EM-0363). Often, the tanks offer minimal headspace and are so cluttered with pipes and other vertical obstructions that deployment of long-reach manipulators becomes an impractical option.

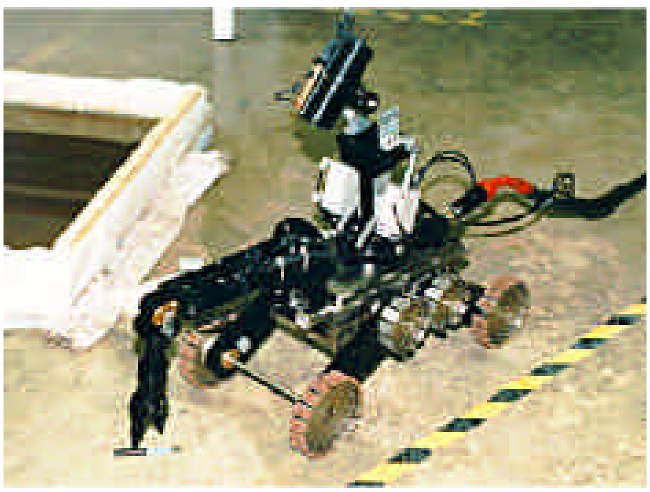

Figure 1. Scarab III vehicle demonstrates dexterity during acceptance testing

A smaller vehicle system is needed that can deploy waste retrieval, sampling, and inspection tools into these tanks. The Oak Ridge National Laboratory (ORNL), along with ROV Technologies, Inc., and The Providence Group, Inc., (Providence) has developed the Scarab III remotely operated vehicle system to meet this need. The system also includes a containment and deployment structure and a jet pump-based, waste-dislodging and -conveyance system to use in these limited-access tanks. The Scarab III robot (Figure 1) addresses the need for a vehicle-based, rugged, remote-controlled system for collection of representative samples of tank contents (Ref.2).

How it works
The remotely operated vehicle system consists of three primary components: the vehicle (Scarab III), the Deployment and Containment Module (DCM), and the control consoles.

The Scarab III remote vehicle, which was built by ROV Technologies, Inc., is designed to operate either submerged under water or in several inches of waste material. The vehicle has four rubber-treaded wheels for traction on slick surfaces and four metal wheels for biting into thin layers of waste material. Articulated drives permit climbing over 8-in. obstacles. There is a manipulator arm that can grasp objects up to 2-in. in diameter and has a wrist capable of 360° rotation and an elbow capable of moving 90° up or down. The manipulator arm is used to grasp the sample collection device and maneuver it to collect the sample. The manipulator gripper end-effector has a payload limit of 5 lb.

The Scarab III chassis is stainless steel for corrosion resistance, and the overall dimensions are such that the unit can be deployed through an 18-in.-diam riser opening. Three on-board cameras provide viewing for deployment, retrieval and driving operations. Two of these cameras are mounted on the front and rear of the chassis. The third camera is mounted on a turret that provides 270° of pan and 90° of tilt. This camera can also be placed atop an extendible boom for surveying tank walls.

The DCM provides containment and storage for the Scarab III vehicle. Two winches are used to deploy the vehicle and ancillary equipment through an access port at the bottom that interfaces with the tank riser. There are also access ports mounted at either end of the containment structure for sending equipment in and out of the DCM. Piping and quick disconnect fittings are also provided for connecting to a high-pressure washer for decontamination of vehicle and ancillary equipment inside the DCM.

The control consoles are lightweight, modular units that are portable for ease of setup within a small area. The main console provides power to the other consoles that contain the joystick and levers for operation of the Scarab III vehicle and the monitors for the onboard cameras.

Potential markets

Scarab III is designed primarily for radioactive waste sampling and inspection for underground storage tanks and has direct applicability to a number of sites across the DOE complex, including ORNL, Fernald, Hanford, Idaho National Engineering and Environmental Laboratory, and the Savannah River Site. Other potential markets could be in the growing decontamination and decommissioning (D&D) activities for inspection of high-radiation areas to aid in determining waste decontamination needs before the disposition of demolition debris.

Commercial availability

Scarab III is manufactured by ROV Technologies, Inc., of Vernon, Vermont. The vehicle is based upon an earlier vehicle model, the Scarab IIa, offered by ROV. Application-specific changes that resulted in development of the Scarab III were fostered by ORNL Robotics and Process Systems Division (RPSD) and funded by OST through the Robotics Crosscutting Program (RBX) and Tank Focus Area. Through extensive cold-testing of the remote system (including the DCM) at the ORNL RPSD Tanks Technology Cold Test Facility (TTCTF) followed by deployment in an underground radioactive waste tank at ORNL, the Scarab III remote system has proven to be a reliable, cost-effective means of sampling and inspecting tanks.

Deployment Summary

Tank T-14 deployment at ORNL

Tank T-14 is an inactive underground tank located under ~1 ft of soil just north of the New Hydrofracture Facility (Building 7860) in the Melton Valley area of ORNL. The tank is a rectangular, reinforced concrete structure with a calculated capacity of ~57,000 gal. Installed in 1979, the tank functioned as an overflow emergency waste tank for the underground injection process at the New Hydrofracture Facility. The tank was taken out of service when the hydrofracture process was terminated in 1984. In September 1997, the tank inlet line was cut and capped.

Because of limited accessibilityto the tank interior using conventional means, the only available analytical data for the tank contents were obtained in 1996 when a sample was withdrawn from a point just below the access hatch located at the southwest corner of the tank. While these data were quite valuable for gross characterization of the contents at this single point, more representative data from across the tank bottom were required to support planning for final tank remediation. The Scarab III system was identified as well suited for deployment into the tank for a campaign to collect and retrieve samples from various locations within the tank. These samples could then be composited to provide more representative material for analysis and characterization.

The Scarab III system was delivered to ORNL in April 1998, at which time some initial tests of the vehicle's capabilities to maneuver were checked out at the RPSD facilities for use by the Gunite and Associated Tank (GAAT) project. However, funds for deployment were redirected, so the system was stored for future use. In April and May 1999, the Scarab III system performed numerous tests at the TTCTF to simulate collection of a sample from a horizontal steel tank. These tests included maneuverability in and on various materials including a bare steel surface, to sand, vermiculite, resin, clay, and other materials to simulate the unknown conditions to be encountered in Tank T-1. Operations in the DCM and deployment and retraction of the vehicle were also performed. At the end of cold testing, it was discovered that Tank T-1 had 3-4 ft. of liquid in it that would need to remain for safety reasons. Samples collected from the tank indicated that approximately 12 in. of resin was present on the tank floor. Unfortunately, cold testing at the TTCTF had already proven that the Scarab III had difficulty traversing resinous materials. Thus Tank T-14, which had similar sampling constraints and less than 6 in. of a non-resinous sludge, was selected as the new target for deployment of the Scarab III system. The Scarab III system was successfully deployed from May 26–28, 1999, for collection of a representative sample and thorough tank inspection in Tank T-14. Currently, the Scarab III vehicle is stored inside the DCM at ORNL awaiting its next assignment.

Advantages over baseline

The advantages of the Scarab III r system over the traditional sampling technologies of collection with sample tubes from discrete points of access is self-evident, but they were not specifically measured. It would be too dangerous, impractical, and costly to send workers into the tanks just to compare approaches. In addition, the traditional sampling device could not collect multiple samples across the bottom of the tank nor inspect the outer reaches of the tank. Once in the tank, the Scarab III vehicle could collect samples from any point on the bottom of the tank and with the use of video inspection could determine whether to composite or segregate these samples.

Regulatory concerns

There are no regulatory issues that limit applicability of the Scarab III system.

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Licensing information

The Scarab III vehicle and consoles are available for purchase from ROV Technologies. Inc.
The DCM was designed and built by the ORNL RPSD.

Other

All published ITSRs are available on the OST web site 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 Scarab III is 2086.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

Components
The Scarab III system is comprised of three main subsystems: The Scarab III vehicle, the DCM, and the control consoles.

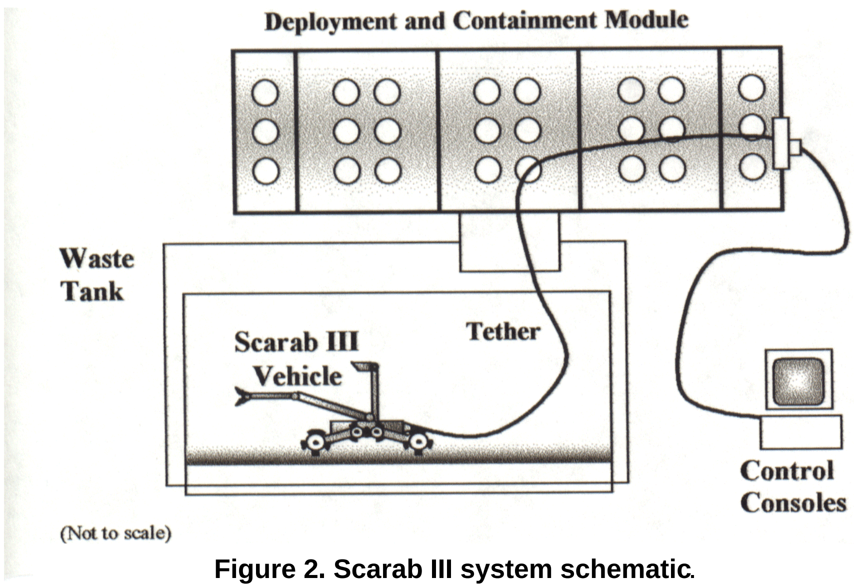

Figure 2. Scarab III system schematic.

The Scarab III vehicle (Figure 1) is designed to operate either submerged in liquid or in several inches of sludge. The vehicle comes equipped with three cameras: two black-and-white fixed-focus cameras mounted in the front and rear ends of the vehicle's housing and a third color camera with 25X zoom mounted on top of a turret. The articulated drive allows the vehicle to climb over 8-in. obstacles. The vehicle can turn via skid steering within its own length. The vehicle is equipped with a 2 degree-of-freedom (DOF) manipulator arm with gripper.

With the turret camera folded, the vehicle cross section is reduced to 16.875 in., permitting deployment through relatively small access openings such as those commonly found on storage tanks. The final weight of the deployed version of the Scarab III is 125lb. Rubber-treaded metal wheels allow the vehicle to maneuver through waste material that would have jammed the treads on earlier models.

The DCM provides containment and storage for the Scarab III vehicle. Control consoles include a joystick for controlling forward, reverse, left, and right turning motions and rotation of the turret (on the top deck) and the turret camera tilt. These devices provide manipulator movement, turret camera zoom and focus, and front and rear toe actions and are all controlled from this console. A color video printer allows snapshots to be collected and printed on the spot. The monitors display front, rear, and turret camera views, and there is a videocassette recorder (VCR) and monitor to record and display any of the other views available. External camera views (from overview or DCM cameras, for example) can also be captured and recorded.

Applications
The Scarab III system was developed to provide the means for sampling and inspecting radioactive, underground, horizontal tanks that otherwise could not be sampled with traditional sampling and inspection equipment. Rugged design and sturdy construction make the system well suited for deployment into underground storage tanks.

The Scarab III vehicle is fully submersible and can withstand high-pressure water decontamination. It is designed to be deployed from, and stored in, the DCM to minimize exposure to the environment and to facilitate reuse of the equipment.

Scarab III vehicle details

The 125-lb vehicle is teleoperated, which means an operator in a remote location with no preprogrammed routine controls it. The vehicle is also skid steered; that is, its speed and direction are controlled by a joystick that directs motion of the wheels on either side of the chassis. If one chooses, the wheels can be replaced by tracks_, two on the front toe mechanism and two on the rear toe mechanism. The tracks are commercially available and easily replaced. Maximum vehicle speed is 0.5 ft/s. The vehicle manipulator arm is capable of wrist rotation up to 360 degrees, elbow movement up or down 90 degrees, and a gripper opening to accommodate a 2-in-diam object weighing up to 5 lb.

The vehicle also comes equipped with three cameras: Two black-and-white fixed-focus cameras mounted in the front and rear ends of the vehicle's housing and, a color camera with 25X zoom mounted on top of a turret. The vehicle top plate (turret) also provides the pan-and-tilt capability and the mounting point for the camera or extendable boom, capable of telescoping from 55 to 83 in. to access areas out of reach of the vehicle itself.

A tool interface plate is mounted on the front of the vehicle, while a tether and strain relief is connected to the back top deck of the vehicle. The tether is the vehicle's lifeline because it provides compressed air (to the pneumatic turret), electrical power, and signal lines.

Support systems

The Scarab III support systems include the DCM and the control consoles. The DCM provides containment and storage for the Scarab III vehicle (Figure 3). This unit includes two winches that are used for deployment of the vehicle and ancillary equipment. An access port in the bottom of the DCM structure provides the interface point between the DCM and the tank to be accessed. A 20-in. bag-in/bag-out port allows removal of contaminated materials or samples, and a transfer chamber with double doors provides easy access for passing in tools and parts. Multiple glove ports on the DCM permit operator interface for maintenance and other supporting activities such as paying out tether as the vehicle is lowered into a tank or composting samples collected. Gross-level decontamination of the Scarab III vehicle is also performed within the DCM with a high-pressure washer.

Figure 3. The containment structure at the Tank T-14 site

Installation and deployment
The Scarab III vehicle is transported to the site in the DCM, which is placed over and connected to the tank riser. The vehicle is then readied for deployment by lowering the turret camera so that it is flat on the vehicle, and the manipulator arm is lowered to 10degrees below horizontal to ease deployment through the DCM and tank riser interface. Once ready, the tether restraint is connected to the winch, and the vehicle is raised with the winch and positioned over the tank interface point.

The vehicle is then lowered through the riser interface with close communication between the DCM support crew and the vehicle operator, who uses the turret camera in the down position and the front camera to guide the lowering of the vehicle. Once the vehicle is through the interface, the turret camera is raised, and the manipulator arm is raised to 90 degrees above horizontal to protect it during landing on tank bottom.

The winch and vehicle are then lowered gently by the DCM support crew based upon direction received from the vehicle operator. Once the vehicle operator has signaled touchdown of the front of the vehicle, the winch is lowered quickly to get the back of the vehicle down on the tank floor to prevent damaging the manipulator arm by resting too much weight on it for an extended period.

Once the vehicle is on the bottom of the tank, the remote operator guides it through the tank for sampling and inspection. The DCM operators take direction from the vehicle operator for tether management.

System Operations

Control consoles for vehicle operation (Figure 4) are lightweight and modular. The Vehicle Operator Control Console (VOCC) houses a joystick for controlling forward, reverse, left, and right turning motions for the vehicle. A second joystick controls rotation of the turret (or top deck) and the turret camera tilt. Other console components are permanently mounted in sturdy shipping crates that can be packed up quickly and easily between field deployments. The Main Control Console (MCC) provides power to the VOCC and is the primary station for transferring video and control signals between the vehicle and other consoles. Manipulator movement, turret camera zoom and focus, and front and rear toe actions are all controlled from this console as well. A color video printer allows snapshots to be collected and printed on the spot. The Monitor Console (MC) displays front and rear camera views from the vehicle. The Record Console (RC) displays turret camera view, but also houses a VCR and monitor to record and display any of the other views available. External camera views (from overview or DCM cameras, for example) can also be captured and recorded.

Figure 4. Scarab III control consoles.

SECTION 3

PERFORMANCE

Demonstration at Tank T-14

Project Background

Tank T-14 Description

Tank T-14 is an inactive underground tank located under ~1 ft of soil just north of the New Hydrofracture Facility (Building 7860) in the Melton Valley area of ORNL. The tank is a rectangular, reinforced concrete structure with a calculated capacity of ~57,000 gal. The maximum envelope of the tank is ~26 X 29 X 15 ft deep, with a wall thickness of ~1 ft. The tank floor is sloped to a 2 X 4 X 1-ft deep sump. A series of seven precast concrete, span-deck panels comprise the roof of the tank. Access to the tank interior is via a 2.5 by 3-ft hatch located above the sump area (Figure 5). Steel framing to support a sump pump further reduced the accessibility through the hatch.

Figure 5. Tank T-14 Site - access hatch prior to sump pump removal

Installed in 1979, the tank functioned as an overflow emergency waste tank for the underground injection process at the New Hydrofracture Facility. The tank inlet is a 12-in. steel gravity drain line originating in the Well Cell of Building 7860. A 1.5-in. steel discharge line allowed pumping of accumulated liquid from the tank sump back to the Slotting Waste Collection Tank in Building 7860. The tank was taken out of service when the hydrofracture process was terminated in 1984. In September 1997, the tank inlet line was cut and capped. The sump discharge line was valved closed but left intact. In preparation for deployment of the Scarab III system for sludge sample retrieval, the soil overburden was excavated from the tank in the spring of 1999.

Because of limited accessibilityto the tank interior using conventional means, the only available analytical data for the tank contents were obtained in 1996 when a sample was withdrawn from a point just below the access hatch on the northwest corner. Video taken at this same time indicated that the material varied in consistency across the tank, thus indicating varying concentration of contaminants from those seen at the access point. Consequently, a more representative sample from across the tank was required for remediation planning.

Remote waste sampling at Tank T-14

Because of this limited accessibility to the tank interior using conventional means at the access point, a remote means for sampling the far reaches of the tank was required. The Scarab III system was identified as well suited for deployment into the tank for a campaign to collect and retrieve samples from various locations within the tank. These samples could then be composited to provide more representative material for analysis and characterization.

After a readiness review was completed, the Scarab III system was relocated to the Tank T-14 site on May 24, 1999. To accommodate system installation, it was first necessary to remove an existing sump pump and its associated piping from the tank access hatch area. Because the access opening was located directly above the tank sump, a steel platform was installed over the sump as a “touchdown” pad for the Scarab vehicle. An overview camera and lights were also installed in the tank to provide additional visual feedback to the vehicle operator during in-tank activities.

The DCM was set in place above the Tank T-14 access hatch (Figure 6), and all mechanical and electrical connections were completed. A flexible sleeve was field fabricated and installed at the DCM/tank interface to provide confinement for contaminated material that could possibly become airborne during vehicle insertion, retraction, or in-tank operations. The system operator's consoles were installed in an unused portion of the nearby New Hydrofracture Facility.

Figure 6. Deployment and Containment Module being installed at Tank T-14 Site.

Following a series of preoperational system checks, the Scarab III vehicle was lowered from the DCM through the interface sleeve and into the interior of tank T-14 on May 26, 1999. The tank access opening was still partially obstructed by a steel channel frame that had supported the previously removed sump pump. This frame reduced the rectangular tank opening to 15_ in by 25_ in., requiring that the vehicle be "angled in" during the insertion. As the Scarab III vehicle was lowered through the reduced opening, a turret camera bracket was knocked out of position when the unit came into contact with the tank structure. As a result, the turret camera tilt function was lost for the remainder of the deployment.

After the vehicle came to rest on the touchdown platform, system operations personnel at the control console began sample retrieval operations. The vehicle was driven off the platform and the manipulator "scoop" end-effector was positioned against and driven into the tank sludge by the forward motion of the vehicle. Using the vehicle's response to control inputs in conjunction with the visual feedback provided by the vehicle and overview cameras, the operator was able to determine when an adequate volume of sludge material (about one tablespoon minimum) was collected in the Scarab III manipulator scoop. The vehicle was then driven to a collection bucket located at the touchdown platform. Using the motion of the manipulator arm and vehicle movement, the operator deposited the retrieved sludge sample into the collection bucket and then maneuvered the vehicle to a different location of the tank to collect the next sludge sample. In this manner, a total of four sludge samples were retrieved during the first day of in-tank activities while logging 4 h of vehicle operating time.

During operation, sludge depths were estimated to range from 2 to 6 in. while the consistency of the material varied from "…red clay to crusty concrete to chocolate ice cream...". Midway through the effort, the lighting system installed in the tank failed, as did the tank overview camera pan feature. The deployment team was able to successfully implement "work-arounds" such that these failures had no significant impact to the mission.

Sludge retrieval continued on May 27 with collection of five additional samples for a total of nine sludge samples for the entire campaign. The sample collection bucket was extracted from the tank by a technician working through the gloveports located on the DCM (Figure 7).

Once in the DCM, the samples were composited in a small collection jar, which was then removed through the DCM bag-in/bag-out port for transport to laboratory facilities for analysis. The Scarab III vehicle logged approximately 3.6 operating hours on the final day of the sampling campaign. Before retraction from the
tank and gross-level decontamination in the DCM, operation of the Scarab III vehicle was demonstrated for Management and Integration (M&I) contractor management representatives. The system was then demobilized and is currently in storage at ORNL awaiting future deployment opportunities.

Figure 7. Sample bucket being extracted from DCM-tank interface.

Cold testing the waste retrieval system

Cold-testing of the Scarab III system was performed at the cold-test facility, which is located within the RPSD complex at ORNL. This facility provided the opportunity to demonstrate that the vehicle could be inserted and retracted through a small diameter (18 in. simulated riser pipe using the winch assembly contained in the DCM. The functionality of the vehicle was demonstrated in a pit structure located directly below the riser in both “clean” and surrogate waste (sand, vermiculite, and resin material) conditions. Capabilities demonstrated during cold-testing included sample collection and inspection operations, obstacle negotiation and avoidance, and decontamination of the vehicle using a high-pressure spray in the DCM.

As part of the testing, the Scarab III was operated in a foot of thick, sticky surrogate waste. The vehicle had previously performed quite well in heavy surrogates up to 8 in. in depth, during which operators used a "toes down" approach to raise the main housing of the vehicle up out of the sludge. This technique allowed the wheels to roll without building up sludge in front of the housing. Once the surrogate depth was increased to 1 ft, however, the vehicle housing could not be raised above the material, and an “inchworm” approach was implemented to slowly move through the surrogate waste. While the vehicle did eventually traverse the pit in this manner, deployment of the Scarab III in sludge depths greater than 8 in. is not advisable unless the consistency of the sludge is relatively fluffy.

Following a successful pressure test of the DCM, cold- testing of the Scarab III system was completed during the week of May 3, 1999. Overall, cold-testing was conducted with no significant difficulties encountered. Several hardware repairs were required, however, including replacement of a camera and a failed electrical connector, and repair of the manipulator elbow motor and associated wiring. Operators found all maintenance of the vehicle relatively easy to implement during cold-testing.

Results

The Scarab III system performed quite well and satisfied successfully all objectives of the Tank T-14 sampling campaign. Observations from cold testing (Figure 8) and in-tank operations indicated that the vehicle could operate effectively in radioactive sludge up to about 8 in. in depth. Operating time for retrieval of the required nine waste samples was 7.6 h. Many of the techniques developed and practiced extensively during cold-testing proved quite valuable during the Tank T-14 sample collection activities and ensured a smooth and successful campaign. These samples will be used to characterize the waste to support tank remediation decisions. Videotape records were created and are available for essentially all in-tank activities.

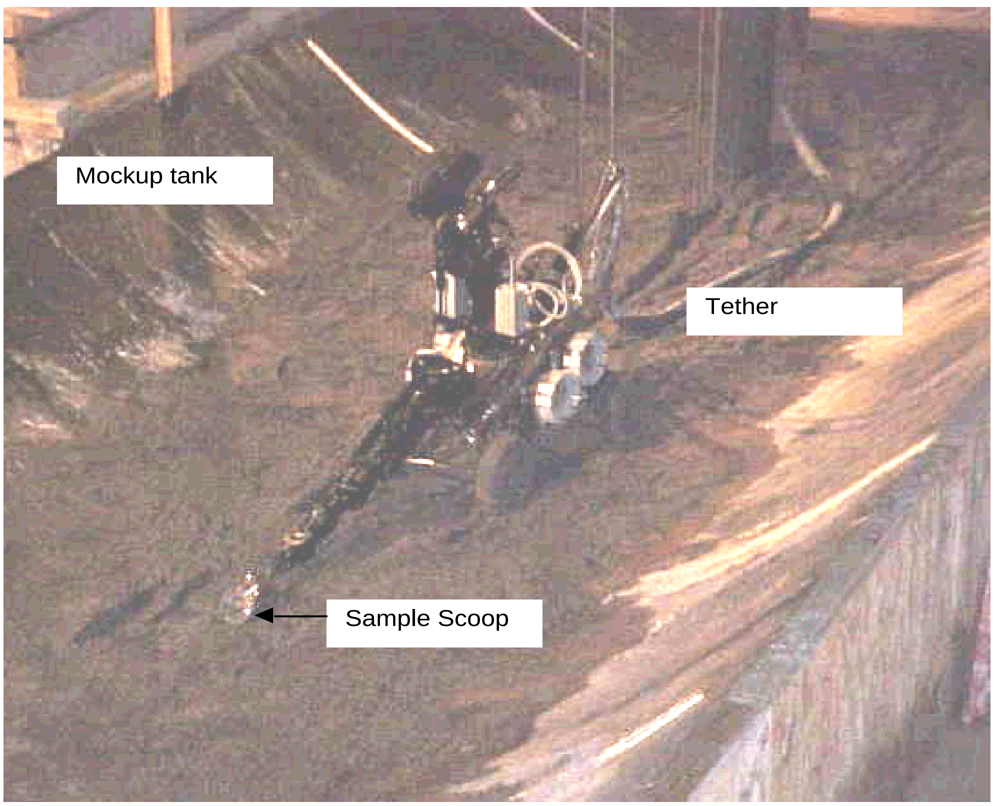

Figure 8. Scarab III sample collection in mockup tank.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The Houdini I and II systems developed by RedZone Robotics, Inc., have also been used successfully for tank sampling and inspection associated with the larger Gunite tanks at ORNL. However, the Houdini remote systems are much larger requiring a larger access to enter the tank to perform this work. This larger equipment is also more difficult than the Scarab III to perform maintenance on. The Houdini can operate in greater depths of sludge because of its larger size.

Technology Applicability

The Scarab III system can be broadly used to sample and inspect the interior of underground radioactive tanks in which traditional sampling devices can not collect a representative sample. There are many tanks across the DOE complex in which this technology can be applied.

Key considerations are the available access to the tank interior, depth of tank residual material, and surface area for DCM. These factors are applicable for the following reasons.

- The Scarab III vehicle requires an 18-in.-diamor larger access to enter the tank.
- The Scarab III vehicle operational efficiency in sludge greater than 8-in. thick is nonproductive.
- The DCM requires a large, flat area for safe placement over tank riser interface.
- The consoles must be placed in a structure within 300 ft of tank access where they can be kept safe and dry.

Commercialization and Sponsors

The Scarab III vehicle is manufactured by ROV Technologies, Inc. (ROV), which also offers a variety of other remotely operated vehicles of various sizes. The Scarab III is a customized version of the Scarab product line built to specifications generated by ORNL RPSD and Providence. The DCM was designed by the ORNL RPSD and built in Oak Ridge. Integration of the vehicle and controls with the DCM were performed by ORNL. Providence performed operations during cold-testing and field deployment. Design, development, and cold-testing were funded by OST RBX and coordinated with Accelerated Site Technology Deployment activities sponsored by OST TFA and the ORNL Environmental Management Program.

SECTION 5

COST

Introduction

This section compares the manpower costs associated with using the innovative technology with those of sampling the tanks via manned entry and manual sampling. The case considered is analogous to that of the actual Scarab III system field deployment in Tank T-14. Specifically, only one riser opening is available, but the sediment contained in the tank is not uniform throughout. In this situation, the use of a long-handled grab or tube sampler to obtain a waste sample below the access point is insufficient. The alternative is to lower a team of two people into the confined space to manually collect the samples for analysis.

Methodology

The costs associated with developing and deploying the Scarab system are compared with a manned entry into the tank(s) for sample collection.

First, consider the costs associated with the development and initial deployment of the Scarab III system (ORNL Doc. ETS-99-0170):

Development & Fabrication:	$750,000
Pre-deployment Cold Testing:	$100,000
Field Deployment at T-14:	**$147,000**
Total:	$997,000

Cost per deployment will vary for each application depending upon the specific readiness review, performance requirements, and preparation for each site. Daily operating costs once in the field are typically about $4,000, primarily for labor for the operating and support crew. Now that the system has been completed and successfully deployed, utilization costs should be greatly reduced for follow-on deployments. Actual costs for field setup could be as low as $6,000 to $10,000, excluding the cost of approval and authorization paperwork. The system could now be mobilized, operated for 3 days and demobilized for field costs of $25,000 to $30,000.

A manned entry into Tank T-14 would have incurred essentially the same up-front costs for site preparation, readiness review documentation, personnel training, and site health physics and safety support. The cost of transporting the DCM to the site and setting up the Scarab III's modular control system would be of the same order of magnitude as expenses associated with procuring and erecting a containment tent over the tank. Likewise, the crew sizes and training required would be the same for either a Scarab deployment or a manned entry.

Next, consider the relatively low radiation levels (~100 mR/hr) associated with Tank T-14. At Oak Ridge, workers are not allowed to exceed the 150 mR/quarter dose limit, which means that crews manually sampling the tank would only be allowed entry for approximately one hour per quarter (considering the conservative dwell times allowed by most Health Physics technicians). The confined space entry "buddy" requirement would mandate at least two crewmembers in the tank during sampling. Finally, given the time that would be expended donning and doffing protective clothing (including respirators); entering and exiting the tank; and collecting and transferring the sample materials from the tank, it is not unreasonable to assume that at least four hours would be required to complete sampling activities. That would equate to burning up (or maxing out the dose restriction) for at least six crewmembers for one quarter. If a conservative estimate of $50/hr per crewmember is used, the total cost to sample one tank (including time lost that quarter for burnout) is $200,000

(4 man-hr/tank x 2 men / 1.5 hr/man stay time x $50/hr x 520 hrs/qtr = $156,000 per tank)

The ROV took approximately 8 hours to retrieve 9 samples from this same environment. However, the real benefit of the Scarab is that it can be deployed again with minimal repeat of readiness review, training, etc. More importantly, it can be deployed in much worse radiological and thermal conditions with no increase in cost. Once burnout becomes an issue requiring multiple crews for manned entry, costs start increasing rapidly. The table below demonstrates how quickly personnel costs increase as dose rates rise and stay-times decrease.

Table 1. Comparison of labor costs associated with Scarab III vs. manned entry

Dose Rate (mR/Hr)	Stay Time (Min)	Minimum Crew Required/ Tank	Manned Entry Crew Cost ($)	Scarab Deployment Crew Cost ($)
100	90	6	156,000	4,000
200	45	11	286,000	Same
300	30	16	416,000	Same
400	23	21	546,000	Same
500	18	27	702,000	Same
1000	9	54	1,404,000	Same

Cost Conclusions

Clearly, the higher the dose rate in a given tank, the less practical manned entry becomes and, therefore, the more cost-effective the Scarab III system becomes as a sample retrieval tool. The unit is particularly useful in situations where more than one tank must be sampled. As noted previously, total field deployment costs fall dramatically from $147,000 for an initial deployment to less than $30,000 for follow-on deployments.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

No special permits are required to operate Scarab III. The tank sampling and inspection would generally come under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA) project umbrella with all the necessary permitting and environmental impact issues considered in appropriate project documents. That was the case with Scarab III deployment in Tank T-14, where tank sampling was in support of the FFA tank characterization efforts.

Scarab III achieves all as low As reasonably achievable (ALARA)) exposure goals because it dramatically reduces worker exposure during sampling.

Secondary waste streams generated during Scarab III operations include expended parts, decontamination supplies, and ultimately disposal of the vehicle. Working within the DCM and directing decontamination waters back into the tank before the DCM is removed will minimize this secondary waste generation. The bulk of the ancillary equipment and the vehicle will be stored in the DCM after decontamination for reuse at the next tank.

Safety, Risks, and Community Reaction

The Scarab III system reduces the risks associated with high exposure to radiation while following good ALARA and industrial hygiene practices. The deployment, retraction, decontamination,and maintenance of the vehicle are accomplished through the DCM, thus reducing the risk to workers and the environment further.

The community reaction is positive since use of the Scarab III system to sample and inspect tanks will facilitate remediation decisions and site cleanup.

SECTION 7

LESSONS LEARNED

Implementation Considerations

Technical and regulatory constraints must be considered early in any proposed waste retrieval, sampling, and inspection project. Adequate lead-time for equipment design, integration, and most particularly operator training must be provided. This section describes the maintenance experience and the constraints associated with deployment.

Scarab III maintenance experience
Several hardware repairs were required during cold-testing of the Scarab III system. These repairs included replacement of a camera and a failed electrical connector; repair of the manipulator elbow motor and associated wiring; and replacement of drive and tilt motors. Operators found all maintenance of the vehicle easy to implement during cold testing. The excellent cooperation of the ROV Technology, Inc., supplier with expediting part shipment greatly enhanced the turn-around time on maintenance activities. Eventually, a spare part inventory was accumulated that minimized vehicle down time, thus increasing operating time.

The Scarab III vehicle operated well in the various material with the exception of the resin, but this was overcome by modifying the vehicle-operating technique to "inch worm" through the material. Thus, varying vehicle operating technique to suit the material is important. The consoles that support vehicle operations must be kept in an environmentally stable enclosure because of the sensitivity of the electronic equipment.

Lessons learned program
As part of cold-testing and implementation, a maintenance and daily log was kept to record operation of the Scarab III system. This information collected during cold-testing was used to operate the Scarab III vehicle more effectively in the field for Tank T-14 sampling activities. This information is available for reference for future deployments.

Technology Commercialization

Scarab III is manufactured by ROV Technologies Inc., and its development has been fostered by ORNL RPSD and funded by OST and Environmental Management. Through extensive cold-testing of the remote system (including DCM) at the ORNL RPSD TTCTF followed by deployment in an underground radioactive waste tank at ORNL, the Scarab III remote system has proven to be a reliable, cost-effective means of sampling and inspecting tanks. The system could also be used for waste retrieval by attaching a retrieval end-effector to the tool plate on the chassis. The system is currently in storage at ORNL awaiting its next assignment.

SECTION 8

REFERENCES

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APPENDIX A

ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DCM	Deployment and Containment Module
DOE	Department of Energy
EM	Office of Environmental Management
EM-40	Office of Environmental Restoration
EM-50	Office of Science and Technology
FETC	Federal Energy Technology Center
ft	foot (feet)
ft/s	foot (feet) per second
gal	gallon(s)
gal/min	gallon(s) per minute
ITSR	Innovative Technology Summary Report
lb	pound(s)
MC	Monitor Control
MCC	Main Control Console
M&I	Management and Integration
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
OST	Office of Science and Technology
Providence	The Providence Group, Inc.
psi	pounds per square inch
RC	Record Console
RCRA	Resource Conservation and Recovery Act
RBX	Robotics Crosscutting Program
ROV	Remotely Operated Vehicle
TFA	Tanks Focus Area
TTCTF	Tanks Technology Cold Test Facility
VOCC	Vehicle Operator Control Console