SUCCESSFUL DEPLOYMENT OF THE SCARAB III REMOTELY OPERATED VEHICLE FOR COLLECTION OF SLUDGE SAMPLE FROM UNDERGROUND RADIOACTIVE WASTE STORAGE TANK

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ABSTRACT

In May 1999, the Scarab III remotely operated vehicle was successfully utilized to retrieve sludge samples from numerous locations within Tank T-14, an inactive underground radioactive waste storage tank at Oak Ridge National Laboratory (ORNL). This activity completed the first deployment of the Scarab III system in a radiological environment, and resulted in the collection of representative samples of Tank T-14. The Scarab III system was developed under the auspices of the Department of Energy (DOE) Office of Science and Technology (OST) and the Robotics Crosscutting Program in coordination with the Tanks Focus Area. Deployment was performed as a joint project funded by the ORNL Environmental Restoration Program and DOE OST Accelerated Site Technology Deployment (ASTD) Program. This system is a robotic operating platform originally developed by ROV Technologies, Inc. to perform inspection, sampling, and clean out of reactor pools. The system was modified for inspection/sampling of underground tanks with small accesses containing several inches of sludge across the DOE complex. The key modifications included use of stainless steel construction for corrosion prevention, higher capacity drive motors to compensate for the increased weight of stainless steel, chassis sized for 45.7-cm (18-in) diameter riser openings, rubber-treaded metal tracks for improved traction, and several control system modifications.

The ORNL Robotics and Process Systems Division (RPSD) designed and provided oversight for fabrication of a deployment and containment module (DCM) to support the deployment of the Scarab III remote system. The DCM provides storage, containment, interface with tank, glove ports, bag-in/bag-out ports, transfer chamber, and decontamination capabilities. In addition, the Scarab III requires a control console for vehicle operation and video/photo documentation. The Scarab III system was integrated with the DCM and tested at the ORNL Tank Technology Cold Test Facility (TTCTF) prior to deployment in a radiologically contaminated tank.

After successful integration and operation at the TTCTF, the Scarab III system was deployed in Tank T-14 satisfying all objectives of the sampling campaign. Observations indicated that the vehicle could operate effectively in radioactive sludge up to about 20.3 cm (8 in) in depth. Operating time for retrieval of the required nine waste samples was 7.6 hours. 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. Videotape records were created and are available for essentially all in-tank activities. The system has since been demobilized and placed in storage at ORNL awaiting future deployment opportunities.

PROBLEM STATEMENT

DOE is responsible for cleaning up and closing over 300 small and large underground tanks across the DOE complex that are used for storing over 3,785,400 L (1,000,000 gal) of high- and low-level radioactive and mixed waste (LLW and MLLW). The contents of these aging tanks must be sampled to analyze for contaminants present to determine final disposition of the tank and its contents. Access to these tanks is limited to small diameter risers that only allow for sample collection directly below these openings. In order to collect a more representative sample without exposing workers to tank interior, a remote-controlled retrieval method must be used. Many of the tanks have vertical obstructions and limited headspace that makes deploying a long reach manipulator impractical. In addition, many of the storage tanks have access penetrations that are 45.7 cm (18 in) in diameter and, therefore, are not suitable for deployment of large vehicle systems like the Houdini (1).

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 vehicle system also includes a deployment and containment structure, and a jet pump-based waste dislodging and conveyance system for use in these limited-access tanks.

TECHNOLOGY DESCRIPTION

The Scarab III system is comprised of three main subsystems: The Scarab III vehicle, the DCM, and the control consoles as shown in Fig. 1.

Scarab III Vehicle

The 56.7-kg (125-lb) vehicle is teleoperated, which means an operator in a remote location with no pre-programmed routine performs controls. It is also skid steered; a joystick that directs motion of the wheels on either side of the chassis controls its speed and direction. If desired 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 0.15 m/sec (0.5 ft/sec). The vehicle manipulator arm is capable of rotation up to 360 degrees, elbow movement up or down 90 degrees, and gripper opening to accommodate a 5-cm (2-in) diameter object weighing up to 2.3 kg (5 lbs).

The vehicle also comes equipped with three cameras: two black-and-white fixed focus cameras are mounted in the front and rear ends of the vehicle's housing while the third unit, a color camera with 25X zoom, is 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 139 to 210.8 cm (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-connect to the back top deck of the vehicle. The tether is the vehicle's lifeline. It provides compressed air (turret's pneumatic), electrical power, and signal lines. 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 facilitate reuse of the equipment.

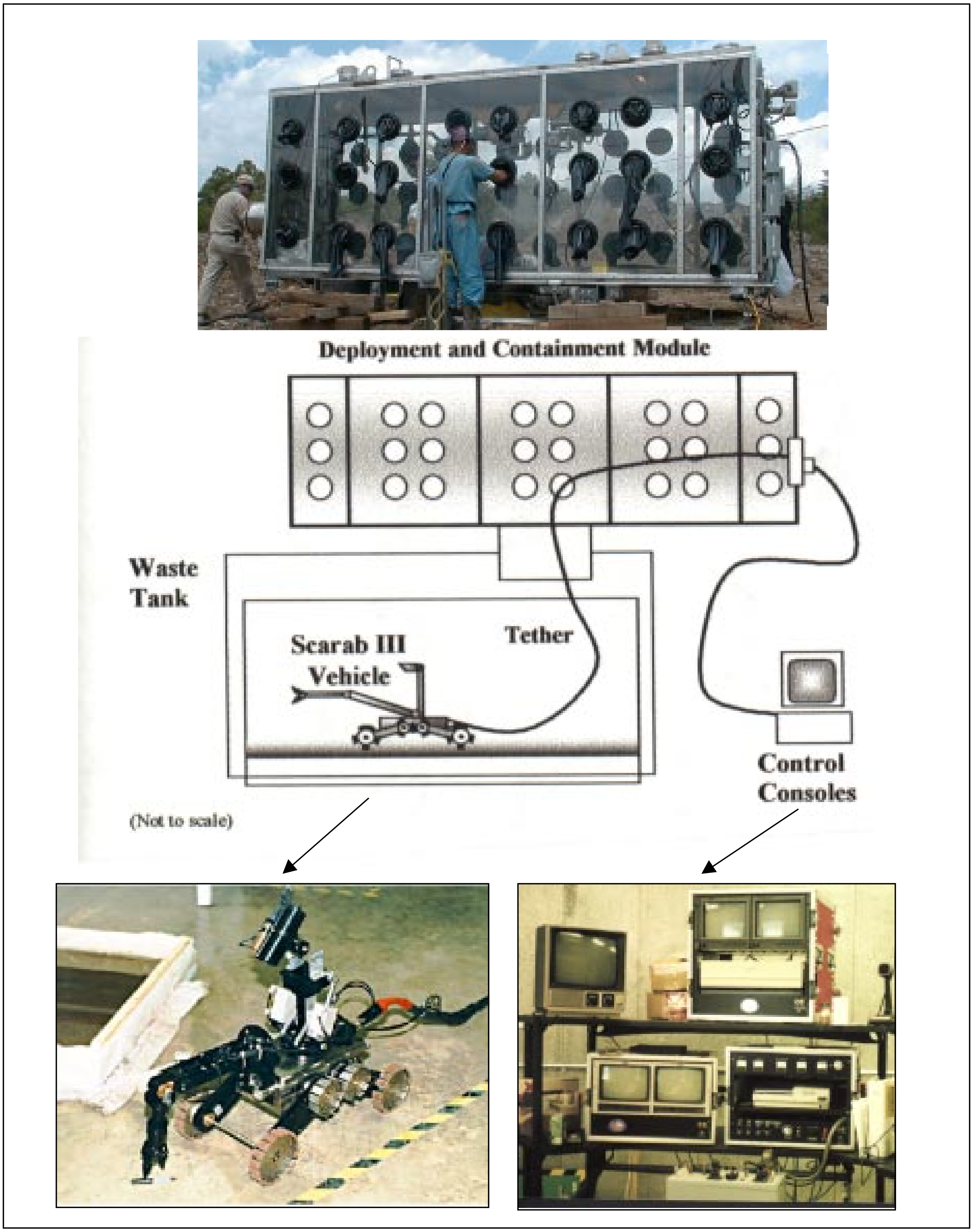

Fig.1. Scarab III System Setup.

Deployment and Containment Module

The DCM provides containment and storage for the Scarab III vehicle (see Fig. 1). This unit includes two winches – one that is used for deployment of the vehicle and the other is a spare. A riser interface port in the bottom of the DCM structure provides the interface point between the DCM and the tank to be entered. A 50.8-cm (20-in) diameter 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.

Control Consoles

Control consoles for vehicle operation (Fig. 1) 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) of the vehicle as well as 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 displays front and rear camera views from the vehicle. The Record Console 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.

Installation and Deployment

The Scarab III vehicle is transported to the site in the DCM that is placed over and connected to the tank riser. The vehicle is then readied for deployment by lowering the turret camera so that it lays flat on the vehicle and the manipulator arm is lowered to 10 degrees below horizontal to ease deployment through the DCM tank interface riser. 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 front camera to guide the lowering of the vehicle (Fig. 2). 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.

Based upon direction received from the vehicle operator the DCM support crew then lowers the winch and vehicle gently. As soon as the vehicle operator signals a touch down of the manipulator arm and front tracks of the vehicle the winch is lowered quickly to get the back of the vehicle down on the tank floor. This prevents damaging the manipulator arm by resting too much weight on it for an extended period.

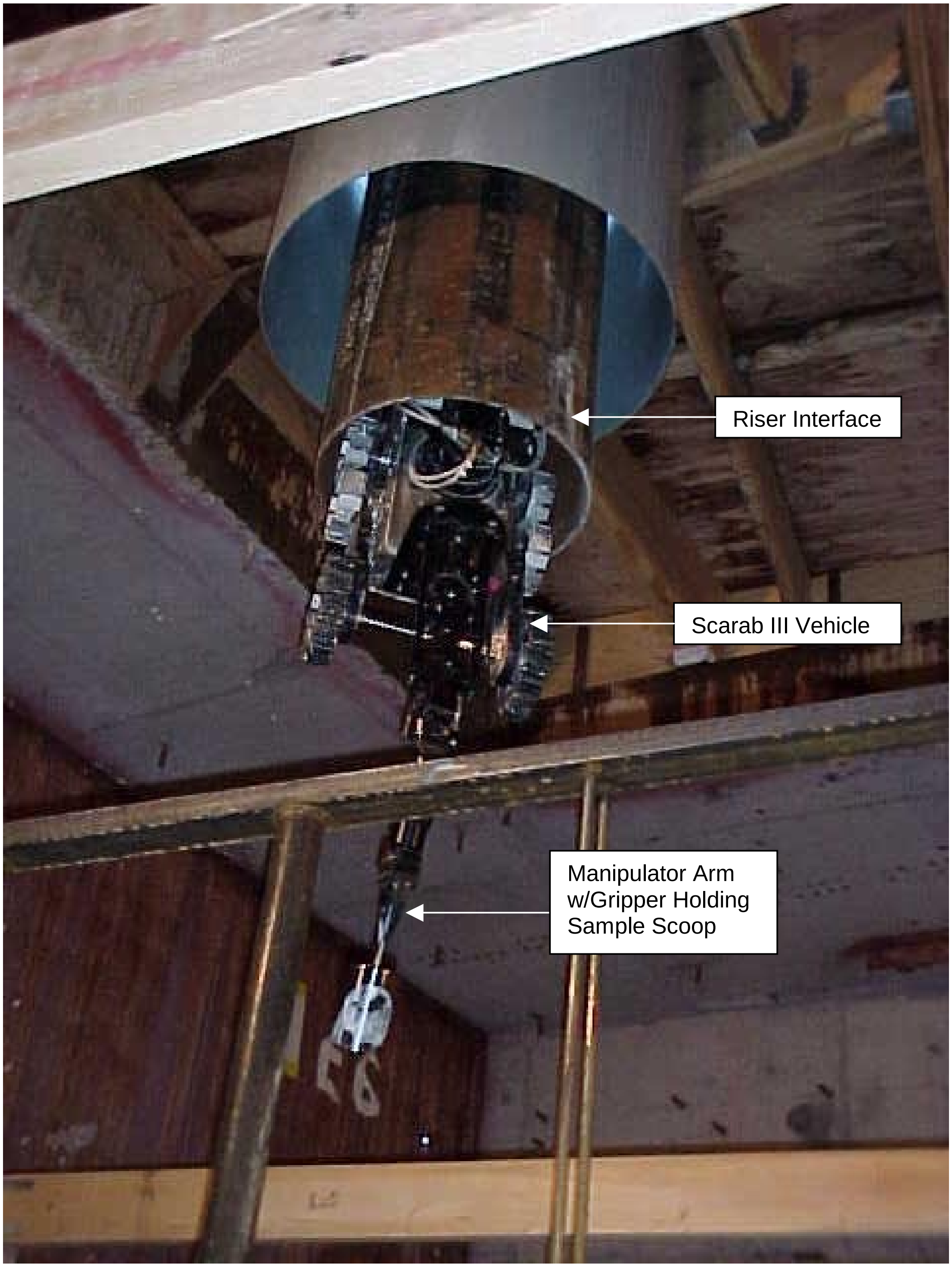

Fig. 2. Scarab III vehicle entering tank at TTCTF through riser.

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

DEMONSTRATION AT TANK T-14

Tank T-14 Description

Tank T-14 is an inactive underground tank located under approximately one foot 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 approximately 215,768 L (57,000 gal). The maximum envelope of the tank is approximately 7.9 by 8.8 by 4.6-m deep (26 by 29 by 15-ft), with a wall thickness of approximately 0.3 m (1 ft). The tank floor is sloped to a 0.6 by 1.2 by 0.3-m deep (2 x 4 x 1 ft) sump. A series of seven pre-cast concrete span-deck panels comprise the roof of the tank. Access to the tank interior is via a 0.8 by 0.9 m (2.5 by 3-ft) hatch located above the sump area. Steel framing to support a sump pump further reduced the accessibility through the hatch.

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 30.5-cm (12-in) diameter steel gravity drain line originating in the Well Cell of Building 7860. A 3.8-cm (1.5-in) diameter 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.

Due to limited accessibility to 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 at the far end of the tank was of a different consistency thus varying concentration of contaminants than those seen at the access point. This required a more representative sample from across the tank be collected and analyzed for remediation planning.

Remote Waste Sampling at Tank T-14

Due to 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 remotely operated vehicle 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 completion of a readiness review, the Scarab III system was relocated to the Tank T-14 site on May 24, 1999 (Fig. 3). To accommodate system installation, it was first necessary to remove an existing sump pump and it's 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 "touch down" pad for the Scarab III 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 (Fig. 3) 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

Figure 3. DCM being installed at Tank T-14 Site.

become airborne during vehicle insertion, retraction, or in-tank operations. The system operator's consoles were installed in an unused portion of Building 7860.

Following a series of pre-operational 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 40 by 64 cm (15.75 by 25.25 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 touch down 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 angled 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 (approximately one-tablespoon minimum) was collected in the Scarab III manipulator scoop. The vehicle was then driven to a collection bucket located at the touch down 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. An operator then retracted the collection bucket into the DCM where the sludge was removed and composited into a sample jar (Fig. 4). The collection bucket was then lowered back into the tank to receive 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 four hours of vehicle operating time. Sludge retrieval continued on May 27, 1999 with collection of five additional samples, for a total of nine sludge samples during the entire campaign. The sample jar containing a composite of these nine sludge samples was then removed through the DCM bag-in/bag-out port for transport to laboratory facilities. The Scarab III vehicle logged approximately 3.6 operating hours on the final day of the sampling campaign.

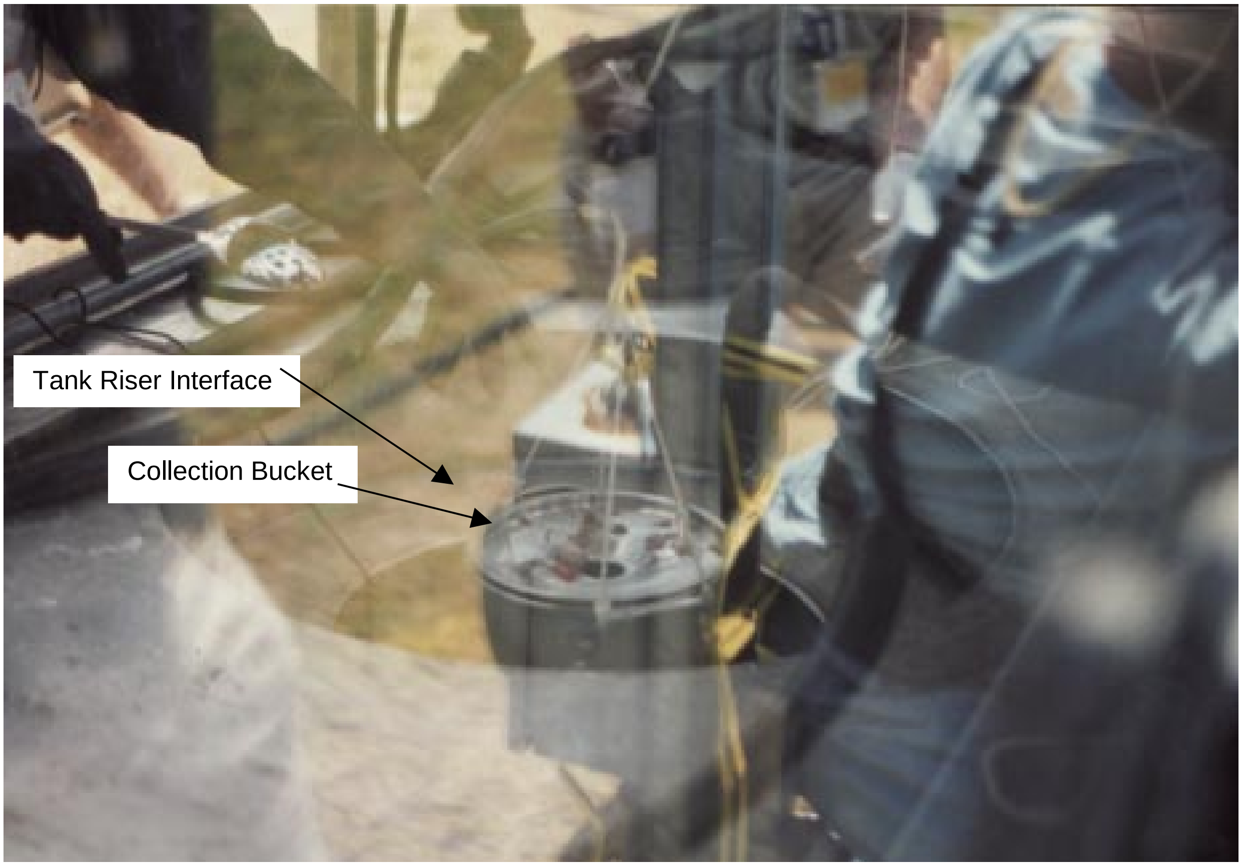

Fig. 4. Scarab III sample collection and compositing in collection bucket as seen through DCM.

During operation, sludge depths were estimated to range from two to six inches 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.

At the completion of sampling activities, the Scarab III vehicle was retracted from the tank and gross-level decontamination was completed in the DCM. The system was then demobilized and is currently in storage at ORNL awaiting future deployment opportunities.

CONCLUSIONS

The Scarab III system performed quite well and was able to successfully satisfy all objectives of the Tank T-14 sampling campaign. Observations from cold testing and in-tank operations indicated that the vehicle could operate effectively in radioactive sludge up to about 20.3 cm (8 in) in depth. Operating time for retrieval of the required nine waste samples was 7.6 hours. 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.

The Scarab III remotely operated vehicle system can be broadly applied to sample and inspect the interior of other 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 for deployment are as follows.

- The Scarab III vehicle requires a 45.7-cm (18-in) diameter or larger access to enter the tank.
- The Scarab III vehicle operational efficiency decreases significantly in sludge depths greater than 20.3-cm (8-in).
- The DCM requires a large, flat area for safe placement over tank riser interface.
- The consoles must be placed in a structure within 91.4 m (300 ft) of tank access where it will be kept safe and dry.

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 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 cost for field set-up 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. It should also be noted that refurbishment cost prior to deployment and minor maintenance is to be expected of the Scarab III system due to wear and tear on the mechanical parts thus a minimum of $5000 spare parts budget should be budgeted.

Additional information describing the performance, cost, and regulatory acceptance of the Scarab III technology is published in the Innovative Technology Summary Report available on the OST Web site at http://em-50.doe.gov under "Publications" (4).

REFERENCES

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