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SCARAB III REMOTE VEHICLE DEPLOYMENT FOR WASTE RETRIEVAL AND TANK INSPECTION*

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ABSTRACT

The Robotics Technology Development Program now known as the Robotics Crosscut Program, funded the development and deployment of a small remotely operated vehicle for inspection and cleanout of small horizontal waste storage tanks that have limited access. Besides the advantage of access through tank risers as small as 18-in. diameter, the small robotic system is also significantly less expensive to procure and to operate than larger remotely operated vehicle (ROV) systems. The vehicle specified to support this activity was the ROV Technologies, Inc., Scarab. The Scarab is a tracked vehicle with an independently actuated front and rear "toe" degree-of-freedom which allows the stand-off and angle of the vehicle platform with respect to the floor to be changed. The Scarab is a flexible remote tool that can be used for a variety of tasks with its primary uses targeted for inspection and small scale waste retrieval. The vehicle and any necessary process equipment are mounted in a deployment and containment enclosure to simplify deployment and movement of the system from tank to tank. This paper outlines the technical issues related to the Scarab vehicle and its deployment for use in tank inspection and waste retrieval operations.

Introduction

The Fiscal Year 1998 Robotics Crosscut program technical task plan (TTP) for tank waste retrieval included a task to examine the use of the Scarab remote vehicle for waste retrieval from small horizontal waste tanks. These tanks typically have exceptionally small diameter access risers, which make it difficult to introduce remotely operated equipment into the tanks. The TTP also specified the examination of the use of jet pump-based waste retrieval systems with the Scarab.

The Oak Ridge Old Hydrofracture Facility (OHF) horizontal tanks were typical of those that the Scarab was designed to address. These tanks are buried below ground level, constructed of steel, and range in capacity from 13,000 to 25,000 gallons. Tank lengths ranged from 28-ft to 44-ft long and they were between 8 and 10.5 feet in diameter with 18-in diameter risers (most of the riser was buried). Gross waste retrieval was performed in the summer of 1998[1] leaving less than 6-in of waste in the bottom of each tank. This waste was highly corrosive and caustic with a relatively high radiological level predicted

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(up to 50 rads/hour). Two of the tanks were rubber lined. Use of the Scarab was planned for sampling and characterization, small-scale sludge waste retrieval, object retrieval, and final inspection. Since several of these tanks were typically clustered together in a "farm", it was necessary that the entire retrieval system be capable of moving quickly from tank to tank within that area.

The proposed solution for tank inspection and waste retrieval under these circumstances was to deploy the Scarab and any associated equipment in a single package named the deployment and containment module (DCM). Operations were kept as manual as possible with few controls and no automation to minimize costs. The original design included a horizontal box structure of stainless steel with steel panels on the ceiling, ends and floors, and with Lexan™ side panels. Glove ports populated the Lexan™ sides to support maintenance. The horizontal box was divided into three parts with a center section for attachment to the riser itself, one side compartment for vehicle-related items, and one side compartment for process equipment. The original concept included a vertical tower box on top of the horizontal box's center section to support a jet pump mast, but this was later deleted in favor of a horizontal jet pump concept for the process side of the box. The deletion of the tower was desirable since the "sail area" of the structure made it susceptible to turning over in high winds.

The ROV Technologies Scarab

The original specification called for the use of a Scarab IIA vehicle; however, the need for modifications to the vehicle to make it appropriate for waste tank use pushed ROV Technologies to design a new model, the Scarab III, shown in Figures 1 and 2. Specific modifications included exchanging most of the aluminum body parts for stainless steel for corrosion resistance, an exchange of tracks for rubber-treaded metal wheels, a decrease in vehicle cross section so that it could pass through 18-in. tank risers, and a change in the drive mechanism. As delivered, the Scarab III system included the vehicle, three cameras, a manipulator, a top mount pan and tilt unit for camera or boom deployment, tool interface plate, a boom, a tether, and an operator control station.

The Scarab III remote vehicle was designed to operate either submerged underwater or in several inches of sludge with the primary restriction on sludge depth being the ability to see to drive remotely via on-board cameras. Articulated drives were provided to permit climbing over 8-in. obstacles, and the vehicle can turn via skid steering within its own length. With the top camera folded down in back, the vehicle cross section reduced to 16.875-in. The final weight of the stainless steel version of the Scarab was 125-lb. The original Scarab drive configuration used front and rear articulated tracks with front and rear motions independent but left and right side motions coupled so that the front and rear of the vehicle could be adjusted to change the stand-off and angle of the vehicle with respect to the floor. Scarab III kept the drive articulation but replaced the tracks with rubber-treaded metal wheels. This permitted operation in sludge with some gravel content where tracks would have jammed. In addition, some of the drive mechanism was moved internal to the body, and the external drive chains were enclosed in a sealed housing packed with grease. The smaller cross section body cavity dictated a redesign of the drivetrain to repackage the motors and gearboxes. The increased weight of the stainless steel body also required the use of larger drive motors. The front of the vehicle provided a tool plate based on a standard 2-in. pipe flange for attachment of tools weighing up to 25 lbs with a center of gravity up to 1 foot from the vehicle body. The tether and strain relief connected to the back of the top deck of the vehicle. The vehicle top plate provided the pan and tilt degrees-of-freedom (DOF) and the mounting point for the boom and camera.

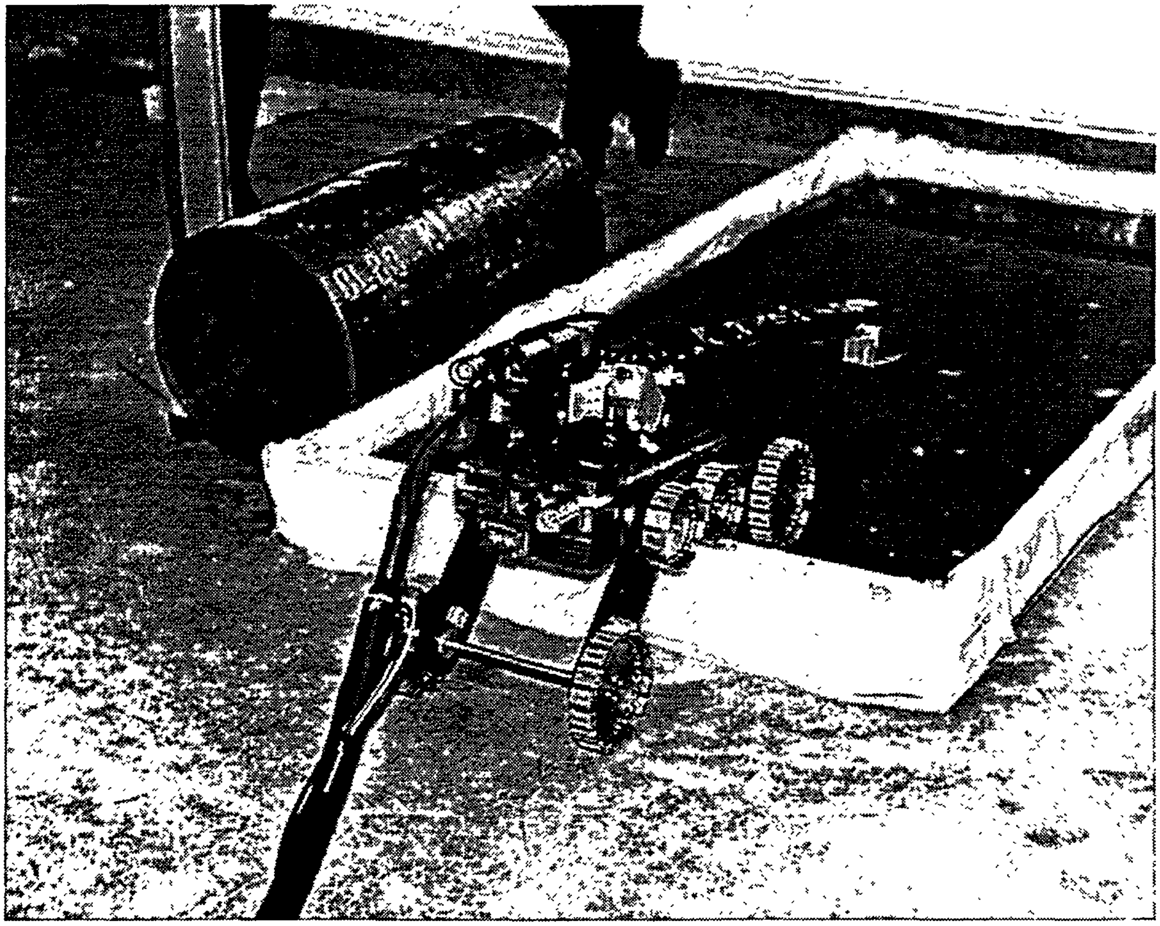

Fig. 1. Scarab III during acceptance testing.

The body of the vehicle enclosed built-in black-and-white cameras and adjustable intensity lights in the front and rear. These cameras were low light fixed lens cameras. These fixed cameras were very useful in providing reliable reference frames for remote driving. The rear camera had the added value of keeping track of the tether. However, tools mounted to the front body tool flange plate could occlude the front camera. The third camera was mounted to the top of the vehicle on the pan and tilt mechanism. This unit, which was a color camera with an exceptional 25:1 zoom lens, a motorized focus adjustment, and separate adjustable light. This camera was most useful as the primary remote-driving and tank inspection camera. All cameras and lights were designed for both underwater and open-air use.

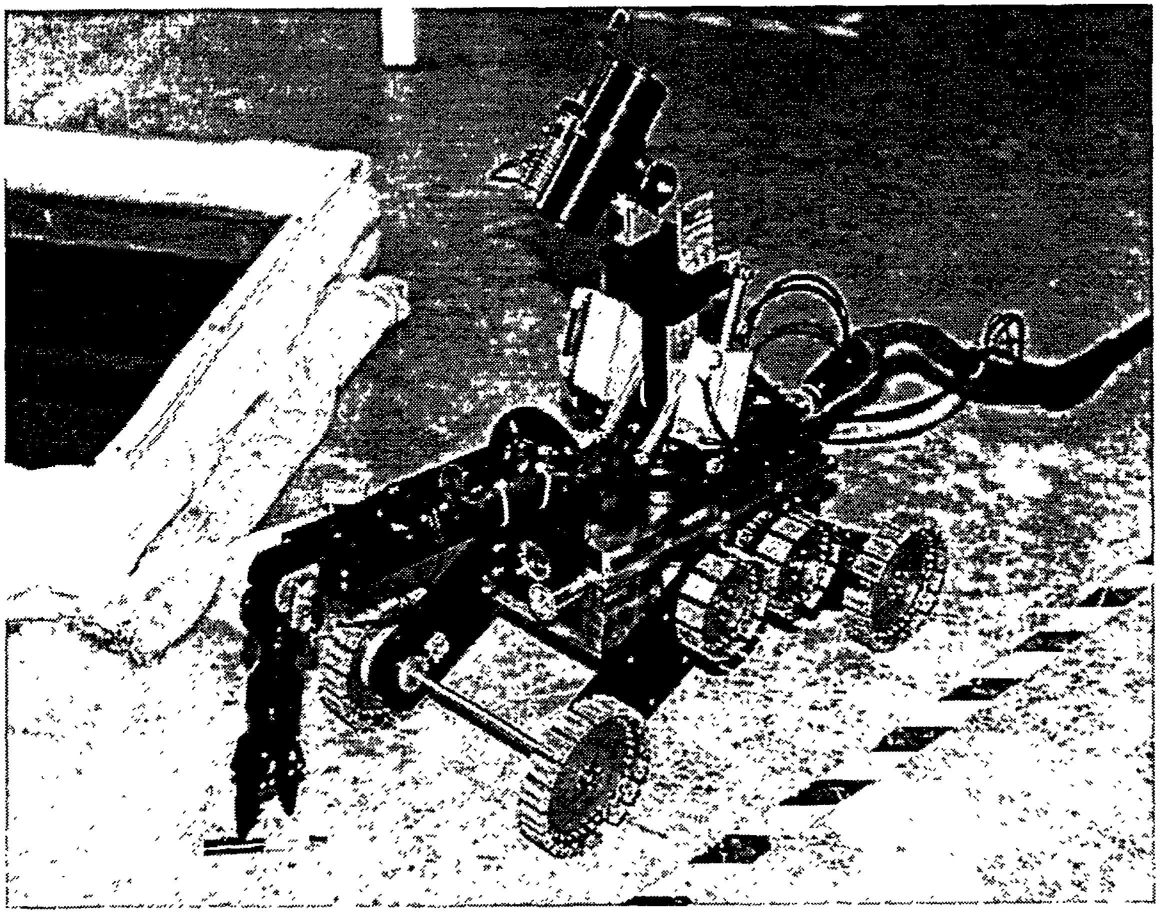

Fig. 2. Scarab III during acceptance testing.

The manipulator provided was a "2-DOF plus gripper" design by ROV Technologies. The base DOFs included a 300-degree roll followed by a 200-degree pitch elbow. Vehicle platform vertical motion increased the manipulator ranges of motion by giving the arm base vertical translation and angular motion. The gripper capacity was approximately 100-lb, but the arm lift capacity was about 5-lb. The arm is bolted to the 2-in mounting flange on the front of the vehicle; therefore, either the arm could be mounted or a waste retrieval tool could be mounted, but not both. The primary function of the manipulator was for sample retrieval and collection of stray objects that may have dropped into the waste over the years. This unit was not intended as a dexterous manipulator and was designed for on/off control.

The pan and tilt unit, on the vehicle top deck, was designed to take either the color camera or an extending boom. The boom was capable of telescoping between 55-in and 83-in. from the floor in the vertical position. In addition, the color camera could be mounted on the end of the boom. The pan motion was designed with an electric drive, while the boom tilt was pneumatic based on a 90 psi air supply and solenoid valves in order to be able to lift the boom to full vertical at full extension. In addition, the color camera tilt was driven by an electric drive for more precise control. The purpose of the boom was to permit close sampling and inspection of tank walls considerably out of reach of the vehicle itself.

The vehicle power, controls, and air supply passed down through the tether that connected to the back of the vehicle via watertight connectors, and the whole length was sleeved with a heat shrink jacket. A steel cable acting as a strain relief, also passed along the entire length of the in-containment tether section and attached to the back of the vehicle. A strain relief bracket was added to support the tether at the vehicle end so that pulling on the tether could retract the vehicle, if necessary. The tether was divided into two sections with 75-ft of cable inside containment to deploy the vehicle and 325-ft of cable outside of containment to route power and control from the deployment site to the operator control station. The tether passed through containment at one of the 8-in flanges in the ends of the containment box via RTV sealed connectors. Fourteen of those blank 8-in flanges were provided on the DCM for interfacing various tools to the enclosure.

The operator control station, shown in Figure 3, was divided into four separate shippable boxes and was designed for operation off of a standard 30-in by 60-in office table through a single 120VAC circuit. The main box contained all power supplies and system interconnections along with some basic control switches for vehicle toe motions and peripherals. Two of the boxes contained a total of four video monitors, a VCR, and screen printer. The vehicle operator control console was a separate smaller box with proportional joystick and switch controls for most of the functions on the vehicle itself. The primary advantage of this particular operator station was its compact size and low and simple power requirements.

Waste Retrieval Technology

Based on previous experience in the ORNL Gunite tanks remediation efforts, jet pump-based retrieval of sludge was the suggested baseline for use in residual waste removal from small horizontal tanks. In this approach, a high-pressure water pump, shown in Figure 4, supplied potable water to a jet pump. The jet pump injected high-pressure water out the outlet side of the pump through nozzles across a venturi, which created a high vacuum on the inlet side of the pump. A vacuum hose was connected to the pump inlet on one end and attached to the vehicle on the other end. Waste was to be vacuumed from the tank and into the hose where it would be combined with the motive water from the high-pressure pump and accelerated out the exhaust end of the jet pump. The motive water was then, by definition, part of the waste stream. The jet pump system used during testing utilized approximately 10 gpm motive water at 7000 psi.

Tests were conducted manually and with the suction head mounted on the vehicle for retrieval of simulated waste material (bentonite clay) from a large metal pan. The ROV had difficulty maneuvering with any of the waste hoses that were tried. However, a 1-in line was deemed marginally acceptable even though the efficiency (waste retrieval per quantity of motive water consumed) was low. While previous manual testing had indicated that the 2-in line was capable of better retrieval rates, vehicle cold testing had shown that it was too difficult for the ROV to maneuver with the larger hose. The tests can be summarized by saying that, for supernate, jet pump retrieval was able to collect 4.2 gallon of waste for every 1 gallon of motive water consumed; however, for sludge removal after supernate had been removed, the jet pump was only able to collect .08 gallon of sludge for every gallon of motive water consumed. Therefore, the retrieval rate varied from 43 gpm for supernate to 8 gpm for solids. The residual waste is typically slurry for which the retrieval rate would vary between these two extremes depending on the density of the slurry. The final result was that jet pump retrieval for the Scarab was only practical for residual tank waste and would have required extensive in-tank operating sessions even to remove small amounts of waste. The test results reported here reflect ideal conditions and not the difficult process of directing suction nozzles while remotely driving in round-bottomed tanks with low light and possible obstructions.

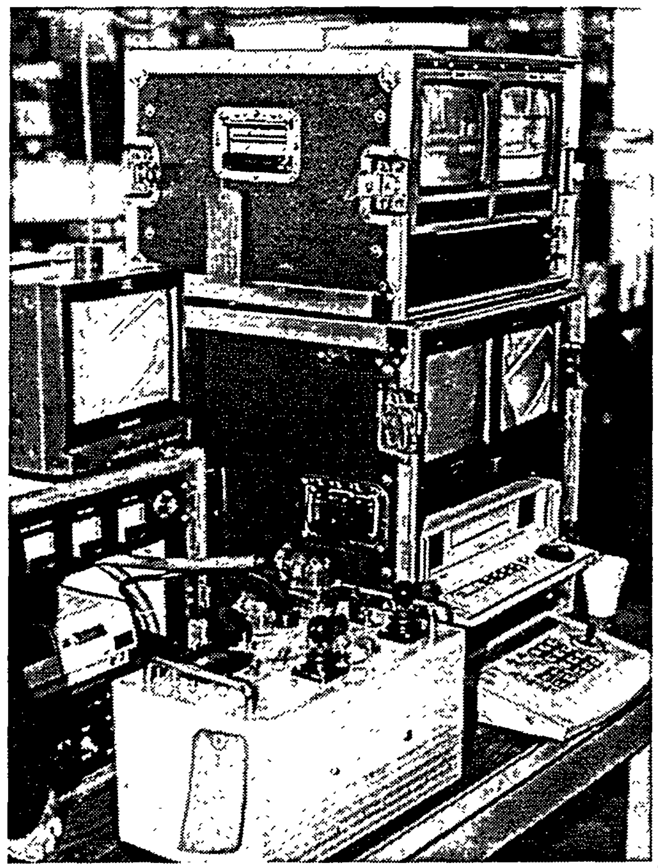

Fig. 3. ROV Technologies Scarab operator station.

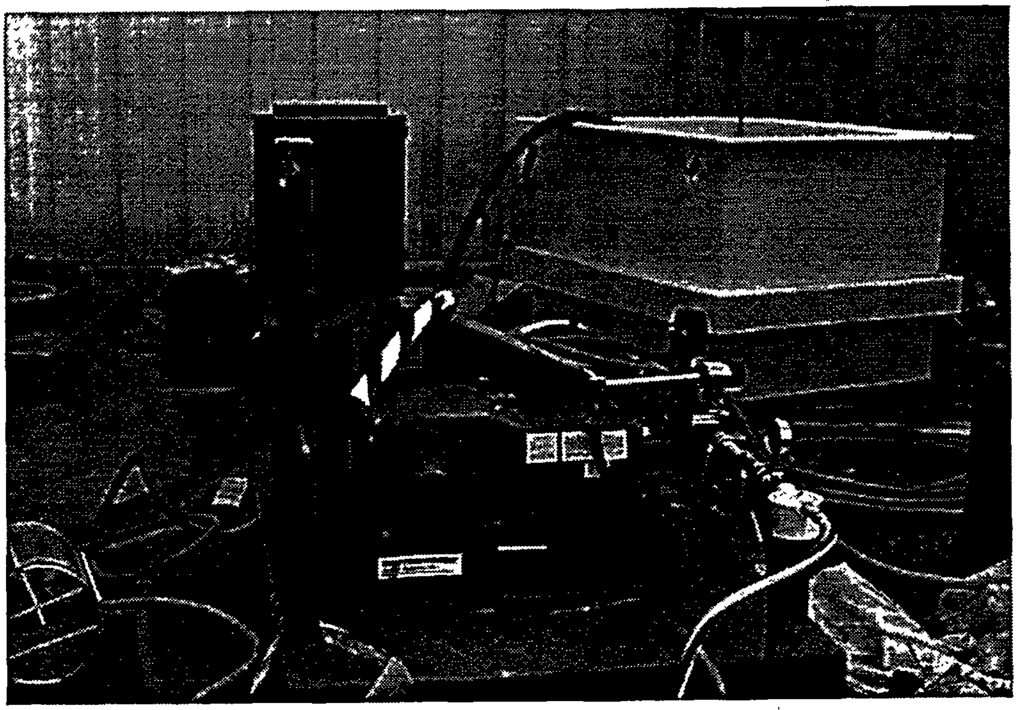

Fig. 4. Jet pump pallet.

Deployment and Containment Implementation

The DCM, shown in Figure 5, was designed based upon the idea that the entire system should be self-contained for quick and easy transport from one tank to the next. The only major component that was kept separate was the high-pressure pump pallet. Therefore, a rather large package was designed to accommodate the need for containment between the DCM entrance/egress port in the center section and the tank riser interface and to provide room for a vehicle storage and maintenance area on one end, and a process equipment area on the other end. The entire box had lifting eyes on top of the structure for a straightforward crane pick. The box itself was 16-ft long, 4-ft wide, and 6-ft high and constructed of stainless steel. The clear side panels were Lexan™ and had three tiers of glove ports. Most of the glove ports located on the middle levels were designated to be capped off unless they were specifically needed. The box originally had outrigger legs with adjustable feet, but a design review during consideration of its use for the Gunite tanks remediation project required a shift to an elevated platform. While this would slow moving from tank to tank and created minor problems dealing with operator access to the glove ports, it did also allow use on a wider range of tank riser sizes.

A tower was originally intended to mount on top of the center section of the DCM which would have made the DCM look like an upside down "T". The tower was required only if the jet pump needed a rigid mast to deploy it low into deeper tanks. The tower was eventually deleted from the design and the mast opening on top of the DCM was covered with a plate. This change resulted from concerns about the stability of the structure in high wind. Modifications to the design of the waste retrieval process to allow the jet pump to be mounted in a fixed position on the process side of the DCM also eliminated the need for the tower in shallow horizontal tanks. Deeper larger round tanks such as the Gunite tanks would have required a long mast; however, waste retrieval by the Scarab was not recommended for large tanks due to the low retrieval rate anticipated. Although cold testing of the retrieval process equipment was completed, due to cost and schedule constraints, the waste retrieval portion of the Scarab system was not integrated into the DCM. Installation of the process-piping fittings was completed so that waste retrieval capability could be added at a later date, and the remaining retrieval hardware was put in storage.

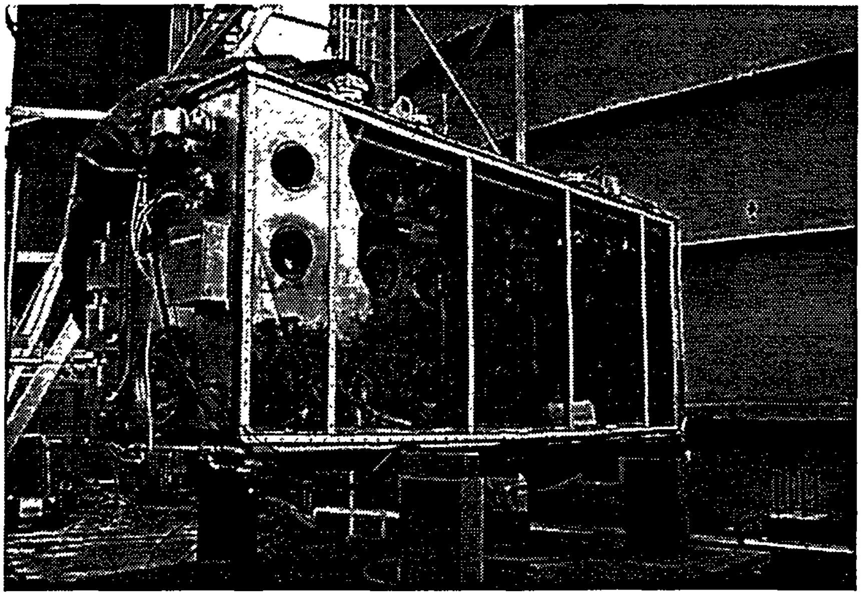

Fig. 5. Deployment and Containment Module.

The vehicle end of the DCM, shown in Figure 6, was used to mount the control for the winches, winch pass throughs, and vehicle tether electric and pneumatic connections. Almost all equipment pass throughs into the box were designed to be via 8-in flange ports. These included cameras, lights, and decon spray washer pressure lines, as well as the winch and vehicle signals shown in the figure. The use of flange ports permitted relatively quick and easy removal for repair with minimal break in containment. The flange ports were placed on both ends of the box and distributed over the top on both sides. A bag-out port was included on one end as well so that the vehicle could be removed if necessary for major hands-on maintenance after decon. However, the preferred mode of repair was to work on the vehicle through the glove ports while it rested on the enlarged floor section of the DCM.

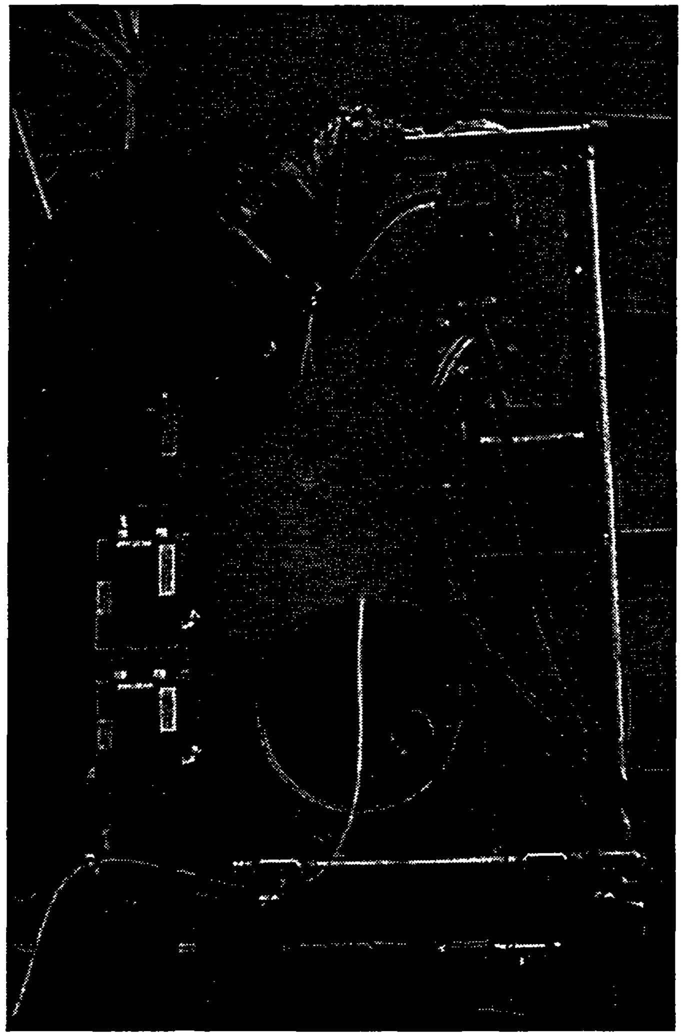

Fig. 6. DCM Bag-out port and control pass-throughs.

The process end of the DCM, shown in Figure 7, was used to mount not only process hardware but also the electrical panel and a custom-made transfer chamber that had been rescued from salvaged equipment. The transfer chamber had inside and outside doors to maintain containment and was included so that small equipment and tools could be passed into the DCM easily with minimal risk of breaking containment. It was the intent that any samples or hardware passing out of the DCM would still have to pass through the bag-out port on the other end.

Switching for all DCM power was done at the electrical panel at the process end of the DCM. Power to the panel was provided by two 60-ft sections of 208VAC 3-phase cable terminated by a welding receptacle on the disconnect end. This provided a single point electrical connection to the DCM for minimal setup time. The 60-ft sections were specified to simplify manual cable handling during setup since the cable was heavy. All circuits at the panel were 110VAC. Weather resistant 110VAC outlets were mounted on the outside corners of the DCM as well as on the inside of the box.

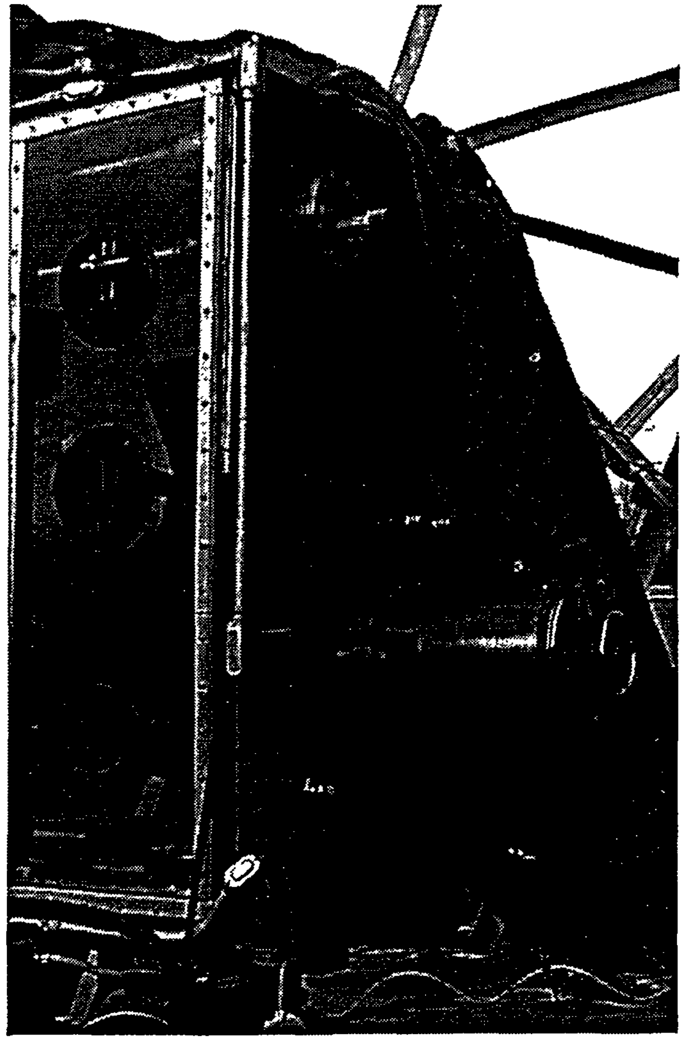

Fig. 7. DCM Transfer Chamber End.

Lifting to deploy the Scarab and any auxiliary hoisting required, such as for retrieving waste samples, was provided by two winches mounted on trolleys on a rail in the ceiling of the DCM. The vehicle deployment scenario called for attaching one winch cable hook to the Scarab and then manually attaching the tether to the winch cable with cable ties, which would then have to be cut off as the vehicle was retracted. While the tether of the Scarab was hypothetically capable of being used to retract the vehicle in the event of a failure, this was not intended for use in routine operations. This and the need to minimize the costs, size, and complexity were the reasons that a motorized tether reel was not selected. This required lifting equipment that could pay out long lengths of cable horizontally as well as vertically. While these units were designated "winches," they were also designed for use for "hoisting" purposes. A brake was not included, but the use of worm gear drive made them nonbackdrivable. The winch lifting capacity was rated at 1200 lbs.; the intended maximum lift for Scarab III operations is ~ 200 lbs. While the primary intended use of the second winch was retrieving small sample buckets, it was identical to the first winch and provided redundancy in the event of an equipment failure.

The DCM also provided two cameras, two spot light fixtures, and four-pressure washer quick release fittings through the ceiling 8-in flanges. The cameras and lights were mounted at opposite ends of the DCM. The pressure washer fittings were on opposite sides of the DCM center section. A separate commercial pressure washer kept outside of the DCM was used to provide the motive water for washing. The spray wands were kept internal to the DCM and could be connected to any of the four fittings as convenient. The floor of the DCM tapered slightly down to center so that any wash would drain back into the tank through the riser interface. The tank riser interface on the bottom of the DCM was modified to take a decon spray ring as designed for the Gunite tank remediation project; however the main decon function was intended to be supplied by manual spray washing as the vehicle was retracted.

Deployment Site Selection

During the scope of this project, three different deployment sites were considered. These sites included the ORNL OHF tanks, ORNL Gunite tank W-5, and finally the Federal Facility Agreement (FFA) tanks T-1, T-2, and WC-20. While design and fabrication of the Scarab system took much longer than had been originally anticipated, there have also been significant logistics problems with the deployment. The OHF tanks were flushed out by using a borehole miner, which had previously been developed by EM-50. At the completion of the primary cleanup activity, the OHF Project Team decided that it was not necessary to deploy the Scarab III system for additional waste removal. Application to Gunite tank W-5 clean out had similar results. The tank was classified as clean enough after the initial mixing and pumping operations to remove the bulk of the waste. In addition, tank W-5 was too large and too deep to be considered an optional application for the Scarab system. At this point, waste retrieval was dropped as the primary Scarab function and the focus was shifted to sampling and inspection, which is its intended use on the FFA tanks at Oak Ridge.

Summary

Examination and deployment of the ROV Technologies Scarab vehicle for residual waste retrieval, sampling, and inspection for small horizontal buried waste tanks was the original scope of this project. The DCM was designed to serve as a relatively low cost deployment and containment system that could be quickly moved from tank to tank. Minimal setup time and minimal peripheral support systems were the primary drivers in the design. Cold testing of the vehicle system and the waste retrieval system has been completed. The Scarab III system is currently scheduled to perform sampling and inspection in one or more of the ORNL FFA tanks in last spring of 1999. Qualification testing on a mock-up of the FFA tanks will be conducted in February and March of 1999. Status of this testing and the FFA deployment will be included at the presentation of this paper.

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