

# LINEAR SCARIFYING END-EFFECTOR DEVELOPED FOR WALL CLEANING IN UNDERGROUND STORAGE TANKS\*

**Curtis Fitzgerald, Jr.**  
**Oak Ridge National Laboratory**  
**PO Box 2008**  
**Oak Ridge, TN 37831-6304**  
[Fitzgeraldcl1@ornl.gov](mailto:Fitzgeraldcl1@ornl.gov)  
**phone: 865-576-9253**

Diedre Falter  
The Providence Group, Inc.  
10330 Technology Drive  
Knoxville, TN 37932  
[dfalter@providence-group.com](mailto:dfalter@providence-group.com)  
phone: 865-218-8712

R. Eric Depew  
The Providence Group, Inc.  
10330 Technology Drive  
Knoxville, TN 37932  
[depewre@providence-group.com](mailto:depewre@providence-group.com)  
phone: 865-218-8711

## ABSTRACT

This paper describes the development and performance of a Linear Scarifying End-Effector (LSEE) designed and fabricated for deployment by a remotely operated vehicle. The end-effector was designed to “blast” or “scarify” in-grained residual contamination from gunite tank walls using high-pressure water jets after the bulk sludge had been removed from the tanks using an integrated suite of remotely operated tools. Two generations of the LSEE were fabricated, tested, and deployed in the gunite tanks at the Oak Ridge National Laboratory, with varying levels of success. Because the LSEE was designed near the end of a four-year project to clean up the gunite tanks at Oak Ridge, a number of design constraints existed. The end-effector had to utilize pneumatic, hydraulic and electrical interfaces already available at the site; and to be deployable through one of the containment structures already in place for the other remote systems. Another primary design consideration was that the tool had to effectively extend the reach of an existing remotely operated vehicle from six ft. to at least ten ft. to allow cleaning the tank walls from floor to ceiling. In addition, the combined weight and thrust of the LSEE had to be manageable by the manipulator mounted on the vehicle. Finally, the end-effector had to follow an autonomous scarifying path such that the vehicle was only required to reposition the unit at the end of each pass after the mist had cleared from the tank. The prototypes successfully met each of these challenges, but did encounter other difficulties during actual tank operations.

## 1. INTRODUCTION

The U.S. Department of Energy (DOE) is responsible for cleaning up and closing over 250 large, aging, underground tanks that have been used to store tens of millions of gallons of high- and low-level radioactive and mixed waste. The waste’s radioactivity precludes humans from working in the tanks.

At the Oak Ridge Reservation this problem has been addressed, in part, by integrating and deploying a suite of remotely controlled technologies—consisting of a long-reach manipulator, a vehicle and a high-pressure sluicing system—to remove the waste from the tanks.

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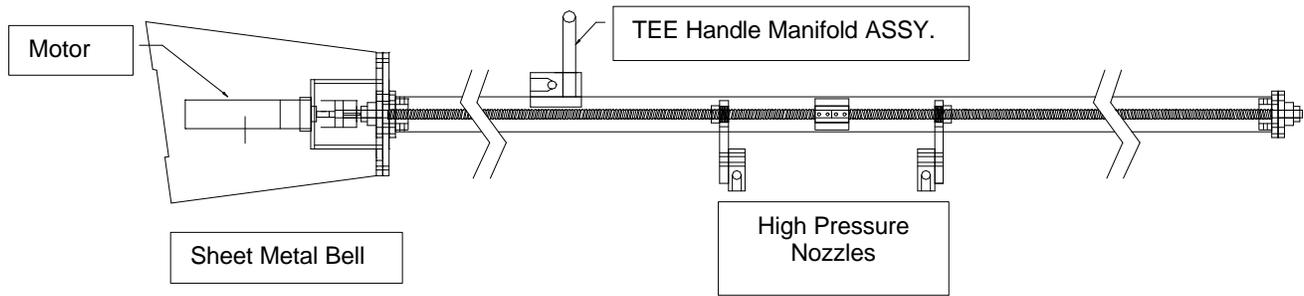
Papers describing the Modified Light Duty Utility Arm, Houdini Remotely Operated Vehicles, and Waste Dislodging and Conveyance System will also be presented at this conference. This integrated suite has already been implemented in the Gunite and Associated Tanks (GAAT) Remediation Project at Oak Ridge and used successfully to clean two 25-ft. and five 50-ft. tanks. During the course of these tank remediation operations, methods for improving the efficiency of waste retrieval operations were sought and a number of special end-effectors were developed to fill gaps in the retrieval technologies available for use prior to this project.

Remediation of the gunite tanks included scouring the tank walls with high-pressure water after the bulk sludge was removed from the bottom of the tanks. During the cold test phase of the GAAT project, the long-reach manipulator was selected as the most suitable deployment platform for wall-cleaning operations. Scarifying the walls produced a dense mist that made it extremely difficult for the teleoperated vehicle to maneuver around the tank while maintaining a constant standoff distance with the scarifying end-effector. The long-reach manipulator, on the other hand, could have the cleaning paths preprogrammed and then essentially “fly blindly” while executing the required wall-cleaning operations. This method worked well on the 25-ft.- diameter tanks where the arm could be used to scarify the circumference of the tank from a centrally located riser. However, once remediation of the 50-ft.-diameter tanks was initiated, it became necessary to move the long-reach arm to a riser in each quadrant of the tank in order to complete scarification of the walls. Each move resulted in approximately two weeks of delay in resuming waste retrieval operations. At this point, the vehicle was reconsidered as a deployment platform for scarifying operations since its tether, with a nominal length of 150 ft., made it possible for the vehicle to reach all areas of the tank when deployed from a single riser location.

## 2. DESIGN

The LSEE was designed to minimize the amount of thrust developed at a lever arm of approximately 6 ft. This was accomplished by balancing the thrust of two nozzles about a center point. To maintain this balance of thrust while traversing the height of the tank walls, two opposing-pitch-threaded rods were rotated to produce a linear motion with a range of approximately 10 ft. Rotation was produced by a small, reversible pneumatic motor, weighing just 3½ pounds, which was mounted on the end of the end-effector. The pneumatic motor, with gear reduction, did lend itself to a limited speed control and combined with the ACME threads to produce an optimum traverse rate of about 10 ft. in 90 seconds. The housing of the end effector was a stainless steel 2-in. schedule 40 pipe with a 1-in. slot cut longitudinally to combine with the opposing pitch ACME thread screws producing the linear motion.

An existing umbilical cord and controller unit was pressed into service for the LSEE. Since only four conductors were available in this umbilical, the controls for the end-effector were necessarily simple. Rotational direction of the pneumatic motor was controlled via limit switches providing momentary pulses to a latching relay that, in turn, controlled a four-way solenoid valve connected to the two ports on the motor. A different version of the control unit was fabricated for each of the two generations of the prototype end-effectors. The first version deployed had all of the controls operated on 110 V and located in a “sheet metal bell” under the scarifier (See Fig. 1). The manipulator available for use required protection from the possibility



**Fig. 1 The Linear Scarifying End-Effector uses rotating jets to clean tank walls.**

of an electrical short circuit so a ground fault interrupter (GFI) was installed in the electrical supply. The harsh and conductive environment led to the premature failure of this arrangement with the ground fault interrupter tripping out at 5 mA. The second arrangement of the controls placed only the limit switches in the tank environment. The four-way valve was moved from the “sheet metal bell” installed in a control box, and operated on 24VDC, thus eliminating the need for GFI. The four-conductor umbilical was used only for the control logic necessary to operate the latching relay. Nozzles with a fan tip opening of 40° were chosen for delivery of the high-pressure water and provided 1 ft. of coverage at a 1-ft. standoff. The cleaning efficiency dropped off significantly for larger standoff distances. Rotating jet nozzles were considered but it was felt the added weight and complexity would not be justified. At approximately one ft. from the wall surface and traveling on a ten ft. long vertical beam 90 seconds were required to clean a 10-sq. -ft. section of the tank wall. The process water is supplied from a high-pressure pump at approximately 7,000 psig and a nominal flow of 10 gpm. Restricting the airflow with a needle valve in the air supply roughly controlled traverse speed control. Due to the minimum airflow requirements at the motor stall point a maximum speed reduction of approximately 25 percent was achieved.

### 3. COLD TESTING

Once the end-effector was fabricated, cold testing was necessary to verify the functionality of the unit before deployment into a radiologically contaminated environment (See Fig. 2).

During cold testing, the end-effector was initially operated without high-pressure water to check the unit’s mechanical operation and to set travel limits. The limit switches were set to allow travel to within 1/8 in. of the mechanical hard limit. During this test an anomaly was discovered with regard to operation of the pneumatic motor. On rare occasions, the motor would fail to restart. Further testing indicated that either a slight nudge of the nozzles or momentarily swapping the air supply port would correct this problem. This potential failure was deemed intolerable by project management; therefore, a “kick starter “ wheel was added to the end of the drive shaft. This wheel could be rubbed against the tank wall to help restart travel of the nozzles.

Several hours of operation were achieved prior to operation with high-pressure water. Hydraulic static pressure tests of 10,000 psig were conducted, with the nozzles removed and plugs installed, to verify hydraulic integrity. This was followed by hydraulic pressure testing with short-term operation over a range of pressures from 500 to 7000 psig. The only significant finding from these tests was that operation of the nozzle holders became steadier as the pressure increased due to the nozzle holders being thrust against and riding on the inside of housing. The



**Fig. 2 The LSEE is shown mounted on a test stand prior to cold testing.**

final test performed was an endurance test at full pressure (7000 psig) with no interruption or interference for a period of two hours. This time period equated to approximately 10 percent of the total expected in-tank operating time of the tool. Plans called for the end-effector to be abandoned in place in the tank once operations were completed. The LSEE passed this test with no difficulties noted and was subsequently transferred to the tank farm for deployment.

#### 4. DEPLOYMENT

The sludge remaining in the South Tank Farm tanks was a diverse mixture of fission products, heavy metals, lab wastes, and pH controlling caustics. This mixture has proven to provide a challenging environment for the remediation equipment implemented there. The first

LSEE prototype was deployed into Tank W-8 following completion of bulk sludge retrieval. At this time it contained two to four-inches of residual sludge with a very high water content. Since testing the vehicle and its Schilling Titan III manipulator with the LSEE had not been feasible during cold testing, nozzles that would limit water pressure development to 1500 psig (thereby limiting the thrust development) were installed on the end-effector. During the first in-tank deployment, an effective scarifying strategy was developed. The vehicle's manipulator was positioned where it could use the shoulder rotate actuator to position the LSEE for three to five 1-ft.-wide wash cycles. The original concept of the sheet metal bell was to position the LSEE at its appropriate position near the wall of the tank then allow the base of the bell to rest on the floor of the tank. This was to allow the floor to take some of the mechanical load off of the manipulator. However, this proved to be too cumbersome and time consuming once it was established that the manipulator was capable of handling the load and thrust. Over the course of the deployment, the controls for the original LSEE end-effector were constantly in direct contact with the sludge. This took its toll on the four-way solenoid valve. On the second day of deployment the GFI used for equipment protection tripped and could not be reset. A decision was made to abandon the LSEE in place.

Deployment of the second prototype took place during a period between pumping operations on the next tank, Tank W-9, while there were still approximately six to eight inches of sludge remaining in the tank. The implementation strategy for this tool was developed based on lessons learned from deployment of the first LSEE and progress was much faster washing the walls. Although this second generation tool was designed for water pressures of up to 30,000 psig, pressures of only 3000 psig were used to minimize the amount of mist generated and to maintain in-tank visibility as long as possible. Total operational time was in the neighborhood of seven hours over two shifts with approximately 40 percent of the tank wall washed. Control problems were encountered with the Titan III manipulator that caused the arm to fault to a "limp" condition and collapse into the sludge with the LSEE. Once the LSEE had been dropped and retrieved from the sludge a couple of times, the ACME drive screws and the housing were coated with sludge and a mechanical jam ensued. Although attempts were made to wash the sludge from the housing and screw threads, and to force rotation through the mechanical jam created by the sludge, only momentary success was achieved. Once again, a decision was made to abandon the end-effector in place.

## 5. SUMMARY

Although limited success was achieved with the actual deployments of the scarifying end-effectors, the LSEE concept was demonstrated as a viable alternative for extending the wall-scarifying reach of vehicles like the Houdini up to 10 ft. or more. These prototypes would have greatly benefited from a more complete cold test program including a realistic deployment scenario and extended operational time in the grasp of the vehicle's on-board manipulator. None of the failures that occurred would have been difficult or expensive to correct had they surfaced during cold testing.