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REMOTE SYSTEMS FOR WASTE RETRIEVAL FROM THE OAK RIDGE NATIONAL LABORATORY GUNITE TANKS*

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ABSTRACT

As part of a Comprehensive Environmental Response, Compensation, and Liability Act Treatability Study funded by the Department of Energy, the Oak Ridge National Laboratory (ORNL) is preparing to demonstrate and evaluate two approaches for the remote retrieval of wastes in underground storage tanks. This work is being performed to identify the most cost-effective and efficient method of waste removal before full-scale remediation efforts begin in 1998. System requirements are based on the need to dislodge and remove sludge wastes ranging in consistency from broth to compacted clay from Gunite (Shotcrete) tanks that are approaching fifty years in age. Systems to be deployed must enter and exit through the existing 0.6 m (23.5 in.) risers and conduct retrieval operations without damaging the layered concrete walls of the tanks. Goals of this project include evaluation of confined sluicing techniques and successful demonstration of a telerobotic arm-based system for deployment of the sluicing system. As part of a sister project formed on the Old Hydrofracture Facility tanks at ORNL, vehicle-based tank remediation will also be evaluated.

I. INTRODUCTION

Throughout the operational history of the Oak Ridge National Laboratory (ORNL), production of radioactive and other hazardous chemical wastes has occurred as a result of normal facility operations. In order to collect, neutralize, and store these wastes, 12 underground tanks were constructed of gunite, a form of concrete applied in layers. Built in the 1940's, the gunite tanks have since been removed from service due to age and changes in liquid waste system needs and requirements. These tanks, along with four nearby stainless steel units, are known as the Gunite and Associated Tanks (GAAT). The bulk of the radiochemical waste was removed from the tanks during the 1980's using standard hydraulic sluicing techniques. However, a waste "heel" remains to be removed. The heel consists of soft sludge generally 0.15 - 0.2 m (6 - 8 in.) deep with depths of up to 0.43 m (1.4 ft) and radiation levels up to 100 Rad/hr maximum at the waste surface. Each tank also has a

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supernatant layer above the sludge, the volume of which varies from inches in one tank to several feet in others.

In 1994 the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency, and the Tennessee Department of Environment and Conservation agreed that a Comprehensive Environmental Response, Compensation, and Liability Act Treatability Study offered the opportunity to identify cost-effective remediation approaches for the GAAT by providing information to reduce cost and technical uncertainty and better define acceptable remedial action strategies. In order to incorporate the technology advances developed by the DOE Office of Technology Development (OTD), the ORNL Environmental Restoration Program has established partnerships with the Tanks Focus Area (TFA) and Robotics Technology Development Program (RTDP). These partnerships involve highly interdependent and cofunded design, development and testing activities. Under the auspices of the Treatability Study, a technique known as confined sluicing, which utilizes a high-pressure, low-volume water jet integrated with a jet pump, will be demonstrated and thoroughly evaluated. The confined sluicing operation that is being designed will employ a Waste Dislodging and Conveyance (WD&C) system for waste retrieval deployed using either an arm (see Fig. 1) or vehicle based system. The resulting data will be compared with archived cost and performance data from a low-pressure, high-volume hydraulic sluicing technique known as past practice sluicing, which was used for bulk sludge retrieval in the early 1980s. The end goal of the GAAT Treatability Study is to come away armed with the knowledge and hard evidence necessary to propose and defend a reliable and cost-effective remediation strategy for the remaining gunite tanks. Because of the similar technical requirements for cleanup of the Old Hydrofracture Facility (OHF) tanks, technology evaluation efforts will be shared. The OHF project will perform the evaluations of a vehicle based approach for deploying the same WD&C system designed for the GAAT.

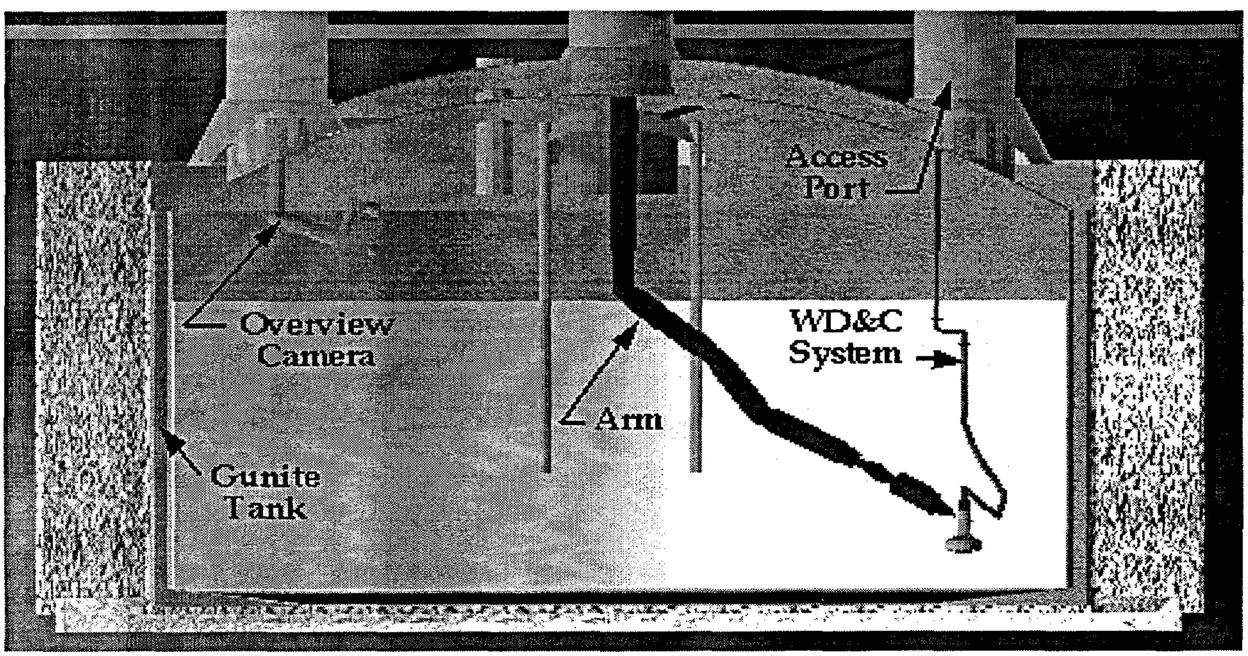

Fig. 1. Arm Deployment of WD&C System in Gunite Tank

II. SYSTEM DESCRIPTIONS

The confined sluicing approach to tank waste retrieval consists of four primary systems which can be considered on an individual basis. The Waste Dislodging and Conveyance System (1) forms the core of the waste recovery strategy, and yet depends on either the manipulator system (2) or the in-tank vehicle system (3) for positioning to achieve full tank coverage. The control system (4) is necessary to direct and integrate the activities of the other primary systems as well as a number of auxiliary components, such as the viewing, containment, decontamination, high efficiency particulate air (HEPA) and waste conveyance piping and equipment systems. Each of the primary systems will be discussed below.

A. Manipulator System

Arm based retrieval will be performed using the Modified Light Duty Utility Arm (MLDUA), a modified version of the Light Duty Utility Arm (LDUA) currently being fabricated by Spar Aerospace Limited (SPAR) for use in tank characterization campaigns at the Westinghouse Hanford Company (WHC).[1] Development of the LDUA system is a TFA project being leveraged by ORNL. Like the WHC LDUA, the MLDUA will consist of a dual section, telescoping vertical mast, a five link arm, a deployment and containment system, and remote control capabilities. The system will have eight degrees of freedom (see Fig. 2) and is intended for operation in essentially a Selective Compliance Assembly Robot Arm configuration after deployment. The eight degrees of freedom include: 1) mast extension (~14.9 m [49 ft] to deployed shoulder), 2) shoulder rotation (±π rad [±180°]), 3) shoulder pitch (0 - 1.83 rad [0 - 105°]), 4) elbow 1 yaw (±1.75 rad [±100°]), 5) elbow 2 yaw (±1.75 rad [±100°]), 6) wrist pitch (±1.75 rad [±100°]), 7) wrist yaw (±1.75 rad [±100°]), and 8) wrist roll (±π rad [±180°]).

The two most significant modifications required to support the waste retrieval mission for the ORNL gunite tanks include an increased payload from 34 kg (75 lb) to 91 kg (200 lb), and an extended reach from 4.1 m (13.5 ft) to 4.6 m (15.0 ft) as measured from the shoulder joint to the tool interface plate. The tool interface plate will allow the use of a variety of tools or end-effectors. Electrical and pneumatic/hydraulic connections are provided in the tool interface plate. One end-effector, a gripper end-effector capable of operating with the increased payload, is also included in the MLDUA system.

An extended reach is desirable to allow maximum coverage of the tank walls and floor with the MLDUA and to minimize the number of new risers that must be installed in the tanks. With the current

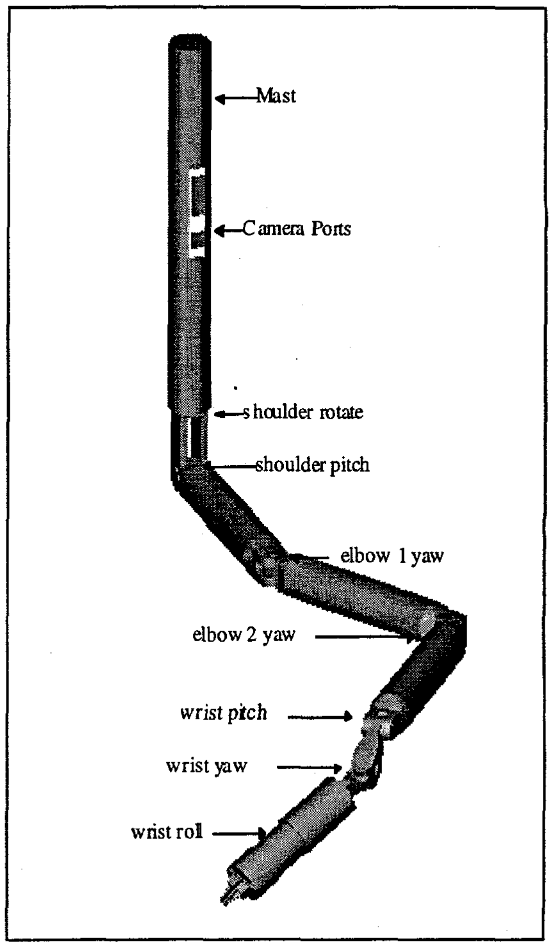

Fig. 2. Modified Light Duty Utility Arm

MLDUA design, reaching the full volume of the six tanks that are 7.6 m (25 ft) in diameter or smaller will be possible using a center access port, while the full volume of the six 15.2 m (50 ft) diameter gunite tanks may be reached using four access ports located along cross diagonals.

The MLDUA is designed for deployment from a pallet which is transported to the site on a trailer. The pallet includes outriggers suitable for either mounting on a bridge structure spanning a tank or directly on footers if a bridge structure is not provided. Provisions for accurate alignment of the MLDUA containment housing with the tank riser interface and confinement enclosure will be provided. Other pallets will carry the hydraulic power supply and the at-tank instrument enclosure, which will provide an interface between the MLDUA and a control trailer up to 152 m (500 ft) from the MLDUA.

Telerobotic operation will be accomplished using overview cameras as well as cameras mounted on the arm. The MLDUA will incorporate a pair of cameras embedded in the mast, utilizing an ORNL customized design that will provide approximately π rad (180°) of horizontal coverage and approximately 1.05 rad (60°) of vertical coverage. The cameras are mounted in a section of the mast which rotates with the shoulder. The gripper end-effector will also include a camera mounting location and connectors for close-up inspection.

In addition to the camera systems, the MLDUA will include a variety of sensors. These include joint position and a six-axis force/torque sensor at the interface between the arm and the gripper end-effector.

As delivered from SPAR, the MLDUA will be capable of teleoperation from the control trailer and will include an interface to provide sensor data to, and accept position commands from, a higher level control system. The MLDUA position control will be compensated for structural deflection, to provide the needed positioning accuracy. A basic approach to redundancy resolution will also be included.

B. In-Tank Vehicle

The second system to be evaluated as part of these tank technology demonstrations will consist of an in-tank vehicle capable of deployment through a 0.6 m (23.5 in.) riser. The vehicle must be capable of operating while partially submerged and maneuvering through sludge and supernatant within a tank. Cold testing of commercially available systems identified through an announcement in the Commerce Business Daily is planned to begin in November of 1995. Each vehicle system to be demonstrated will be evaluated on vehicle deployment and recovery, mobility, sludge decontamination (water washdown), controllability, general utility, reliability, maintainability and compatibility with the GAAT and OHF tank environments.

Although a detailed description of the final vehicle system cannot be determined until after the comparative evaluations in the Tanks Technology Cold Test Facility (TTCTF) described below, all viable candidates must be capable of certain basic maneuvers. The most critical requirement is the ability to retrieve waste. This means that the vehicle must be capable of acquiring and positioning various tools, primarily a confined sluicing end-effector (CSEE), for operation on the surfaces of the waste sludge and for cleaning or sampling up to 1.2 m (4 ft) on the vertical walls of the tank. The tools will be designed to weigh less than 27 kg (60 lb) and limit external forces due to tool umbilicals and dynamic loads to less than 32 kg (70 lb) in any direction. All tools will fall within an envelope of 0.41 m (16 in) by 0.61 m (24 in) and will include a grasp handle.

The vehicle system must be capable of operation both in air and when submerged in a supernatant with a pH ranging from 7 to 11 and a specific gravity of approximately 1. In addition, the vehicle must be capable of maneuvering over or through up to 0.61 m (2 ft) of sludge with a specific gravity of approximately 1.9. The dose rate within the GAAT and OHF tanks is known to be not more than 100 Rad/hr, and an accumulated dose of not more than $1x10^5$ Rad can be expected during retrieval operations over a six month period. While radiation detectors are optional, the system must include an onboard camera and a minimum of two tilt sensors oriented at 1.57 rad (90°) with respect to each other to provide the operator with a warning of an impending overturn. Proximity sensors will also be mounted on the vehicle to allow monitoring of the distance from tank walls in any direction so that collisions with the walls or other equipment in the tank can be circumvented. In the event of a single point failure, the umbilical cable must support remote removal of the vehicle from the tank.

Teleoperation will be the primary mode of operation for the vehicle, based on video from an overview camera system and the onboard camera. All communications between the control system and vehicle will be via a single tether, at least 23 m (75 ft) long, that incorporates all onboard video, sensor input/output, power and control signals. The control system must be capable of operating the vehicle at a distance of 152 m (500 ft) from the tank, but may interface to a patch panel at the surface of the tank.

C. WD&C System

Both the MLDUA and the in-tank vehicle are required to operate the WD&C system. The WD&C system is comprised of the CSEE, and a waste conveyance system with a jet pump. The CSEE is a high-pressure (3000 - 7000 psi) water jet cutting tool with rotating nozzles (see Fig. 3). The jet pump is a lightweight pump with no moving parts. The pump operates on high-pressure (5000 - 7000 psi) motive water.

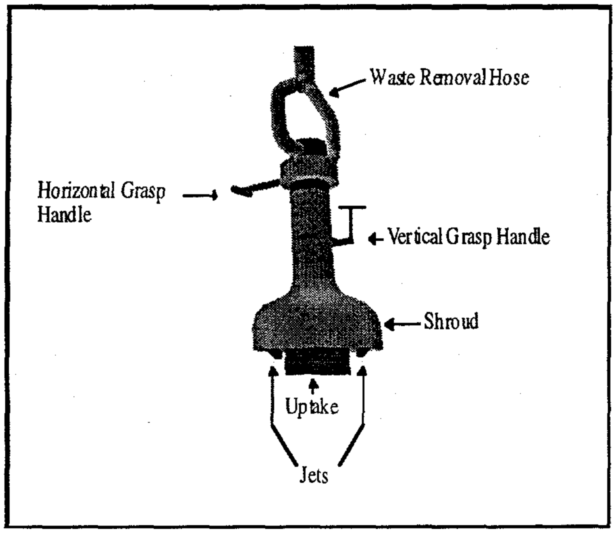

Fig. 3. Conceptual Sketch of Confined Sluicing End-Effector

The system, which is currently under development in collaboration with the TFA participants at University of Missouri-Rolla (UMR), Pacific Northwest Laboratory (PNL), WHC, and Advanced Systems Technology, Inc. (AST) will be used to cut, dislodge, and remove radioactive waste and will also be capable of scarifying concrete walls and floors.

D. Integrated Control System

The final major system to be discussed is the control system. The controls portion of the tank technology demonstrations will facilitate operation of each of the primary systems and a variety of other auxiliary subsystems. These auxiliary systems include viewing, containment, decontamination, HEPA, and waste conveyance piping and equipment. Additionally, the control system will provide for independent operation of each of the subsystems and coordinated operation in a manner which will attempt to maximize mining efficiency, ease of operation and flexibility while ensuring safety. A graphical representation of the control system interfaces is shown in Fig. 4. The control systems for the MLDUA and In-Tank Vehicle will be delivered as part of each subsystem; development of control systems for the WD&C, auxiliary components, and control system integration will be performed at ORNL. A number of control system modifications are being developed in collaboration with the RTDP to enhance the performance of the MLDUA.

The MLDUA control system will provide for both remote (i.e., from the Operator Control Trailer [OCT]) and local (i.e., from the tank superstructure bridge) operations associated with the deployment and operation of the MLDUA. The system will provide: a subsystem controller, which will perform all of the basic control algorithms necessary for the MLDUA mast, arm and deployment systems; a control console, from which high and low level control of the mast and arm from the OCT will be possible; a control pendant, which will provide for low level control of the system from the bridge; and a high level control interface, which will provide a mechanism for integrating and coordinating control of the MLDUA with the other subsystem controllers. Flexible structure damping algorithms, currently under development at PNL and ORNL, as well as a function-based sharing control scheme and a new sensor-based control method for impact control and force regulation, under development at Washington University, are being developed in collaboration with the RTDP for integration with the SPAR delivered controller.

The primary mode of operation for the In-Tank Vehicle will be teleoperation from the OCT. Camera views from an overview camera system and a vehicle mounted camera will provide video feedback to the vehicle operator who will use hand controllers to perform variable rate control of vehicle mobility and manipulation. While development of a High Level Control System (HLCS) is not envisioned for the vehicle, feedback from samples and sensors in the waste transfer piping will provide efficiency information which can be used by the vehicle operator to adjust vehicle position, velocity, and end-effector position.

The instrumentation and controls for the WD&C will control and monitor the operation of the WD&C system and provide an operator interface in the OCT. Initial deployment of the WD&C into the tanks will be performed with controls located on the bridge. There are essentially two distinct types of operating conditions for the WD&C arm; independent operation (required whenever the gripper end-effector of the MLDUA or In-Tank Vehicle is not engaged with the CSEE), and coordinated operation (required whenever a gripper end-effector is engaged with the CSEE). Coordination between the MLDUA and all active joints on the WD&C arm will be required to provide

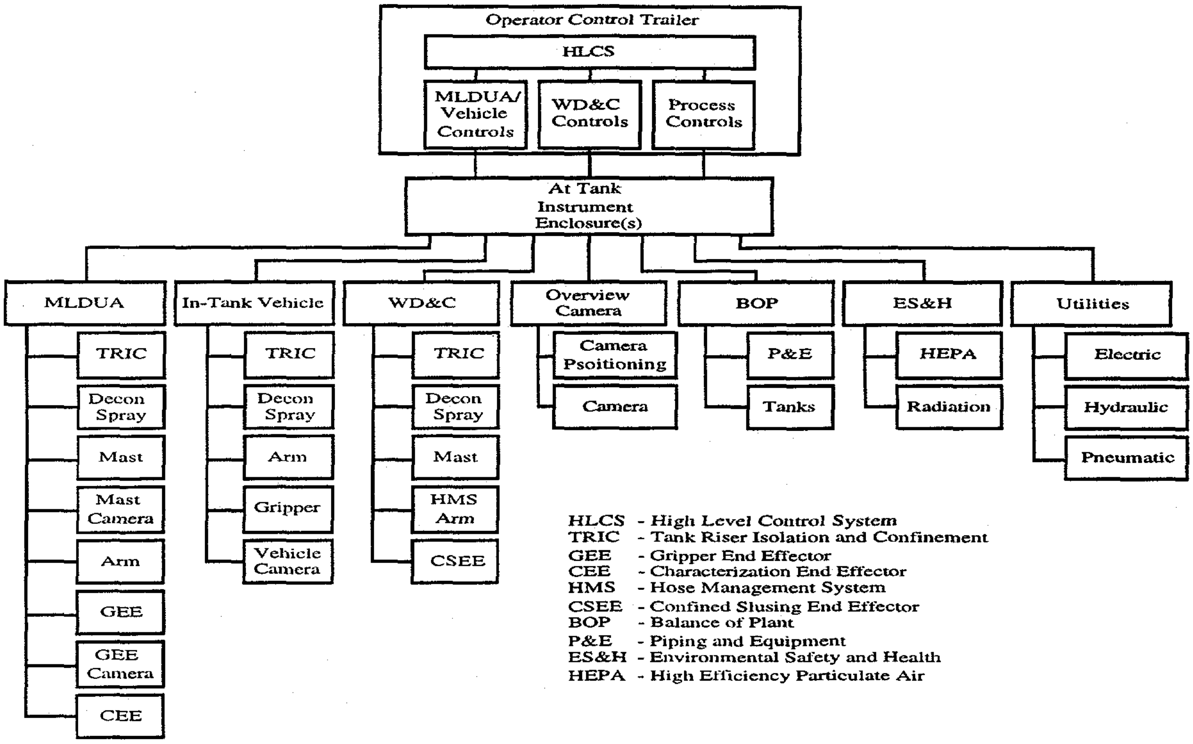

Fig. 4. Tank Technology Control Interfaces

collision avoidance. Initially, this coordination may be accomplished manually by operators of the two systems: the MLDUA (including the gripper end-effector), and the WD&C. Eventually, an HLCS is envisioned which, when added to the design, will provide one operator with integrated control of both systems.

III. TANKS TECHNOLOGY COLD TEST FACILITY (TTCTF)

All of the systems discussed above will be cold tested and evaluated in the TTCTF developed largely by the TFA at ORNL. Experimenters cells constructed as part of the Experimental Gas-Cooled Reactor are being modified to simulate a section of a gunite tank with an adjacent observation platform. Surrogate sludges will be used to test the ability of the MLDUA, in-tank vehicles and the WD&C system to operate under conditions expected in the gunite tanks. Cold testing within the TTCTF is scheduled to begin in the Fall of 1995.

The cells were originally constructed to perform experiments during reactor operation and therefore are built with 0.6 m (24 in.) thick concrete walls and ceilings. The cell interior is 4.7 m (15.5 ft) high, 7.3 m (24 ft) deep and circumferentially 8.8 m (29 ft) to 12.2 (40 ft) wide. The cells are closed with three 1.633×10^4 kg (18 short ton) capblocks which have been removed to provide access. A steel shielding wall between two cells has been removed to provide an observation area in one cell and a test area in the adjacent cell.

A platform has been constructed above the test cell to provide the same elevation as will be encountered at the Gunite Tank area and to support the MLDUA, WD&C, and vehicle support equipment. The test cell will be configured (with temporary concrete blocks) to provide two or more areas for differing surrogate sludge mixtures. Piping and pumps, which are separate from the sluicing pumps and piping, will be provided to handle the routine transfer operations between the sludge settling area, the sludge and water storage area, and the test area. An above-ground, dry-surrogate test area will be provided for a portion of the vehicle tests.

A nearby storage building has been converted into a control room for the tests. All equipment, cameras, lights, and vehicles will be controlled and operated from the control room since this will be the method of operation during field deployment. For test and qualification purposes, video cameras inside the test cell and on the MLDUA will provide the only visual feedback. Recording devices in the control room will record all tests.

IV. PROGRAM STATUS

Design of the MLDUA is nearing completion with a Detailed Design Review to be held in December, 1995. Procurement of long-lead components has already been initiated and fabrication of the unit is scheduled to begin in January, 1996. The unit will be delivered to the Oak Ridge site in September, 1996 for checkout and integration with the other retrieval subsystems. Field deployment in the gunite tanks is scheduled for early 1997.

A request for proposals for commercially available vehicle systems was issued in September, 1995. Demonstration contracts will be placed with 2-4 vendors by October, 1995 to support participation in comparative evaluation testing that will begin in November, 1995. Each vehicle system will spend two weeks at the TTCTF and will be run through a series of performance tests designed to assess vehicle effectiveness in meeting operational requirements of high-activity waste tanks. Contingent upon the results of these comparative evaluations and funding availability, a second phase of procurement activity involving purchase of a single vehicle system may begin in February of 1995. Field deployment of a final system would follow in early 1997.

Most of the baseline testing for determining the design for the WD&C system is at or near completion. PNL and UMR will issue a report on the development testing of the CSEE. PNL will perform the design, procurement, fabrication, and delivery of the CSEE by May, 1996. The remainder of the WD&C design will be performed by ORNL and AST, and is also a deliverable for May, 1996. Mock WD&C equipment has been fabricated and installed, and some preliminary testing has been completed. This mock equipment will undergo further testing in support of the design and is expected to be used during the vehicle testing program beginning in November, 1995.

V. SUMMARY

Preliminary design activities for the MLDUA, WD&C and other subsystems are largely complete. Detailed design for all subsystems will be completed by the end of December, 1995. A viable commercial vehicle system, if available, will soon be identified as a result of the comparative evaluations. Planned enhancements to the Spar control system are in the earliest stages of development, but are still on schedule to meet all milestones imposed by the Treatability Study.

Together, these systems comprising the remote waste retrieval component of the GAAT and OHF tanks will afford regulators, operational personnel, and the public alike the opportunity to assess potential costs, technical difficulties and benefits associated with a confined sluicing waste retrieval strategy for both arm- and vehicle-based deployment scenarios. These data will be compared with previous waste retrieval efforts and the most viable solution for future operations will be selected.

Early studies indicate that the original cost estimate of $400 M for full remediation of the gunite tanks can be reduced by at least a factor of 4 through careful evaluation of the treatment alternatives and application of the appropriate systems for these tanks.

Teaming of the ORNL Environmental Restoration Program with the OTD TFA and RTDP allows for considerable cost savings during the design and operations phases. Commitment of the ORNL to field evaluation and integration of OTD technologies offers the opportunity to pioneer use of these technologies for ORNL and the remainder of the DOE Complex.

ACKNOWLEDGMENTS

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