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LIGHT DUTY UTILITY ARM DEPLOYMENT IN HANFORD TANK T-106

G. R. Kiebel

July 1997

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Prepared for the U.S. Department of Energy
Under Contract DE-AC06-76RLO 1830

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The successful deployment and operation of the Light Duty Utility Arm (LDUA) System in Hanford Underground Storage Tank T-106 could not have been accomplished without the dedicated support and teaming effort of the Hanford Tank Waste Remediation System (TWRS/EM-30) Characterization Operations team which provided both manpower and co-funding for the deployment.

Special acknowledgment is given to the members of the LDUA Program team that provided essential support equipment and software along with engineering expertise necessary to accomplish the successful deployment. Members of the team included:

- Pacific Northwest National Laboratory (PNNL), Betty Carteret, Program Manager
- Idaho National Engineering Laboratory (INEL), Cal Christensen, Team Lead
- Oak Ridge National Laboratory (ORNL), Dr. Barry Burks, Team Lead
- Westinghouse Savannah River Company, Frank Heckendorn, Team Lead
- Sandia National Laboratory (SNL), Diane Callow, Team Lead

Commercial Suppliers that were instrumental in providing key components and subsystems of the LDUA System were:

- Spar Aerospace Limited - LDUA Subsystem
- Los Alamos Technical Associates - Riser Interface, Decontamination, Tools
- Hi-Line Fabrication and Engineering - Balance of Plant Equipment
- H&N Electric - Power/Control Equipment

SUMMARY

An existing gap in the technology for the remediation of underground waste storage tanks has now been filled by the Light Duty Utility Arm (LDUA) System. On September 27 and 30, 1996, the LDUA System was deployed in underground storage tank T-106 at Hanford. The system performed successfully, satisfying all objectives of the in-tank operational test (hot test); performing close-up video inspection of features of tank dome, risers, and wall; and grasping and repositioning in-tank debris. The successful completion of hot testing at Hanford means that areas of tank structure and waste surface that were previously inaccessible are now within reach of remote tools for inspection, waste analysis, and small-scale retrieval. The LDUA System has become a new addition to the arsenal of technologies being applied to solve tank waste remediation challenges.

The LDUA program is a development effort that has gone far beyond simply demonstrating a prototype system in a laboratory environment. The production of a field-deployed system that is ready for continuous operation required a significant effort that included:

- Environmental hardening of the equipment (outdoor exposure and in-tank hazards: radiation, corrosive chemicals, flammable gas, etc.).
- Providing the infrastructure to support the deployment (people, procedures, training, and equipment, etc.).
- Obtaining the approval to deploy (design pedigree, configuration documentation, safety documentation, environmental documentation, and satisfying the elaborate readiness review process).

A teaming relationship between the developers and end users was established from the outset and has been a key factor in the successful deployment and transfer of LDUA technology. A teaming relationship was also established among multiple U.S. Department of Energy (DOE) sites and national laboratories to share expertise and to apply common solutions to common site needs. A partnership between developers, end users, and industry has applied commercial expertise guided by specific knowledge of site requirements and restrictions in delivering state-of-the-art systems. This successful teaming arrangement has resulted in significant cost and schedule savings and is a model for future technology development programs.

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GLOSSARY

Abbreviations, Acronyms, and Initialisms

ATIE	At-Tank Instrument Enclosure
CE	Cognizant Engineer
CTF	Cold Test Facility
DOE	United States Department of Energy
DOE-RL	United States Department of Energy-Richland Operations
EE	end effector
FMEF	Fuels and Materials Examination Facility
GEE	Gripper End Effector
HRSVS	High Resolution Stereo Video System
LDUA	Light-Duty Utility Arm
MDS	Mobile Deployment System
MEEES	Manual End Effector Exchange System
NEC	National Electrical Code
INEL	Idaho National Engineering Laboratory
OAS	Optical Alignment Scope
OOVS	Operations Overview Video System
ORNL	Oak Ridge National Laboratory
ORR	Operational Readiness Review
OVS	Overview Video System
PNNL	Pacific Northwest National Laboratory
PASS	Purge Air Supply System
PDS	Power Distribution Skid
PIC	Person In Charge
PRT	Plant Readiness Team
SCS	Supervisory Control System
SDAS	Supervisory Data Acquisition System
TFA	Tank Focus Area
TIP	Tool Interface Plate
TRIC	Tank Riser Interface Confinement System
TWRS	Tank Waste Remediation Systems
VAC	Volts, Alternating Current
VDRS	Video Display and Recording System
VPM	Vertical Positioning Mast

LIGHT DUTY UTILITY ARM DEPLOYMENT IN HANFORD TANK T-106

INTRODUCTION

On September 27 and 30, 1996, the Light Duty Utility Arm (LDUA) System was deployed in underground storage tank T-106 at Hanford. The system performed successfully, satisfying all objectives of the in-tank operational test (hot test); performing close-up video inspection of features of tank dome, risers, and wall; and grasping and repositioning in-tank debris. This paper describes the results of that test, the preparations leading up to it, and the key provisions in the program that made it possible.

System Description

The LDUA System (Figure 1) is designed to deploy a variety of tools, called end effectors (EE), into underground waste storage tanks to perform inspection, waste analysis, and small-scale retrieval tasks. It consists of the following main subsystems:

<u>Light Duty Utility Arm (LDUA)</u>[a]: The LDUA is a 4.7-m (13.5-ft) long robotic arm that provides excellent dexterity due to having seven joints. It is a sealed unit with all utilities carried internally. End effectors are mounted on the end of the LDUA by attachment to a Tool Interface Plate (TIP) with mating service connectors. It is capable of carrying a 34-kg (75-lb) payload.

<u>Vertical Positioning Mast (VPM)</u>: The LDUA is mounted on the end of a 14-m (47-ft) long, two section telescoping mast. VPM motion can be selectively controlled as an eighth joint in LDUA resolved motion.

<u>VPM Housing</u>: The VPM Housing provides containment for radioactive contamination for the VPM and LDUA and functions as a storage container when they are fully retracted into it.

<u>Mobile Deployment System (MDS)</u>: The MDS (Figure 2) transports the LDUA between tanks. It is a truck-based unit that can elevate the VPM Housing to the deployment (vertical) position or lower it to the transport (horizontal) position. It has outriggers that extend to provide a stable base for deployment.

<u>Operations Control Trailer (OCT)</u>: In-tank operations of the LDUA System are remotely controlled by operations personnel stationed in the OCT, which is placed outside the tank farm perimeter fence. The OCT provides control stations for the LDUA and end effectors and a complete video display and recording capability.

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[a]The LDUA has been developed by Spar Aerospace Ltd. from technology that originated with the Space Shuttle Remote Manipulator System (SSRMS).

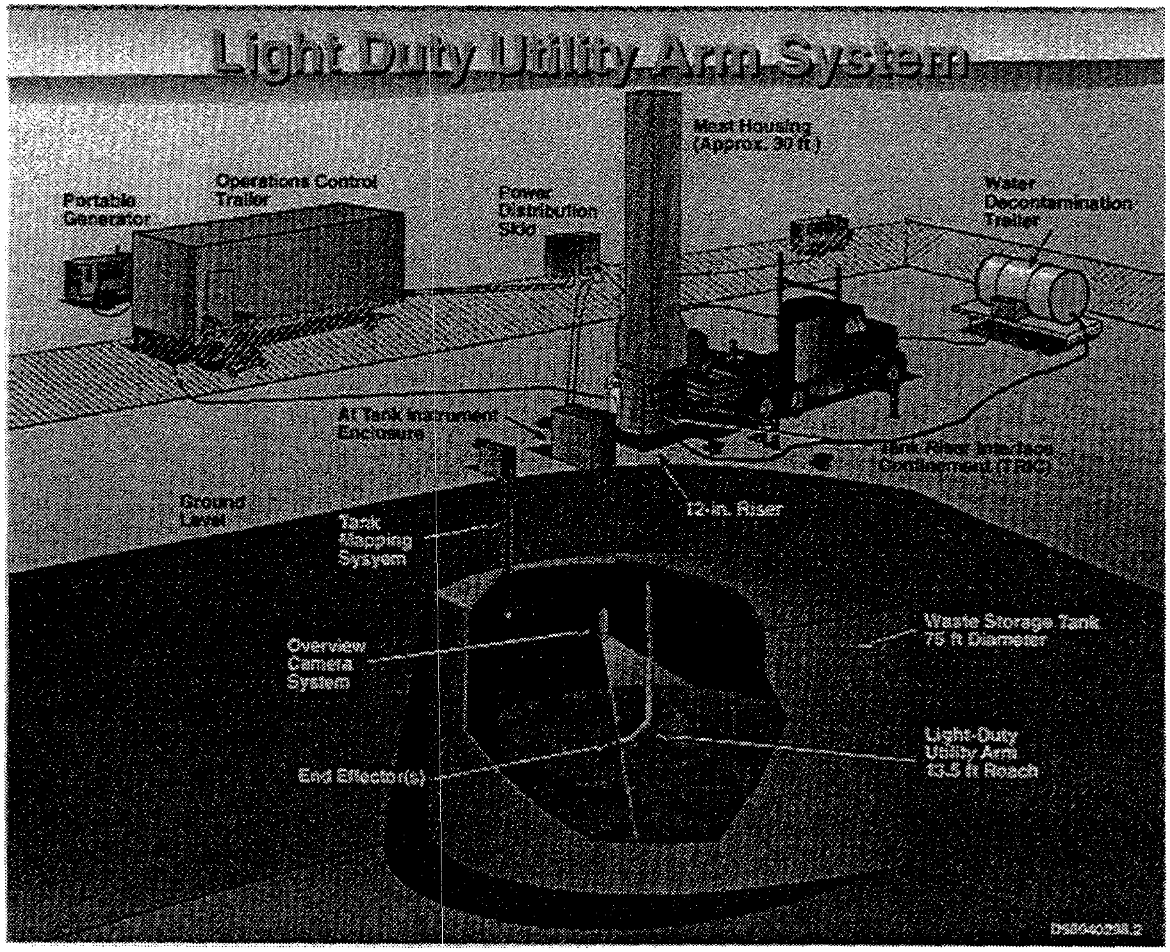

Figure 1 - System Overview

<u>At-Tank Instrument Enclosure (ATIE)</u>: Control electronics and other equipment for the end effectors are mounted in the ATIE, which is placed near the MDS by the tank entry port. Signal conversion for signal transmission via fiber optics to the OCT is accomplished in the ATIE.

<u>The Tank Riser Interface and Containment (TRIC)</u>: The TRIC (Figure 3) maintains an atmospheric seal between the VPM housing and the riser. It attaches directly to the riser and connects to the VPM housing via a flexible boot. It also contains a water decontamination module, a radiation monitor, and a riser isolation valve. The upper portion of the TRIC is an enclosure with windows and glove ports that allow operators to work on the LDUA and end effectors. The Manual End Effector Exchange System (MEEES) allows end effectors to be mounted and dismounted from the LDUA.

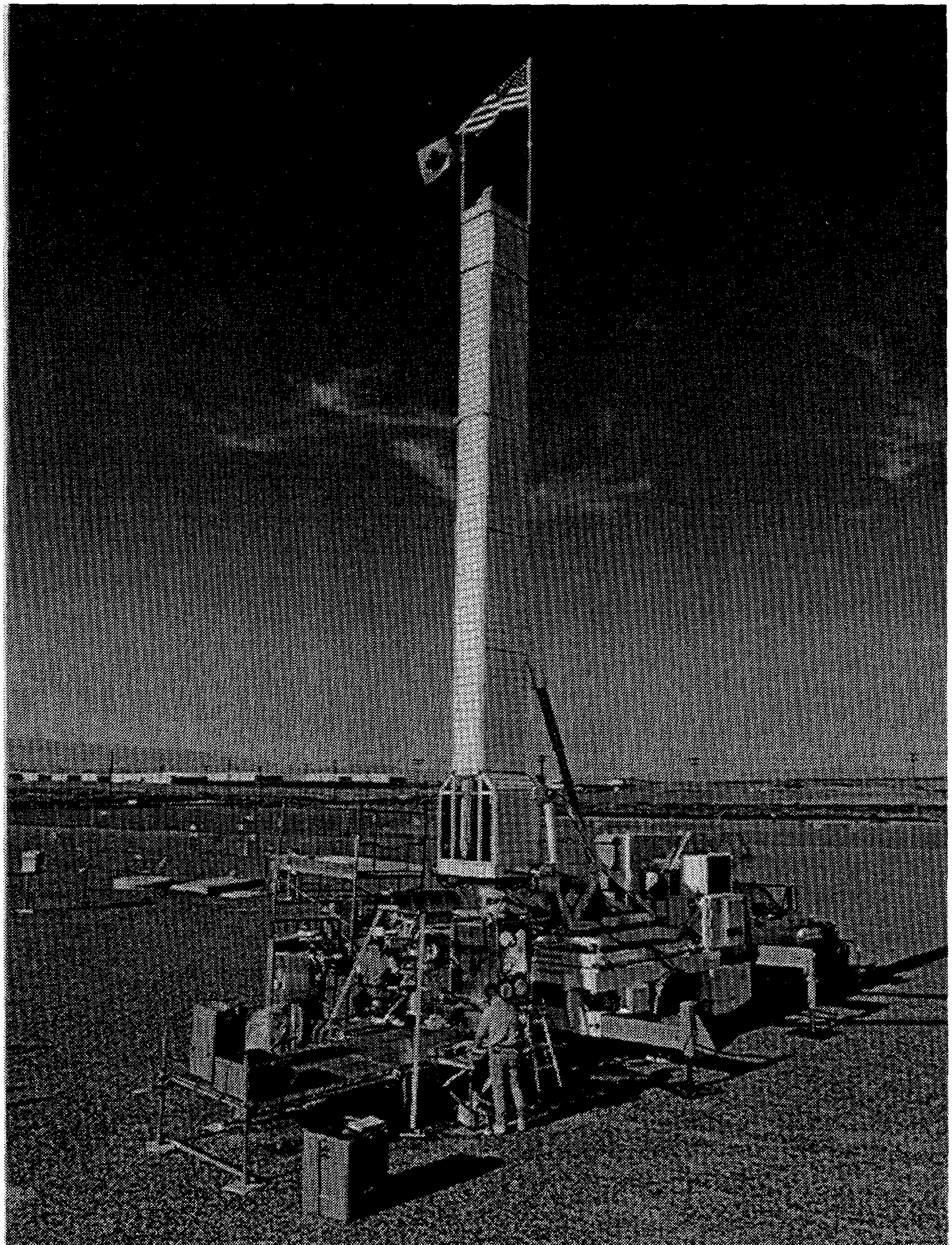

Figure 2 - LDUA System at T-106

Decontamination Water Supply System (DWSS): The DWSS supplies pressurized water at up to 3.45-MPA (500-psi) at 5.7-L/min (1.5-gal/min) to the Water Decontamination Module on the TRIC. The Water Supply System is trailer mounted and has a 1900-L (500-gal) storage tank (to limit the amount of water added to the tank) and a pump.

Overview Camera System: The Overview Camera System provides the ability to observe and record in-tank operations of the LDUA. It is deployed into the tank through a separate riser, which can be as small as 10-cm (4-in). There are two different equipment systems that can be used as the Overview Camera System. The first is the Video In-Tank Inspection System (VITIS), which is an existing system at Hanford. The second is the Overview Video System (OVS), which was developed in the LDUA program. The OVS is presently the only system that can be used on flammable atmosphere tanks at Hanford. At TWRS's request, it was delivered separately a year ahead of the rest of the LDUA System and has been in frequent use since. The VITIS was used for the hot test because the tank chosen for the hot test did not have a flammable atmosphere, and because the OVS was wanted for other work.

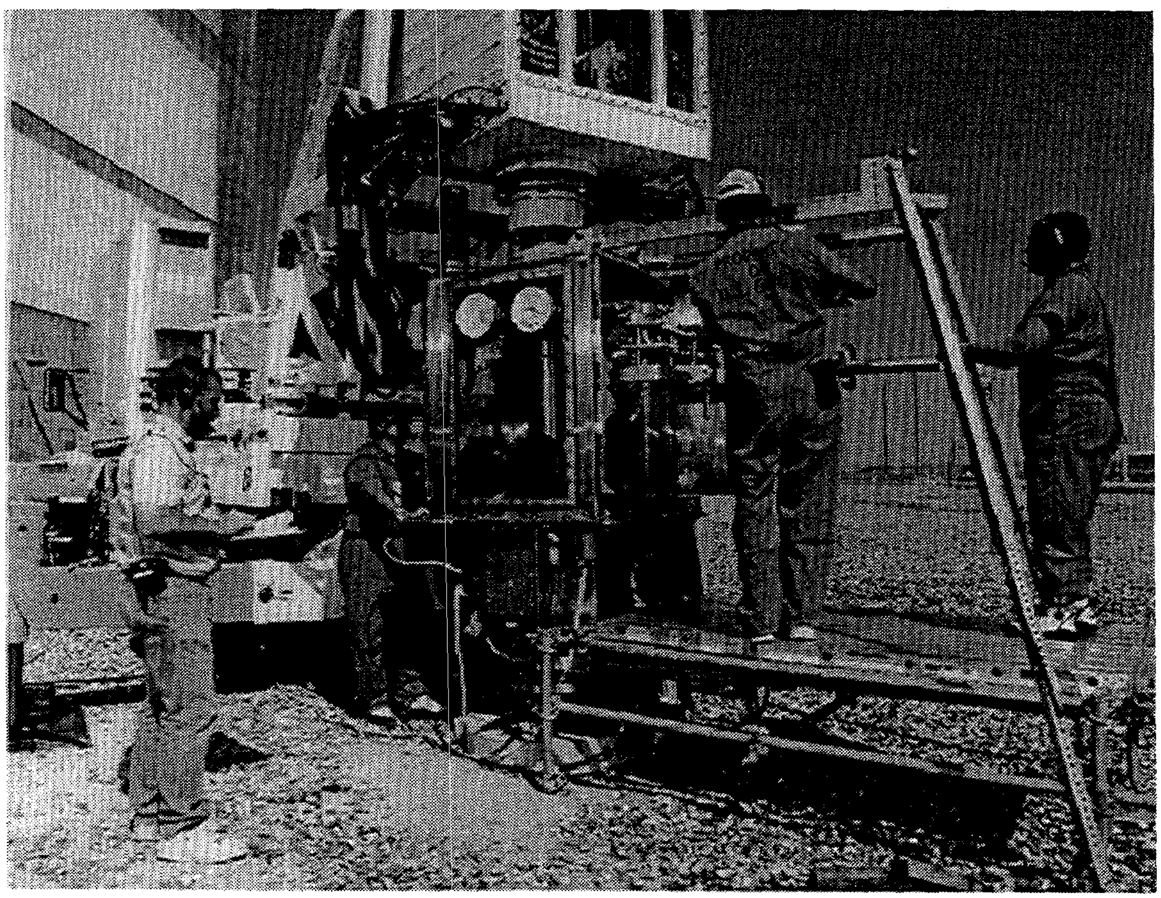

Figure 3 - LDUA System TRIC

Background

Development of the LDUA System was initiated in fiscal year 1993 in response to a request from Hanford's Tank Waste Remediation Systems (TWRS) (EM-30) to the U.S. Department of Energy (DOE) Office of Technology Development (OTD) (EM-50) to provide a system with the capability to deploy various sensor packages and small-scale retrieval devices to areas of the underground storage tanks that were not accessible using existing techniques. These techniques were crude and were limited to performing operations in areas directly below existing risers ("pole-in-a-hole"). The task was assigned to the Underground Storage Tanks - Integrated Demonstrations (UST-ID) program within the OTD and it continues today under the Tanks Focus Area (TFA) of the Office of Science and Technology (OST), which are the successor organizations to UST-ID and OTD, respectively.

The LDUA program has benefited from the involvement of multiple DOE sites and national laboratories, enabling participants to share knowledge and support common site needs for tank waste remediation programs [1]. The design and implementation team included Idaho National Engineering Laboratory (INEL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Sandia National Laboratories (SNL), Savannah River Site (SRS), and Westinghouse Hanford Company (WHC)[b]. Two additional LDUA Systems are being built and will be deployed at ORNL and INEL. A fourth unit will be installed and operated in a cold test facility at Hanford to support applications development, training, and to troubleshoot problems with fielded systems.

PREPARATION

Technology Transfer

The goal of the LDUA project was not only to demonstrate new technology, but to assure that it was successfully transferred to the end users for field use. This was a bigger job than simply demonstrating a prototype system in a non-hazardous laboratory environment where test conditions can be tightly controlled. The system had to be designed and built to withstand the rigors of field deployment and the hazardous environment of underground waste storage tanks, which included:

Outdoor Environment:

- Wind
- Rain
- Sunlight
- Temperature extremes
- Dust

[b] This part of the program has since been moved to PNNL as part of the Project Hanford Management Contract (PHMC) transition process.

In-Tank Environment:

- High radiation levels
- Highly corrosive chemicals (both alkaline and acidic)
- Flammable gas atmospheres
- Radioactive contamination (ability to be decontaminated)

Additionally, the system was required to have a comprehensively documented design pedigree in order to be approved for use. Formal design reviews were conducted at the conceptual, preliminary, and final stages of the design. An independent review committee was convened for each review and its approval was required in order to continue with the next phase of the project. All comments generated by review process were tracked in a database and all comments had to be closed prior to final approval to fabricate the system. Extensive investment in the development of safety systems and reliable recovery methods was required to ensure safe and reliable operation. The combination of hardening systems for field conditions, design of safety features, and extensive documentation requirements are estimated to have roughly doubled the cost of the unit, as compared to a prototype or demonstration system.

Early in the project, a programmatic decision was made to involve end user organizations in all phases of the project. This was a key factor in assuring a timely acceptance and deployment of the system. A particularly valuable tool in this effort was a professionally facilitated Value Engineering (VE)[c] study that was performed at the preliminary design stage of the project. The goal of this study was to assess and clarify the system design, testing, training, turnover, and operation of the LDUA System, and to produce the following deliverables:

- An updated operations scenario
- A transition/turnover approach
- A draft cost estimate for annual operations
- A projection of operations staffing requirements
- An action plan to resolve any open items

Representatives from all the organizations participating in the LDUA development and deployment (engineering, operations, environmental compliance, health physics, etc.) were included on the team that conducted the study. The results, therefore, were based on the best available knowledge and had buy-in from all the organizations that would have to ultimately support the deployment. The strategies established by this process were so sound that they did not have to be modified during the remainder of the project. Another valuable benefit of the study was feedback to the design team from the operations organizations that enabled improvements and cost reductions to be incorporated in the final design.

Following the VE study, the division of roles and responsibilities between the developers (EM-50) and the users (EM-30) was formalized initially in a responsibility

[c] Value Engineering is a formal methodology for analyzing systems from a cost versus function perspective. Facilitators are certified as Value Engineers by the Society of American Value Engineers.

matrix directly linked to the project Work Breakdown Structure. Subsequently, a memorandum of understanding (MOU) defining the specifics of financial obligations for both parties was signed, and ultimately a unified task plan delineated required actions and responsibilities for supporting field deployment of the system. These types of agreements are extremely important in documenting commitments of the parties and can be vital in maintaining continued funding by both parties.

It has been the primary responsibility of EM-50 to deliver the LDUA System to Hanford and qualify it for deployment through extensive cold testing. Documentation of the system design basis and providing training to operations personnel have also been provided by EM-50. The primary responsibility of EM-30 has been to deploy the LDUA System and perform the hot test, including providing safety and environmental documents and obtaining required site reviews and approvals for deployment. Both organizations, of course, supported each other wherever appropriate.

Equipment Qualification

The LDUA System was qualified by a cold test process that included testing at the subsystem level, integration testing, and a final acceptance test of the complete system. This process was defined by a cold test plan [2]. Each subsystem was made operational and functionally checked when it arrived at Hanford according to a Calibration, Grooming, and Alignment (CG&A) procedure appropriate to the subsystem. Following CG&A, each subsystem was integrated with the growing LDUA System and integration testing was then performed to verify that it inter-operated with the rest of the system. When the LDUA System was fully integrated, an acceptance test was performed according to a formal Acceptance Test Procedure (ATP) [3]. The results of the ATP were issued in a formal Acceptance Test Report (ATR) [4]. Although the cold test process was the responsibility of EM-50, all its provisions, particularly the ATP, were reviewed and approved by the appropriate EM-30 organizations.

The objective of the acceptance test was to demonstrate that the LDUA System was operational, that it could perform all the functions required to deploy it into the initial underground storage tank for hot testing, and that it could be operated safely. Test procedures were organized, as nearly as practicable, to reflect the tasks to be performed in an actual deployment campaign including both normal and off-normal conditions. Also, where practicable, test procedures called for equipment to be operated using the actual TWRS operating procedures, helping to verify their correctness. The acceptance test was confined to operating the LDUA System within its nominal performance specifications and did not attempt to define the outer limits of the performance envelope.

All the cold test activities were performed in the Cold Test Facility (CTF). A special facility was needed because it had to provide at least 13.7-m (45-ft) of clearance above simulated ground level and a simulated tank area that reaches at least 9.1-m (30-ft) below ground level with enough room to fully deploy and, extend, and exercise the LDUA. A portion of Building 427, the Fuels and Materials Examination Facility (FMEF), was chosen to be the CTF in 1993 by a formal engineering evaluation study [5] because it satisfied these critical conditions. Various pieces of test support equipment, such as simulated tank risers, were installed in the CTF.

A project management decision was made prior to the ATP to postpone some specific portions of the ATP in order to help recover schedule. EM-30 funding to support the deployment and hot test was only available in Fiscal Year 1996 and that became a compelling deadline on the project. The postponed portions of the ATP involved features of the LDUA System that would not be required for the hot test. These were:

- Purge system failure recovery (T-106 was not a flammable atmosphere tank)
- Deployment through out-of-plumb riser (Riser 6 in T-106 was nearly plumb)
- Minimum headroom deployment sequence (T-106 had plenty of clearance between waste and riser)
- The Optical Alignment End Effector (a simpler, alternate alignment fixture was used)
- The LDUA shoulder camera (T-106 allowed adequate visibility from just the VITIS)

Personnel and Procedure Qualification

In the months immediately preceding deployment of the LDUA System, an operating team was assembled by EM-30 and arrangements were made within the existing tank farms operations infrastructure to support the deployment. The operating team included a cognizant engineer, a field supervisor (referred to as a Person-In-Charge or PIC), and an operating crew consisting of four Nuclear Process Operators (NPO) was assigned.

Operating procedures were prepared and approved. As a starting point, EM-50 provided an outline version of the operating procedures. This outline was based on the operating scenario established during the design phase of the project and upon the Operation Manual (OM) for each piece of equipment. EM-30 then created the actual operating procedures from the outline by applying the proper formatting; terminology; standard tank farm operating practices, and safety, environmental, and radiological provisions. The procedures went through a long review and approval process that overlapped the ATP and the personnel training processes.

A training program was established for the operating crew and for the key craft personnel that would be needed to support setup, takedown, and maintenance of the equipment. The initial part of the training was conducted inside the CTF and was focused on in-tank operations. The LDUA vendor, as part of the purchase contract, provided a week of training divided approximately equally between classroom sessions and hands-on operation. A computer-based simulator for the LDUA and VPM was provided by the LDUA vendor to support the training. It was well received by the operators and was extremely useful because access to the actual LDUA System was limited. In the week following the LDUA vendor training, the EM-50 cognizant engineers provided training on their particular subsystems. Approximately two full days were used for these training session, which individually lasted approximately one-half day each. An additional three days were provided exclusively for hands-on practice in operating the integrated LDUA

System. At this point, each operator was focused on one of the following specialty areas for the remainder of the training:

- LDUA operation
- MDS operation (pendant controlled)
- End effector operation
- End effector exchange and riser alignment

Following the initial training, the LDUA System was moved outdoors to a training area adjacent to the FMEF building. This training area (unofficially christened the "South Tank Farm") was equipped with a pair of 5-m (16-ft) long simulated 30-cm (12-in) risers set into the ground. This area provided excellent outdoor field conditions for the operators to practice above-tank operations such as equipment setup and takedown, cable and hose interconnection, vehicle operation, and riser alignment. Although not performed as a formal test, this outdoor training activity was an excellent confirmation that the LDUA System equipment would perform in an outdoor environment. Approximately one additional week of training was performed outdoors.

The specialization by the operators allowed the hot test training to be streamlined, but normally (and in the future) there would be more cross-training so that each operator will have the opportunity to become qualified to operate all parts of the system and to provide coverage for operator absences. Training was streamlined in this fashion to save cost and schedule and was possible because EM-50 had committed to fielding a full engineering team to assist the operators in performing the hot test.

Equipment Turnover

Ownership of the first LDUA System passed conditionally from EM-50 to EM-30 between cold test and hot test. EM-30 (specifically, the Hanford Characterization Equipment Engineering organization) became fully responsible for operation and maintenance of the system; however, EM-50 remained responsible for completing items needed to bring the equipment to full readiness for unlimited operation, such as the postponed ATP items and certain equipment maintenance and upgrade items. Ownership was formally transferred by a Technology Transfer Agreement, signed in September 1996, that spelled out the commitments and responsibilities of each party.

A set of configuration documents was delivered with the system. These consisted of original drawings and documents; vendor drawings, documents, and component information sheets; and drawings and documents from other DOE sites and national laboratories. They were organized by subsystem and category (see Appendix A) and were maintained and controlled by a designated custodian in a locked set of file cabinets under the control of the LDUA design organization. EM-50 was responsible for making any revisions to these documents as necessary from its post hot test work on the system. EM-30 was responsible for final disposition of the documents into plant document control.

Operational Readiness

An evaluation (in the form of an engineering study) was conducted to select the best tank for the hot test. The criteria included providing low hazard (relatively speaking), providing a representative environment for typical operations, having an access riser near the tank wall (to allow close-up inspection by an end effector), and having a low waste volume to allow maximum extension of the VPM into the tank. Tank T-106 was selected from among the 133 single shell tanks at Hanford by the engineering study. It is a 2000-m^3 (533,000-gal) tank with a residual waste volume estimated at less than 75-m^3 (20,000-gal) in approximately a 16-cm (6-in) layer of sludge on the tank bottom. In the 1970s this tank leaked over 380-m^3 (100,000-gal) of liquid waste into the surrounding soil and was subsequently pumped, isolated, and stabilized. It entered service in 1947, making it among the oldest Hanford tanks.

Final approval to deploy the LDUA system was obtained through a formal and rigorous Operational Readiness Review (ORR) process. The specific details of this process for the LDUA were established in a formal plan document that specified 17 core requirements (summarized in Appendix B) that the LDUA System and the operations infrastructure would have to satisfy in order to be approved. The plan defined specific criteria for satisfying each requirement and specified items to be reviewed for each criteria. The readiness requirements for the LDUA System were the same requirements levied by DOE Order 5480 on the startup of any nuclear facility; however, a graded approach was used in establishing the criteria that took into account both the nature of the LDUA System as portable equipment and its similarity to systems that had already been approved for operation. This graded approach focused the review on the aspects of the system that deserved the most scrutiny and avoided wasting time and effort on areas that either did not apply, were not significant, or which had already been adequately established by another, similar, system. Because the LDUA was the first robotic system to be deployed in underground nuclear waste storage tanks at Hanford (or anywhere else), particular emphasis was placed on assuring that safety had been adequately addressed and formally reviewed, that operating procedures and training were adequate, and that the operating personnel demonstrated acceptable proficiency in running the system.

The actual ORR review was conducted by three independent review teams. The first stage of the ORR process was conducted by a Plant Readiness Team (PRT) that was composed of tank farm operating and engineering staff. This team reviewed each readiness requirement according to the criteria established in the plan and prepared an affidavit to close out each criteria item. The PRT members were charged with personally verifying these items by direct observation. When satisfied, the PRT prepared a final report. A contractor ORR team was then convened to independently review and approve the results of the PRT effort. Finally, an independent DOE ORR team was convened to perform a final review and to give final approval to deploy and operate the LDUA System.

Safety was a significant issue for the LDUA System (as it is for any equipment deployed in underground storage tanks). Although the final review and approval of the safety aspects of the system was part of the ORR, the process of assuring safety was an integral part of the effort from the beginning. A formal safety plan document [6] was prepared at the conceptual design stage of the project that established the tasks necessary to produce the safety documentation and reviews to verify that the system would be safe to deploy. Appropriate reviews were performed by independent safety organizations at the LDUA System design reviews and at other designated points in the project. The safety assurance process had the following key points:

- A Preliminary Safety Equipment List (PSEL) was produced at the conceptual design stage. It identified the preliminary safety classification of the LDUA System equipment.

- A Hazard Operability Study (HAZOPS) was performed during the design stage and repeated after fabrication of the system. It identified hazards associated with use of the LDUA System in all Hanford tanks.

- An Unreviewed Safety Question (USQ) Evaluation was performed near the time of the acceptance test to determine that proper controls were in place for deploying the LDUA into Tank T-106 and performing the hot test. A Safety Assessment (SA) for T-106 deployment was prepared to support the USQ Evaluation.

The ORR process can be very costly and time consuming and can be a big challenge to the budget and schedule in the deployment of developmental systems. The following key strategy items adopted by the LDUA project to manage this challenge:

- limit the scope of ORR approval to a single, relatively benign tank (as opposed to approval for all tanks)
- limit operations to an operational test (as opposed to unlimited production operations)
- stay with already established safety boundaries (as opposed to establishing new limits).

This strategy postponed resolution of some of the more difficult safety issues, such as qualifying the equipment for operation in flammable atmospheres and watch list tanks. Incremental ORRs will be performed to grant approval for future deployments. Once the flammable atmospheres issue is resolved, the ORR process for each deployment should be considerably streamlined.

DEPLOYMENT

Operations Test Procedure

The hot test of the LDUA System was defined and controlled by a formal Operations Test Procedure (OTP) [7] that was prepared by EM-30. The OTP called for the LDUA System to demonstrate essentially all the functions that would be required in a typical tank campaign including:

- System setup
- Alignment to riser
- Deployment of end effectors

- In-tank operations
- System takedown

In-tank operations consisted of performing close-up video inspection of tank features using the High Resolution Stereo Video System (HRSVS) end effector and of grasping and repositioning in-tank debris using the Gripper End Effector (GEE). The time to perform the in-tank portion of the hot test was limited by the OTP to two days maximum, so in-tank operations were performed on targets of opportunity rather than according to a detailed inspection plan.

System Setup

The LDUA System was set up by transporting its components to the tank farm, placing them in their operating position, interconnecting them, and connecting to a source of main power (480 VAC). The actual setup of the LDUA System at T-106 required about two 8-hour work shifts and involved craft personnel (for example, crane operators, millwrights, and electricians) in addition to the normal crew of operators and the PIC.

Riser Alignment

The LDUA System must be accurately aligned prior to deployment into the tank because there is little clearance between the inside diameter of the 30-cm (12-in) access riser (nominally, 30.25-cm [11.91-in]) and the maximum outside diameter of the LDUA and VPM 26.7-cm (10.5-in). Alignment is accomplished by adjusting tilt and translation axes of the VPM housing while observing the impingement of laser beams on the interior of the riser. The laser beams are projected into the riser from an alignment fixture that is temporarily attached to the bottom of the VPM outer tube. There are four beams placed in a square pattern on a circle centered on the VPM, but slightly larger in diameter than the VPM. Perfect alignment with a perfectly straight riser is indicated when none of the laser beams touch the inside of the riser. In practice, some beam-to-wall contact may occur because actual risers are not perfectly straight and they have surface corrosion and intrusions from weld seams. In that case, the operators try to equalize the beam-to-wall contact for opposing lasers. The alignment fixture can be rotated to check beam-to-wall contact at different parts of the riser.

Riser number 6 was used for entry into tank T-106. It is 4.9-m (16-ft) long, which is about the maximum for single shell tank risers at Hanford. Prior to staging the LDUA System at the tank farm, a plug gage was used to verify that riser number 6 had an adequate clear path for deployment and to assess its straightness and deviation from the vertical. The plug gage also had decontamination spray heads that were used to dislodge debris from the inside of the riser and to reduce the level of surface contamination. Riser number 6 was found to be very nearly dead plumb and not discernibly bent. However, it does have a sizable weld intrusion which caused some anxious moments (but no contact) during the first tank entry. The alignment procedure took approximately two hours to complete, and was performed at night to maximize the visibility of the riser and laser beams to the operator.

It is expected that this operation could be performed in daylight, but it would be less convenient, requiring sunshades on the TRIC.

Close-up Video Inspection

The LDUA was initially deployed into T-106 with the HRSVS end effector [8], which is equipped with a matched pair of close up color video cameras that provide approximately 4X magnification at a camera-to-subject distance of 98-cm (38-in). Video output can be displayed and recorded in the OCT either as single camera views or as a combined stereographic image. A pair of black and white distance cameras is also provided to aid the operator in gross maneuvering of the LDUA and in placing the HRSVS in position to use the close-up cameras. The area lamps (1 kilowatt) from the VITIS system provided plenty of light for the distance cameras. The HRSVS itself provides up to 350-watts of direct lighting by means of 35-watt halogen reflector bulbs that can be selectively switched on and off in pairs to vary the lighting intensity for close- up inspection.

The HRSVS was used to examine a number of features in the tank:

- A 30-cm (12-in) riser approximately 2.5-m (8-ft) from the one containing the LDUA.
- Portions of the concrete tank dome
- The interface between the steel tank liner and the dome
- The angle-iron stiffeners on the tank liner
- Portions of the carbon steel tank liner, especially weld seams

The LDUA and HRSVS provided video images of features of the tank that had not been seen in such close-up detail with existing methods. The video quality was good. Images were sharp and clear and the LDUA was a good camera platform. There was some oscillation when moving, but it was gentle, slow, and quickly damped, and did not cause any blurring or difficulty in seeing detail. Stereographic images provided clear depth perception of features including pits of various sizes that were observed in the tank liner and in some welds.

There were a number of functions that could be usefully added to the HRSVS for future deployments - a sensor to measure the distance to objects being observed, a means of measuring the size of features being observed, the ability to continuously adjust the lighting intensity, and the ability to vary the magnification of the close-up cameras.

The LDUA was manually operated in performing the video inspection. Joint rate mode was used for moving the end effector from one part of the tank to another, but resolved motion in tool mode was used during the actual close-up inspection. This mode was very intuitive and easy to use, and the operator was able to follow both horizontal and vertical weld seams and was able to examine the circular lip of the 30-cm (12-in) riser in one continuous motion.

The operator also made use of the World Model in positioning the HRSVS. This is a 3D computer graphic model of the LDUA System and the tank into which it is deployed. The LDUA and VPM models are linked to the LDUA control system and accurately track the position of the actual units providing real-time information to the system operator. The tank model is constructed from existing drawings of the tank. The LDUA model is registered to the tank model using the compass bearing of the long axis of the MDS (obtained by surveying for the hot test), the height of the bottom of the VPM housing above the entry riser, and the tilt angle of the VPM Housing (obtained from on-board inclinometers). The operator can selectively view the World Model from any angle to help see the configuration of the LDUA and its relationship to the tank structure. This can be very a useful adjunct to the Overview Camera System which is limited to one viewing angle. In T-106, the ability to view the LDUA from above in the World Model was very helpful in positioning the HRSVS to be perpendicular to the tank wall and at approximately the correct standoff distance. The Overview Camera System could not show the distance from the tank wall, nor the angle of approach.

The World Model can also preview LDUA motions in simulation mode and detect collisions with tank structures. However, this capability was not required nor used in T-106 because the operating area was uncluttered. This feature can be of critical importance in obstacle avoidance in congested operating areas and in providing enhanced perspective in evaluating distance to objects in the tank.

In-tank Object Manipulation

The test procedure called for the operator to use the Gripper End Effector to locate, grasp, and lift a section of steel tape free of the waste surface in which it was embedded (the tape was discarded from a manual level monitor device [9]). This was successfully accomplished and there appeared to be nothing preventing the LDUA from bringing the tape entirely out of the tank if the operator had so chosen, but no provisions had been made for handling it in the TRIC and the OTP expressly prohibited doing it. This test demonstrated that the LDUA and GEE could be operated with some finesse in approaching and grasping a small, thin object that is lying in an arbitrary orientation. Also, it had been proposed that the LDUA be used in the future to recover or reposition these steel tapes to prevent them fouling equipment used to retrieve waste, and the test confirmed its ability to do so.

The Gripper End Effector is equipped with a pair of color video cameras that give the operator a close-up view of the jaw area and some distance viewing capability out to approximately, 4-6-m (15-ft) (limited by the on-board lighting of the end effector). The video from the cameras can be displayed and recorded in the OCT either as single camera views or as a combined stereographic image. Two continuously adjustable 35-watt halogen reflector bulbs provide lighting for the video cameras. The jaws of the Gripper End Effector are pneumatically actuated and the operator has proportional control of both position and grip force. The jaws must be moved slowly, however, due to the narrow diameter and long length of the pneumatic lines between the control valves (mounted in the ATIE) and the actuator in the GEE. This characteristic of the system has been a slight inconvenience for the operators, but not really a problem.

The LDUA was manually operated with the Gripper End Effector. Joint rate mode was used for moving the end effector into the general area of the steel tape and resolved motion in tool mode was used for the final approach and grasping. This mode was very intuitive and easy to use, and the operator was able to accurately place the jaws over the tape without contacting the nearby surface of the waste. The depth perception afforded by the stereographic video display was useful in the final positioning of the Gripper End Effector over the steel tape.

The OTP provided for an optional radiation surveying test using the Gripper End Effector. This test would have obtained a set of gross gamma radiation measurements at various points on the waste surface by using a gamma probe (supplied by TWRS) that would have been deployed into the tank through an adjacent riser. The Gripper End Effector would have grasped the probe once it was inside the tank and the LDUA would have positioned it near the surface of the waste. This was a very feasible task for the LDUA System to undertake; unfortunately, due to schedule and budget conflicts, the probe could not be made available for the hot test.

System Operation

The LDUA System was designed for two operators to control in-tank operations from the OCT, one operator controlling the LDUA and the other the end effector and video displays and recorders [10]. Two other operators remain inside the tank farm fence to perform end effector exchanges and to decontaminate the VPM, LDUA, and end effector as they are withdrawn from the tank. Health Physics Technicians are also present to monitor for contamination and safe radiation levels. A fifth operator operates the Overview Camera System from inside the tank farm. All operators work together during setup, riser alignment, and takedown.

All the operators are in continuous radio communication with each other and the Person-In-Charge (PIC). Other personnel, such as the LDUA Cognizant engineer and various subject matter experts, are provided with radio units as necessary. The particular radio units chosen for the LDUA were excellent and allowed the operating team to closely coordinate their activities. Each radio was contained in a lightweight battery- powered module that the could be clipped to the user's belt. It was equipped with a headset with an integral microphone and provided simultaneous receive and transmit capability. This allowed the user's hands to be free and allowed a more natural talking/listening style than a manually switched or voice-activated design. Indeed, it was possible, with a little care, to carry on two separate conversations at the same time.

In the early stages of the LDUA Project, there was some concern about the design of the control system with respect to the intended operators of the system. The LDUA System was a more complex system than was currently being operated by the tank farm NPOs at Hanford and it was all to be computer based. Accordingly, some user testing with NPOs was performed during the design phase of the project with simulated user interfaces [11]. These tests indicated that there would be no problem with the ability or attitude of the NPOs in operating a relatively sophisticated robotic system, or in doing so from a computer graphic console. Experience through the training and hot test has confirmed this.

The design of the OCT was carefully chosen based on lessons learned in operating similar control trailers. The OCT was made as large and wide as practicable and was finished inside with carpeting on the walls and floor for dust control, static control, and sound deadening. Modular office-type furniture was used throughout for storage and work surfaces. The OCT layout was designed to separate the operators from any observers and spectators to reduce any distractions. The LDUA operator and end effector operator are located in the front of the OCT. This operating area provides the controls and video displays that they require, and it is purposely small to allow good communications between them. This operating area can accommodate one or two other people comfortably. The rear area of the OCT is the visitor area that is designed for use by other people who have a need to observe and evaluate the LDUA mission as it is occurring without distracting the operators. It is provided with its own video monitors and a control console to select what they are displaying. The hot test provided a good test of layout of the OCT. There were many spectators (upwards of ten at a time) who had a legitimate interest in witnessing the achievement of a significant project milestone. There were, however, some moments of distraction when visitors were invited into the operating area. This was managed, however, by establishing limits on the number and by clarifying who had authority to direct the operators.

The hot test also helped confirm the roles and responsibilities of the people that will be involved in a typical LDUA System deployment. There must be a single individual solely responsible for the overall coordination of in-tank activities and that person must be present in the operating area of the OCT. Normally, this would be the Cognizant Engineer. The LDUA operator and end effector operator are completely occupied by running their respective parts of the system, and are too busy and too narrowly focused to perform this role. The PIC also cannot perform this task because he or she is responsible for the overall safety of operations and must be able to go wherever circumstances dictate. There could, on occasion, be one additional person in the operating area. This person would be responsible for monitoring and evaluating the information being gathered and operation being performed to determine that it was adequate. Additional subject matter experts or mission specialists would be accommodated in the visitor area of the OCT and coordinated by the Cognizant Engineer.

System Takedown

The takedown of the LDUA system is essentially the reverse of setup. Cables are disconnected and stored, and equipment is surveyed for contamination and packed accordingly for transport out of the tank farm. This required approximately two 8-hour work shifts to complete. Radiation-detection equipment indicated minimal levels of contamination on the LDUA when removed from T-106; therefore, use of the water decontamination system was not required. The system was subsequently released for use in non-radiological controlled areas following a thorough survey outside the tank area. In future deployments, it is anticipated that only the inside of the TRIC and the outside of the LDUA, VPM, and end effectors will be contaminated on a regular basis.

Test Exceptions

The hot test was performed as a low-risk intermediate step between the cold test and full commissioning of the LDUA System. Some surprises due to actual tank farm and in-tank conditions were expected and, indeed, were observed. Most problems were minor; however, one problem was significant. The MDS pitch axis moved approximately 0.3 degree while the LDUA was deployed in the tank with the HRSVS end effector. This was enough to cause contact with the riser and some minor damage to the silicone rubber boot when the LDUA was withdrawn from the tank. The major cause was suspected to be slippage of the pitch axis mechanical brake due to a coat of paint that was mistakenly applied to the friction surface during a field touch up of some rust spots on the MDS. The pitch axis hydraulic actuator builds up a slight increase in internal pressure during the brake locking procedure, and this had been observed to cause slippage of the brake until the factory paint had been removed. A secondary cause of the change in angle was thought to be a deflection of the VPM Housing frame due to uneven heating by direct sunshine, but this was estimated to be a much smaller effect. Since the potential for large-scale slippage was estimated to be low, an administrative limit on pitch axis drift of 0.1 degree (after riser alignment was restored) was established as an abort condition for the subsequent deployment of the Gripper End Effector. Although drift was observed, it never reached the abort limit. This problem will be diagnosed and resolved as part of an open item resolution process prior to the next deployment. The results of the OTP were presented in a formal Operability Test Report (OTR) [12].

AREAS FOR IMPROVEMENT

The LDUA System is operational and ready to enter continuous service. However, as with any first-of-a-kind system, there have been parts of the LDUA System that were less satisfactory than others, or which would benefit more than others from changes in the design. This section lists the most significant areas for improvement as of the completion of the hot test. Some changes to the LDUA System may be made before final turnover to operations.

Riser Alignment

The major deviation from vision to reality in the LDUA System has been with the riser alignment process and the parts of the system that support it. These include the X, Y, Roll, Pitch Table (the part of the MDS that changes the angle and translation of the VPM housing), the controls associated with it, and the Optical Alignment Scope (OAS) end effector (not used for the hot test for reasons that will be explained below).

As originally envisioned, the riser alignment process was similar to that described earlier in this report, except that it was to be performed remotely from the OCT. The OAS, when mounted to the end of the LDUA, was to provide the laser beams and a video camera to enable the operator to see down the riser from the OCT. The position of the X, Y, Roll, Pitch Table was to be adjusted by the operator using remote controls in the OCT. Remote operation was necessary in the original design because the mounting and dismounting of end effectors was to be a remote operation and the original mechanized version of the TRIC did not allow the operators to have good access to the riser. By the time that the TRIC design was simplified to its present manual version, the OAS and MDS designs were already well along and were not changed, due, at least in part, to a desire to preserve the future option of upgrading to a mechanized TRIC.

The OAS had to be abandoned because of a change in the design of the VPM. The VPM inner tube was not exactly concentric with the VPM outer tube. In order to place the laser beams properly, the OAS needed to be both concentric with the VPM outer tube and perpendicular to it. Initial testing was done with the system at Hanford using a clamping fixture that attempted to force the OAS into the required position. However, results were disappointing and a decision was made to proceed with a simple fixture that clamped directly onto the VPM outer tube and had its own lasers. This proved successful and was ultimately used for the hot test.

Given that the riser alignment process does not need to be performed remotely, it is the consensus opinion of both the engineering and operations teams that the operation of the LDUA System could be improved by the following changes:

- Change the actuators on the X, Y, Roll, Pitch Table from hydraulic cylinders to jackscrews. This would eliminate any drift problems, allow more precise placement of each axis without overshoot, and allow changes in alignment to be made safely even when the LDUA and VPM were deployed in the riser.
- Provide direct local control of the X,Y, Roll, Pitch Table (like the outriggers) instead of controlling them through the main computer. This would be simpler and more reliable.

The reasons that the riser alignment function required more sorting out than other parts of the system are instructive. The riser alignment function of the system spanned several of the LDUA System. This posed several difficulties:

- No single supplier was responsible for making it work. That was the responsibility of the system integrator, WHC.
- The interfaces between subsystems had many more de facto requirements than could be practically anticipated and specified.
- The actual riser alignment function could not be sorted out until all the equipment was delivered to Hanford, and this left little time to identify and correct problems.

The situation was exacerbated by measures taken by the project to contain cost growth and schedule slippage by expediting the final design phase and fabrication phase of the LDUA, VPM, and MDS. This tended to reduce the amount of communication between the WHC and vendor engineering teams, and the situation with the concentricity of the VPM tubes was not discovered by WHC until the system was assembled by the vendor and ready to test.

The project identified the riser alignment issue as important to the system from the conceptual design phase, and a serious effort was made to address it from outset. For example, 3D computer graphic simulation was used to verify the process and key system specifications (i.e., MDS axis travel and resolution). The problems noted occurred in spite of the project's best intentions, but they would have been far worse without the attention that was given.

Changing VPM Tube Sequence

The second major area for improvement would be in the selection of the VPM tube sequence. The LDUA control system allows the operator to designate which of the VPM tubes (inner or outer) moves first, and at what position the transition to the other tube is made. The problem is that presently the change in sequence can only be made when the VPM is fully stowed, and this causes some operational difficulties and limitations. It would significantly improve the operating efficiency of the system if the VPM tube sequence could be changed while the VPM is deployed.

Graphic User Interfaces (GUI)

There are some parts of the Graphic User Interfaces (GUI) for the LDUA Console and for the SDAS Console that could be improved to help operability of the system. The categories that these improvements to the GUI are grouped into, with an illustrative example given for each category, are listed below. Appendix D contains the list of all software comments, including all those pertaining to the GUI.

- <u>Operator convenience</u>: A "Home LDUA Joints To Zero" command would be more convenient for the operator than requiring him/her to create a joint auto sequence with all the joints set to zero.

- <u>Better grouping of controls and displays for tasks</u>: The controls for the video switch, video recorders, and the end effector are on different SDAS control screens. The operator is slowed down searching for the right screen.

- <u>More informative error messages</u>: Error messages do not always tell the operator which specific joint has caused the error condition. This can increase the time needed to find and correct the problem.

- <u>Some controls/displays are hard to use</u>: The windows in the dialog box for saving and opening auto sequences files are too narrow to show the full name of the file.

- <u>Better protective features</u>: The "Purge Off" control causes the LDUA to immediately go into the limp condition. There should be a pop-up dialog advising the operator of the consequences and allowing him/her to change her mind.

The situation with the GUI exists despite the fact that the project recognized and addressed the need for attention in this area. For example, user testing was done during the design phase with both the LDUA Console and the user interface for the World Model. Engineering evaluation was also done for the SDAS control screens.

Ergonomics of the TRIC, MEEES, and MDS

This aspect of the system received more comments by the operating crew than any other, which is not surprising since it involved the most manual operations such as climbing, reaching, lifting, tightening/loosening, and so forth. A detailed list is provided in Appendix C.

Software Integration and Reliability

The reliability of the LDUA System software has been less than desirable in some areas, for example, the SDAS position client/server (the software that obtains the position of the LDUA from the LDUA controller and communicates it to the SDAS system). This is seen mainly as an integration problem involving communications and timing issues. The software components involved were provided by different suppliers, they communicate with each other by network, and they are real-time software (being required to simultaneously support both deterministically scheduled events and asynchronous ones). It is extremely difficult to test the individual components well enough by themselves to guarantee that they will inter-operate with no problems when combined because it is hard to create a test environment that duplicates the conditions of the final system. Not enough time was available prior to the hot test to completely sort out the SDAS position client/server software. Since it was not mission critical, it did not receive the priority. The lesson here is that sufficient time and resource, and access to the equipment, must be provided to sort out integration issues with complex software.

CONCLUSIONS

The successful completion of the hot test by the LDUA System means that it can do the job it was designed for and should be put into full operation as planned. It fills an existing technology gap and provides DOE with a flexible and adaptive tool box of technologies to assist in a wide range of issues, including:

- Tank integrity assessment, both visual and other non-destructive examination (NDE) methods
- Small-scale waste sampling
- In-Situ waste analysis
- Small-scale debris removal and waste retrieval
- Support tank monitoring and off-normal event response/recovery.

The task of developing a new technology and deploying it directly into the field is much more complicated than producing a laboratory prototype, requiring the equipment to be hardened to meet field conditions and requiring a very formal and thoroughly documented design process. Organizations attempting to do such development must clearly understand these requirements.

The approach used by the LDUA Project provides a successful model upon which future projects within the DOE can be based, particularly as shrinking budgets drive sites to increased participation in cooperative efforts in solving common problems. The arrangement used by the LDUA project, of teaming the prime developer organization with end users, other DOE sites and laboratories, and industry, was successful and met the challenges of developing a new technology that could be successfully transferred to end users. Sharing of technology development costs, leveraging single contract procurement for all sites, and sharing testing facilities and documentation all add up to significant savings in cost and schedule in addressing tank remediation issues from a national perspective.

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APPENDIX A

LDUA SYSTEM CONFIGURATION DOCUMENT SUMMARY

Configuration documentation for the LDUA subsystem was organized by subsystem, and a consistent set of document categories was established for all subsystems.

SUBSYSTEMS

No.	Name
1000	LDUA Baseline System
2000	LDUA and Deployment System
3000	Tank Riser Interface and Confinement (TRIC) (Includes: 3150, 3160, 3340, 3350, 3520)
3660	Manual End Effector Exchange System (MEEES)
4100	Operations Control Trailer (OCT)
4200	Supervisory Control and Data Acquisition System (Includes 4400)
4300	At-Tank Instrument Enclosure (ATIE)
5130	Power Distribution Skid (PDS)
5140	Power Interface Module (PIM)
5230	Purge Air Supply System (PASS)
6210	Overview Video System (OVS)
6230	High Resolution Stereo Video System (HRSVS)
6260	Common Video End Effector (CVEE) Support Equipment
6510	Gripper End Effector (GEE)
8100	Riser Characterization Equipment
8200	Operations Overview Video System (OOVS)

DOCUMENT CATEGORIES

Calibration, Grooming, and Alignment (CG&A)

This category contained the results of the CG&A process for the subsystem.

System Design Description

This category was empty for most subsystems. The design description for the LDUA Baseline System was filed under Subsystem 1000. Individual subsystems occasionally provided supplemental design description information in this category, at the discretion of the Cognizant Engineer.

Released Drawings

This category contained released WHC drawings.

Engineering Change Notices (ECNs)

This category contained ECNs to released WHC drawings.

Other Drawings

This category contained drawings which were not released WHC drawings, such as vendor drawings, drawings from other DOE sites, sketches, etc.

Post Delivery Acceptance Test

This category contained the test procedure and test report for post delivery acceptance testing of the subsystem and/or subsystem components. The test report was a WHC Supporting Document. The test procedure had a signature approval sheet, but was not WHC Supporting Document.

Integration Test

Testing that was done with the subsystem. The test report was a WHC Supporting Document. The test procedure had a signature approval sheet, but was not a WHC Supporting Document.

Operation and Maintenance Manual (OMM)

This category contained the OMM for the subsystem.

Component Information/Catalog Cuts

This category contained vendor information, such as data sheets, user manuals, etc., for components used in the subsystem.

Miscellaneous Background Information

This category contains documents that provide background information about interpretations or waivers of national codes or DOE orders that affected the design. This category was used sparingly and not as a catch-all.

Software Configuration Documentation

An additional category, "Software Documentation," was added for Subsystem 4200 and 2000. This category had the following subcategories:

CSRS (Computer Software Requirements Specification)
CSDD (Computer Software Design Description)
Software Testing
User Documents
Software Code
V&V (Verification and Validation) - (Includes Software Development Plan)
Configuration Management

APPENDIX B

OPERATIONAL READINESS REVIEW REQUIREMENTS SUMMARY

This is a summary list of the requirements that appeared in the LDUA Operational Readiness Review plan:

1. There are adequate and correct procedures and safety limits for operating the process systems and utility systems.

2. Training and qualification programs for operations and operations support personnel have been established, documented, and implemented. The training and qualification program encompasses the range of duties and activities required to be performed.

3. Level of knowledge of operations and operations support personnel is adequate based on reviews of examinations and examination results, and selected interviews of operating and operations support personnel.

4. Facility safety documentation is in place that describes the "safety envelope" of the facility. The safety documentation should characterize the hazards/risks associated with the facility and should identify mitigating measures (systems, procedures administrative controls, etc.) that protect workers and the public from those hazards/risks. Safety systems and systems essential to worker and public safety are defined, and a system to maintain control over the design and modification of facilities and safety-related utility systems is established.

5 A program is in place to confirm and periodically reconfirm the condition and operability of safety systems, including safety-related process systems and safety-related utility systems. This includes examinations of test records and calibration of system instruments which monitor limiting conditions of operations or that satisfy technical safety requirements. All systems are currently operable and in a satisfactory condition.

6. A process has been established to identify, evaluate, and resolve deficiencies and recommendations made by oversight groups, official review teams, audit organizations, and the operating contractor.

7. A systematic review of the facility's conformance to applicable DOE orders has been performed, non-conformance have been identified, and schedules for gaining compliance have been justified in writing and formally approved.

8. Management programs are established, sufficient numbers of qualified personnel are provided, and adequate facilities and equipment are available to ensure operations

support services (e.g., training, maintenance, waste management, environmental protection, industrial safety and hygiene, radiological protection and health physics, emergency preparedness, fire protection, quality assurance, criticality safety, and engineering) are adequate for operation.

9. A routine and emergency operations drill program including training has been established and implemented.

10. An adequate startup or restart test program has been developed that includes adequate plans for graded operations testing to simultaneously confirm operability of equipment, the viability of procedures, and the training of operators.

11. Functions, assignments, responsibilities, and reporting relationships are clearly defined, understood, and effectively implemented with line management responsible for control of safety.

12. The implementation status for DOE Order 5480.19, Conduct of Operations Requirements for DOE Facilities, is adequate for operations.

13. There are sufficient numbers of qualified personnel to support safe operations.

14. A program is established to promote a site-wide culture in which personnel exhibit an awareness of public and worker safety, health, and environmental protection requirements and, through their actions, demonstrate a high-priority commitment to comply with these requirements.

15. The facility systems and procedures, as affected by facility modifications, are consistent with the description for the facility, procedures, and accident analysis included in the safety basis.

16. Training has accounted for document/procedure changes.

17. The technical and management qualifications of contractor personnel, responsible for facility operation, are adequate.

APPENDIX C

OPERATOR COMMENTS

This section is a summary of comments by the Nuclear Process Operations that were given at a post deployment briefing.

Tank Riser Interface and Confinement (TRIC) and Manual End Effector Exchange System (MEEES).

1. The MEEES should have longer overhead rails to allow more room to handle the end effectors outside the TRIC. The work platform should be longer, also, and should be equipped with steps.

2. The mechanical brakes for the MEEES overhead trolley have bolts that stick out and are snagging points. Also, the brakes have worn out in a single deployment.

3. The upper glove ports on the TRIC are too high from the standpoint of both effective reach and visibility.

4. The TRIC pass-out port is in a poor location. It would be better on the TRIC door or low between two glove ports.

5. The TRIC HEPA filter is annoying to have to mount and dismount when transporting the TRIC.

6. The VPM to TRIC flexible boot should be made of a transparent material, and should be held with quick-connect clamps rather than screw type hose clamps (slow and tedious to apply and tighten).

7. The hand wheel operator for the Riser Isolation Valve is awkward to use (it is almost on the ground). It would be better with some kind of extension.

8. The manual decontamination spray wand is in the way and needs a better stowage when not in use.

9. The cover plate for the riser access hole in the bottom of the TRIC enclosure should be smaller, lighter, and easier to grasp with gloves.

Mobile Deployment System (MDS)

1. The scaffolding used to access the MDS pitch axis brake bolts should be made to attach directly to the MDS structure instead of being a freestanding structure. It is a nuisance (and time consuming) to have to carry the freestanding scaffolding back and forth several time during a deployment. The directly attaching version could be left in place.

2. Containers to hold the brake bolts should be provided near where they attach. This would keep them from being misplaced and from getting dirt and dust on them.

3. The brake bolt wrench is hard to use. It needs a lot of force to reach the torque setting required by the brake bolts and the work platform does not provide much choice of places to stand. Some kind of torque multiplier would be appreciated. Time could be saved by providing two wrenches, one for each side of the MDS, with storage containers to keep them right on the MDS near the brake positions.

4. The Emergency Stop button on the control pendant is easy for some operators to accidentally actuate.

5. There should be a place to hand or place the pendant when not in use so that it doesn't fall on the ground.

6. A small storage trailer for transporting and storing the smaller paraphernalia for the system would be very useful.

7. The Purge Air Supply System (PASS) compressors are in front of the MDS truck headlights.

Laser Alignment Fixture

1. A carrying case should be provided.

2. The contact points with the VPM outer tube are short. Some care must be taken to be sure that they are on a good flat portion of the VPM and not over a bolt hole.

Supervisory Data Acquisition System (SDAS)

1. The controls and displays needed to switch the video displays and control the recorders are on different screens than the ones for the end effector. The operator spends a lot of time trying to find the correct screen.

2. The controls for the Operations Overview Video System (OOVS) should be within reach of the SDAS operator.

3. The Gripper End Effector (GEE) jaws are slow.

4. It would be a good idea to provide a dedicated VCR for each video source. These could be manually controlled and just left running. The operators worry about missing an important piece of video with only the two switched VCRs.

APPENDIX D

SOFTWARE COMMENT SUMMARY

This section contains the list of software comments that were accumulated as a result of LDUA System cold test and hot test. The comments are in "raw" form, that is, understandable to the LDUA Cognizant Engineering team, but not necessarily self-explanatory.

No.	Comment
B1	The "LduaHomeToZero" command from the pendant, and the "unstow" command, both have a problem if there is an existing auto sequences in the buffer. The "LduaHomeToZero" command causes the preexisting sequence to execute, the "unstow" command apparently just fails to do anything until the motion is aborted.
B3	Purge pressure should be displayed on the LDUA page of the LDUA Console. This parameter is important for the operator to monitor (affected by LDUA/VPM motion, indicates boot leakage, avoid limping LDUA in flammable tank, etc.), and switching between the LDUA and System pages on the Console while operating the LDUA is impractical for one operator to perform on a regular basis.
C6	There should be an "are you sure you want to do this" dialog pop up that appears when the "Purge Off" button is pushed. This pop up should explain that the LDUA will unconditionally go limp if the command is issued, and it should allow the operator to cancel.
D0	There should be an "are you sure you want to do this" dialog pop up that appears when the purge mode is changed from flammable to non-flammable tank mode. This pop up should explain the seriousness of issuing this command, and it should allow the operator to cancel.
B2	The shoulder yaw joint position was observed to be -360 degrees in error: i.e., actual position was 118 degrees and the indication was -242 degrees. Is there a flaw in the software?
B8	There should be an "Acknowledge All" button for errors and warnings (especially warnings). Sometimes the system spews out quite a few messages and acknowledging them one by one is a real pain.
B10	There should be a way to change the VPM tube sequence from the pendant.

C2 There needs to be more efficient way to obtain the "LDUA home joints to zero" function on the LDUA Console (we have to re-zero the LDUA joints every time the we want to move the VPM, and the LDUA has gone into the lock mode while inside the VPM). Might be done in several ways: 1) intrinsic command (best way); and 2) button on the joint auto sequences dialog screen that set all the joint values in the edit line to zero.

C3 Display should indicate when the position data is not valid, for example, before purge on, or when LDUA is limped.

C4 Warning and Error messages should identify which specific joint is at faulted or affected. Sometimes it is easy to tell which one is meant by other system indications, and sometimes it is not.

C10 The select VPM axis command fails intermittently from pendant when VPM is at top position.

C11 There should be a way to change the VPM tube sequence while the VPM is deployed. Presently, the VPM must be stowed in order to do this

C12 When operating in the diagnostic mode, the LDUA Console should display the net distance between the inner and outer VPM tubes so that the operator can avoid contact between the inner and outer tubes which could unwind the winches. This display could be a single live number with upper and lower limits displayed, or it could be two live numbers with one number representing the margin from the lower limit and the other number representing the margin from the upper limit (0 would mean at the limit, positive numbers would mean safe clearance, negative number would mean improper clearance).

D2 The home LDUA command (from the pendant) appears not to work when the VPM housing is tilted to 5 degrees from vertical.

D3 The distance that the TIP extends below the VPM outer tube when in the inner/outer sequence should be increased to permit an end effector to be mounted. This is not presently possible because the indentations on the LDUA TIP for engaging the MEEES collar are covered by the bottom of the outer tube.

B4 The file dialogs for reading and writing auto sequences files are hard to use. The width of the fields that display path and file names need to be much wider. We are only getting the first few characters in some cases and cannot read the whole file or path name. Also, it does not seem possible to navigate up/down the directory structure by just clicking on entries in the list fields.

B5 The VPM will go to 14-m (-551.6- in), but an auto sequences will only accept **-549** as a maximum value.

B9 There is no sensor installed for the VPM gate valve pressure supply in the LDUA. The LDUA Console indicator for it needs to be removed (or the sensor installed on the system).

C0 There is a problem with the SGCS software whenever the Real robot and the Simulation robot have their LLTI connection active at the same time. Whenever the Real robot is connected, the Simulation robot flies apart. We have a temporary work-around. If we disable the production of deflection compensation packets in the IGRIP shared library, the problem goes away. The problem may be in the Spar code or in the IGRIP code, or both. We are suspicious of a particular section of the deflection compensation packet stuffing code. It appears to be off by one joint.

C1 Auto sequences files should allow comments to be inserted (it is not necessary to modify to the auto sequences dialog screens to display these comments or to enter them. We can use an external text editor for that).

C5 Warning and Error message numbers should be displayed as part of the messages on the LDUA Console (it is presumed that the numbers given in the Spar Software Manual for pendant error codes would be suitable for this). This provides a concise, unambiguous way to reference messages, and to look up corrective actions in the operating manual.

C8 The "Stow" and "Unstow" buttons should be moved to the LDUA screen, or there should be a status indicator added to their present location to give the operator some feedback that the command has been accepted and is in progress. Presently, the only way to tell is to pop back to the LDUA screen, which is awkward. Progress messages during the stow/unstow process would be nice also - some of the other commands have them.

D1 There should be two new indicators for each LDUA joint to indicate that the joint is enabled to move: the first indicator would tell that the joint was clear of the VPM outer tube and the second indicator would tell that the joint was clear of the riser. Presently, the system just refuses to move the joint if it is inhibited by one of these interlocks, and operator must guess why based on messages that list several possibilities without specifying a particular one.

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