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REMOTE VIEWING END EFFECTORS FOR LIGHT DUTY UTILITY ARM ROBOT

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ABSTRACT

Remote viewing end effectors have been developed and fielded for the very large Light Duty Utility Arm (LDUA) robot, being developed by Department Of Energy (DOE) for remediation functions in underground storage tanks (UST). The combination of the LDUA with the end effectors helps to assess the condition of the four million (nominally) liter (1.2 million gallon) underground tanks and their contents as a part of the remediation process. The LDUA will extend 15 meter (49 ft) vertically down into a UST, through a 0.3 meter (12 in) opening, and reach 3.6 meter 12 ft) horizontally, while deploying a 25 kilogram (55 lb) end effector. All operational controls are over a 250+ meter (900 ft) tether.

The Optical Alignment System (OAS) is an end effector that will be deployed first to confirm proper alignment and clearance of the LDUA as it enters a tank, and provide the first LDUA views of inside of the tank. It incorporates vertical passage lasers, and clearance measuring diode lasers, to assure proper initial alignment and precise wall distance measurements respectfully. Additionally, an innovative pattern of laser lines will provide the remotely located operator a visual alignment confirmation pattern, in conjunction with the high resolution video camera and high intensity lighting.

The High Resolution Stereo Video System (HRSVS) is an end effector deployed to provide both wide area tank views and high magnification stereo images of areas of concern. The stereo images are provided in multiple steps of predictable magnification, giving on screen images of known reference size. The stereo images are viewed using a "Crystal Eyes", multiple viewer, display. The wide area cameras give multiple, non stereo, images of different magnifications for orientation purposes, and are viewed individually.

The Still Photography System (SPS) end effector provides remote stereo 35 mm film camera capabilities, that will be used for archiving and examination purposes. Film retains a ten times image quality advantage over high resolution video systems. A quick film change out system is provided for the modified

electronic, auto focus, camera. Remote scene composition and zoom control is provided for both film cameras through coupled video cameras.

All of the end effectors couple to the LDUA, for all services and support, utilizing a specially designed interface plate. The end effectors were designed for all internal wiring and to meet flammability requirements. The LDUA with end effector must meet Class 1, Division 1 requirements.

Demonstration testing of all components and the LDUA has begun at the Cold Test Facility at the Hanford site. LDUA units will be delivered to Hanford, Idaho, and Oak Ridge sites for underground storage remediation efforts.

I. INTRODUCTION

The Robotics Development Groups at the Savannah River Site (SRS) and at the Hanford site have developed remote video and photography systems for deployment in underground radioactive waste storage tanks at the Department of Energy (DOE) sites as a part of the Office of Science and Technology (OST) program within DOE. Viewing and documenting the tank interiors and their associated annular spaces is an extremely valuable tool in characterizing their condition and contents and in controlling their remediation. Several specialized video/photography systems and robotic End Effectors have been fabricated that provide remote viewing and lighting. All are remotely deployable into and out of the tank, with all viewing functions remotely operated. Positioning all control components away from the facility prevents the potential for personnel exposure to radiation and contamination. Only the remote video systems will be discussed in this paper.

Field versions of the Portable Overview Video System, the Optical Alignment End Effector, and the High Resolution Stereo Video End Effector were completed and delivered to the Hanford Cold Test Facility (CTF) for qualification testing and deployment. An Optical Alignment End Effector, a High Resolution Stereo Video End Effector, and a Stereo Photography End Effector were also delivered to Idaho National Engineering Lab. These systems will be used in radioactive waste tanks at Hanford or Idaho in the future. Details are covered in the following sections. These systems represent the maturing designs of remote tank entry stand-alone systems and tank entry robotic visual inspection End Effectors.

Remote video and photography systems for deployment in Underground Storage Tanks (USTs) will significantly increase the information available concerning the tank conditions and contents during all phases of remediation. The low cost and light-weight remote systems capable of small port entry into hazardous, or flammable, environments provide another valuable tool in the assessment and remediation of limited knowledge areas. The systems will enhance the operation of other equipment in the tank, such as the Light Duty Utility Arm (LDUA), and will provide a "first-in, last-out" view of all remote operations, further increasing the confidence in remediations. The potential for personnel exposure to hazardous materials and radiation will be reduced with the application of such equipment.

II. Background

A cooperative program has been underway with multiple DOE sites to develop remediation systems and techniques for UST high-level waste containments typical of many sites. The SRS and the Hanford site contain the largest number of USTs and are the major players in developing specialized video systems for deployment within these tanks.

In response to a need for new and improved technology, the DOE Office of Science and Technology (OST) was created. To complete this task, several major new technology demonstration efforts were initiated. One such effort is the UST program. This program focuses on the characterization and remediation of underground radioactive waste storage tanks and is funding the development of the LDUA system. The LDUA system consists of a seven degree of freedom robotic arm, which will function as a deployment platform for various surveillance and inspection End Effectors, and a mobile deployment vehicle to maneuver the system to waste tanks. End Effectors that will assist in these tasks will be developed by DOE laboratories, industry, and academia.

The SRS and the Hanford site are developing the remote viewing systems to be used in conjunction with the LDUA. Remote viewing will be used to assist in positioning and controlling the LDUA in USTs and as the end product of a portion of its work. Remote close-up, high resolution, and stereo views of tank components and contents will be gathered by the LDUA using the remote viewing End Effectors.

In the past, tank surveillance and inspection was performed by lowering film cameras, primitive video cameras, and other instruments through existing risers to positions directly below the riser and obtaining data from a single location, possibly at multiple elevations. The capability for positioning cameras, sensors, or other equipment at multiple orientations away from the riser axis did not previously exist, and remote visual inspection operations have been hindered by these limitations. The photographic methods, which have predominated, are particularly limiting since they are not useful in real time.

The field of remote video/viewing is now being used extensively in other areas to extend the data gathering and control of personnel into environments not suitable for entry. The provision for viewing remote locations from a safe distance has allowed inspection, documentation, and verification of pipes, tanks, vessels, ducts, rooms, and pits.

This report addresses the development of the remote video and photography technology for the LDUA, in the form of End Effectors which are positioned by the LDUA. All will be used in conjunction with the "hot" deployment of the LDUA at Hanford, and may also be used in other applications; some systems are already in use in radioactive tanks at Hanford.

III. TASK DETAILS

The USTs are nominal 4.5 million liter (1.2 million gallon) tanks used to store liquid high-level radioactive waste that is generated by the sites and awaiting final disposal. Approximately 200 USTs exist at SRS and Hanford, and smaller numbers exist at other DOE sites.

The waste tanks are of two general configurations: single shell and double shell. A wide variety of internal tank configurations are in use depending on tank service. These internal configurations vary from nearly free of obstructions to containing hundreds of distributed vertical cooling coils.

Both general types are of flattened shape (wider than high), with all types having a sealed carbon steel primary tank. The double shell tanks have a dry secondary containment pan. The annular space between the tank wall and the secondary containment wall is continuously monitored for liquid intrusion and periodically inspected and documented.

The single shell tanks have only a concrete support structure around the primary tank wall with no annular space. Wells have been drilled in the surrounding areas to monitor for any tank leakage.

The interior conditions of the tanks and dry annular spaces have been historically monitored with remote still photography. A wide variety of 35 mm or 120 mm film cameras have been manually deployed to record and document tank structures and conditions.

IV. LIGHT DUTY UTILITY ARM PROGRAM

The Light Duty Utility Arm (LDUA) Integrated System is a truck-mobile robotic in situ surveillance and inspection system designed to remotely inspect, map, and characterize waste and waste tank conditions. The LDUA Integrated System is being initially developed for use in the single shell tanks, of which Hanford has 149.

A major objective of the UST program is to demonstrate waste retrieval technologies in preparation for UST remediation and waste disposal. Waste retrieval is directly dependent on knowledge of chemical and physical properties of waste, and on operating experience in the tank environment. Because the in-tank environment precludes human entry, a remote system is required to deploy characterization and retrieval devices. The requirement for a light duty device to meet the characterization needs and operating experience will be addressed with the LDUA. The system will include the robotic arm and all required subsystems working as an autonomous field unit.

The deployed LDUA system will include the truck-based robotic arm, the tank top support frame, the remotely located control trailer, and all other support devices. The overview video units will be deployed as separate units that interface to the robotic arm. All controls and services will be consolidated to tank top interfaces prior to transmission on the more than 275 meter (900 foot) tether to and from the control trailer. The long distance is required to allow most personnel to work only in "clean" areas.

The LDUA system will minimize any potential for personnel exposure to radiological hazards. A special emphasis is being placed on minimizing any set-up time or maintenance time requiring personnel to be present on the tank top. Figure 1 shows the LDUA and Hanford style waste tank.

V. REMOTE VIDEO AND PHOTOGRAPHY END EFFECTORS

The remote video and photography system End Effectors are being provided for mounting on the LDUA, coupled through remote tool changers. They are assisted by overview video units positioned prior to the LDUA deployment into the tank and will remain in use until the arm is removed, the overview units are not a part of this paper. The End Effectors are used by the deployed LDUA to make specialized inspections and documentation, as required to document the UST environment.

The End Effector systems are remotely positioned by the LDUA to provide specialized viewing. The high resolution stereo video unit provides remote stereo viewing for the characterization of suspect anomalies such as corrosion and cracking. The stereo photography unit implements the inherent higher resolution of film-based systems while providing the remote operator with real-time scene composition on fully automatic cameras. The optical alignment system provides a multiplicity of visual indications and direct measurements to assure proper alignment of the LDUA with the tank entry riser.

All system controls use the "over the coax" technology to address the long distances to remotely located personnel. All systems include optional fiber optic coupling to the remotely located operator which can be utilized as required.

All systems are designed to NFPA-70 Class 1, Division 1 requirements to satisfy those deployments that require flammable atmosphere protection. Protection is included for all portions, including cabling, with constant pressurization and electrical interlocking.

A. Common Features

The achievement of the Class 1, Division 1 flammability rating is accomplished with the pressurized and interlocked method. The single, contiguous, "housing" is protected through the entire LDUA mast to the termination of the end effector housing. This "housing" is pressurized with flow though air from the safe area to an exhaust at the lowest end of the end effector housing. Double flow sensing interlocks are combined with intrinsically safe pressure sensing within the camera housing to complete the system.

The End Effector units provide all required lighting within the head package with eight or more each 35 watt halogen lamps providing the illumination required be the very large UST's. All end effector controls are remotely located in the control trailer, positioned up to 275 m (900 ft) away. All system controls, camera functions, and positioning are performed from the remote location. The remote connections for each system consist of a single pair of coaxial cables or fiber optic strands. The system controls are intermixed with the video signals. This simplified connection scheme allows for rapid relocation of systems and minimizes the impact of cable costs and deployment.

A common control system is used with all of the end effectors shown below. Their primary control is through a supervisory computer work station, and all units are capable of standalone operation, for testing and trouble-shooting purposes.

B. High resolution stereo video end effector

The High Resolution Stereo Video System (HRSVS) is an End Effector system deployed by the LDUA which provides high resolution predictable size inspection of suspect anomalies. Figure 2 shows the HRSVS.

A special lens system is used to allow constant size viewing from an adjustable standoff distance; and shadow producing lighting is provided to resolve potential crack anomalies. This is supplemented with the ability to change stepwise the magnification of both stereo viewing cameras. Four choices of magnification are provided by dual rotating lens turrets, which also provide left to right stereo image alignment. Color stereo video is provided by non radiation hardened cameras. Black-and-white radiation hardened cameras are applicable to this device but are a less desirable choice.

The HRSVS includes an adjustable optical system that allows the distance between the LDUA and the object to vary so that there is no significant change in the remotely viewed size of the suspect anomaly. The size predictability eliminates the potential confusion associated with over or under magnification that can occur in totally remote operations.

The remotely located operator can adjust the stereo focus, convergence, and alignment as required. A "Crystal Eyes" viewing and recording system is used in the control trailer to convert the stereo viewed images into a multiple operator display.

The HRSVS also provides two additional general area cameras located in the tip of the end effector, to provide overall LDUA viewing. They are equipped with a preselected pair of wide to narrow field of view camera lenses, as required. It is anticipated that most deployments would utilize one wide and one narrow view camera and lens combination. Since both are provided to the operator simultaneously, the two views would be the most useful for LDUA positioning.

C. Stereo still photography end effector

The Stereo Photography System (SPS) provides for stereo film-based documentation and archiving of tank interiors. Using film provides a resolution ten times higher than that with modern video systems. The SPS incorporates electronic 35 mm film cameras and video cameras. The 35 mm cameras have been modified for remote control and coupled to video cameras for remote scene viewing. The remote video viewing provides for scene composition, aiming, and magnification. The system is intended to support off-line stereo film comparisons and is not necessarily intended for remote stereo direct view. Figure 3 shows the Optical Alignment System.

Both film cameras are remotely controlled through modifications to the electrical controls of the fully automatic cameras, including zoom, auto focus, and shutter control. Through the view finder, video cameras allow the operator to view the scenes before taking pictures, and adjust the alignment etc. accordingly.

High intensity lights are provided for illumination. Strobe lights were built for the units but steady lights proved superior when tested in simulated field operations.

D. Optical alignment scope end effector

The Optical Alignment Scope (OAS) provides multiple methods of sensing the proper alignment of the LDUA and the tank riser, both prior to entry and during passage through the riser. Laser dot projectors (four each) visually indicate the passage diameter and area of the LDUA from a position above, outside of the riser. Figure 4 shows the OAS.

Laser line projectors (four each) visually indicate the LDUA alignment as it is passing through the riser. Laser distance measuring devices (eight each) indicate the precise standoff distance of the LDUA from the upper and lower end of the OAS. All of the above data is incorporated into the color video signal returned to the remotely located operator. The laser distance measurements are also provided in serial form at the remote operators location for direct coupling to a supervisory computer.

The laser distance measuring lasers are high accuracy, short range, devices to measure the offset of the OAS from the riser pipe wall at locations at the top and bottom of the OAS. The four top and bottom sets are displayed to the remote operator in selectable sets of two at a time, or output as serial data to the supervisory computer. By comparing top and bottom sets the tilt can be measured, and by comparing opposite sets the pipe centering can be measured.

The line lasers emit a pattern of four orthogonal lines that are only visible where they intersect the riser pipe walls. The arrangement results in a pattern of eight lines visible on the pipe, as seen in the inset view on the figure. The lines nearest each other are actually one each from adjoining line lasers. The pattern shown is for a correctly aligned LDUA. A misaligned LDUA will give a non symmetrical pattern of lines where one pair is closer together and the opposite side pair is farther apart. Any tilt of the LDUA, relative to the riser, will give pairs of lines that either diverge or converge. The visual feedback can give an instant indication of correct alignment.

The point lasers are used for initial alignment and will be visible on the riser pipe wall if any point on the pipe is nearer than the acceptable pipe offset from the LDUA. The point and line lasers are not used at the same time and are controlled from the remote operator location.

The OAS is intended to provide a final level of assurance of proper LDUA (267 mm (10.5 in) diameter) and tank riser (305 mm (12 in) diameter) alignment. The multiplicity of indicators are intended to provide the most useful and precise indicators to the operators for LDUA alignment and to measure riser straightness.

VI. FIELD EXPERIENCE

The HRSVS has been qualified and deployed in a radioactive UST at Hanford. An additional HRSVS and two OAS units are now undergoing qualification and testing at Hanford. A HRSVS, a OAS, and the SPS are now undergoing qualification and testing at the Idaho site, in preparation or their receipt of a LDUA.

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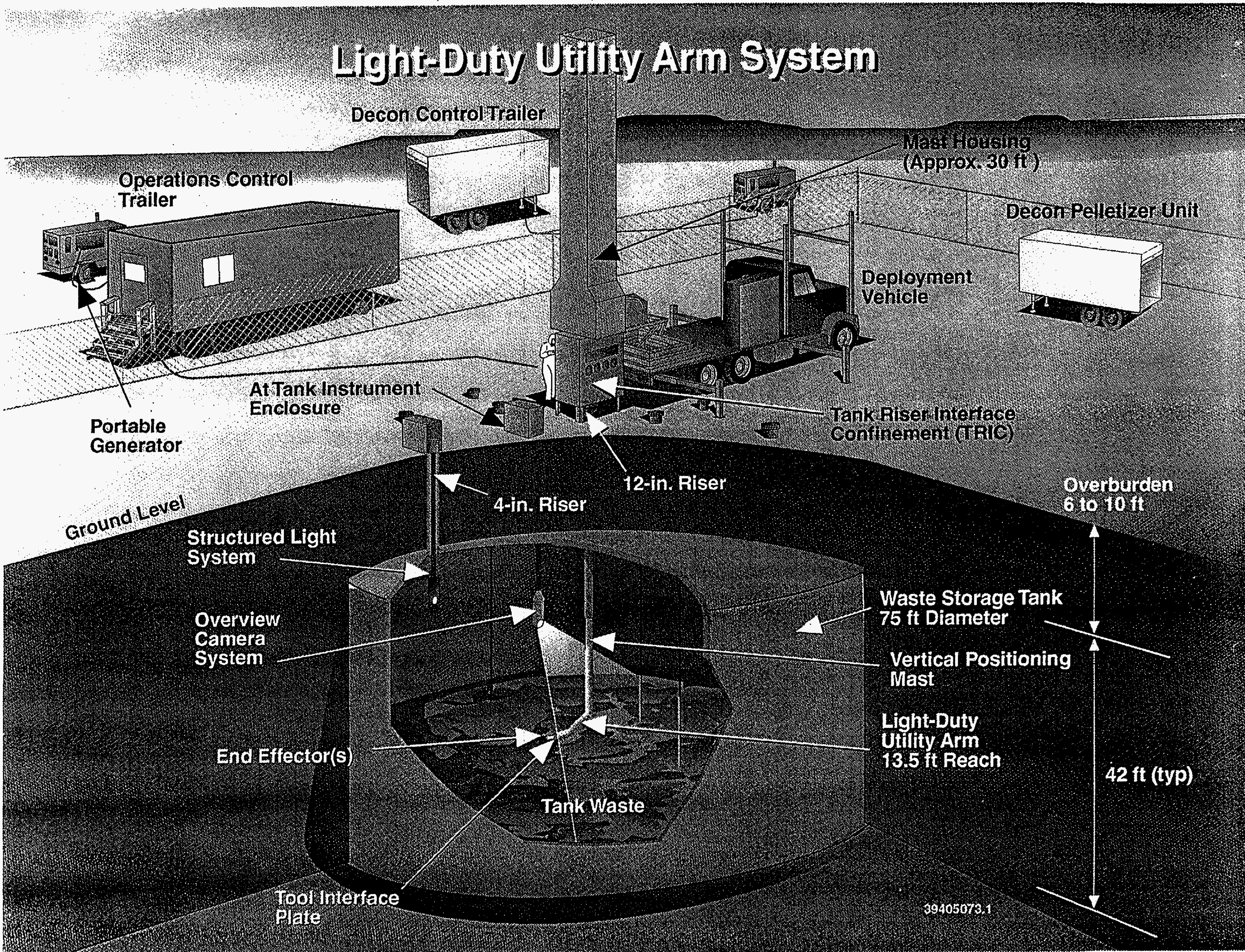
Light-Duty Utility Arm System
Decon Control Trailer
Mast Housing
(Approx. 30 ft)
Operations Control
Trailer
Decon Pelletizer Unit
Deployment
Vehicle
At Tank Instrument
Enclosure
Tank Riser Interface
Confinement (TRIC)
Portable
Generator
12-in. Riser
4-in. Riser
Overburden
6 to 10 ft
Ground Level
Structured Light
System
Waste Storage Tank
75 ft Diameter
Overview
Camera
System
Vertical Positioning
Mast
Light-Duty
Utility Arm
13.5 ft Reach
End Effector(s)
42 ft (typ)
Tank Waste
Tool Interface
Plate
39405073.1

FIGURE 1

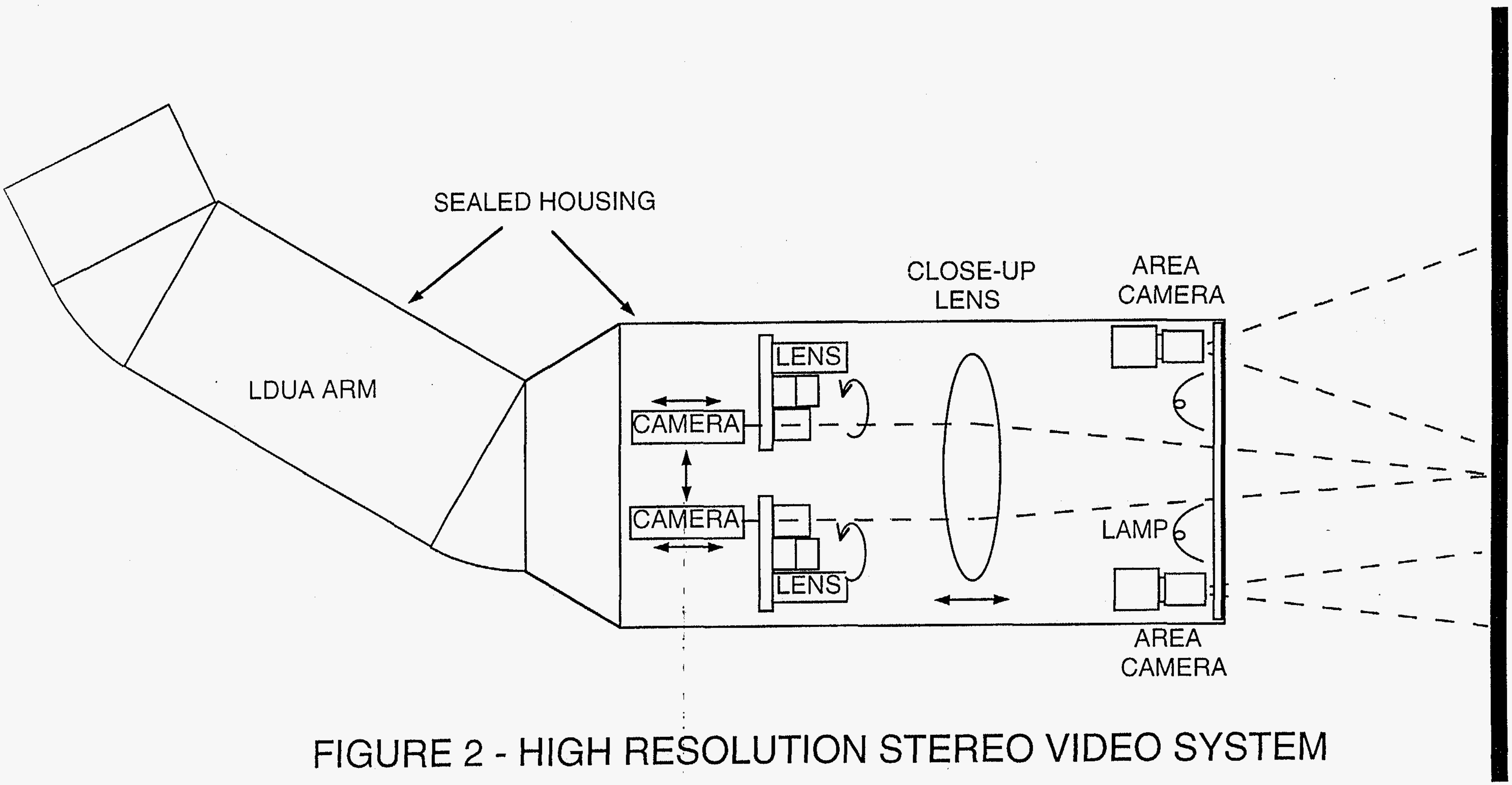

FIGURE 2 - HIGH RESOLUTION STEREO VIDEO SYSTEM

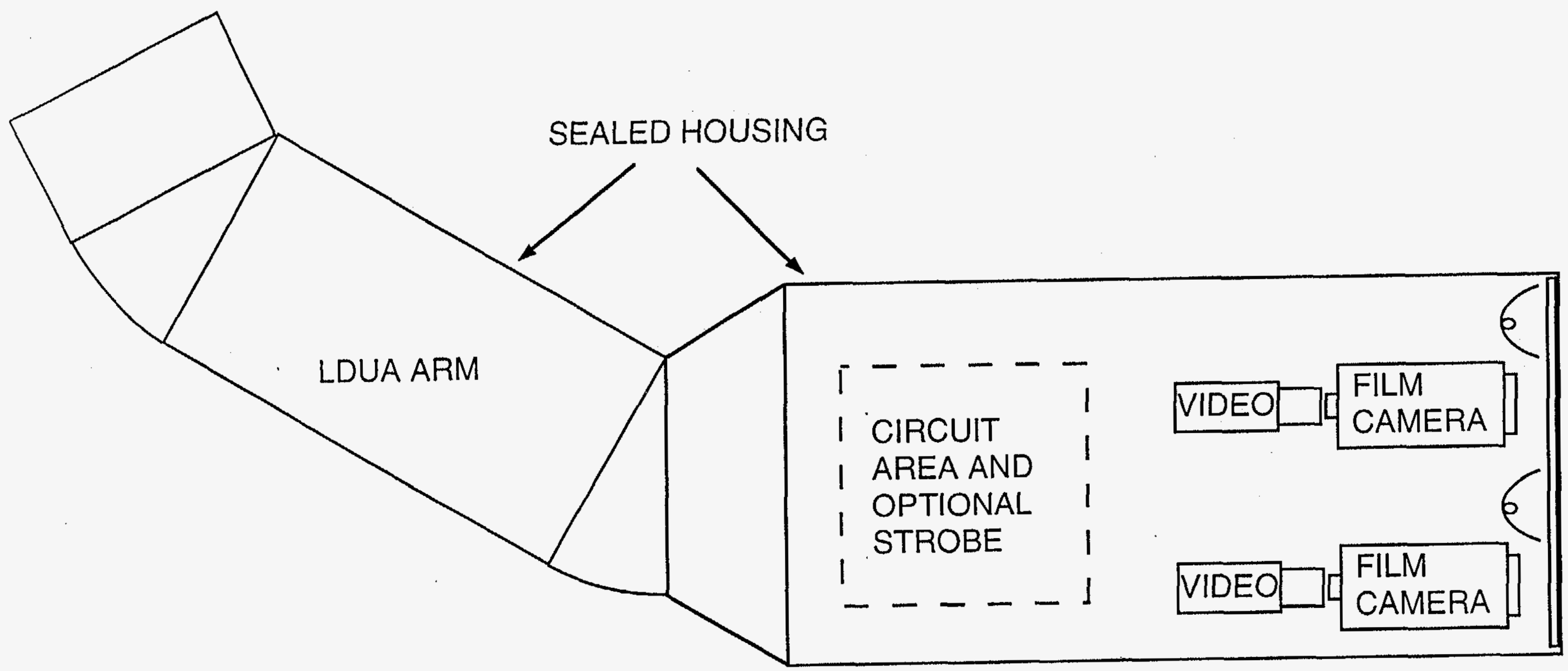

FIGURE 3 - STILL PHOTOGRAPHY SYSTEM

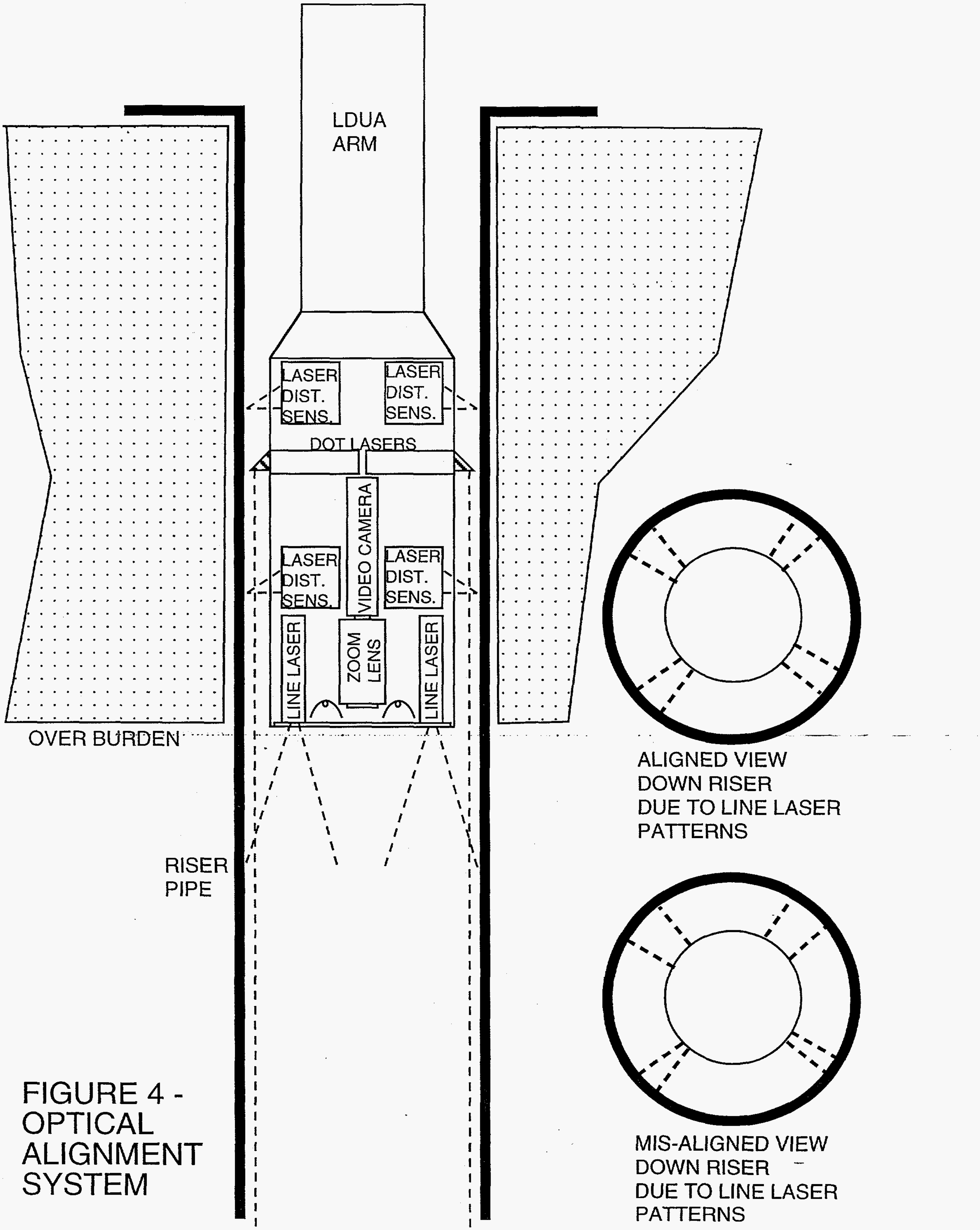

FIGURE 4 -
OPTICAL
ALIGNMENT
SYSTEM