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Conf-921102--26-Rev.1

WSRC-MS-92-203, REV 1

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WSRC-MS--92-203-Rev.1

DE93 002172

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A paper proposed for Presentation/Publication
at the ANS 1992 Internaltional Conference
Chicago, IL
11/15-20/92

SPECIALIZED VIDEO SYSTEMS FOR USE IN WASTE TANKS

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ABSTRACT

The Robotics Development Group at the Savannah River Site is developing a remote video system for use in underground radioactive waste storage tanks at the Savannah River Site, as a portion of its site support role. Viewing of the tank interiors and their associated annular spaces is an extremely valuable tool in assessing their condition and controlling their operation. Several specialized video systems have been built that provide remote viewing and lighting, including remotely controlled tank entry and exit. Positioning all control components away from the facility prevents the potential for personnel exposure to radiation and contamination.

The video systems includes camera, zoom lens, camera positioner, and vertical deployment. The assembly enters through a 125 mm (5 in) diameter opening. A special attribute of the systems is they never get larger than the entry hole during camera aiming etc. and can always be retrieved. The latest systems are easily deployable to a remote setup point and can extend down vertically 15 meters (50ft). The systems are expected to be a valuable asset to tank operations.

BACKGROUND

The Savannah River Site (SRS) is a nuclear materials production facility operated by the Westinghouse Savannah River Company (WSRC) for the United States Department of Energy (DOE) and was established in the early 1950s to produce nuclear materials for defense purposes. The 777 km^2 (300 mi^2) complex is located in South Carolina and is composed of many separate plant operations, including fuel and target fabrication, nuclear reactors, chemical separations, and numerous waste handling facilities.

The Savannah River Technology Center (SRTC) is also operated by WSRC, and its purpose is to provide technical research and support for site operations. The Robotics Development Group (RDG) is part of SRTC, and its mission is to develop, apply, and support robotics, remote technology, and remote video/viewing to improve safety, reduce personnel radiation exposure and contamination potential, increase productivity, and reduce manpower costs.

The particular field of remote video/viewing is now being used extensively to extend the data gathering and control of the 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.

One specific area that is the subject of this report is the quantification of the large site waste tank interiors and the surrounding dry annular spaces. Assessing the condition of these areas is a necessary step in control of the waste storage tanks. Historically, remote still photography has been used for this purpose. The limitations of that method have led to the development of remote video systems.

1.0 INTRODUCTION

The SRS waste tanks are nominal 4.5 million liter (1.3 million gallon) underground tanks used to store liquid high level radioactive waste generated by the site, awaiting final disposal. The typical waste tank (Figure 1) is of flattened shape (i.e. wider than high). The tanks sit in 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 latter was historically accomplished with remote still photography.

The deployment of 35mm film cameras on booms to perform the inspections has residence time and shielding concerns and efforts have been underway for some time to replace them. The first efforts produced the annulus camera systems detailed in later sections. These systems remove the operator from the vicinity of the waste tank top openings after initial equipment set up.

The information contained in this article was developed during the course of work under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy.

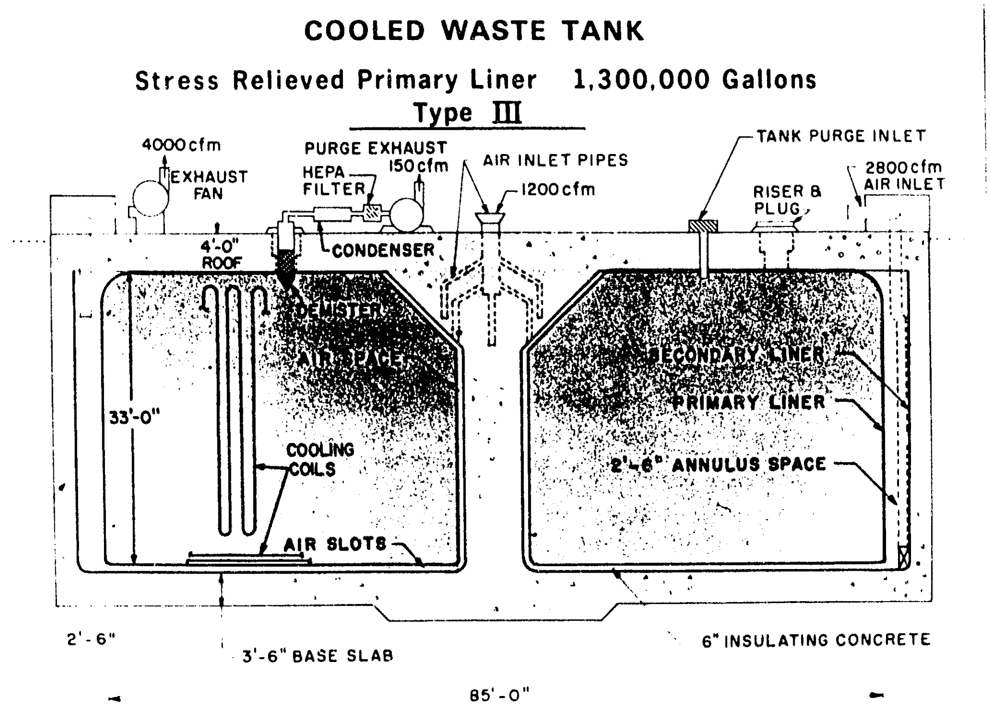

Figure 1 TYPICAL SITE WASTE TANK

In-Tank Precipitation (ITP) is a new process in which a salt solution is decontaminated by batch process methods in existing waste tanks. In different waste tanks, this decontaminated salt solution is prepared by a combination of precipitation, adsorption, and filtration. These three processes generate foam which in turn causes a potentially combustible precipitate to form on the interior of the waste tank walls and cooling coils throughout the tank. The purpose of the ITP video inspection system is to monitor for corrosion and condition of the waste tank walls and to verify the extent of foam generation and combustible solids accumulation within the tank. Because the ITP process is new, no electronic method of continuous viewing the interior of the waste tanks has been demonstrated.

2.0 COMMON DESIGN CONSTRAINT

This paper addresses both the earlier work on a tank annulus viewing system and the latest ITP camera system, the latter system resulting from a more complex series of requirements that also incorporated all of the earlier tank annulus viewing requirements.

The major premise of this work is the acceptability of the visual outputs and corresponding image storage. The obvious base point for this is the 35mm film images that have been historically captured and archived. The best of video images, in either black-and-white or color, have improved significantly over recent years but do not approach 35mm images, on a side by side comparison. The strength of the video approach is the ability to gather an order of magnitude higher number of images in the same time frame.

Also, the new higher resolution recording formats are used; in particular, the S-VHS (S-video) is an excellent compromise between higher resolution and acceptable cost.

The viewing systems are required to be portable to the entry point and are modular in design in order to both allow for flexibility in application and also ease of repair. The systems were required to be set into place over, but not entering, the tank port. After personnel have moved back to a protected area, the camera deployment system inserts the camera package vertically downward up to 15 meters (50 ft).

Each 4.5 million liter waste tank is surrounded by an annular area used for the containment of waste should any leaks be found in the main tank shell. Periodic inspections are performed to check for tank shell leaks. Previously, the method of inspecting the annular area involved lowering a boom fitted with a 35 mm camera and lights into the annulus and taking a pattern of photographs in previously defined direction and depth.

This method has been found to be inefficient, and therefore a remote video system which provides "live" images was developed. This new system would allow the operator to control the camera position and video tape the results for future viewing.

Camera housings to be inserted vertically into either the tank or annular space would be required to enter with the camera directed downward, for both insertion control and size constraints, through a 127 mm. (5 in) diameter port located on a platform on top of the tank. Each assembly must be lowered and raised using a remotely controlled deployment tool on top of the tank. Both housings have the capability of panning clockwise and counterclockwise 350°.

Since one of the largest concerns was prevention of any assembly getting stuck in a tank, a "never bigger than entry" concept was developed for both systems addressed in this paper. One additional desirable attribute to a tank or annulus inspection system is the ability to look up above horizontal to inspect tank roof structures. The ability was achieved in the ITP system.

3.0 THE ANNULUS CAMERA SYSTEM

The original tank annulus viewing system is deployed on a "Bi-Stem" mechanism which provides for a 10 meter (33 ft) "pole" in a 1 meter (3 ft) package. The equipment is an outgrowth of space technology developed by "Spar Incorporated" of Canada. The pole is unrolled as two interlocking metal bands from which the camera package is hung (Figure 2). The device is similar in concept to two retracting metal tape measures that are rigid in one plane and flexible in another. Later version of the Bi-Stem device can extend to 20 meters (66 feet) downward vertically.

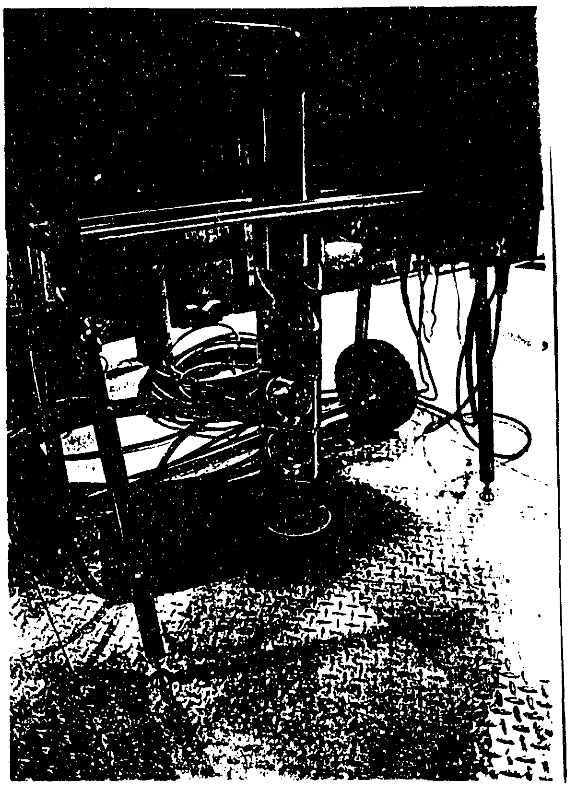

Figure 2
BI-STEM CAMERA DEPLOYMENT SYSTEM

The camera package uses an up-down and package rotate in lieu of the more traditional pan and tilt motion normally associated with camera aiming mechanisms. This design gives a package that has a full field of view while maintaining the "never bigger than the entry hole" concept. This concept is believed to provide a nearly fool proof

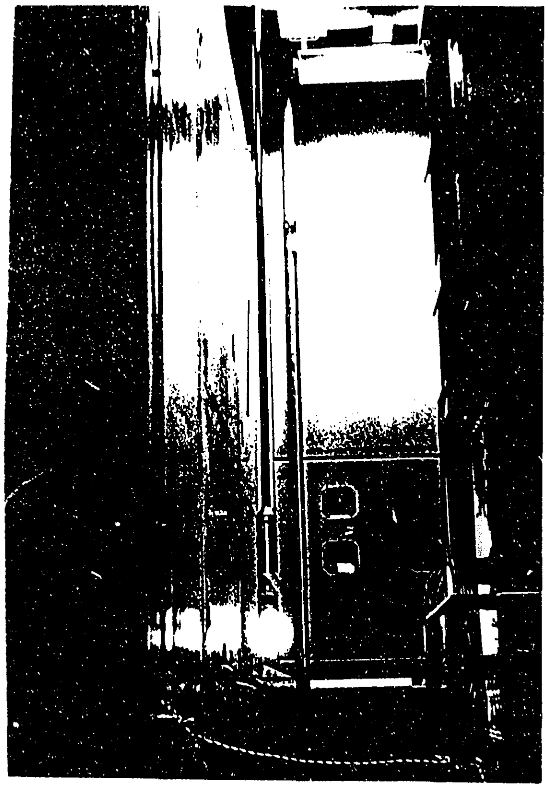

Figure 3
SIMULATION OF TANK ENTRY DEPLOYMENT

High intensity, low voltage, lights are incorporated into the side of the rotating portion of the camera housing and aim with the camera. The housing rotates from the upper end. As it rotates, the lights mounted in the side are aimed with the camera. The camera is actually looking straight down at all times, and a first surface mirror redirects the view to horizontal. External electronics correct the reversed mirror view to the proper perspective. The system suffers from one major shortcoming in that the weight of the Bi-Stem device significantly restricts portability.

Two high intensity PAR 36 halogen lamps (a standard industry size) are mounted in the side of the housing facing horizontally. The Annulus system will use 100 watt lamps of varying beam dispersion. Wide angle to very narrow beam lamps are available and will be used on an application specific basis.

The intermittent nature of the annulus inspections allows for the use of non radiation hardened video camera and lenses. Either a black-and-white or color chip camera will be used based on the current requirements. The black-and-white camera requires only 10% of the light required by a comparable color camera. However, in some applications color rendition is required to determine the composition of color camera to 10,000 rads of cumulative dosage in separate tests. The radiation hardened version of camera and lens will cost for components only $15,000. This compares to $1500 for the non radiation hardened versions.

The tank annulus system has been completely developed and fielded. The ITP system used this design as a basis from which further development proceeded.

4.0 THE ITP SYSTEM DESIGN

The annulus camera system had the major design constraint that the camera housing must fit within a 127 mm. (5 in.) diameter port. The ITP system has this same constraint plus additional concerns. The tank annulus system was used as a base point onto which additional design criterion were added. The most significant differences in design requirements were the weight and the need to repackage the system to an electrical classification of Class 1 Division 1.

The ITP process generates benzene vapor and hydrogen gas. Consequently, no part of the system could ignite solids by radiant or conductive heat. The maximum temperature of any part of the inserted camera system was not to exceed 300 °C. The camera and lights used for this inspection were to be capable of providing a view 12m (40 ft) away horizontally and 10m (33 ft) away vertically.

Due to the temperature and viewing requirements, possible light sources were limited. The light source chosen for the ITP system consisted of two 100W, 12V Halogen flood lights. These were chosen due to their low cost, availability, and excellent light output. The low voltage lights have been found to work well in radiation environments. The normal embrittlement seen in radiated filaments is offset by the inherent ruggedness of low voltage filaments.

For the ITP camera system it was very desirable to provide for both horizontal and down looking vertical viewing, the latter specifically for the purpose of aiding in position control. The assembly is remotely deployed into a tank with varying liquid level, as opposed to the annulus camera being deployed into a dry area of known dimensions.

The requirements for electrical classification of Class 1 Division 1 are current worst case expectations of the ITP tank interior. It was assumed that a benzene vapor level above the Lower Explosive Limit (LEL) could be present. Based on this assumption, the system has been designed as a sealed and actively pressurized housing. Continuous monitoring of internal pressure is provided and is interlocked to all power going to the camera and light housing.

The combustible nature of the tank atmosphere necessitated a completely sealed and pressurized camera housing. All electrical parts, including the lights, were enclosed within the housing. As an added safety measure, a pressure switch was mounted within the electrical/air junction box located on the cable reel. If the interior housing pressure drops below the regulated internal pressure (signifying a leak within the camera housing), all electrical power, except cable reel power, is shut off, the latter being located external to the tank.

The ITP system will be used over long time periods and will require the use of radiation hardened camera and lenses. During the demonstration efforts, non hardened cameras will be used to minimize expenses.

The final constraint for the ITP camera system was weight. The customer requested a modular system which would be easy to assemble in less than 15 minutes. Each component of the system could weigh no more than 23 kg. (50 lbs.). The number of components was not significant, provided the entire system could be assembled within the stated time frame.

5.0 THE SYSTEM COMPONENTS

Both the Annulus camera and ITP video systems are comprised of three basic parts: the camera housing, the housing deployment tool, and the system controls. The camera housing contains a video camera, a motorized zoom lens, and high-powered lights. The housing is cylindrical, measuring 120 mm (4.75 in.) in diameter. Because of the orientation of the camera mounted within the housing, a mirror is attached to the lower end to provide a horizontal view.

The controls for each system consist of a video monitor, external VCR jack, and switches for camera positioning and view adjustment. They have the capability of being located up to 15 m (50 ft) from the rest of the assembly.

<u>The Annulus Camera System</u>

a. Deployment Tool

Lowering the camera housing into the annular space was achieved by using a telescoping Astro Aerospace Bi-Stem capable of extending 10 meters (33 ft.). The Bi-Stem box contains two coils of type 301 stainless steel strips nested in opposition so that when the strips are unwound simultaneously, a high strength tubular boom is extended from the box. This Bi-Stem was mounted on a stand such that when the coils are unwound, the boom extends downward. A more recently available version in the same overall package can reach 20 meters (66 ft) in the downward direction.

The electrical cabling enters the top of the Bi-Stem box and runs between the unwinding stainless steel strips so that as the housing is lowered, it is pulled within the boom. The boom does not rotate when the housing pans, but the cable within it does. Because the cable endures a minor amount of twisting, no slip rings have been used in this design.

The stand the Bi-Stem is mounted upon is height and width adjustable. This was found to be necessary because of the piping and equipment running alongside or above different ports. Many ports are so congested that entry into the opening is very difficult. The width adjustment is made possible by attaching the Bi-Stem box to a 90 kg (200 lb) capacity drawer slide mounted to the stand. A threaded rod and crank is used for adjustment. Wheels are mounted so that the stand assembly is transportable.

b. The Camera Housings

The waste tank annulus area is normally dry, and because inspections are only performed periodically, the video equipment contained within the housing is not radiation-hardened. Because there is no electrical classification for the annular area, wires running from the housing to the lights are bundled together and are protected by enclosure within the Bi-Stem tube. The components are protected to prevent the wires etc. from being caught on obstacles.

The camera housing assembly is attached to the lower end of the boom and is vertical in orientation. The housing, which contains the camera and lens, is attached to the boom by the bearing (Figure 4). The Annulus camera assembly has two lamps mounted below the camera on the lower end of the housing. A first surface mirror is mounted below the housing and converts the down looking camera into a horizontal looking camera, while maintaining the required diameter.

For the non radiation hardened applications a Hitachi VKC350 S-video type color camera and motorized zoom lens were mounted within the housing, or a low light black-and-white camera of similar design is fitted. The camera and lens provide for a very high quality video picture for remote analysis.

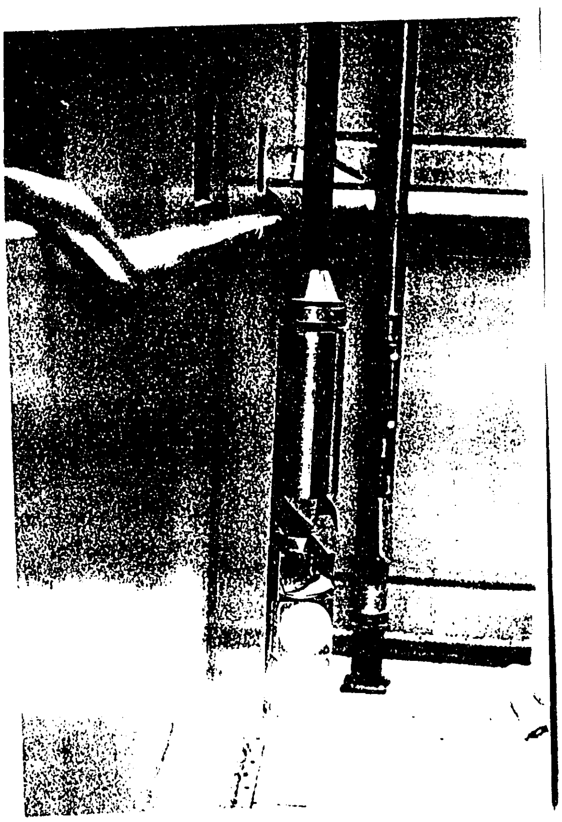

Figure 4 ANNULUS CAMERA HOUSING

The housing is rotated by an internally located motor which rotates the entire housing relative to the support flange, the latter being the interface between the Bi-Stem and the camera housing.

The ITP Camera System

a. Deployment Tools

The Annulus camera is deployed on the Bi-Stem mechanism described earlier in this report. This provides an excellent deployment package but is too heavy to be practical in many deployment scenarios. The requirements of the ITP camera are such that a more transportable deployment system was required. A special flexible deployment system has been developed and demonstrated. It combines compactness, low weight, and simplicity into a single package.

A motorized cable reel is used to lower the ITP camera housing into the waste tanks. A flexible conduit (FC) of entirely non metallic construction is used to both support the camera housing and to enclose the required wiring. The characteristics of the FC are such that the deployed camera package is stable, even in modest side winds.

An attempt was made to find a small, lightweight off the shelf cable reel with an air fitting and ample electrical connections. No such device was found to be commercially available. The alternative was to have a reel specially made. The final weight of the reel including the motor but excluding the conduit and cable was 13 kg (27 lbs.). It contains 26 slip rings: 8 each 10 Amp. rings and 18 each 2 Amp. rings. Its dimensions did not exceed 700 mm (27 in), and it was fitted with a reversible electrical motor for pay out and take up.

The electrical cables supplying power to the video equipment were fed through a section of 19mm (0.75 in.) flexible lightweight non-metallic conduit which was wrapped around the cable reel. This conduit was irradiated to 3 x 10^7 rads of Co60, and was recommended to be acceptable for this application up to 1 x 10^7 rads. The conduit also served as a pathway for the air to pressurize the housing. The supply end of the conduit is connected to the air/electrical junction box mounted on the reel, and the opposite end is connected to the camera housing.

b. The Camera Housing

The ITP camera housing is based on the above housing design with refinements. The lamps are the same, mounted in the upper side of the housing facing horizontally. The mounting flange is of improved design but is similar. This housing is entirely sealed and pressurized. An electrical pressure switch is used to sense the pressure in the housing and shutdown all power to the housing in the event of loss of pressure. These provisions are to provide the required electrical classification protections.

The lights are incorporated into the flange mounted upper end of the camera housing, similar to the Annulus camera design. The lower end viewing mirror, which normally provides for the horizontal viewing from the vertically mounted camera, is remotely adjustable. The plane of the mirror tilts from parallel to the centerline of the camera housing to 110° from the initial position. The first position moves the mirror out of the field of view of the camera and provides a straight down view. As the mirror tilts, it provides views over a changing angle. When it reaches 90°, a horizontal view is provided, like the Annulus camera. As rotation continues, the view is tilted up from the horizontal and provides limited viewing in the upward direction.

The assemblies provide viewing from within 1 meter (3 ft) of the housing out to a design distance of 20 meters (66 ft). The limiting factor at the farthest distance is the light availability. At the extreme distances, the tank components are viewed section by section. To view the entire tank interior at once would require an impractical amount of light.

Visual monitoring within the ITP waste tanks is necessary while the waste is being processed. Because of the high levels of radiation present (one tank's level was estimated at 3300 rad/hr), both the camera and lens are radiation-hardened. For our application, we chose a black- and-white "Insight Visions" 75 Series camera and a "Fujinon" H6X12AN zoom lens. Both items are rated to 1x 10^8 rads cumulative dosage.

The Insight camera is a small one piece radiation hardened camera that simplifies the wiring to the camera housing significantly. All other small radiation hardened cameras are two piece designs (a radiation hardened head and non-hardened electronics) that require complex cabling systems.

The housing assembly is attached to the conduit by a compression fitting and strain relief grip. Unlike the two piece annulus camera housing, this housing is one piece with the lights mounted within the housing above the camera. Again, two 12 V, 100 W Halogen lamps were used and mounted 90° from the camera's vertical orientation. This design required a 110° viewing range from straight down to 20° above the horizontal plane. A tilting mirror assembly was attached to the lower end of the housing to provide this.

The mirror is not contained within the housing, and due to the tank atmosphere, a heating element was essential to prevent the mirror from fogging. To provide a source of heat to the mirror, one 12 V, 50 W miniature wedge lamp was contained within a small pressurized housing attached to the back of the mirror. This lamp tilts with the mirror, providing adequate light in the direction of the view. These auxiliary lights are also expected to be useful in some straight down viewing applications. All electrical components for this small lamp are contained within the pressurized housing.

5.0 STATUS AND FUTURE WORK

Both the annulus and ITP video systems have been successfully tested in a mock-up environment and have been delivered for use in the field.

Design changes are currently underway to provide a universal cable reel assembly, complete with the camera housing attachment, so that camera housings may be interchanged for different applications. This will prevent future designs from duplicating those that already exist. Additional enhancements are anticipated.

6.0 ACKNOWLEDGMENTS

The efforts of others involved in this work are greatly appreciated, especially M. Collins, G. Henning, M. Prather, and R. Surratt , all of SRS Robotics development group.

The information contained in this article was developed during the course of work done under Contract No. DE-AC09-89SR18035 with the Department of Energy.

7.0 SUMMARY

Viewing of the tank interiors and their associated annular spaces is an extremely valuable tool in assessing their condition and controlling their operation. Several specialized video systems have been built that provide remote viewing and lighting, including remotely controlled tank entry and exit. Positioning all control components away from the facility prevents the potential for personnel exposure to radiation and contamination. The development of these systems has provided a valuable tool in the inspection and control of large underground radioactive waste storage tanks, while reducing the potential for operator exposure.

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