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# DEVELOPMENT OF A WASTE DISLODGING AND RETREIVAL SYSTEM FOR USE IN THE OAK RIDGE NATIONAL LABORATORY GUNITE TANK


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## ABSTRACT

As part of the Gunite And Associated Tanks (GAAT) Treatability Study the Oak Ridge National Laboratory (ORNL) has developed a tank waste retrieval system capable of removing wastes varying from liquids to thick sludges. This system is also capable of scarifying concrete walls and floors. The GAAT Treatability Study is being conducted by the Department of Energy Oak Ridge Environmental Restoration Program. Much of the technology developed for this project was cosponsored by the DOE Office of Science and Technology through the Tanks Focus Area (TFA) and the Robotics Technology Development Program. The waste dislodging and conveyance (WD&C) system was developed jointly by ORNL and participants from the TFA. The WD&C system is comprised of a four degree-of-freedom arm with backdriveable motorized joints, a cutting and dislodging tool, a jet pump and hose management system for conveyance of wastes, confined sluicing end-effector, and a control system, and must be used in conjunction with a robotic arm or vehicle. Other papers have been submitted to this conference describing the development and operation of the arm and vehicle positioning systems. This paper will describe the development of the WD&C system and its application for dislodging and conveyance of ORNL sludges from the GAAT tanks. The confined sluicing end-effector relies on medium pressure water jets to dislodge waste that is then pumped by the jet pump through the conveyance system out of the tank. This paper will describe the results of cold testing of the integrated system. At the conference presentation there will also be results from the field deployment. ORNL has completed fabrication of the WD&C system for waste removal and is full-scale testing, including testing of the confined sluicing end-effector.


## I. INTRODUCTION

The Waste Dislodging and Conveyance system was developed to retrieve legacy residual wastes from the ORNL Gunite And Associated Tanks. The system was also designed to perform a concrete scarifying activity that may be required for removal of any contaminated concrete due to any waste isotope migration.

The retrieval process known as confined sluicing is an advanced development for cleaning waste residues from tanks. These residual wastes remained from a previous sluicing campaign conducted in the early 1980s.

## II. BACKGROUND

The Gunite And Associated Tanks at the U.S. Department of Energy's ORNL were built to collect, and store a portion of the neutralized acidic radioactive and hazardous chemical wastes. These tanks were constructed between 1943 and 1951 and were constructed of gunite (a mixture of cement, sand, and water sprayed onto a stainless steel framework). The tank farm is comprised of a total of 16 tanks : six 50 Ft diameter tanks, two 25 Ft diameter tanks, four 12.5 Ft diam tanks, and four small diameter stainless steel units. The tank farm is divided into two groups: North and South Tank Farms because it is divided by the main street of ORNL (**see Photograph 1**).

Many of the tanks were originally a part of the historic Manhattan Project of World War II and were used for collecting waste from radiochemical separations operations emphasizing separation of pure plutonium metal. After the war, ORNL utilized these tanks for collecting radiochemical and hazardous wastes from various laboratories in support of nuclear energy research and development.

The tanks were decommissioned in the 1970s because of potential risk to the environment and the public. An effort known as sluicing was conducted between 1982 and 1984 with approximately 90% of the waste being removed, treated and transported to stainless steel tanks at the Melton Valley Tank Farm at ORNL for long-term storage. However, that process was designed for bulk sludge removal, leaving behind residual wastes material that could not be retrieved by this technology.

Currently, the residual waste volumes are approximately 49,000 gallons of radioactive sludge and solids, and approximately 346,000 gallons of supernatant. Because of the potential risks to human health and the environment, a remediation effort is being addressed under the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

## III. WASTE DISLODGING AND CONVEYANCE SYSTEM

To retrieve the residual radioactive and hazardous wastes from the GAAT tanks, development of an advanced technology was necessary. This requirement led to the development of the waste dislodging and conveyance system (WD&C). This system was designed to cut/dislodge and simultaneously sluice the waste to a temporary storage tank or above ground processing system(s). The WD&C system was designed to operate with either a robotic arm or a remotely operated vehicle, as it is incapable of independent operation.

To accomplish the design and development of this system, the Environmental Restoration project team employed the services of several organizations. ORNL entered into a Memorandum of Understanding with the Pacific Northwest National Laboratory (PNNL) for design and fabrication of the Confined Sluicing End Effector (CSEE). PNNL employed the services of the University of Missouri-Rolla to lead the design of the CSEE and Waterjet Technologies, Inc. (WTI) for fabrication of the unit[1].

Advanced Systems Technologies, Inc, performed the design of the Hose Management System that included the Hose Management Arm.

Jacobs Engineering and Lockwood-Greene Engineering collectively, with assistance from Lockheed Martin Energy Systems, Inc., and Lockheed Martin Energy Research, Corp., produced the design of the Flow Control Equipment and Confinement Box (FCE\CB) system and the Balance of Plant (BOP) control system.

Controls for the WD&C and the BOP were designed and installed by Lockheed Martin Energy Research, Inc., staff. LMES assisted in the design of the BOP controls and installation

The WD&C Hose Management System (HMS) is comprised of several pieces of equipment which include: (a) a CSEE; (b) a jet pump; (c) the Hose Management Arm (HMA), a 4 degree of freedom arm where the mast and arm links are constructed of 2 in-ID pipe that also serve as a conduit for the waste slurry (**see Photograph 2**). The WD&C is also comprised of the FCE\CB that mates to the HMS and interfaces with either tank W-3 or W-4 of the North Tank Farm, dependent upon the tank selected for sluicing operations. The FCE\CB is equipped with the sluicing discharge piping including valving for flow control, a flushing system, and instrumentation for measuring the discharge flowrate, density, and temperature (**see Photograph 3**).

The HMS is also comprised of a Confinement Box (CB) and a Storage Tube (ST) for housing the HMA. The CB provides: (1) secondary containment for the waste piping located inside the CB; (2) operator access for operational and maintenance activities via glove ports; and, (3) structural/mechanical support for the mast, HMA, and ST. The ST is a long cylindrical container that stores the HMA. A 10 ton hoist is mounted at the top of the ST for deployment and retraction of the HMA.

## IV. HOSE MANAGEMENT SYSTEM

The HMS of the WD&C system was developed for support of the CSEE, to provide a conveyance system for waste retrieval, and to management of the HMA when connected to the Modified Light Duty Utility Arm (MLDUA) gripper end effector (GEE) or the robotic vehicle gripper (**see Photograph 4 and 5**).

Management of the HMA is performed locally at the HMS Confinement Box or remotely at the Operations Control Trailer (OCT). The control system is capable of managing and positioning the arm and the CSEE for engagement by the robotic units.

The HMA supports a hose bundle consisting of an approximate 9 foot long length of 2 in-ID conveyance (sand-blast) hose connected to the CSEE and a 3/4 in-ID supply hose for the high pressure water to the CSEE. This unit also supports the control and instrumentation cables necessary for the CSEE operation. The arm-links of the HMA are constructed of Schedule 40 Stainless Steel pipe; the inner link is 8.0 feet long and the outer link is 7.5 feet long. The inner link is connected to the HMA mast via an elbow swivel joint that serves as the shoulder pitch while the inner and outer links are connected by an in-line swivel connected at two 90 degree elbows.

The mast of the HMA is constructed of a half section of 24 in-diam carbon steel pipe with a flat plate welded across the half section to close it. The mast houses a variety of pipe and conduit for control and instrument cables, the CSEE and jet pump's motive water and the waste conveyance line. The mast also houses the jet pump, located near the base, in the conveyance pipe. The HMA is supported from the base of the mast at the shoulder pitch joint and by a cable attached to a winch drive motor that is used to deploy and retract the HMA. A load cell is mounted in line with the cable and will be monitored during periods of operations to determine if any excessive loads are being imposed on this arm.

A plate, appropriately titled the Mast Head Plate, is attached to the top of the mast. This plate interfaces with the Mast Elevate Table (MET) in the CB and provides support to the mast. The MET is equipped with drive systems for elevation and rotation of the HMA. The MET can rotate the mast and HMA +/- 330°, allowing the unit unrestricted access to all tank areas within a tank.

## V. CONFINED SLUICING END EFFECTOR

The CSEE is designed for dislodging and/or cutting of tank waste material and directs the dislodged material toward the inner shroud of the CSEE that is the inlet port for the jet pump (**see Photograph 6**). Because of the potential for isotope migration into tank structures, the unit was also designed to perform scarification of the concrete walls and floors of the various tanks. Concrete cutting requires operational pressures up to 30,000 psi. A single pass scarifying activity is planned for the GAAT operations. After one pass has been completed, a second radiological evaluation of the walls and floor will be conducted for determination of scarifying effectiveness.

The CSEE is constructed of a manifold that houses 3 high pressure water jets positioned 120° apart that are angled inward toward the inner shroud. The jets are positioned approximately 3 inches from the base of the inner shroud of the CSEE. The flowrate of the water jets is 10 GPM at a pressure of 7,000 psi and approximately 5 GPM for pressures near 30,000 psi. An electric motor rotates the jet manifold at speeds up to 1000 RPM and the axis of rotation is normal to the waste surface. The motor is protected by a sealed enclosure. The jet manifold is connected to the motor shaft, which is hollow to supply the high pressure water. The CSEE is equipped with a 2 in-diam conveyance port for attaching the HMA's conveyance hose. Horizontal and vertical grasp handles can be mounted on the unit.

The CSEE was developed, designed and fabricated via a Memorandum of Understanding between PNNL and ORNL. PNNL employed the services of the University of Missouri-Rolla (UM-R) for design and development of the unit. Dr. David Summers and others of UM-R developed several models and conducted various tests for during development of this unit. At the conclusion of the testing period, UM-R fabricated a prototype unit that was tested at PNNL in their Hydraulic Test Bed[2]. This prototype served as the basis for final design of the CSEE. Once the design was finalized, WTI of Kent, Washington, performed the fabrication of the current unit. WTI completed the fabrication of the unit in June 1996 and preliminary acceptance testing was performed at the vendor's site. Final acceptance tests were performed at the PNNL HTB site and ORNL.

Two design constraints for the CSEE included a weight budget of 50 pounds or less and an operational frequency of 5 Hertz or greater. Those constraints were defined limitations of the SPAR Modified Light Duty Utility Arm (MLDUA) as specified by SPAR Aerospace, Lmtd.

Initial testing of the CSEE prototype was performed at PNNL with the unit mounted to a gantry robot. Frequency data along with performance data were collected. Test results on simultant sludge were favorable but not as expected.

HTB testing of the CSEE to demonstrate scarifying of concrete with concrete paver blocks revealed that this particular unit could not meet the design requirement of a 0.25 inch-deep cut on a single pass at a traverse rate of 1 inch/second. Depth-of-cut test results were in the mm range at the maximum operating pressure of 7,800 psi. A series of tests on paver blocks was performed while operating the CSEE with and without jet rotation to determine cut pressure and performance.

Because the CSEE could not meet the specified cut depth requirement on concrete, WTI was commissioned by PNNL to perform concrete cutting tests on gunite simulants to determine cutting pressures that would meet the requirement. Their test results show that cutting pressures up to 30,000 psi are required to provide a 0.25 depth-of-cut at a traverse rate of 1 inch/second. A second CSEE in production, at WTI will be capable of meeting the design specification for and will operate at pressures up to 30,000 psi.

A concern for the integrity of the tank structures when scarifying at such high pressures is duly noted. However, the jet energy is dissipated rapidly and should pose a limited threat to the structures. A factor that could influence tank structure damage is dwell of the unit when at operating pressures greater than 15,000 psi.

## VI. JET PUMP

Another integral part of the WD&C system is the high pressure water jet pump. A limited number of manufacturers offer a high pressure water jet pump. Commercial applications for such pumps are typically for general tank cleaning.

The University of Missouri Rock Mechanics Laboratory had an on going effort to improve on jet pump design.[3]. Several years of experimentation and model development have culminated in the fabrication of the most recent version, the Mark V (**see Photograph** 7). UM-R has been able to improve the performance of the pump by modifying the inlet and discharge ports to use less water pressure to accomplish the same performance observed in other units requiring 7,000 to 10,000 psi operating pressures.

Butterworth Jetting System, Inc., of Houston, Texas (BJSI) manufactures a high pressure water jet pump. A Butterworth pump was initially selected for use with the WD&C conveyance system because its performance was similar to that of the UM-R pump but costing much less (**see Photograph** 8). This pump can be operated at pressures up to 10,000 psi but the unit selected is operated at 7,000 psi and delivers approximately 10 gpm motive water. The Butterworth pump was tested at ORNL and PNNL at different times. The early test results showed that the pump capacity for water is 1:10 (motive water:water) and for slurries is 1:7 (motive water:slurry with a specific gravity of 1.3). The pump was capable of pumping slurries with solids concentration up to approximately 40% (wt/wt) and particle sizes up to 1 inch. Also, the pump was tested against a variety of debris materials that included a size 10 latex rubber glove, a plastic sample bottle, an approximate 5 foot length of string and other materials. The pump showed promising performance and was selected on the basis of cost and schedule. However, since that time the BJSI pump has experienced several failures, all of which are due to erosions of the eductor tube. BJSI constructs the eductor of cast brass and aluminum. The soft material is easily eroded when the high pressure jets impinge on the wall of the eductor. The failures could have been the result of high concentration of sand and gravel or pump cavitation. ORNL, PNNL and UM-R are investigating the jet pump to determine the reason(s) for the failures and to further advance the design.

The BJSI jet pump selected for use with the WD&C System is constructed of a stainless steel manifold with a six jet nozzle array. Three stainless steel jet nozzles, 0.040 in-diam were used in the BJSI pump and mounted 120° apart. A series of tests was performed to determine the performance of the pump operating with three jets versus six jets. Test results indicated that the jet pump equipped with three jets performed very similar to that of the six jets.

The pump's eductor tube is a 15 inch long cast of brass\aluminum port. The end sections are 2 inches in diameter and the throat of the eductor is 1 inch. The eductor helps promote mixing of the motive water with the sluice material(s).

The unit was tested in the ORNL WD&C piping loop configuration. Other mock piping loops were set up at PNNL and UM-R to emulate the HMS configuration. The test results indicated that this pump is capable of delivering the desired flow rates for pumping of tank waste simulants.

## VII. WD&C CONTROL SYSTEM

The control system is remotely configured for various operations from the Operator Control Trailer (OCT). A graphical user interface has been developed by ORNL that interfaces to the low-level control systems of the CSEE, HMA, FCE and the associated Balance of Plant equipment: pump systems, air compressor and valving. From the OCT the WD&C operator will be able to remotely operate the majority of this equipment

The HMS is equipped with DC servo drive motors for deployment and positioning of the HMA inside a tank. The HMA is positioned in a coordinated fashion with respect to the MLDUA or the Houdini unit to maintain slack in the conveyance hose and avoid torque overloads or hose kinking.

At present, control of the HMA from the control console requires teleoperation by the operator. An automated control scheme is in progress that would use the known position of the MLDUA to automatically position the HMA. Since no position feedback is available on the Houidini vehicle the WD&C operator will continue to drive the HMA when performing vehicle-based waste retrieval or scarifying operations.

The high-level control system has been implemented on a UNIX workstation using a VxWorks-based real-time operating system running on a VMEBUS computer for low-level controls. A PC-based controller is used for the BOP systems. This PC communicates with the high-level controller via shared memory on the VMEBUS.

## VIII. FLOW CONTROL EQUIPMENT AND CONFINEMENT BOX

The FCE/CB is approximately 5 Ft Wide X 15 Ft Long X 5 Ft High and contains back and forward flushing equipment, a Coriolis flow meter, an Isolok Sampler, and a Flow (Pinch) Valve.

The flush system is constructed of 1 1/2 in-diam pipe equipped with motorized ON/OFF ball valves. These valves are interlocked to permit flush operation in only one direction at a time. This step is a precautionary measure to protect equipment. The flush system is fed by the low pressure water system at a rate of 30+ gpm and a pressure of 90 psi.

The Coriolis Flow Meter was provided by FMI, Inc. The meter is capable of measuring single and multi-phase flow. However, the unit cannot effectively measure three-phase flow where the gas concentrations exceed 5% by volume. The unit also provides data on the fluid temperature, density, and mass inventory. The mass inventory measurement is a measurement of the flow mass from a tank. The data collected from this instrument will aid in determining the cost and efficiency of the operation.

The Isolok sampler, manufactured by the Bristol Equipment Corporation, is capable of sampling flowing slurries. The Isolok sampler control circuit can be programmed to collect a sample at a predetermined sample frequency.

A pinch control valve, manufactured by Red Valve Inc., is designed to regulate flow in the event that the flow rates exceeds 100 gpm and the radioactivity of the waste is of sufficient levels to require attenuation. However, during testing, results revealed the valve's discharge port restricts flow and a maximum of only 70 gpm could be pumped through this valve using the Butterworth jet pump. Also, line plugging occurred several times because the valve's discharge port is smaller than the line. The unit has since be taken off line.

## IX. WD&C HMS TESTING

The WD&C HMS was installed on the Tanks Technology Cold Test Facility located at ORNL in August/September 1996 (**see Photograph** 9). The controls and instrumentation hardware have been installed and current efforts are underway to complete the full installation of that system. Once the controls and instrumentation have been completed the unit will be operated remotely.

Cold testing has been on going since late August 1996. Preliminary test results indicate each system is working as expected with exceptions noted.

## X. CONCLUSIONS

After final installation of the control system and necessary system modifications, the WD&C system will undergo final testing prior to operations at the GAAT NTF. Adequate operations time and continued testing are necessary to identify such issues as life expectancies of various components and other design concerns. Thus far, the unit has performed favorably.

## ACKNOWLEDGMENTS

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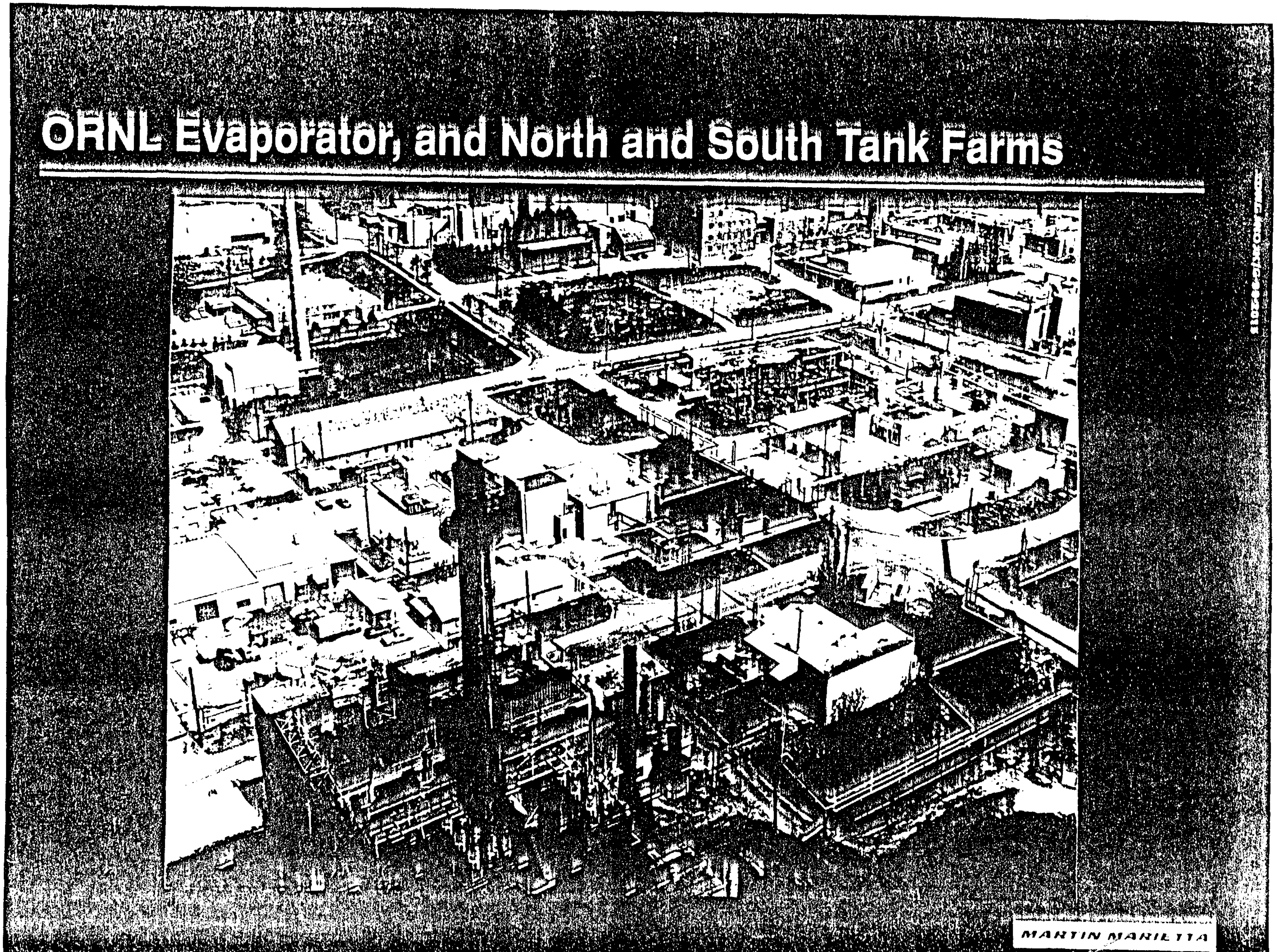
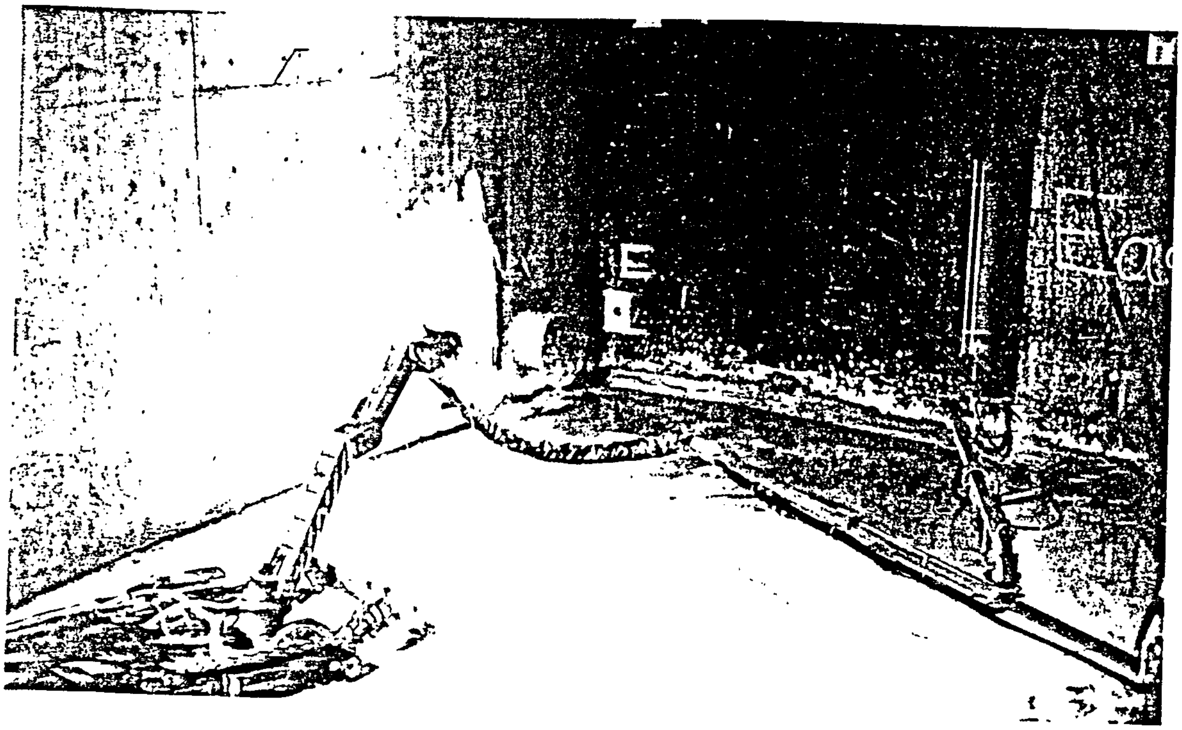
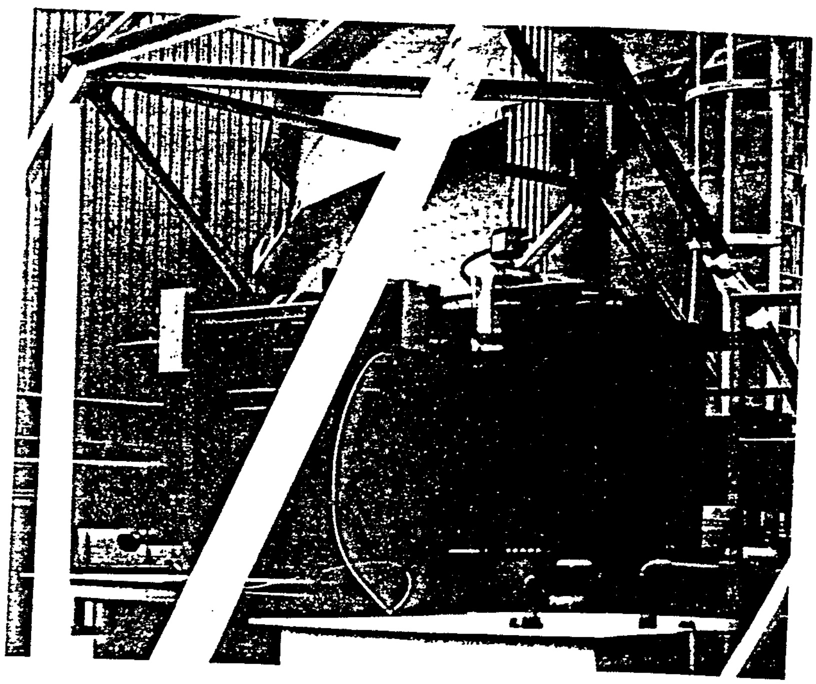


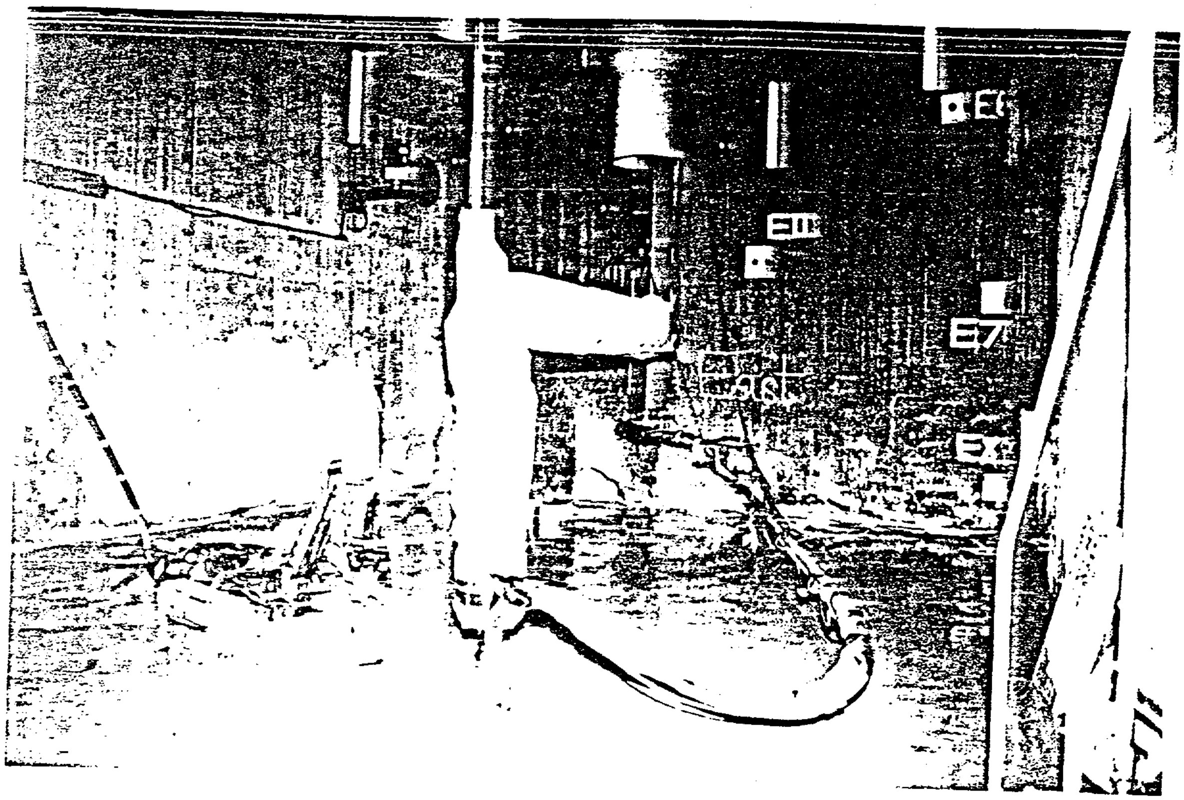

Photograph 1. Oak Ridge National Laboratory Gunite And Associated Tanks North and South Tank Farms



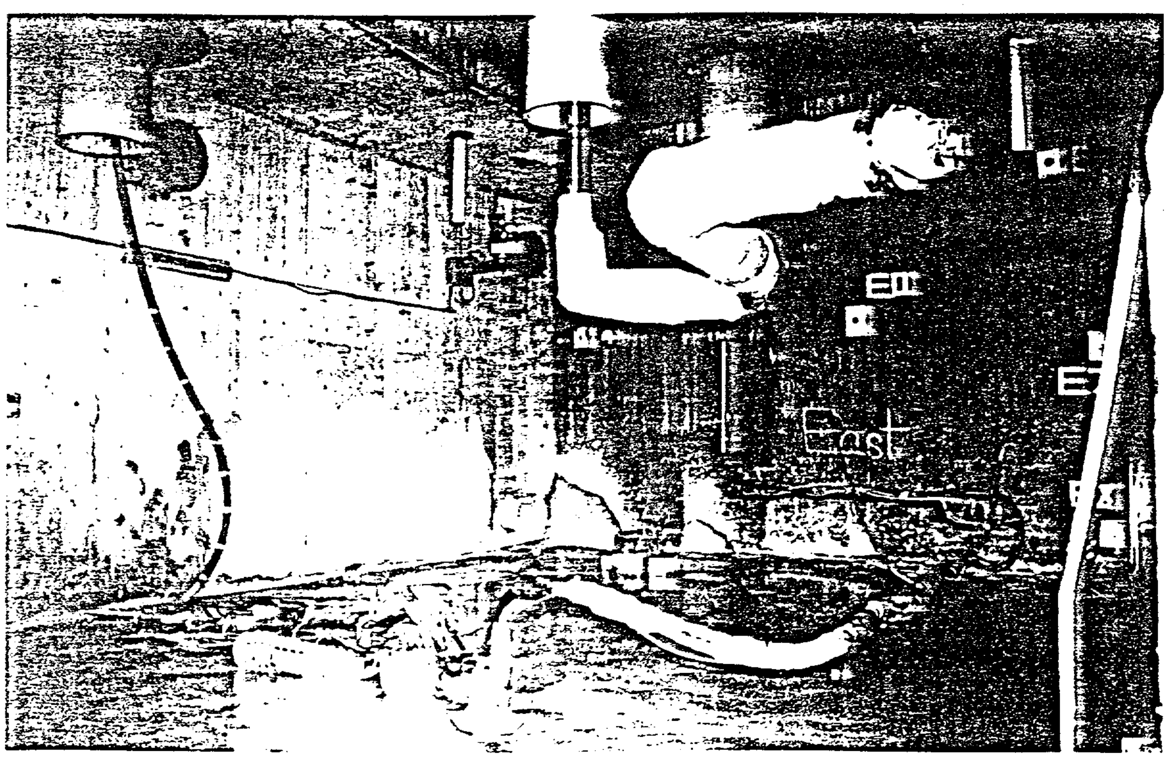
Photograph 2. Waste Dislodging and Conveyance Hose Management Arm



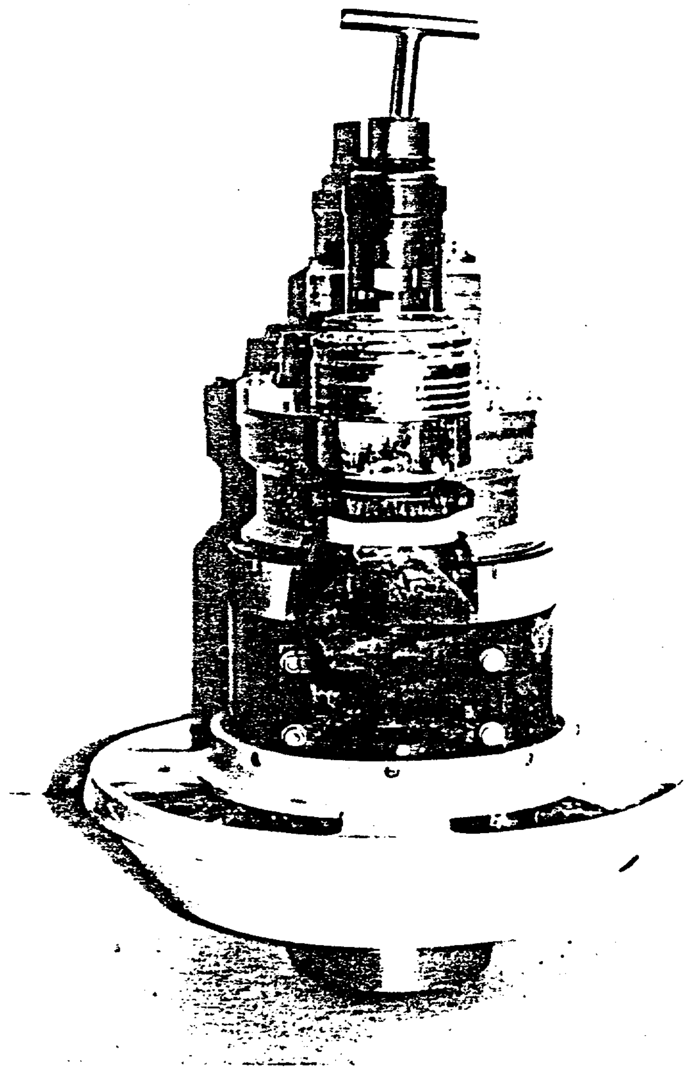
otograph 3. Waste Dislodging and Conveyance Flow Control Equipment and Confinement Box



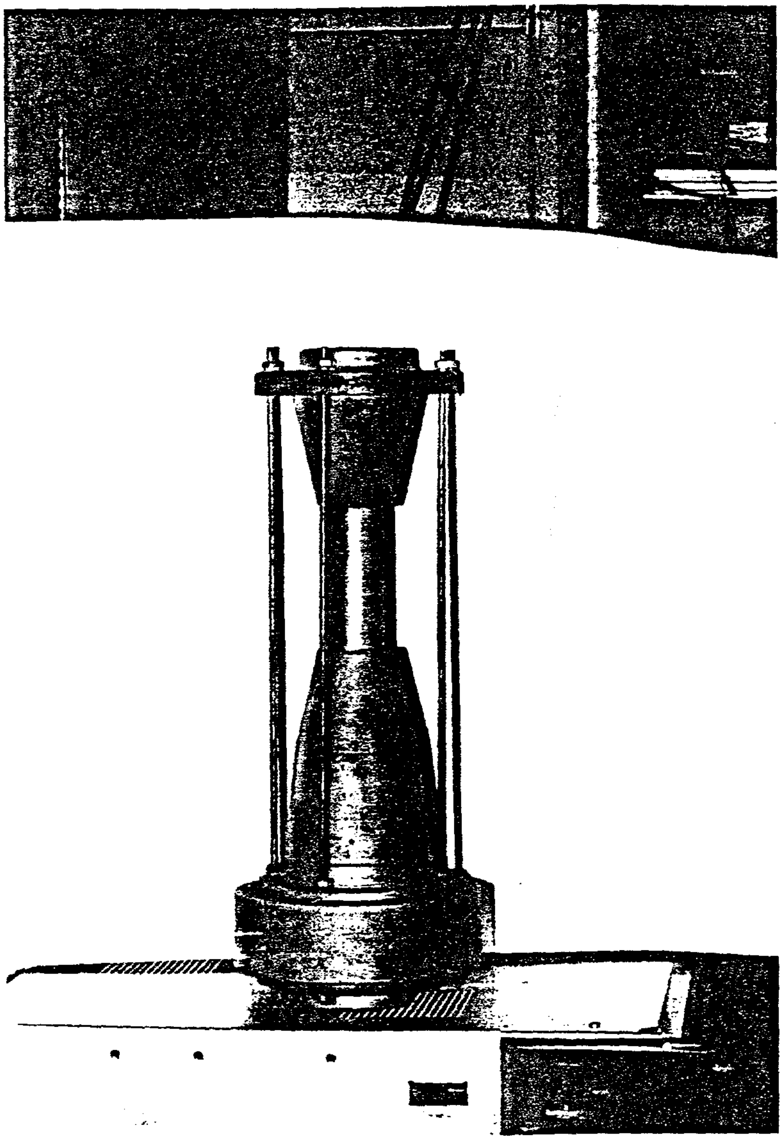

Photograph 4. Waste Dislodging and Conveyance System and the Modified Light Duty Utility Arm



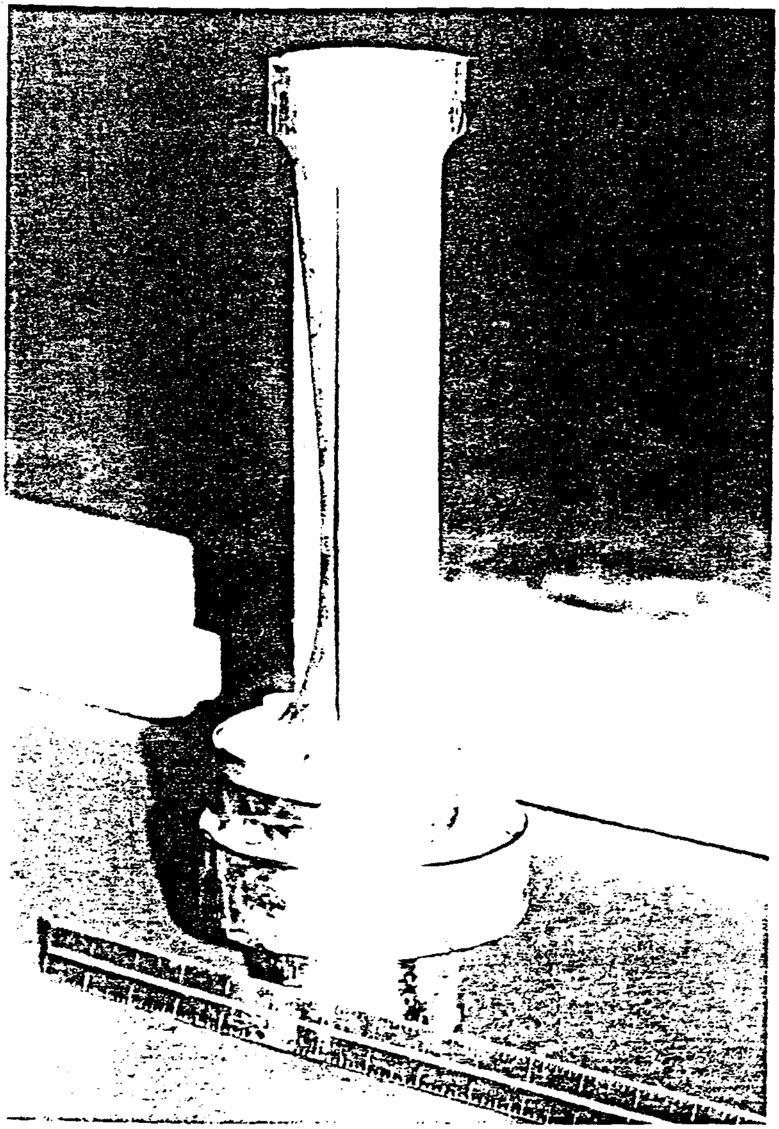

Photograph 5. Waste Dislodging and Conveyance System and the Redzone Houidini Remotely Operated Vehicle



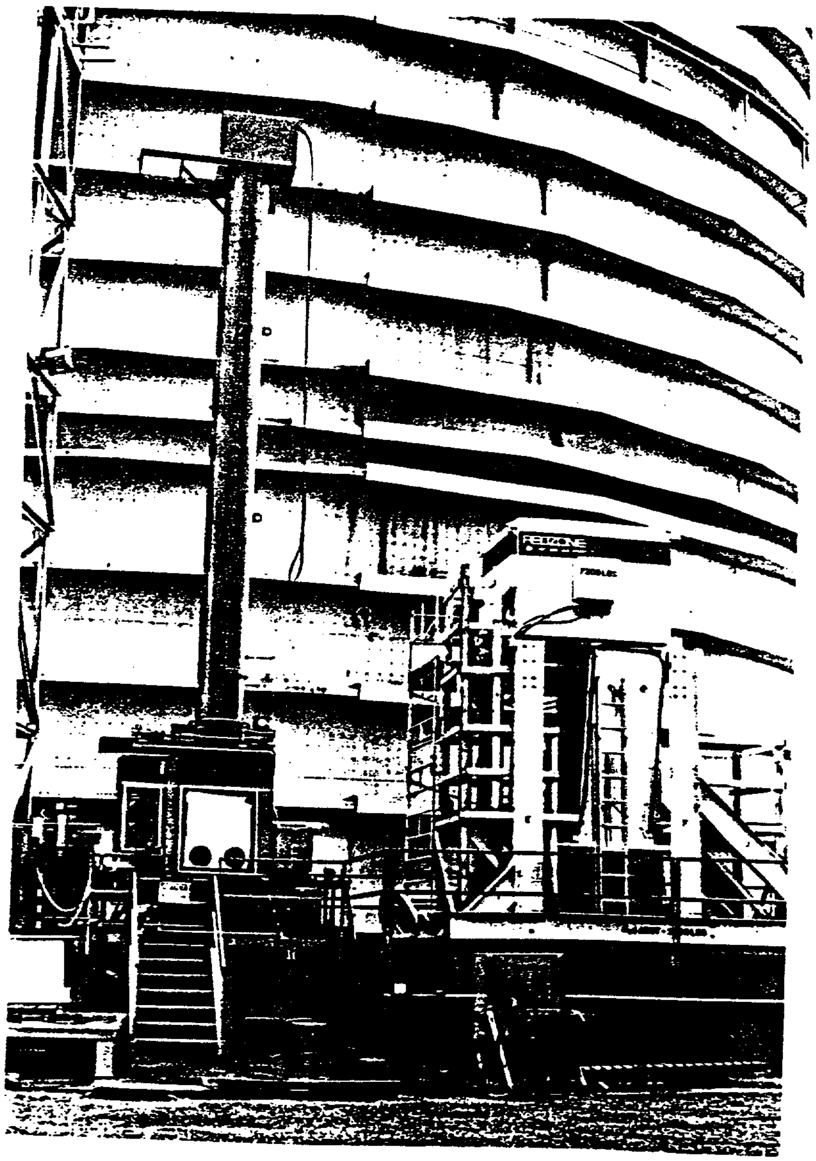
Photograph 6. The Confined Sluicing End Effector



Photograph 7. The University of Missouri-Rolla Mark V Jet Pump



Photograph 8. The Butterworth Jetting System. Incorporate. Jet Pump



Photograph 9. Waste Dislodging and Conveyance System Installed at the Tanks Technology Cold Test Facility