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Development and Testing of Single-Shell Tank Waste Retrieval Technologies

Milestone M-45-01 Summary Report

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1.0 INTRODUCTION

This report summarizes the activities undertaken to develop single-shell tank (SST) waste retrieval technology and complete scale-model testing. Completion of these activities fulfills the commitment of Milestone M-45-01 of the Hanford Federal Facility Agreement and Consent Order (the Tri-Party Agreement) (Ecology et al. 1994). Milestone M-45-01 is a key step leading to the completion of testing of technologies appropriate for retrieval of waste from SSTs.

A series of milestones are identified in the Tri-Party Agreement governing the development of tank waste retrieval systems. The first of these retrieval milestones, M-06-01, was completed in October 1990. The deliverable for Milestone M-06-01 identified candidate technologies that could be applied to SST waste retrieval. It also recommended certain of these technologies for further development and testing. This deliverable included results from initial technology screening tests (Miller 1990).

The second milestone in this series, M-06-02, *Initiate Waste Retrieval Testing in a Scale Model Tank*, was completed in September 1992. Deliverables included a full-scale mock-up demonstration of a sludge removal system, conveyance of the sludge to the top of the simulated tank, and demonstration of systems to remove in-tank hardware (Wisness 1992).

The final milestone, M-45-01 (originally M-06-00), provides a focus for selecting and evaluating promising SST retrieval technologies and addresses each major waste type. The specific requirements of Milestone M-45-01 are as follows:

> "Develop single-shell tank waste retrieval technology and complete scale model testing. Various waste retrieval technologies will be evaluated for retrieving each of the several types of single-shell tank wastes. Emphasis will be placed on optimizing waste removal while minimizing personnel exposure. Promising technologies will be evaluated for each waste type and one or more will be selected for testing using simulated waste in a scale model (minimum 1:12) tank." (Ecology et al. 1994)

Initial activities in support of Milestone M-45-01 included engineering studies that compiled and evaluated data on all known retrieval technologies. Based on selection criteria incorporating regulatory, safety, and operational issues, several technologies were selected for further evaluation and testing. The testing ranged from small-scale, bench-top evaluations of individual technologies to full-scale integrated tests of multiple subsystems operating concurrently as a system using simulated wastes.

The current baseline retrieval method for SSTs is hydraulic sluicing. This method has been used successfully in the past to recover waste from SSTs. Variations of this hydraulic or "past practice" sluicing may be used to retrieve the waste from the majority of the SSTs. To minimize the potential for releases to the soil, arm-based retrieval systems may be used to recover waste from tanks that are known or suspected to have leaked. Arm-based retrieval systems may also be used to recover waste that cannot be removed by sluicing.

Tri-Party Agreement Milestone M-45-03-T01 requires a SST waste retrieval demonstration. Both hydraulic sluicing and arm-based retrieval will be demonstrated in the first SST. Hydraulic sluicing is expected to retrieve most of the waste, and arm-based retrieval will retrieve wastes that remain after sluicing. Subsequent tanks will be retrieved by either hydraulic sluicing or arm-based methods, but not both. The method will be determined by waste characterization, tank integrity (leak status), and presence of in-tank hardware. Currently, it is assumed that approximately 75% of all SSTs will be retrieved by hydraulic sluicing and the remaining tanks by arm-based methods.

The SST waste retrieval systems will be designed and built by commercial vendors. The information developed through the program conducted in support of Milestone M-45-01 will provide a technical resource for potential vendors. The test results also serve as a basis for making selections and/or as a starting point for more specific investigations based on the vendor's particular approach.

Milestone M-45-01 provided a framework for efforts to identify and test promising SST retrieval technologies. The technology development activities completed in support of this milestone demonstrated an adequate basis to proceed with single-shell retrieval implementation. Development of SST retrieval will continue, with emphasis on refining sluicing methods and expanding the capabilities of arm-based retrieval. Adaptations to these retrieval methods will probably be needed to handle unusual waste forms such as cement or spent fuel rods. In parallel with the implementation of retrieval using sluicing and arm-based systems, industry and universities are being asked to identify alternative SST retrieval concepts that would improve on system cost, reliability, maintainability, and worker safety. With 149 SSTs to retrieve, the methods used must be safe, cost effective, and reliable.

2.0 BACKGROUND

The Hanford Site underground waste storage system includes 149 SSTs of various sizes and designs. The waste stored in the tanks varies from tank to tank over a wide range of chemical and physical properties. In addition, certain tanks are known or suspected to have leaked, giving rise to potential restrictions on the approach to retrieving waste from these tanks. These variations in tank design, waste composition, and regulatory considerations pose several complicated technical issues. Thus, more than one method may be required to retrieve waste from all the SSTs.

The SSTs are constructed of reinforced concrete lined with carbon steel. The steel liner covers the inside sides and bottom, but does not extend up to cover the domed top of the tank. The tanks range in size from 208,000 to 3,785,000 L (55,000 to 1,000,000 gal) and 6 to 23 m (20 to 75 ft) in diameter. The tanks also contain various obstructions including pumps, instrumentation, and other types of in-tank hardware including discarded pipe sections, stones, wires, and long steel measuring tapes. Retrieval equipment will access the tanks through risers extending through the tank dome. From tank to tank, these risers vary in number, height, length, diameter, and arrangement or geometry.

Further, the SSTs do not contain the same chemical waste forms. Waste consistency varies between tanks and even within a single tank, ranging from hard salt cake to sludge. The depth and volume of waste remaining in the tanks also varies. Other variables that will effect the design of SST retrieval equipment include radiation level, presence of combustible gases, humidity, and pH variations.

Another factor that will influence the selection of waste retrieval technology is the addition of water to the tank to aid in the retrieval process. Currently, 67 tanks are known or suspected to have leaked; these tanks must be managed to minimize leakage during retrieval. In some cases, this may require use of retrieval methods that add little or no water to the tank waste. Arm-based retrieval is one such low-water-addition technology. Tank Waste Remediation Systems has determined that sluicing will be the primary SST retrieval method; however, where the potential exists for leaking, sluicing may not be acceptable because this retrieval method requires a large amount of liquid.

The retrieval method that meets all the retrieval requirements for a specific tank will be used to remove all the waste from that tank. Current cost estimates indicate that a substantial portion of the cost of retrieving a SST will be for the tank modifications and installation of the retrieval hardware. The required tank modifications and installation are physically quite different for sluicing and arm-based retrieval methods. By installing only one retrieval system per tank, the total cost of retrieval will be minimized.

3.0 REQUIREMENTS

Tank Waste Remediation Systems' mission is to "store, treat, immobilize, and dispose or prepare for disposal the Hanford Site's radioactive tank waste in an environmentally sound, safe and cost-effective manner." Tank Waste Remediation Systems is using a systems engineering process (RL 1992) to define and document the individual functions and requirements that must be performed to accomplish this mission. The function "SST Retrieval" governs the requirements for activities discussed in this document.

Technologies developed in support of Milestone M-45-01 were selected based on a set of well-defined criteria. Selection criteria were divided into two groups: requirements and desirable options. Table 1 summarizes the requirements derived from *Single-Shell Tank Waste Retrieval Study* (Krieg 1990). The requirements pertain to environmental and safety considerations, operating parameters, retrieval rates and productivity, and general design requirements. The desirable options are based on the consensus of the analysts involved in the selection. The most promising technologies are those that meet all of the requirements and most of the desired options.

Table 1. Requirements.

Attribute	Requirement
Radiological release criteria	Shall meet criteria specified in the Hanford radiological design manual for releases to the environment (WHC-CM-1-6, WHC-CM-4-9).
Operating conditions	Must perform intended function under the conditions that exist in the tank.
Operating temperature	Must not increase the temperature of the waste above 240 °C (464 °F) at the waste-tool interface.
Equipment removal	Shall include features that will allow controlled removal of the equipment from the tank after failure.
Decontamination	Shall include features that aid in decontamination and minimize material buildup.
Ventilation	Shall not preclude operation of an active ventilation system on tanks that require it.
Radiation resistance	Materials shall function at a total exposure of 10^7 R gamma.
Waste tank confinement	Shall not damage or breach the SST liner.
Location of waste	Be capable of removing waste from any area within the storage volume of the SST.
Removal rate	Average continuous removal rate for undiluted waste shall be 114 L/min (30 gal/min).
Equipment control	The equipment shall be operated remotely.
Pipe cutting capability	Be capable of cutting pipes from 1.3 cm (0.5 in.) to 107 cm (42 in.) in diameter.
Retrieval capability	Provide retrieval for wastes from liquids, to thick, stiff sludges, to hard, concrete-like salt cake.
Waste transport	Be capable of transporting all forms of retrieved waste to the surface of the ground above the SST.
Maximum loads	Maximum loads on the soil above the tank dome over a minimum 3-m (10-ft) radius are 45,400 kg (50 tons) for the 200-series tanks and 91,000 kg (100 tons) for the 100-series tanks.
Loads against tank	Shall not impose mechanical loads on the tank liner or dome during retrieval.
In-tank obstructions	Be capable of removing in-tank obstructions and solid debris.
Waste properties	Be capable of pumping abrasive fluids at 114 L/min. (30 gal/min.)
Operating time	Support the required production rates.
Humidity, atmospheric pressure, and temperature	Operate at atmospheric pressure, relative humidities up to 100%, and the temperatures listed below. • Waste contacting: 10 to 150 °C (50 to 300 °F) • In tank/out of waste: 20 to 66 °C (50 to °F) • Out of tank: -16 to 66 °C (0 to 150 °F)
Dose rates	Maximum dose rates to operations personnel shall not exceed 0.2 mr/hour.

SST = single-shell tank.

4.0 SINGLE-SHELL TANK RETRIEVAL TECHNOLOGY SELECTION AND TESTING

Milestone M-45-01 states "promising technologies will be evaluated for each waste type, and one or more will be selected for testing using simulated waste in a scale model." To meet this goal, the retrieval task was divided into four functions: mobilize (dislodge) waste, convey waste (out of the tank), disassemble/package the in-tank hardware, and monitor/control the retrieval operation (RL 1992). Each of the retrieval technologies that were tested in support of M-45-01 corresponds to one of these four retrieval functions. The discussion that follows summarizes the retrieval technologies and identifies the corresponding function.

4.1 PAST PRACTICE SLUICING

Hydraulic sluicing is a waste mobilization method that was used to retrieve waste from SSTs from the 1950s through the 1970s. During that time, many technical difficulties associated with sluicing technology were resolved. Because sluicing technology has been successful, it was selected as the primary technology for the current waste retrieval mission. The sluicing system employed to retrieve waste from SSTs in the current mission will use the same operating configuration used in the past, and is referred to as "past practice sluicing." See Figure 1.

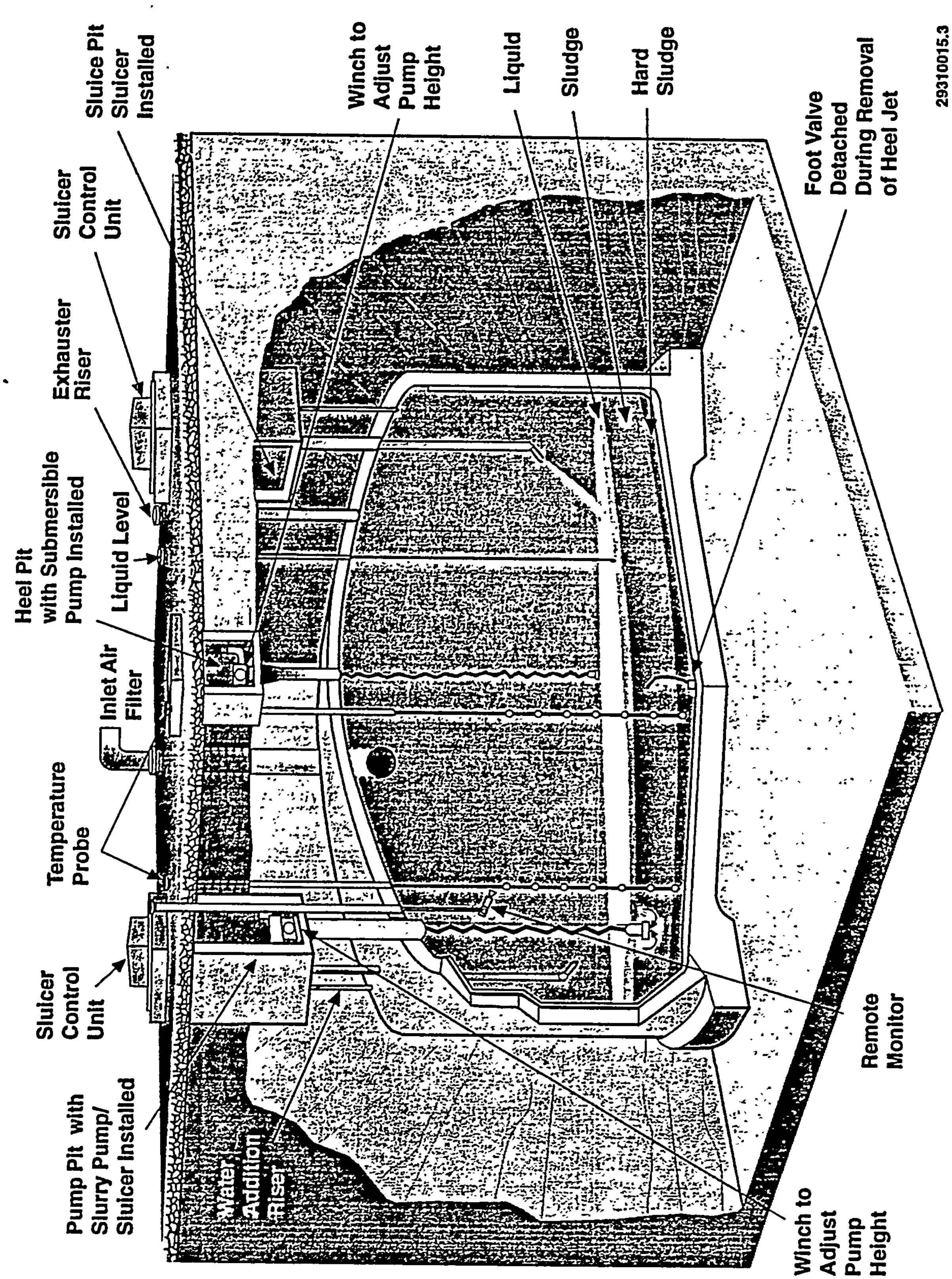
Past practice sluicing will be used to retrieve waste from the first tank. Based on the results of this retrieval, an assessment will be made as to how well past practice sluicing can meet the objectives established for tank cleanout. Issues that may limit the use of sluicing include questions on the ability of sluicing to remove "hard-to-remove" waste forms (sludge and salt cake) and, the acceptability of adding large volumes of water to a tank have led to the investigation of other retrieval approaches and possible enhancements to sluicing.

4.2 EARLY EVALUATIONS OF ALTERNATIVE RETRIEVAL METHODS

Engineering studies performed in 1990 (Krieg 1990) led to feature tests of mobilization and conveyance technologies showing promise for retrieval of sludge and salt cake wastes. For sludge waste, pumping systems considered were centrifugal pumps, positive displacement pumps, eductor (jet) pumps, and scarifiers. Other systems considered were waterjets, air jets, steam jets, carbon dioxide blast, mining equipment, contained sluicing, air conveyance, belt conveyors, screw conveyors/elevators, bucket elevators, and batch conveyers. For salt cake waste, technologies considered were grinders, clamshell buckets, impact devices, pulverizers, and scarifiers, waterjets, air conveyance, and batch conveyors.

These engineering studies evaluated technologies against a broad set of evaluation criteria which included regulatory requirements and desirable features that would improve reliability, safety, and ease of maintenance (see Table 1). The evaluations for a mobilization method concluded that the primary candidates for follow on testing were scarifiers, waterjets, and air jets.

Figure 1. Past Practice Sluicing.



Steam jets, delumpers, and clamshell buckets were secondary candidates. The primary candidate for the conveyance function was air conveyance, with pumping systems and batch conveyors the secondary candidates.

4.3 FEATURE TESTS

Feature tests performed in 1990 allowed Hanford engineers to gain additional insight into the applicability of various technologies. Simple feature tests were performed to determine if the technologies would be effective on salt cake waste simulants or sludge simulants. The results of these feature tests were used to select the technologies that were developed for full-scale testing.

4.3.1 Dislodging Feature Tests

Tests conducted on pneumatically driven needle scalers were qualitative in nature (Squires 1990). Scalers are used in industry to clean welds and slag. The conclusion was that while the scaler was an effective means to dislodge the salt cake material that may be attached to the tank liner, it was not effective in dislodging and/or mobilizing sludge simulants.

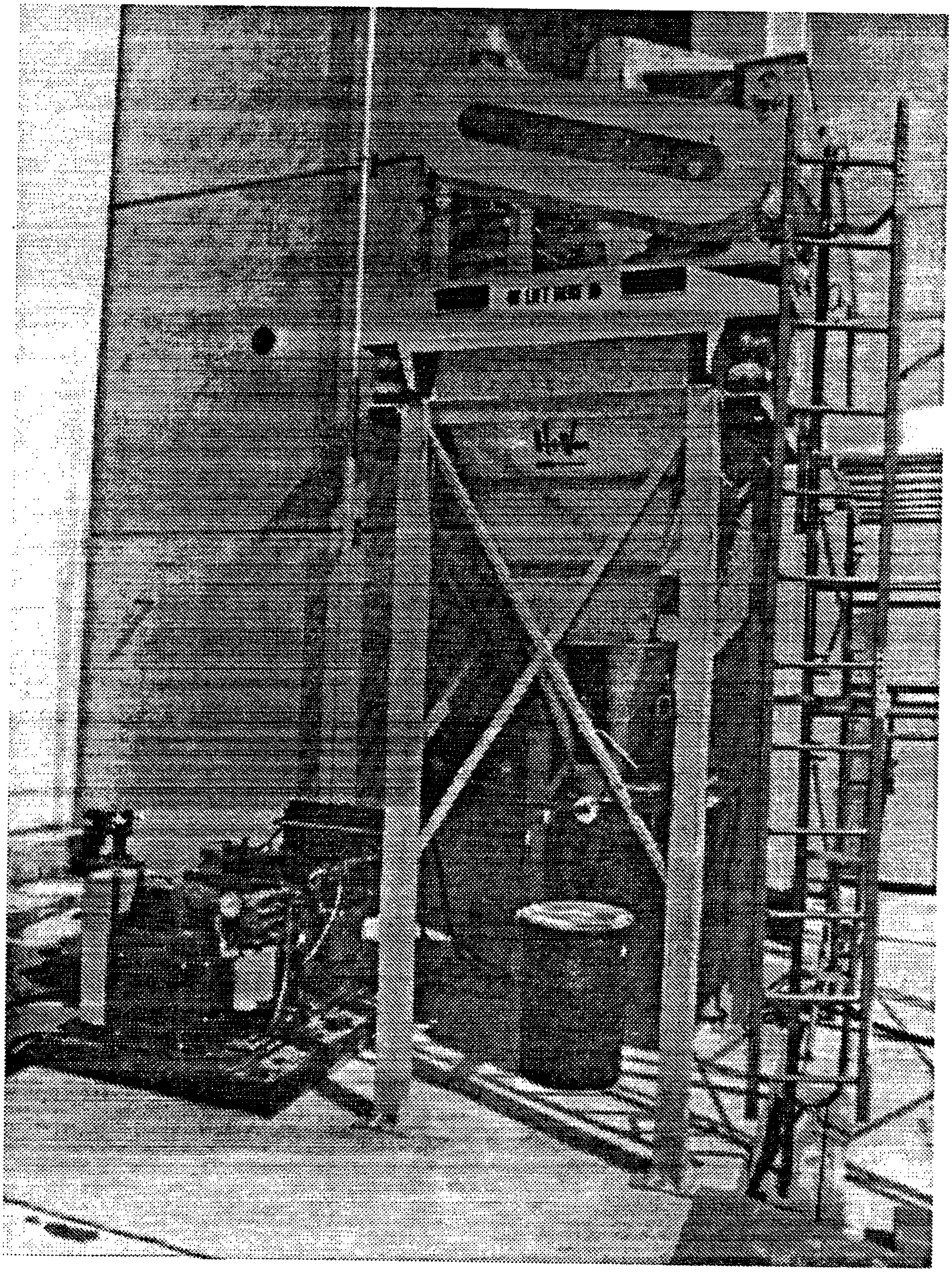
Air jets and waterjets were tested and evaluated in a scarifier configuration by Leist (1990). Air jets showed promise for sludge and soft salt cake dislodging because, in addition to their cutting capabilities, they cause the waste particles to be suspended above the waste surface where the air conveyance system can remove them from the area. Air jets, however, did not work well for hard salt cake removal. Hard salt cake was easily dislodged by waterjets, and waterjets were recommended for further development in a scarifier configuration. Based on tests of single and multiple jet configurations, it was concluded that a multiple jet configuration was more effective for dislodging salt cake.

4.3.2 Conveyance Feature Tests

A positive displacement pump commonly used in the food industry was evaluated (Squires 1990) for the conveyance of two sludge simulants. One simulant was thick (consistency of peanut butter), and the other simulant was less viscous (consistency of sun tan lotion). While this type of pump was capable of propelling the materials, there was a high degree of wear of some of the pump parts.

Initial testing of an air conveyance system (Thompson 1990, 1993) proved it to be an effective method for retrieving simulated sludge. The system that was tested (see Figure 2) was somewhat small in size and capacity for some of the tests performed, but it showed that, with some modifications to the basic design, the technology could be a sound option for waste retrieval. It was suggested that a system using a fluid injection device at the feed nozzle and additional injection units placed along the hose runs may be necessary to lubricate the hose and prevent plugging.

Figure 2. Air Conveyance System.



4.4 PEER REVIEW OF TECHNOLOGY

In 1991, a multi-laboratory and contractor team participated in a peer review (WHC 1991) of the development work up to that time. The peer review concluded that arm-based retrieval systems, using both pneumatic conveyance and waterjet dislodging technologies should proceed into development. The review also concluded that future assessments of manipulators, end effectors, sensors, remote control equipment, system integration, and retrieval operations should be integrated into an overall system. This natural evolution from evaluating individual components of the retrieval system to careful consideration of the overall system allowed for additional focus of testing and development activities.

4.5 ARM-BASED RETRIEVAL

An arm-based retrieval system employs a high load capacity, long-reach manipulator system to deploy the end effectors and conveyance tools needed for retrieval. Figure 3 illustrates a concept for an arm-based retrieval system that could be deployed through a large central riser. The waste is dislodged by the mobilization tool mounted on the end of the arm. Once mobilized, the waste is conveyed from inside the tank to the surface for further processing using an air conveyance system.

The following considerations and requirements formed the basis of evaluation for the tests and demonstrations that followed:

- Payload size and weight
- Access limits
- Accuracy and repeatability limits
- Travel rates
- Dynamic interactions and frequencies
- Reaction forces
- Reliability and maintainability
- Waste removal rates and strategies.

4.6 RETRIEVAL TECHNOLOGY DEMONSTRATION

As part of the technology development efforts, integrated technical demonstrations were held in 1991 and 1992 (Jaquish 1993). The integrated demonstrations established the feasibility of arm-based retrieval systems and various mobilization and conveyance technologies in a SST mockup test bed. The 1991 demonstration emphasized integration of multiple robotic manipulator systems employing user-friendly interfaces. In the following year, end effector tests included the soft waste dislodging and conveyance test apparatus. The waste mobilization tools consisted of a low-pressure waterjet dislodging tool and an air conveyance system coupled together. This was the first attempt at integrating the mobilization and conveyance systems. The test article effectively removed and conveyed sludge over prototypic vertical lift and lateral runs at rates that exceeded target rates (Figure 4).

Figure 3. Arm-Based Retrieval System Concept.

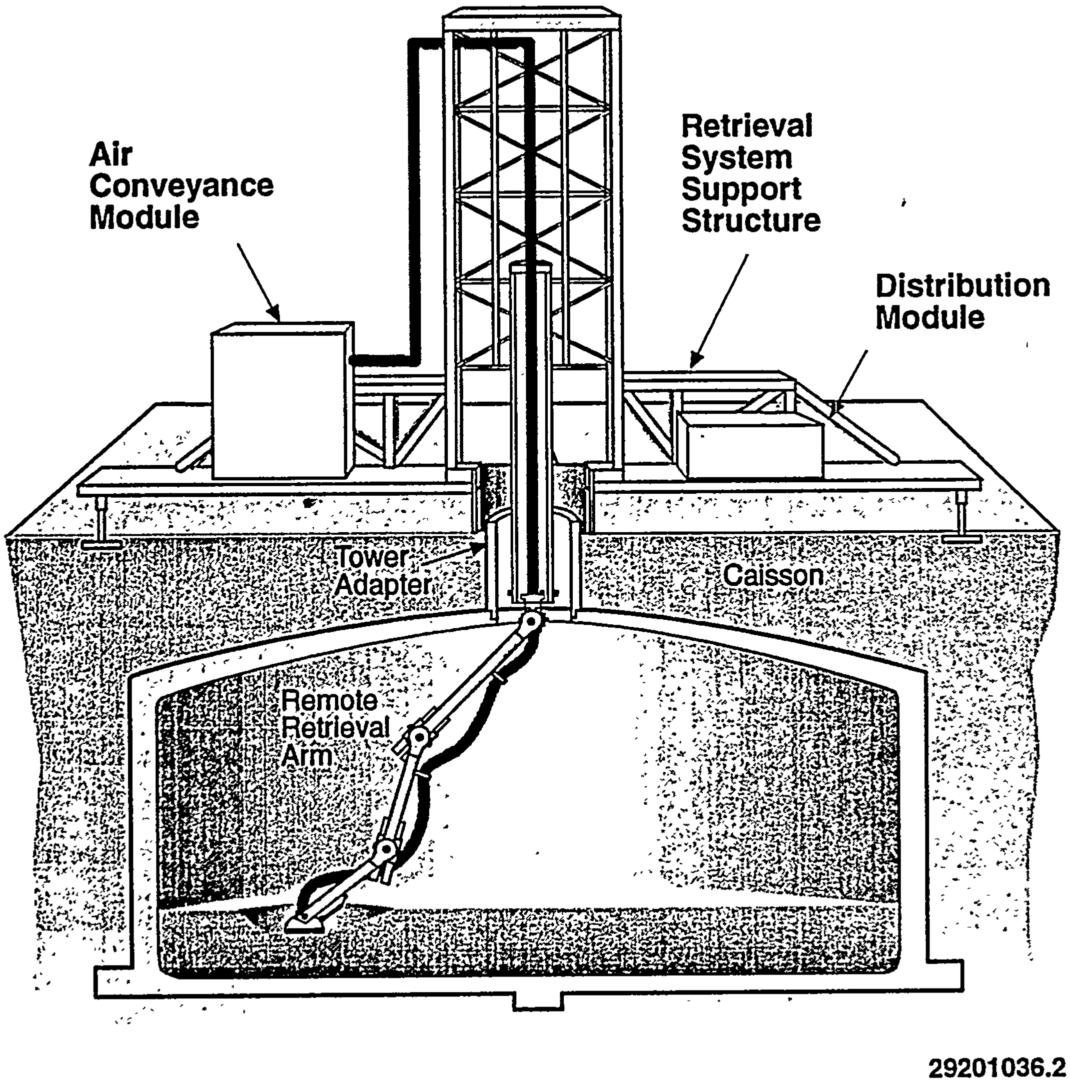
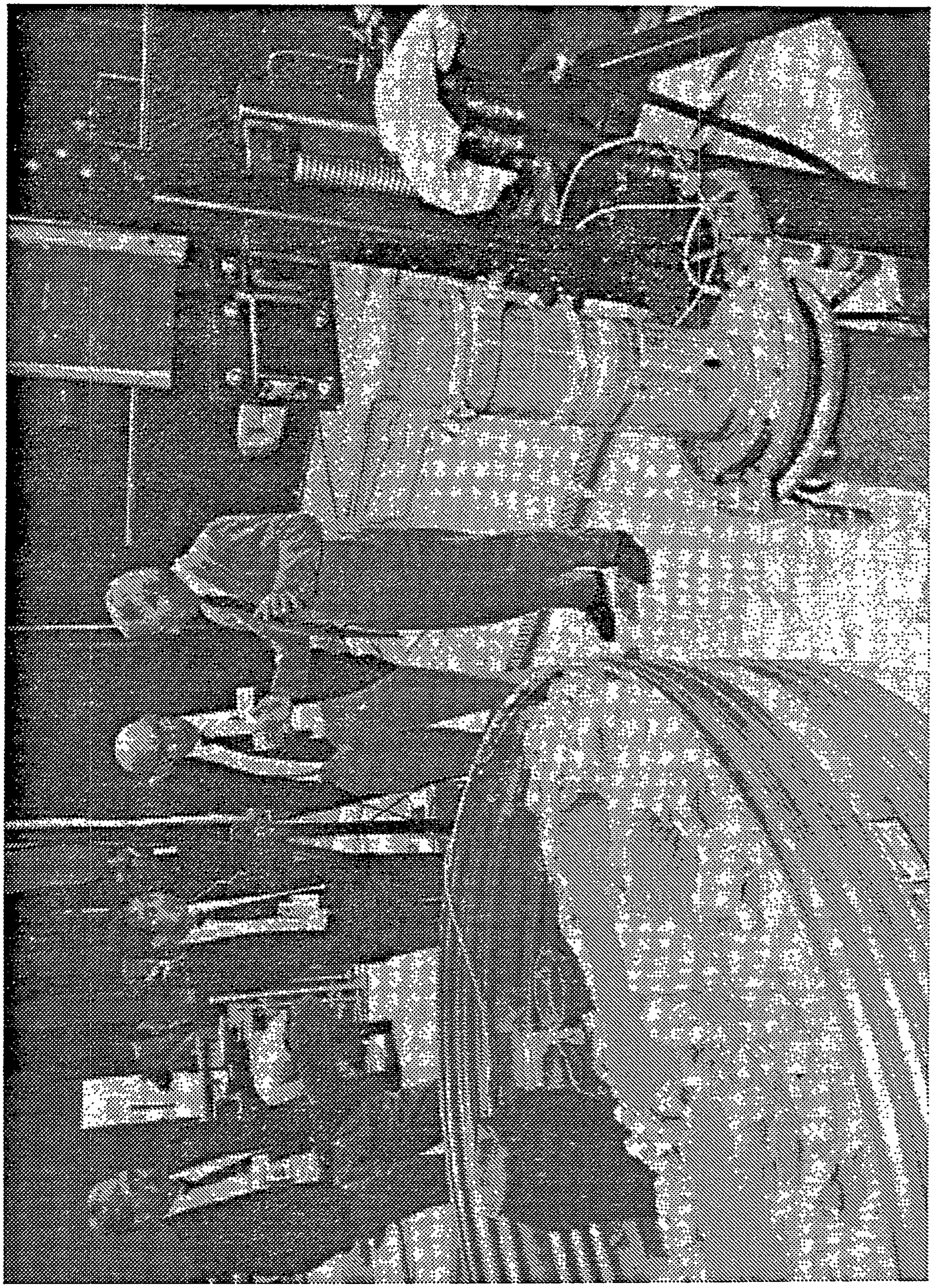


Figure 4. Integrated Demonstration.



4.6.1 Manipulator

Three types of manipulators were installed and operated in the test bed. Each manipulator was intended for a unique application. The largest manipulator was the long-reach manipulator (Figure 5). This manipulator had a large range of motion and a relatively high payload capacity. Attached to the end of the long-reach manipulator was the dexterous manipulator. This configuration was analogous to a human arm and hand: the long-reach manipulator positioned the dexterous manipulator much like an arm positions a hand. Like a human hand, the dexterous manipulator was a lower payload manipulator capable of fine motion for complex tasks. This dual manipulator approach was used to meet the high-payload, broad range of motion, and high-dexterity requirements of the end effectors and sensor systems. The third manipulator installed in the test bed was the inspection manipulator, which may be used for inspection and surveillance in an underground storage tank.

4.6.2 Control System

An objective of the demonstration tests was to improve the man-machine interface. A simplified method of assimilating data and controlling the retrieval system was required. Desired features included an improved understanding of the arm operations within the tank, ability to "practice" operations first, simplified control of the retrieval system, and supervisory oversight of operator commands.

The demonstrated approach focused on a real-time graphical model of the retrieval system and the in-tank environment (Figure 6). The graphical model is the primary interface between the operator and the control system. Through this interface, the operator receives key data and executes the desired operations. Using the model interface, the operator can manually operate the retrieval system in real time or ask the control system to perform preprogrammed activities. Infeasible motions are prevented by the control system's knowledge of the in-tank environment and danger zones.

This approach was successful in simplifying the man-machine interface. Overall retrieval system and tank protection were demonstrated in these tests. Tasks that might have been infeasible or tremendously time consuming were expedited through the control system approach.

4.6.3 End Effectors

A hydraulic impact end effector (Figure 7) demonstrated the ability to fracture salt cake simulants into fragments small enough for removal by the conveyance system (LLNL 1994). This end effector uses low-volume, ultra-high pressure blasts of water.

End effectors were also developed and tested to cut and remove the various pipes, metal tapes, fuel assemblies, and other hardware found in the SSTs. Two types of tools for disposal of in-tank hardware were deemed most promising: plunge shear and abrasive water jet cutters. The plunge shear (Figure 8) was found to be superior to the water jet cutter. The plunge shear met all requirements for cutting small to intermediate size in-tank hardware

Figure 5. Long-Reach Manipulator With Dexterous Manipulator.

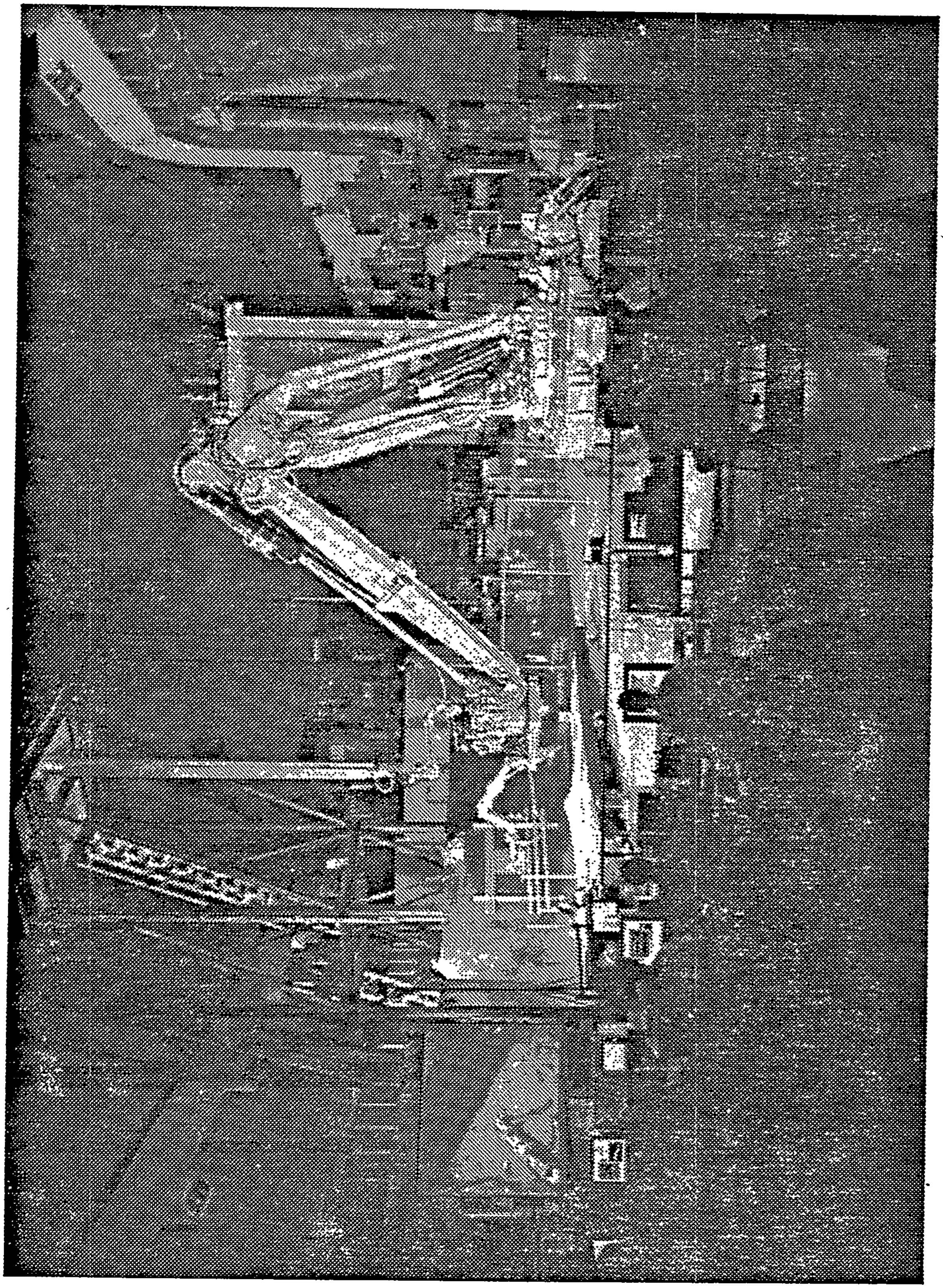


Figure 6. Manipulator Control System Interface.

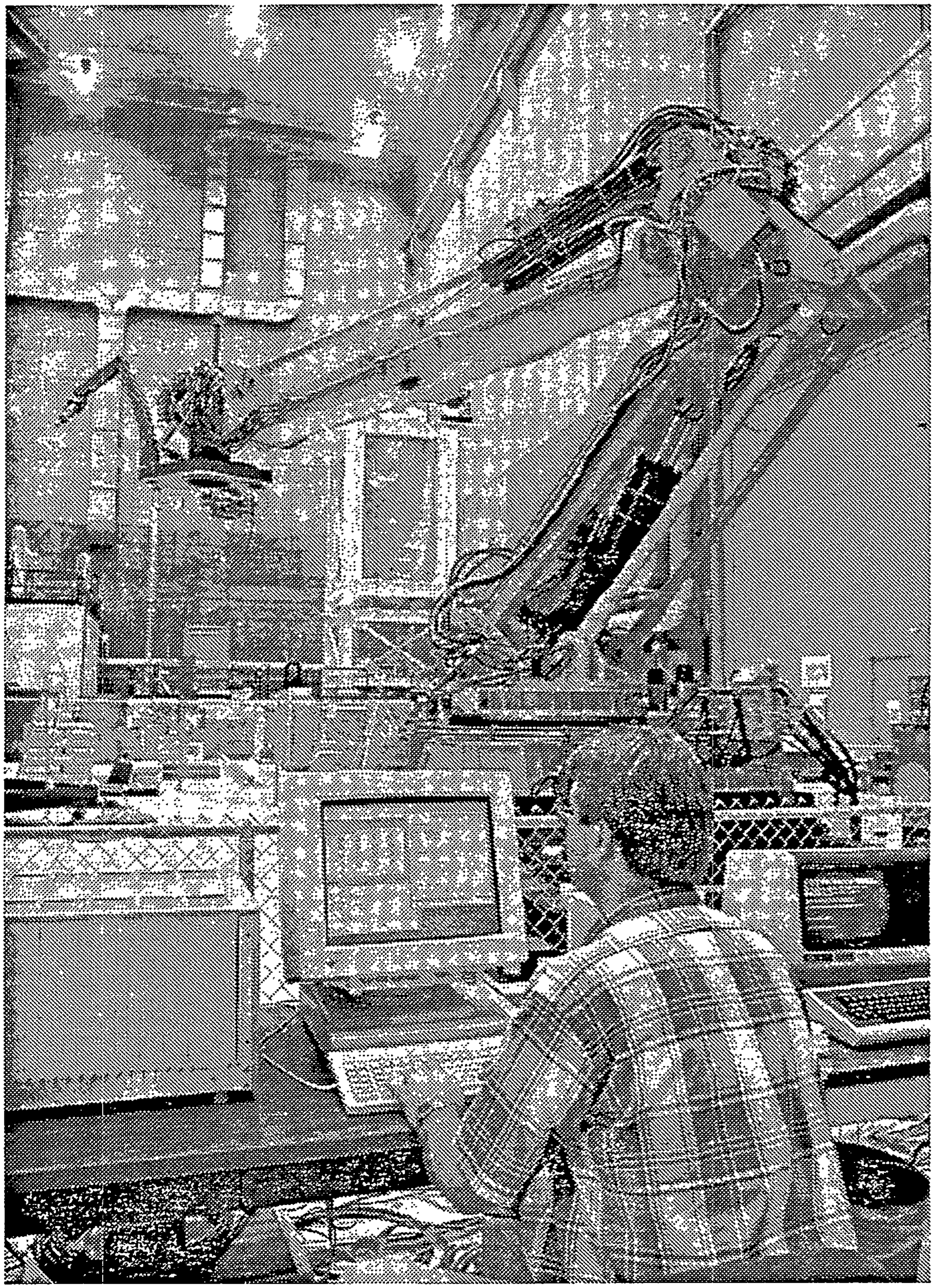


Figure 7. Hydraulic Impact End Effector.

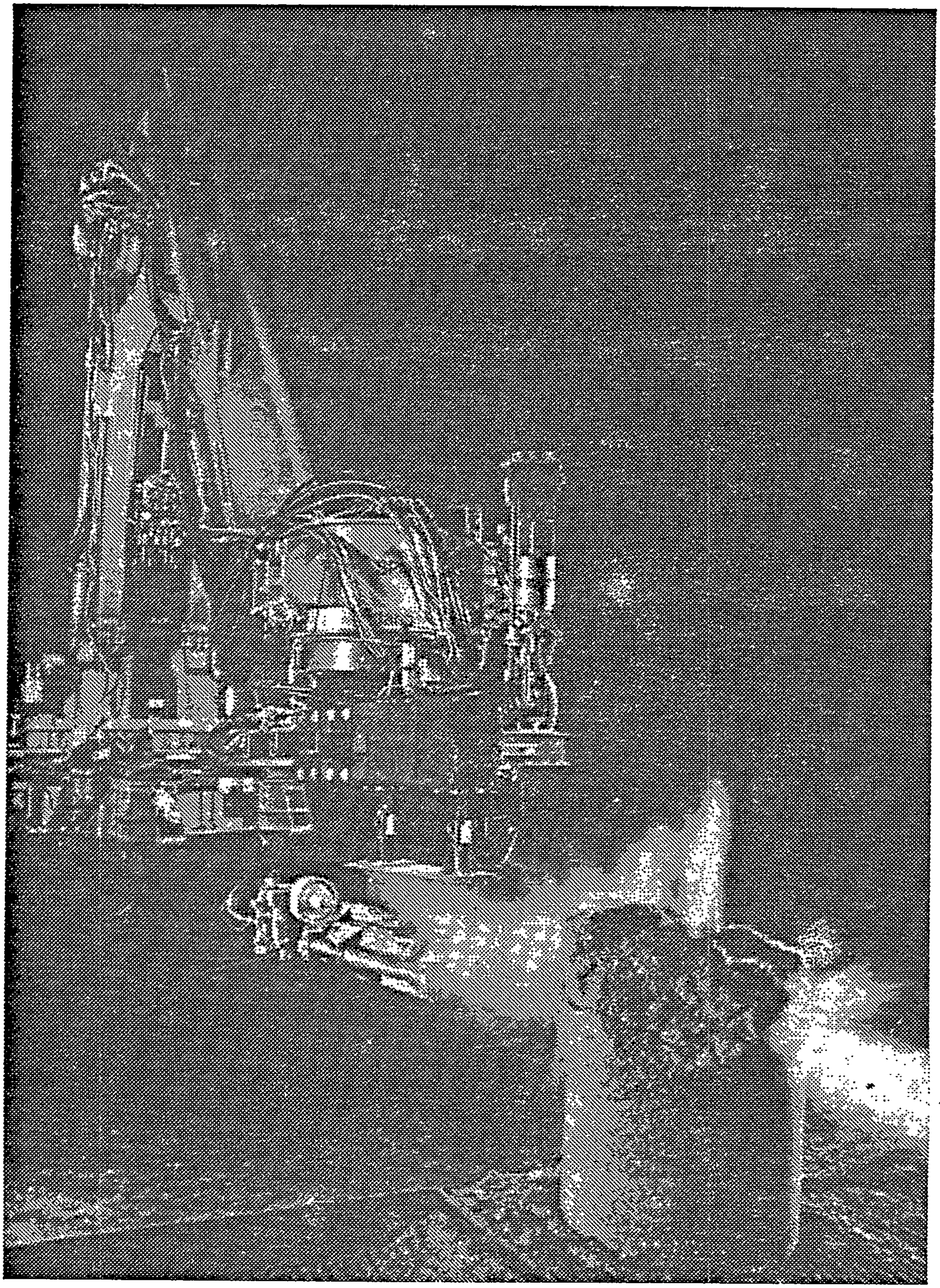
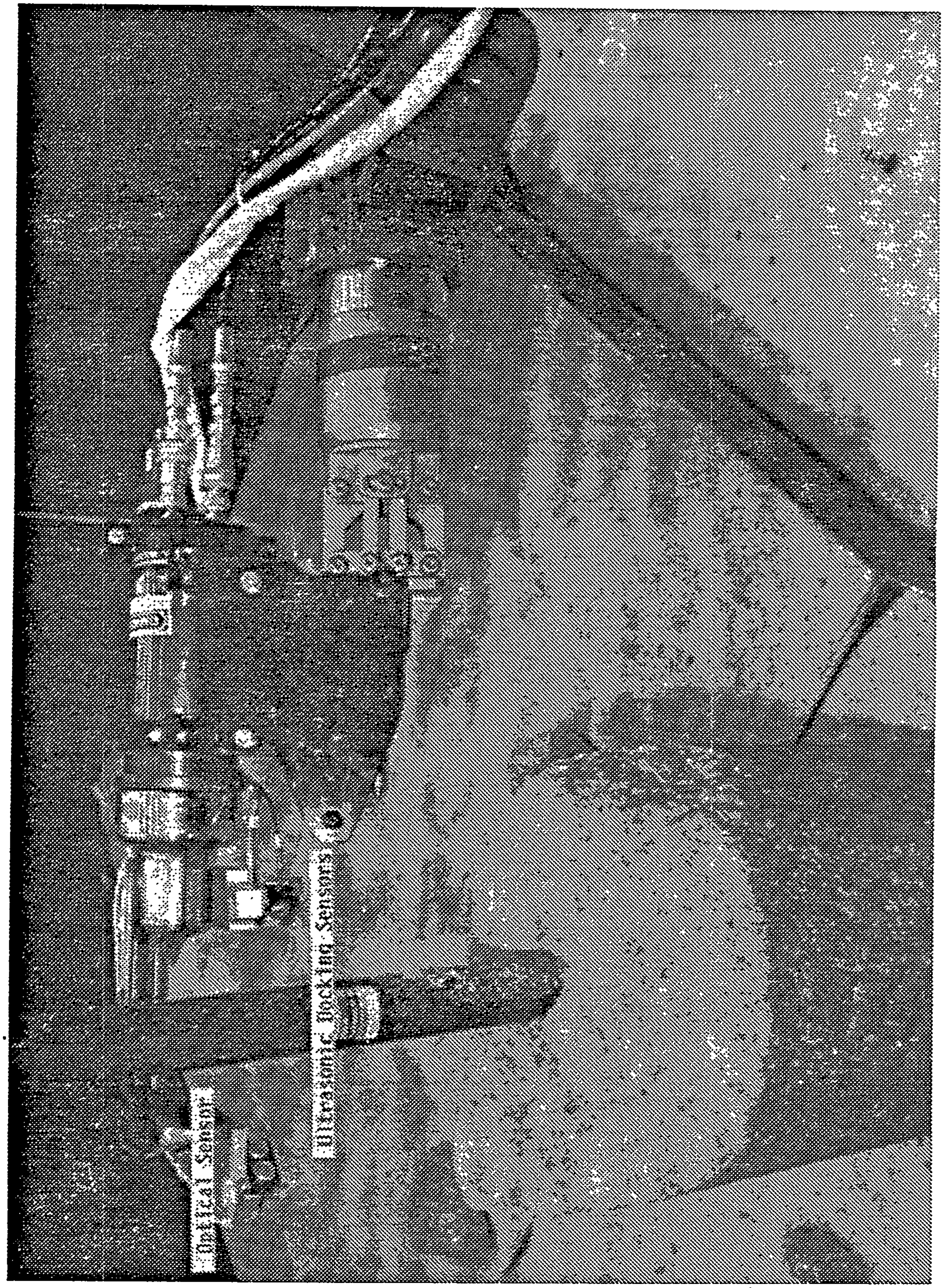


Figure 8. Plunge Shear End Effector.



while minimizing position accuracy requirements and eliminating water addition. Both parameters must be considered during design of a deployment system for a water jet cutter (Oppel 1993).

4.7 RECENT DEVELOPMENT

Further development has occurred since 1992, continuing to focus on those technologies that show high probabilities for success. Results from recent tests indicate that scarifiers using high-pressure waterjets could effectively dislodge both sludge and salt cake (Powell 1994; Rinker 1994). Furthermore, air conveyance was shown to effectively transport sludge simulants as well as "dry" scarified salt cake particles.

Tests performed in fiscal year 1993 substantially advanced the understanding of the processes required to remove waste from tanks. Scoping tests were conducted to determine which of the candidate technologies are likely to be capable of meeting EM-30's waste retrieval needs at Hanford (e.g., average of 114 L/min [30 gpm] waste removed for sludge and salt cake). Further, preliminary examinations were conducted of two types of waste conveyance systems (jet pump and blower-powered conveyance systems). Both were found to offer certain advantages.

Tests conducted by the University of Missouri-Rolla (UMR), Pacific Northwest Laboratory (PNL), and Quest Integrated, Inc. (Quest) determined the depth of waterjet cut into salt cake simulant as a function of jet pressure, nozzle diameter, and traverse speed. Based on these test results, it appears likely that a waterjet-based retrieval system can be designed. The UMR data predict that a salt cake removal rate of 114 L/min (30 gpm) could be attained using relatively low-pressure (276 MPa [10 kpsi]), 151-L/min (40-gpm) waterjets. The PNL-Quest team, which evaluated ultra-high-pressure (345 MPa [50 kpsi]) waterjets, predicts that the 114-L/min (30-gpm) target rate can be met using a flow rate of much less than 151 L/min (40 gpm) of added water.

As part of the development of the soft waste dislodging unit, Westinghouse Hanford Company demonstrated the ability of an integrated soft waste dislodging unit and air conveyance system to mobilize and convey sludge simulant at approximately 360 L/min (95 gpm) with a water addition rate of less than 28 L/min (7.5 gpm) over a 18-m (60-ft) vertical rise. These tests demonstrated the feasibility of the air conveyance technology. Further evaluation will be required to establish design and operating parameters.

An alternative conveyance system for dislodged waste is being developed by UMR (Summers 1994). This system uses a modified version of a commercially available jet pump to provide the suction that lifts the dislodged waste from the tank. Once the waste is entrained in the air entering the conveyance inlet, it passes a short distance before flowing through the jet pump throat. Several 69 MPa (10 kpsi) waterjets are focused in the jet pump throat, and these waterjets will cut up any pieces of sludge or salt cake large enough to become lodged in the pump throat. The resulting mixture is pushed up through a 5-cm- (2-in.-) diameter conveyance line by the momentum imparted by the waterjets. The ability of this modified jet pump to produce the required pressure and flow rate was demonstrated in fiscal year 1993.

5.0 CONCLUSIONS

Milestone M-45-01 has been successfully completed. The milestone provided a focus for developing and documenting a retrieval technology path for SST waste. In support of the milestone, various waste retrieval technologies were evaluated, and promising methods were developed and integrated into a full-scale retrieval demonstration using several types of simulated SST waste. Hard waste (salt cake), soft waste (sludge), and in-tank hardware-dislodging end effectors were demonstrated. The specific technology areas that were examined and the probable application(s) of each technology are listed in Table 2.

Table 2. Applications of Demonstrated Technologies.

Technology/method	Potential application(s)	TWRS function
Hydraulic scarifier (low-, medium-, and high-pressure water jet cutters)	Sludge and salt cake dislodging	Mobilize
Hydraulic impact (high pressure)	Hard waste (salt cake) dislodging and rubblizing	Mobilize
Tank inspection and mapping systems	Characterization of in-tank physical environment	Monitor/control
Plunge shear	In-tank hardware size reduction	Disassemble/ package ITH
Water jet	In-tank hardware size reduction	Disassemble/ package ITH
Control and sensor systems	Characterization of in-tank physical environment and protection of tank and retrieval system	Monitor/control
Manipulator systems	Position waste dislodging and conveyance tools, in-tank hardware tools, and sensor systems	Supports all functions

ITH = in-tank hardware.
TWRS = Tank Waste Remediation System.

By using an integrated remote operator interface to the control system and automated sequences, the demonstration system emphasized methods that will minimize personnel exposure.

A series of tests were conducted to identify the parameters that optimize waste removal rates using several waste simulants. A byproduct of the soft waste dislodging and conveyance tests is data on the end effector reaction loads that can be expected from waste of similar consistency and end effector design. This data is now available to design engineers working on specifying and designing the retrieval components that will be deployed into SSTs.

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