

Tanks Focus Area  
Retrieval Process Development and Enhancements  
FY96 Technology Development Summary Report

M. W. Rinker	K. I. Johnson
D. G. Alberts <sup>(a)</sup>	O. D. Mullen
J. A. Bamberger	M. R. Powell
B. K. Hatchell	D. A. Summers <sup>(b)</sup>

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Pacific Northwest National Laboratory  
Richland, Washington 99352

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(a) Waterjet Technology, Inc.  
(b) University of Missouri - Rolla, Missouri.

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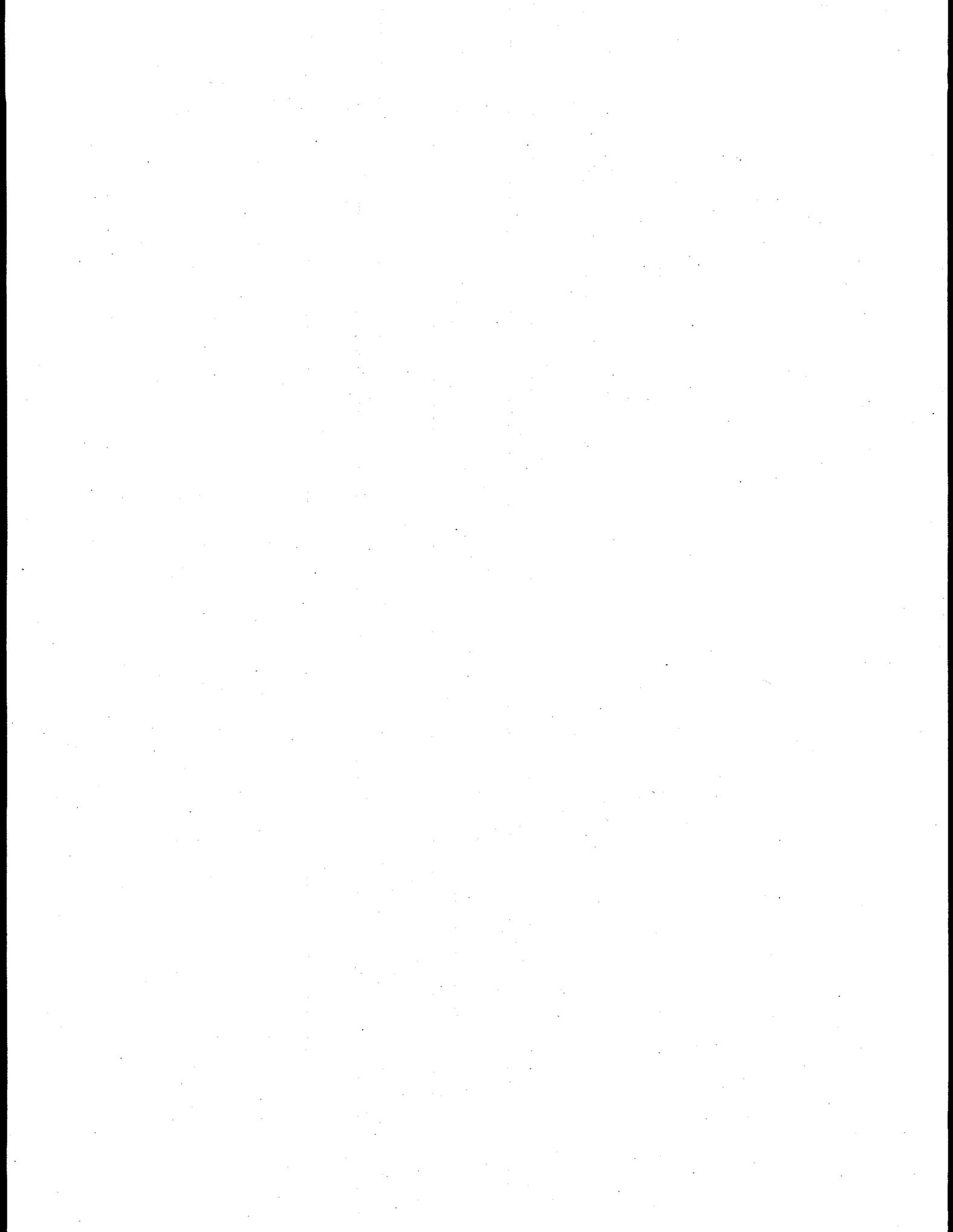
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## **Author's Note**

The purpose of this report is to describe and summarize the Retrieval Process Development and Enhancements technology testing activities in FY96. The detailed final FY96 testing reports from the various Retrieval Process Development and Enhancements technology development subtasks are listed in the appendix of this document. These reports are currently in the draft stage, and not all referenced reports have completed the formal clearance process.



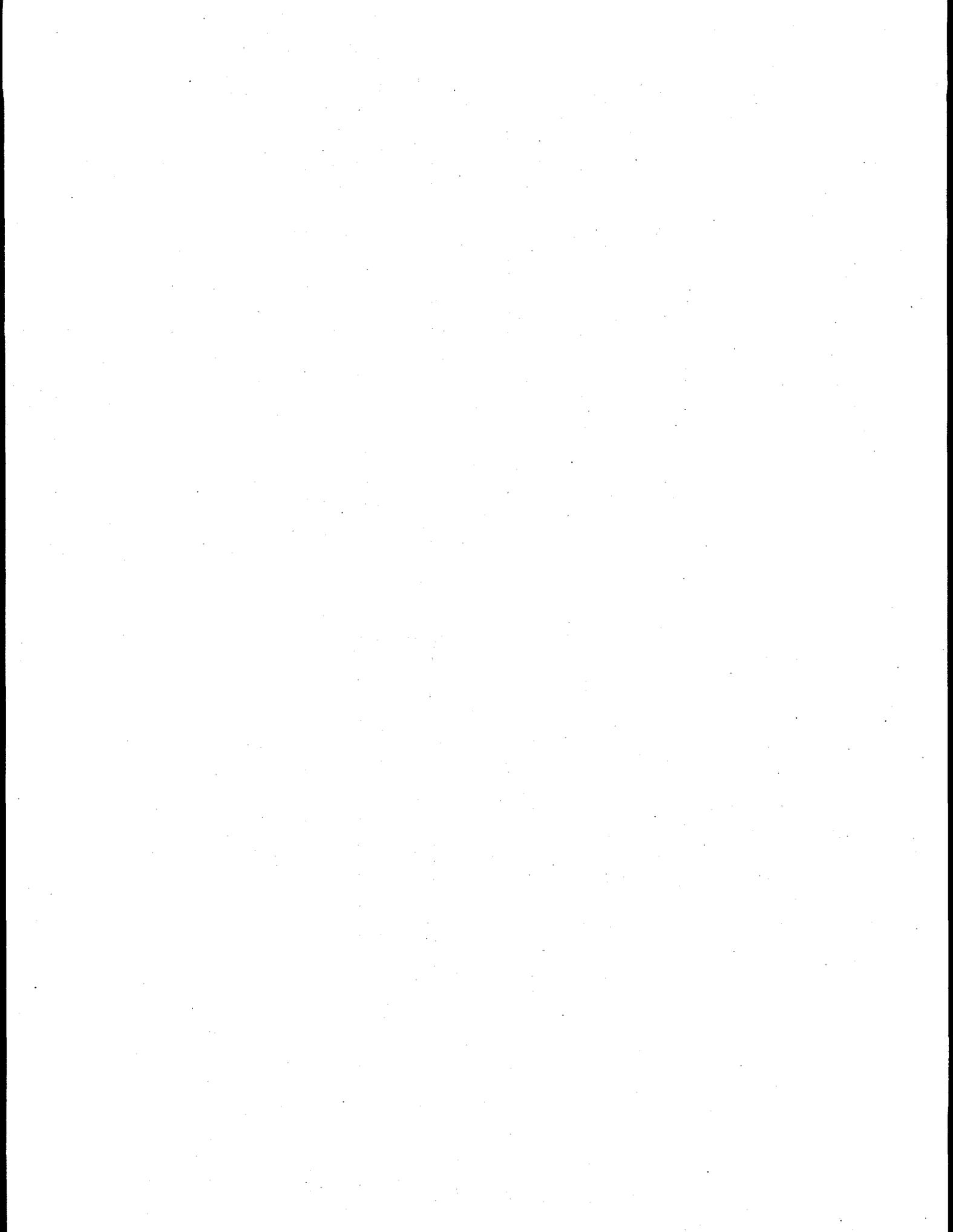
## Summary

The Retrieval Process Development and Enhancements (RPD&E) activities are part of the Retrieval and Closure Program of the U.S. Department of Energy (DOE) EM-50 Tanks Focus Area. The purposes of RPD&E are to understand retrieval processes, including emerging and existing technologies, and to gather data on those processes, so that end users have the requisite technical basis to make retrieval decisions.

Work has been initiated to support the need for multiple retrieval technologies across the DOE complex. Technologies addressed during FY96 focused on enhancements to sluicing, borehole mining, confined sluicing retrieval end effectors, the lightweight scarifier, and pulsed air mixing. Furthermore, a decision tool and database have been initiated to link retrieval processes with tank closure to assist end users in making retrieval decisions.

The main technical accomplishments of RPD&E, based upon FY96 testing, are as follows:

- **Oak Ridge National Laboratory**- RPD&E completed the development and construction of a tank waste retrieval end effector, the Confined Sluicing End Effector (CSEE) for the ORNL Guniting and Associated Tanks Treatability Study (GAAT-TS). The CSEE will be deployed in tanks at ORNL by the Modified Light Duty Utility Arm (MLDUA) and by the Houdini Remotely Operated Vehicle (ROV) in FY97.
- **Savannah River Site** - SRS plans to implement industry-developed, borehole miner extendible-nozzle technology to achieve the dislodgement and comminution of solids in a 24.4-meter (80-foot) diameter, high-level radioactive waste tank. SRS and the Tanks Focus Area RPD&E team are collaborating to configure the technology for in-tank deployment at the site. Also, in FY97, the borehole miner will be deployed at ORNL to Old Hydrofracture Tanks. Deployment at SRS has recently been deferred due to site priorities and budgets.
- **Idaho National Engineering Laboratory** - RPD&E provided guidance to INEL waste retrieval efforts by documenting the necessary functions and requirements of a waste dislodging and conveyance system for the INEL High-Level Liquid Waste (HLLW) tanks. RPD&E personnel also developed a retrieval test end effector to evaluate cleaning strategies for the cooling coils, walls, and floors of the HLLW tanks.
- **Support of the ACTR Project** - As the Hanford EM-30 task titled "Acquire Commercial Technology for Retrieval" (ACTR) builds a database on technologies available from industry for waste retrieval from single- and double-shell tanks at the Hanford site, the RPD&E team has provided technical support to assess the potential of candidate technologies, using criteria established during prior years of RPD&E testing. This activity not only benefited from the RPD&E experience base, but also facilitated information transfer from ACTR throughout the DOE complex. For FY96, this support included development of a testing strategy for vendor demonstrations, observation of vendor demonstrations,



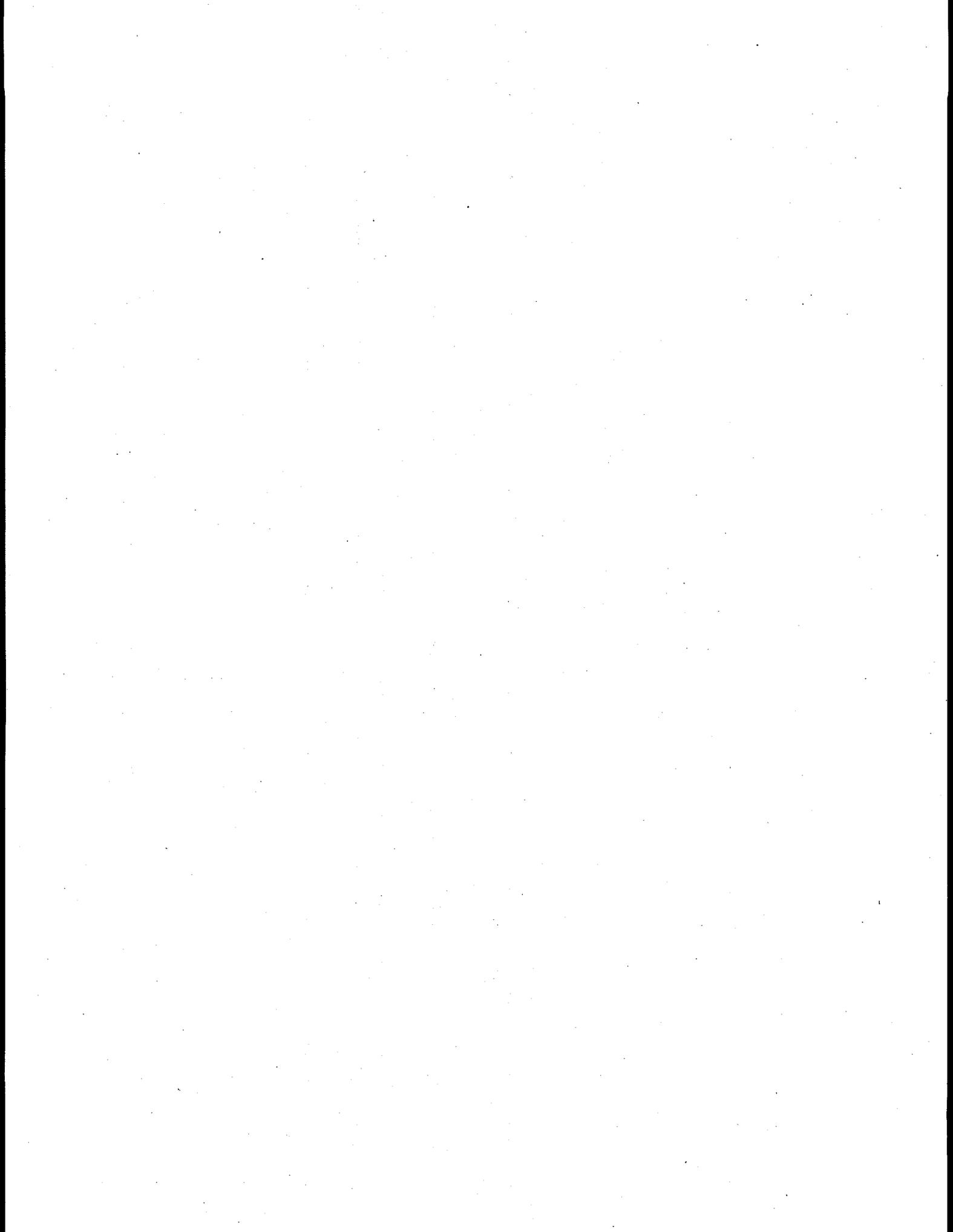
## Acknowledgment

The RPD&E team consists of a group of scientists and engineers from the Pacific Northwest National Laboratory, Westinghouse Hanford Company, Waterjet Technology Incorporated, University of Missouri at Rolla, Failure Analysis Associates, University of Washington, and Pulsair Systems Incorporated. This team exhibited continued leadership in the retrieval process arena through presentations and participation at events including: Spectrum '96, the Fluid Particle Interaction, the Waste Management and Environmental Restoration Education and Research Consortium, the Russian Retrieval Workshop, the Robotics Forum, and Tricipe. The team also hosted several technical demonstrations for the Confined Sluicing End Effector, the Extendible Nozzle, the Borehole Miner, the Pulsed Air Mixer, and the Particle Size Probe. Additional assistance was provided during the design review process to ORNL GAAT-TS, to SRS planning for demonstrations to INEL concerning horizontal V-tank remediation and in discussions with West Valley Nuclear Systems.

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## Glossary

ACTR	Acquire Commercial Technology for Retrieval
APL	Applied Physics Laboratory
comminution	process of reducing a material to powder
CSEE	Confined Sluicing End Effector
CSEETA	CSEE Test Article
DC	direct current
DOE	Department of Energy
DSTs	Double-Shell Tanks
EM	Environmental Restoration and Waste Management
F&R	Functions and Requirements
FY	Fiscal Year
GAAT-TS	Gunite and Associated Tanks - Treatability Study
Gunite	trade name for material used in waste tank construction, similar to shotcrete
heel	hard, solid waste layer found on the bottom of some underground storage tanks
HLLW	High Level Liquid Waste
HTB	Hydraulic Test Bed
Hz	Hertz - a unit of frequency equal to one cycle per second
INEL	Idaho National Engineering Laboratory
LDUA	Light Duty Utility Arm
LLW	low level waste
LWS	Lightweight Scarifier
MHz	mega Hertz, $1 \times 10^6$ Hz
MLDUA	Modified Light Duty Utility Arm
MPW	medium pressure waterjet
MVST	Melton Valley Storage Tanks
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
psi	pounds per square inch
RL	Richland Operations Office
ROV	remotely operated vehicle
RPD&E	Retrieval Process Development and Enhancements
rpm	revolutions per minute
SPAR	SPAR Aerospace Ltd, Toronto, Canada
SRS	Savannah River Site
TFA	Tanks Focus Area
UM-R	University of Missouri - Rolla
UW	University of Washington
WHC	Westinghouse Hanford Company
WTI	Waterjet Technology, Inc. (formerly the Waterjet Systems Division of Quest Integrated, Inc.)



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## 1.0 Introduction

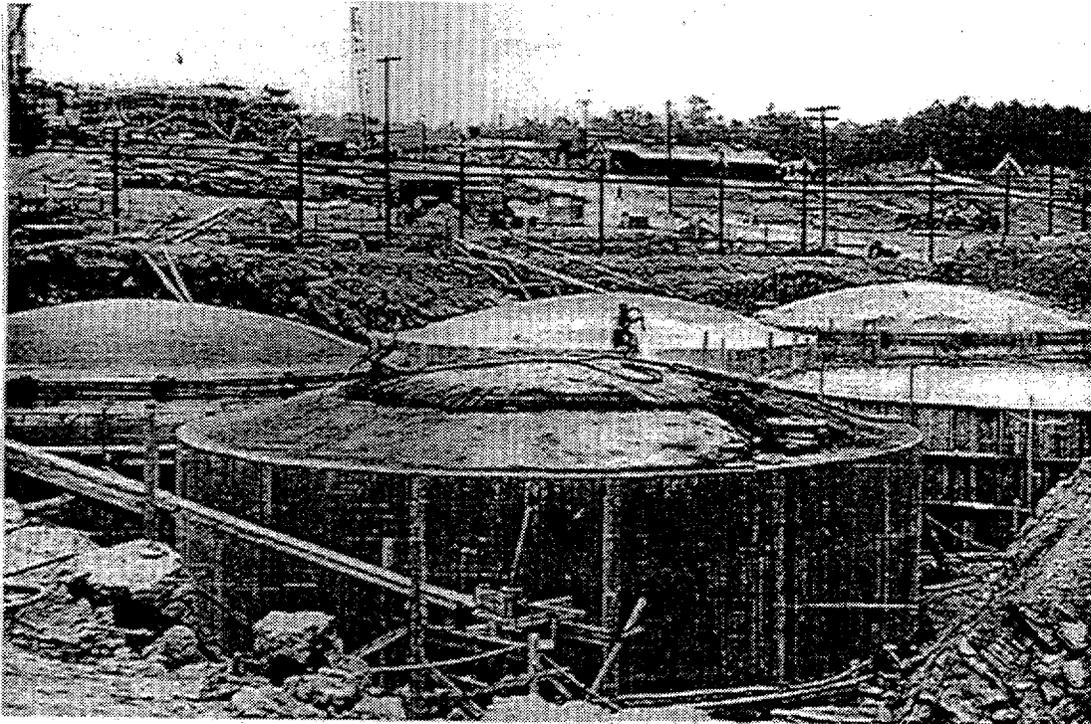
The purpose of this report is to describe and summarize the Retrieval Process Development and Enhancements (RPD&E) activities conducted during FY96 and funded by the DOE EM-50 Office of Science and Technology Tanks Focus Area (TFA), through Technical, Task Plan RL3-6-WT-51. Based upon development and testing efforts, recommendations for ongoing and new work have been provided, including input from end users gathered in a series of needs assessment meetings conducted by the TFA at each site. This report does not replace the detailed reports prepared by the individual investigators within the RPD&E system. For detailed information, refer to the individual reports listed in the appendix.

The overall purpose of RPD&E is to continue to lead the DOE TFA national effort in the basic understanding of waste retrieval. The retrieval process includes waste dislodging, mixing, sluicing, and conveyance in general, and is not specific to any of the various deployment systems. In this process, waste is mobilized in such a way that it can be transferred out of the waste tanks in a cost-effective and safe manner. From a basic understanding of the retrieval process, TFA will provide data to the end users that will assist them in retrieval decision-making. These activities also translate the knowledge gained in testing to fielded deployable systems that have been identified by end users across the DOE complex.

The safe and cost-effective retrieval of waste from underground storage tanks is a major challenge throughout the DOE complex. Within the complex, underground waste storage tanks contain approximately 400,000 cubic meters (106 million gallons) of highly radioactive legacy waste from the DOE weapons programs. It is expected that some or all waste will need to be removed from various tanks, during remediation efforts. Also, each site has distinct differences in tank construction, tank materials, amount of in-tank hardware, waste forms, and tank integrity, as well as differing regulations and clean-up criteria. The RPD&E system addresses these issues in support of end users at Oak Ridge National Laboratory (ORNL), Idaho National Engineering Laboratory (INEL), the Hanford Site, and the Savannah River Site (SRS).

At ORNL, Gunitite™ tanks in the North and South tank farms range from 7.6 meters (25 feet) to 15.2 meters (50 feet) in diameter, as shown in Figure 1. Gunitite is a trade name for sprayed-on concrete, commonly known as shotcrete (a material similar to that used in swimming pool construction). These Gunitite tanks have degraded to the point that in some instances, wire mesh appears to be visible in photographs taken inside the tanks. The waste in the tanks is mostly soft sludge with supernate, although some hard dry sludge is present in several of the tanks. It is expected that various kinds of rubble from spalled Gunitite will be found in the sludge.

The main tank system at INEL that is being considered for deployment of RPD&E technology includes the stainless steel high-level waste underground storage tanks shown in Figure 2. These tanks are lined on the sides and bottom with cooling coils. The cooling coils cannot be removed prior to retrieval, and because they are roughly 7.6 to 15.2 centimeters (3 to 6 inches) from the tank bottom, techniques for

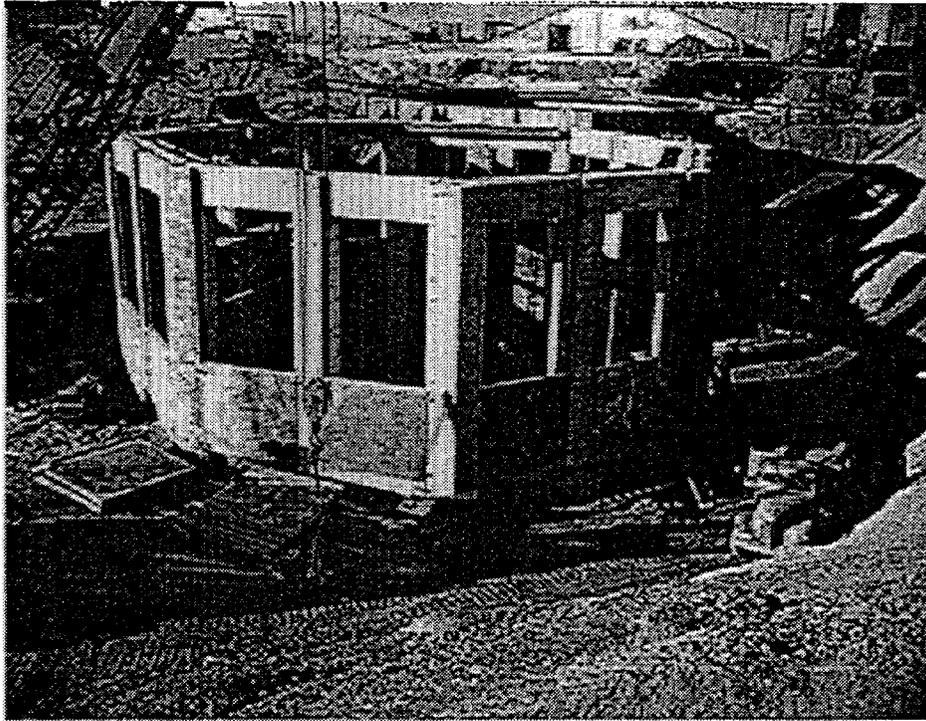


**Figure 1.** Gunite Tank Under Construction at ORNL

cleaning the coils and underneath the coils are required. The waste in the stainless steel tanks is mostly liquid covering a fine sediment layer. In addition, a thin, possibly sticky film (described as a gummy tar-like substance) has also been identified. The liquid waste is highly acidic.

The target problem at Hanford is the waste in the 177 single- and double-shell underground storage tanks. For the 149 single-shell tanks, similar to the tank shown in Figure 3, the major problem is the retrieval of difficult saltcake and sludge in the presence of in-tank hardware and debris. Although use of sluicing methods is expected for many of the tanks, enhancements to sluicing may be required to reduce retrieval time and cost. Furthermore, many of the tanks are suspected leakers and, as such, may require remediation by low water addition methods. Double-Shell Tanks (DSTs) at Hanford and tanks at Savannah River Site (SRS) have wastes that will need to be mixed prior to retrieval. Mixer pumps are currently the baseline for mixing waste in the Hanford DSTs and SRS tanks.

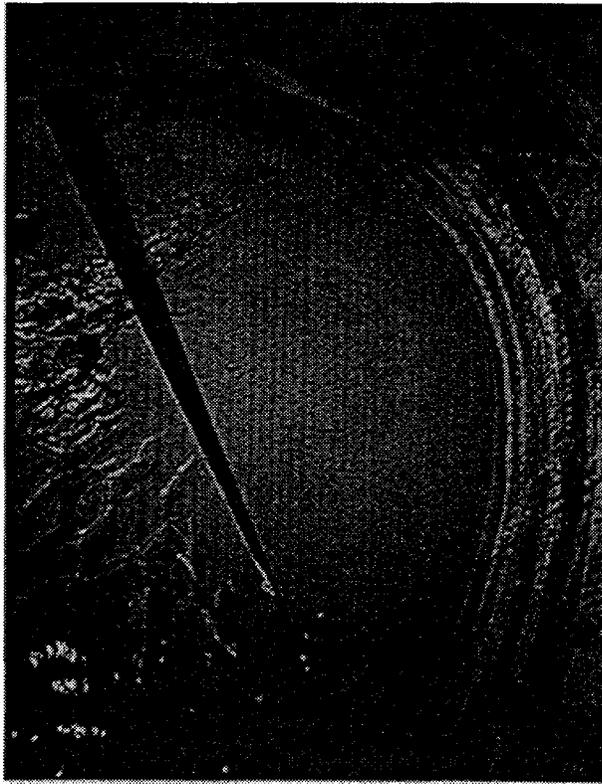
At the SRS, 54 storage tanks are partially aboveground; however, they are vaulted or bermed, which makes them very similar, in terms of waste retrieval, to underground tanks. The tank problems at SRS are somewhat similar to those of the Hanford underground storage tanks; both sites have vast quantities of saltcake and sludge to be removed effectively and efficiently. Furthermore, zeolite still remains from ion exchange processes in several of the SRS tanks. It is unknown whether zeolite, a dense material will break up into solid chunks when struck by sluicing jets or whether it will behave more like beach sand. The interior of one SRS tank is shown in Figure 4.



**Figure 2.** INEL Tank Under Construction



**Figure 3.** Hanford Single-Shell Tank Under Construction



**Figure 4.** Savannah River Tank - Inside Tank 24

## 2.0 Technical Accomplishments

Technical achievements by the RPD&E team in FY96 include providing technologies that address specific retrieval needs for DOE sites. They include the Confined Sluicing End Effector (CSEE) for ORNL, the Extendible Nozzle for SRS and ORNL, and the retrieval end effector for INEL. Other retrieval technologies, such as the Lightweight Scarifier (LWS) and the Particle Size Probe, are under development and meet the needs of multiple sites. Finally, other processes involve enhancements to existing retrieval technologies, including borehole mining and pulsed air systems. Detailed reports on site-specific activities and the other retrieval technologies are listed in the appendix. Technical conclusions and accomplishments of the RPD&E team are summarized in this section.

The technical conclusions and accomplishments include:

- **Oak Ridge National Laboratory** - RPD&E completed the development and construction of a tank waste retrieval end effector, the Confined Sluicing End Effector (CSEE) for the ORNL Gunite and Associated Tanks Treatability Study (GAAT-TS). The CSEE will be deployed in radioactive tanks at ORNL by the Modified Light Duty Utility Arm (MLUDA) and by the Houdini Remotely Operated Vehicle (ROV) in FY97.
- **Savannah River Site** - SRS plans to implement industry-developed, borehole miner extendible nozzle technology to achieve the dislodgement and comminution of solids in a 24.4 meter (80 foot) diameter, high-level radioactive waste tank. SRS and the Tanks Focus Area RPD&E team are collaborating to configure the technology for in tank deployment at the site. The technology will be initially deployed at ORNL to retrieve waste from the Old Hydrofracture tanks in FY97.
- **Idaho National Engineering Laboratory** - RPD&E provided guidance to INEL waste retrieval efforts by documenting the necessary functions and requirements of a waste dislodging and conveyance system for the INEL High-Level Liquid Waste (HLLW) tanks. RPD&E personnel also developed a retrieval test end effector to evaluate cleaning strategies for the cooling coils, walls, and floors of the HLLW tanks.
- **Support of the ACTR Project** - As the Hanford EM-30 task titled "Acquire Commercial Technology for Retrieval" (ACTR) builds a database on technologies available from industry for waste retrieval from single- and double-shell tanks at the Hanford site, the RPD&E team has provided technical support to assess the potential of candidate technologies, using criteria established during prior years of RPD&E testing. This activity not only benefited from the RPD&E experience base, but also facilitated information transfer from ACTR throughout the DOE complex. For FY96, this support included development of a testing strategy for vendor demonstrations, observation of vendor demonstrations, simulant specifications, and development of instrumentation to measure waterjet impact pressure.

- **Pulsed Air** - Tests of pulsed-air mixing plates were performed to correlate mixer design and operating parameters with the ability of pulsed-air mixers to resuspend sludge. Pulsed-air mixers can now be designed for sludge mobilization and mixing applications. A series of tests, using large (full-scale) mixing plates in 45,000 liters (12,000 gallons) of slurry, demonstrated the ability of a pulsed-air mixer to maintain solids in suspension using only a few plates. A feasible pulsed-air deployment concept for a horizontal tank was developed by the University of Washington Applied Physics Laboratory.
- **Particle Size Probe** - RPD&E completed the development of an *in situ* in-line (pipeline) sensor to measure particle size (mean diameter and width distribution) and concentration in tanks and pipelines. The FY96 goal was to develop an integrated method to demonstrate this technology. The sensor has been developed to provide these measurements in near real time. The intellectual property for this sensor has been protected by a pending patent application.
- **Lightweight Scarifier** - The detailed design and fabrication of the Lightweight Scarifier (LWS) was completed and two prototypes were fabricated. The LWS weighs less than 50 pounds. Scarifier testing was initiated to provide baseline operational performance data. Saltcake recipes were specified by the Simulant Development Subtask to create test material in the 14,000 to 28,000 kPa (2000 to 4000 psi) compressive strength range. The objectives for sludge testing were to minimize water flow and pressure for maximum retrieval and to minimize the changes required in the LWS configuration to switch between saltcake and sludge retrieval.
- **Retrieval Analysis Tool** - The Retrieval Analysis Tool effort was initiated in the fourth quarter of FY96 to match tank candidate waste retrieval technologies and process data to specific tank conditions of the tanks, tank farms, and waste. The tool will reduce uncertainty and risk for retrieval technology decision makers, and accelerate the flow of retrieval technologies from the laboratories, through industry, to users. The basis for the tool is a simplified systems engineering approach that defines retrieval actions at all sites.

### 3.0 FY96 Testing and Conclusions

Brief descriptions of the FY96 accomplishments of each of the waste dislodging and conveyance technology development tasks are given in this section. More information can be obtained from the detailed year-end reports prepared by each of the testing development tasks. These reports are listed in the appendix.

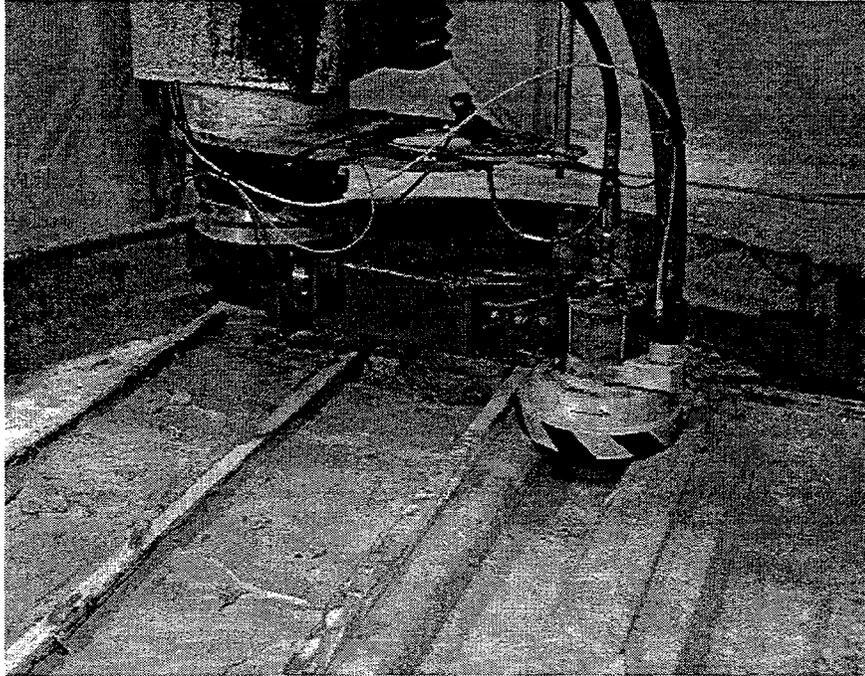
#### 3.1 Oak Ridge National Laboratory - Confined Sluicing End Effector

Retrieval Process Development and Enhancements (RPD&E) project developed a tank waste retrieval tool, the confined sluicing end effector (CSEE) for the Oak Ridge National Laboratory's (ORNL) Gunite and Associated Tanks-Treatability Study (GAAT-TS). In FY97, the CSEE will be deployed in tanks at ORNL and will be deployed by the Modified Light Duty Arm (MLDUA) and the Houdini ROV. The CSEE will be first used to retrieve waste from two tanks in the North Tank Farm. If the technology proves effective, the CSEE will be upgraded as necessary and deployed to retrieve waste from tanks in the South Tank Farm.

The GAAT-TS is tasked with testing and evaluating methods for retrieval of wastes from the buried Gunite tanks at ORNL. Waterjet-based end effectors were selected by the GAAT-TS as one of several retrieval processes to consider, and RPD&E was selected to develop the appropriate technology. In FY95, RPD&E drafted and issued the document *Functions and Requirements for the GAAT-TS Waste Dislodging and Conveyance System* that formed the basis for CSEE specifications and for other retrieval system components to be developed by third parties. In FY96, the RPD&E team developed the retrieval end effector, working in parallel with the developers of the conveyance system, the deployment systems personnel, and the ORNL system engineers and testers. RPD&E team members also provided conceptual design guidance and participated in the design reviews for the GAAT-TS conveyance system.

The Gunite tanks are of uncertain integrity, and it is desirable to remove contaminated Gunite from the interior surface in a controlled manner. Some of the tanks' interior surfaces may be spalled, indicating seriously degraded structure, and it is likely that the CSEE will encounter loose Gunite debris in the waste. The wastes are poorly characterized, moderately alkaline sludges of varying strength and density. Radiation levels are low (100 mR/hr) in the tanks targeted for initial deployment, and moderate (50 R/hr) in some of the other tanks.

The conceptual design work on the CSEE was performed in FY95-96 by the Waterjet Technology Laboratory at the University of Missouri, Rolla (UM-R). UM-R produced a CSEE test article (CSEETA), based on separate-effects testing and earlier test articles. The CSEETA, shown in Figure 5, used a DC servomotor drive, which had been used in two end effectors designed by Waterjet Technology, Incorporated (WTI). The completed CSEETA was sent to WTI and integrated with an existing controller from one of the earlier end effectors. The CSEETA was delivered to Hanford, coupled to a conveyance system patterned after the system planned for GAAT-TS, and tested extensively in the Hydraulic Test Bed (HTB).



**Figure 5. Confined Sluicing End Effector - Test Article**

This testing validated the basic design and provided guidance for refinements. The HTB provided gantry-based deployment to move the CSEE over the waste field to determine performance based on prototypic waste dislodging and retrieval motions.

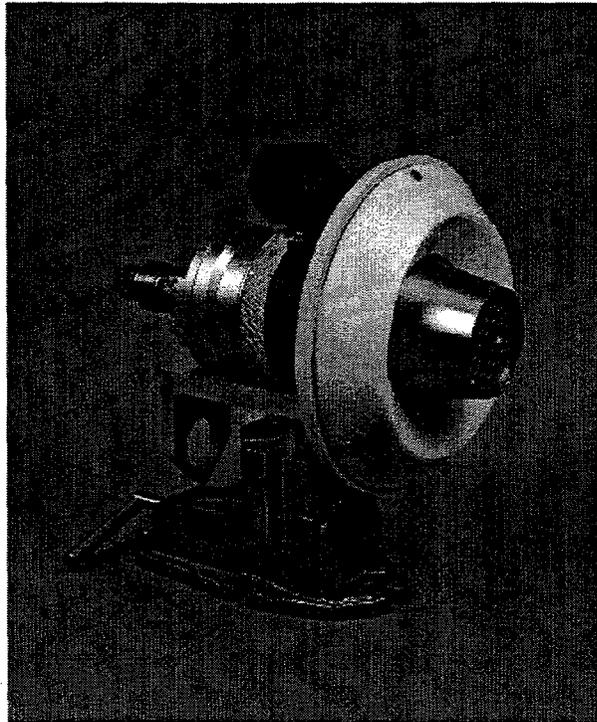
While the CSEETA was being completed at UM-R, WTI was beginning detailed design of the prototype CSEE, and RPD&E was writing the equipment specification. The CSEETA design concept was taken as the basis for the fielded system design. As a result, WTI was able to progress with the design of the motor module, the control system, the main chassis, and part of the waterjet manifold, deferring the jet nozzle and suction inlet details until the initial HTB testing was complete. Interfaces of the CSEE with the Gripper End Effector, which enables the MLDUA to grasp the CSEE, and with the deployment and conveyance systems, were resolved with input from SPAR (manufacturer of the MLDUA) and GAAT-Ts' personnel at the ORNL Robotics and Processing System Division. The 30 percent design review was completed in late February, prior to testing the CSEETA at the HTB.

CSEETA testing started at the HTB in early March 1996 and continued into April. It revealed some unexpected scaling effects in the design of the waterjet array and the inlet shroud. Concept-development testing had been done at low rotation and traverse speeds due to limitations of the UM-R testbed; the early test articles had a comparatively efficient inlet design, which had to be compromised to meet the weight and size requirements of the CSEETA. When the speeds were increased to shift the frequency of

harmonic excitation generated by the CSEE away from the fundamental frequency of the MLDUA deployment arm (0.5 - 1.5 Hz), the inlet scavenging effectiveness decreased markedly. Addition of an inlet discriminator screen further degraded scavenging efficiency. Interactions between the cutting jets, designed to cancel momentum of the streams inside the zone of influence of the suction inlet, were found to be unpredictable. Jet pressure greater than about 1724 kPa (250 psi) resulted in the jets dispersing at the tank floor impact point into fans of water which passed under the inlet without capture and dispersed into the waste simulant. The inlet shroud appeared to fling simulant away from the outer surface, where inadequate clearance-cutting caused the shroud to plow. Some simulant appeared to come from the inside surface, where the centrifugal force induced by the shroud rotation and the momentum transfer from the cutting jets countered the suction of the conveyance system. However, the CSEETA was effective at lower rotational speeds and traverse rates.

Numerous alterations were made to improve the CSEETA inlet nozzle and jet geometry during the HTB testing, and further testing was conducted at UM-R on a similar fixture. Some very dramatic performance gains were demonstrated by some of the configurations tested at UM-R during this phase. However, the configurations that performed best were impossible to package within the physical constraints of the CSEE and the design elements that were already complete. Final guidance on the jet and inlet configuration was provided to WTI in early April, just after the detailed design review. The final design allowed for a hardware limit of stand-off distance and moved the inlet shroud mouth radially inward from its initial location, so the jets would cut more clearance for the rotating inlet shroud. This change was accomplished by tapering the inlet shroud, which also countered the centrifugal pumping action of the original straight cylindrical design. This change also reduced the inlet area and, therefore increased the air velocity at the cost of reducing the open area of the screen, which results in earlier plugging when operating in sludge simulants that included gravel. Tests showed that sludge simulants could be effectively dislodged and mobilized into the suction inlet with 1724 kPa (250 psi) waterjets, which reduces the water consumption and provides a greater safety margin for the tank structure.

The CSEE fielded system, shown in Figure 6, was completed by WTI and acceptance testing was successfully performed June 13 through 17, 1996. The CSEE was then delivered to Hanford where it underwent two weeks of performance characterization tests at the HTB. It performed as expected. The most effective retrieval of sludge up to a 7.6-centimeter (3-inch) depth was at 5.0-centimeters/second (2 inches/second) traverse speed, 60 rpm, and 1724 kPa (250 psi) jets. The first pass typically left a thin layer of slurried simulant, and liquid drained from the surrounding area into the track of the CSEE. This residual slurried material was readily retrieved in a second or third pass. The jets could be run at idle pressure 690 kPa (<100 psi), or even left off, for the second and third passes with little compromise in the final result. The first pass retrieved 29.5 liters/minute (7.8 gallons/minute) of sludge, while consuming 38.2 liters/minute (10.1 gallons/minute) of water at the conveyance jet pump and 8 liters/minute (2.1 gallons/minute) at the CSEE jets. Second and third passes consumed pumping water at the same rate, and retrieved slurry at rates dependent on the remaining depth of sludge. Only a few tests were conducted with quantitative measurement of retrieval rates. A third-pass operation can be expected to retrieve about 1-volume of sludge for 3-volumes of water consumed, and averages about 11.4 liters/minute (3 gallons/minute) when working in sludge without embedded obstacles.



**Figure 6.** Confined Sluicing End Effector - Fielded System

Debris such as wire, rags, rock and gravel, gloves, and dried-out sludge chunks or crystals rapidly clogged the limited area of the inlet screen. In testing, the worst problem was experienced with crushed gravel, which tended to jam the inlet screen cells. Alternative screen designs are being developed to mitigate this problem. Most debris, including the majority of the gravel encountered, could be picked up and carried to a receptacle or specified area, then dropped by valving off the suction conveyance line or jet pump supply. Back flushing with the low pressure water was not always necessary to clear the inlet screen. Sometimes, simply shutting off the suction would drop the debris. Running the CSEE motor was sometimes effective at freeing stuck debris, although it could fly off unpredictably and the spinning eccentric load also produced a harmonic force which might be excessive for the MLDUA.

Further CSEE operational testing will be conducted at the ORNL Cold Test Facility. Some refinements to the hardware are expected. In addition, experience with the equipment will probably lead to significant productivity improvements as the operational procedures and mining strategies begin to mature.

The prototype CSEE exhibited little wear during the HTB testing, and performed reliably. Some wear was noted at the double-lip seal between the rotating manifold assembly and the chassis; this seal prevents leakage of ambient air and fluid into the conveyance entry area in the CSEE, and is not critical to the system performance. It will be critically examined during ORNL cold testing to determine whether wear may allow infiltration of particulates which might add significant friction to the large-diameter seal.

The CSEE also proved reasonably easy to decontaminate. The exterior is readily washed clean with low-pressure fan jets as in the decon spray ring. The interior can be flushed with process water from the conveyance line and residue washed out with a spray wand in the ORNL riser glove box. Decontamination in applications with more highly radioactive wastes will require a remote interior washing system, possibly a modification to the decon spray ring. The motor can and bearing seals proved impervious to 14,000 kPa (2000 psi) fan jets, even at ranges less than 8-inches. Some traces of simulant were found on disassembly, in areas which could be more aggressively decontaminated with the spray wand and, if necessary, washed down again during servicing when working with moderately radioactive wastes.

### **3.2 Savannah River Site - Borehole Miner with Extendible Nozzle**

In FY96, Savannah River Site's (SRS) Tanks 41 and 19 were identified for retrieval demonstration. The contents of these tanks are quite different and pose a variety of challenges. Tank 41 contains primarily saltcake-type waste. One proposed *in situ* processing technique includes a dissolution. This process involves flooding the saltcake surface with water which begins to dissolve the salt. When the liquid reaches the saturation point, the liquid is pumped out of the tank. Tank 19 is believed to be filled largely with 56,780 to 64,350 liters (15,000 to 17,000 gallons) of zeolite, salt, and sludge. Mixer pumps deployed at opposite sides of this tank were operated a number of years ago, resulting in the development of a concentration of solid material away from the mixers. Because the mixers were at opposite sides of the tank, the solids formed an hour glass configuration. Subsequently, water has been added, possibly dissolving some of the salts or influencing the concentrations of zeolite and sludge in the tank. Planned technologies for removal of waste from this tank include pumping out the liquid and testing the solid phase to determine how it can be removed most efficiently. Tank 19 was chosen as the initial deployment site for the extendible nozzle.

#### **3.2.1 Extendible Nozzle Design and Development**

The SRS plan to implement an industry-developed borehole miner with an extendible nozzle to enhance solids dislodging and comminution in a 24.4-meter (80-foot) diameter high-level radioactive waste tank. SRS and the RPD&E team are collaborating to configure the technology for in-tank deployment at SRS. Initial plans were to deploy this technology in FY97 to dislodge hard zeolite deposits remaining at the bottom of Tank 19. Current plans are to identify another tank at SRS with harder, more challenging waste for retrieval in FY98. An alternative currently under consideration is to deploy the borehole miner in FY97 at ORNL to retrieve sludge from the old hydrofracture tanks.

Accomplishments in FY96 supporting borehole miner development and extendible nozzle deployment include:

- Defining the extendible nozzle range of performance through a series of stationary nozzle tests at WTI and a series of extendible nozzle system evaluation tests at Pacific Northwest National Laboratory (PNNL). These tests evaluated the effects on system performance of nozzle diameter, jet pressure, stand-off distance, solid properties, and mining strategy.

- Developing a simulant to bound the properties of the zeolite solids remaining in Tank 19.
- Designing an extendible nozzle system with a 3-meter (10-foot) long extendible arm for radioactive deployment in SRS Tank 19.
- Evaluating the integrated borehole miner concept for deployment at Hanford, ORNL, and the Idaho National Engineering Laboratory (INEL).

### 3.2.2 Background

Borehole mining is an existing technology being developed further for potential application in the retrieval of wastes from Hanford single-shell tanks, Idaho V-tanks, Oak Ridge Melton Valley tanks, Oak Ridge Old Hydrofracture tanks, and SRS tanks. This technology incorporates the deployment of an extendible nozzle for waste dislodging, integrated with a water jet pump for conveyance of the waste. This technology was developed for the oil and gas industry and has strong potential to become a baseline technology for tank waste retrieval as an enhancement to sluicing. In FY96, the performance and deployment aspects of the borehole mining system with respect to underground storage tanks were investigated via nonradioactive demonstration.

The borehole miner consists of two components: an extendible nozzle system for excavation of minerals through small boreholes and a jet pump retrieval system. The extendible nozzle consists of a semi-flexible, extendible, and an erectable arm, that supports a payload at some distance from the entry point in the tank. Extendible arm links range from 5.0 to 30.5-centimeters (2 to 12-inches) in cross-section. These large cross-section links have been designed to support large payloads. An integral jet pump system is used for conveyance. The arm and launching mechanism can be lowered through a relatively small opening for deployment. Inside a tank, the arm can be remotely extended or retracted horizontally and raised or lowered.

The borehole miner incorporates two advances over past sluicing practices. First, the nozzle is deployed on an extendible tension-linked section that can be positioned to impinge directly upon the area to be eroded, significantly improving system performance. Second, retrieval can be accomplished using a close-coupled jet pump, inserted through the same riser, that can function with minimal head. The extendible nozzle technology may significantly improve retrieval by dislodging sludge heels and fracturing saltcake, thereby decreasing the time and water required to provide safe transport of materials in the waste storage tanks.

The extendible nozzle system has several benefits. It enhances sluicing capabilities due to high pressure 3,447 to 20,685 kPa (500 to 3,000 psi), low flow rates of 75 to 757- liters/minute (20 to 200-gallons/minute) and waterjets at small stand-off distances. The extendible nozzle's high pressure waterjet provides increased waste removal volume per unit volume of water. The simplicity of design and operation relates directly to low system costs and low operating costs. The extendible nozzle could also be used to deploy end effectors or manage cable/hose systems. Complete retraction of the extendible nozzle into a compact tool housing allows for deployment through a single, relatively small hole.

The borehole hole miner shown in Figure 7 was deployed underground to centrally mine a 24.4-meter (80-foot) diameter cavity at a depth of 300-feet. The miner's 1.9-centimeter (0.75-inch) diameter nozzle operated at 20,685 kPa (3000 psi) water pressure with a flow rate of 1893 liters/minute (500 gallons/minute). This configuration was used to mine uranium deposits in Wyoming, phosphates in Florida, and tar sands in Canada.

### 3.2.3 Extendible Nozzle Performance Definition

The existing WTI demonstration prototype extendible nozzle shown in Figure 8 is being used for waste retrieval demonstrations. It has a 5-centimeter (2-inch) square arm cross section that holds a high horsepower waterjet nozzle as far as 3-meters (10-feet) from the launching mechanism. This unit can pass through a 30.5-centimeters (12-inch) diameter opening. Factors that affect the scaling up of this design include arm length, payload and dynamic loads, stand-off, mining costs verses system size, and jet pump performance parameters. A similar system was designed for deployment in radioactive waste at SRS.

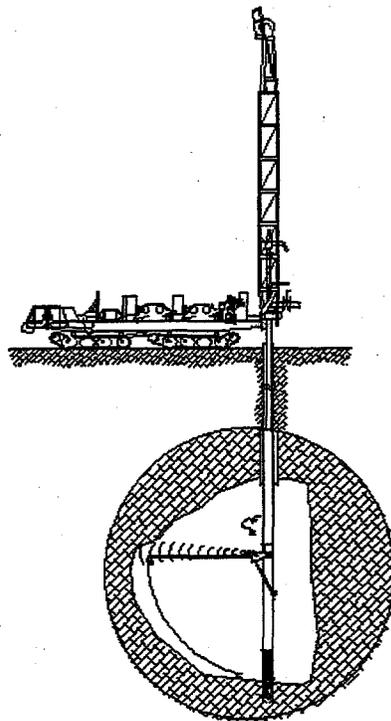
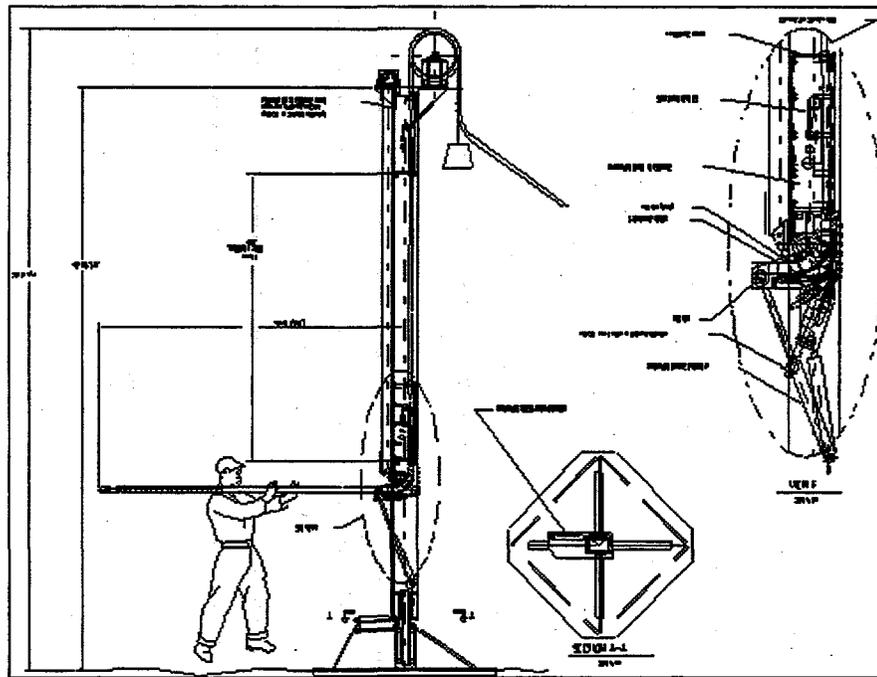


Figure 7. Borehole Miner



**Figure 8.** Extendible Nozzle Prototype

Stationary nozzle tests were conducted at WTI to define the feasibility of this approach. Effects of varying waterjet pressures (3,447 to 20,685 kPa 500 to 3000 psi), flow rates (16 to 61-liters/minute, 50 to 200-gallons/minute), and stand-off distances (6.1 to 15.2-meters, 20 to 50-feet) have been investigated using several saltcake and sludge waste simulants. The results of waste dislodging experiments, to date, show potential for further refinement of this technique. These results helped to define an integrated borehole miner dislodging and retrieval demonstration.

The extendible nozzle tests were conducted at PNNL. These tests evaluated large scale dislodging capability of the borehole miner and the amount of aerosol generation during this process. The test results support extendible nozzle demonstration in a radioactive waste tank. The objective of this task was to develop the experimental data to define system operation in configurations applicable to waste dislodging of solidified wastes.

Tests were performed to evaluate the shape of the waterjet core and the force exerted by the extendible nozzle waterjet as a function of stand-off distance, nozzle diameter, and water pressure. Approaches to mining strategy for extendible nozzles were also evaluated. Jet impact pressure and pressure film data were evaluated to determine the spread of the waterjets. The erosion data will provide a database of jet performance in dislodging waste simulants. The extendible nozzle positioning and nozzle motion will guide development of a mining strategy and deployment approach.

### 3.2.4 Extendible Nozzle Simulants

To specify sluicing or borehole mining system, the tank dimensions, the waste volumes generated during the process, and the waste physical and rheological properties should be bounded. To characterize sluicing performance, the process is separated into: solids mobilization, transport to the retrieval hardware, and retrieval. Sluicing performance indicators associated with jet pumping were identified; however, no simulants were recommended, as integrated extendible nozzle jet pumping tests were not performed during FY96.

Physical properties that are expected to affect sluicing performance include:

1. Shear strength - provides a measure of susceptibility of the solids to erosion, fracture, or cutting.
2. Viscoelasticity - affects how the material breaks, and whether it is deformed rather than eroded.
3. Layer depth - may affect the possibility of using supernate or water to dislodge the solids.
4. Supernate density - may affect the possibility of using supernate to dislodge the solids.
5. Viscosity - affects the ability of the dislodged material to flow to the retrieval device.
6. Particle size distribution and solids settling rates - affects the ease of reusing the supernate after settling and decanting.

### 3.2.5 Borehole Miner Deployment in other DOE Waste Tanks

Borehole miner technology is being investigated as an approach to simplify dislodging and retrieval of hard wastes, such as saltcakes, sludge, hardpan, and other waste types. This approach can be used to clean zeolite and other deposits from tanks at SRS, to remove sludges from tanks at ORNL, to retrieve hard wastes from the Idaho V-Tanks, and, potentially, to retrieve saltcake and sludge from non-leaking single-shell tanks at Hanford.

## 3.3 INEL Waste Retrieval Program

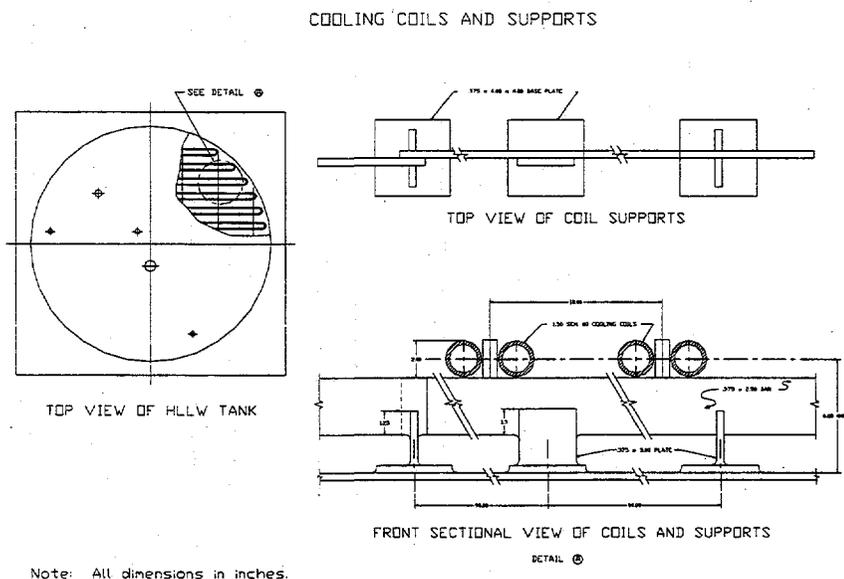
The document, *Functions and Requirements for a Waste Dislodging and Conveyance System for the Idaho National Engineering Laboratory High Level Liquid Waste (HLLW) Tanks* was developed to support the INEL waste retrieval work. This document establishes functions and requirements (F&R) for design of the INEL waste dislodging and conveyance system. This system will be used to dislodge waste from the tank surfaces and convey it to an above ground location for processing. The waste dislodging and conveyance system includes many detailed subsystems, such as the waste dislodging end effector, the manipulator used to position it, the waste conveyance system including its deployment system, the confinement and contamination control system, and the instrumentation needed to control and monitor the waste retrieval process.

The INEL document was developed using the functions and requirements (F&R) document for the ORNL Waste Dislodging and Conveyance System as a template. As a result, the INEL document benefitted greatly from the advanced state of the ORNL system. RPD&E staff (from PNNL and WHC) worked closely with INEL staff to incorporate requirements specific to the HLLW tanks, the waste contained within the tanks, and the procedures and regulations in place at INEL.

### 3.3.1 Development of Retrieval Test End Effector for Cleaning HLLW Tanks

RPD&E support to the INEL waste retrieval effort has included developing a retrieval test end effector to evaluate strategies for cleaning the cooling coils, walls, and floors of the HLLW tanks. This development effort is being conducted by researchers at the UM-R High Pressure Waterjet Laboratory. The end effector design for the INEL tanks addresses a series of challenges different from those considered in other end effector designs to date. Three significant factors have led to changes in the cleaning philosophy that will be applied to HLLW tanks at INEL.

First, the HLLW tanks were constructed with a lattice of cooling coils covering the floors and walls of the tanks as shown in Figure 9. The coils are mounted on a support structure with a stand-off distance of about 15.2-centimeters (6-inches) from the surface of the tank. This complexity of hardware presents many difficult surfaces for cleaning. Second, the floor and cooling coils of the HLLW tanks are covered by a sediment layer, or waste heel, in a nitric acid supernate. This waste heel ranges from 7.6 to 30.5-centimeters (3 to 12-inches) deep, depending on the tank. It consists of particles under finer than the hard large inclusions found at other sites. Some of the solids in the sediment may have similar specific gravity to the supernate, and thus will exhibit flocculent behavior.



**Figure 9.** INEL High Level Waste Tank Internal Configuration

The third fact driving an effective design is those tank inspections have indicated the possible presence of a black tarry substance on the cooling coils, although no specific information is available about its composition or its resistance to cleaning.

The two-pass cleaning strategy is envisioned, based on this waste configuration. First, a rotating array of high pressure waterjets within the retrieval end effector will be used to suspend the sediment and clean waste from the cooling coils and support structure. In the second pass, the retrieval end effector will pass between the cooling coils (at a low stand-off distance from the floor) to suck up the waste suspended beneath the cooling coils.

The INEL end effector design incorporates high-pressure waterjets on a rotating head within a fixed waste conveyance shroud, as shown in Figure 10. This design is a significant simplification of previous designs that included waterjets external to a central rotating suction shroud. The INEL design was adopted because of the absence of hard and thick waste. Without such waste, a jet stream is not required to cut access ahead of the suction shroud. The motor and high pressure swivel are housed in a separate compartment over the cutting and collection chamber. The motor and the high-pressure swivel are similar to components used in earlier systems, for which performance characteristics have already been determined.

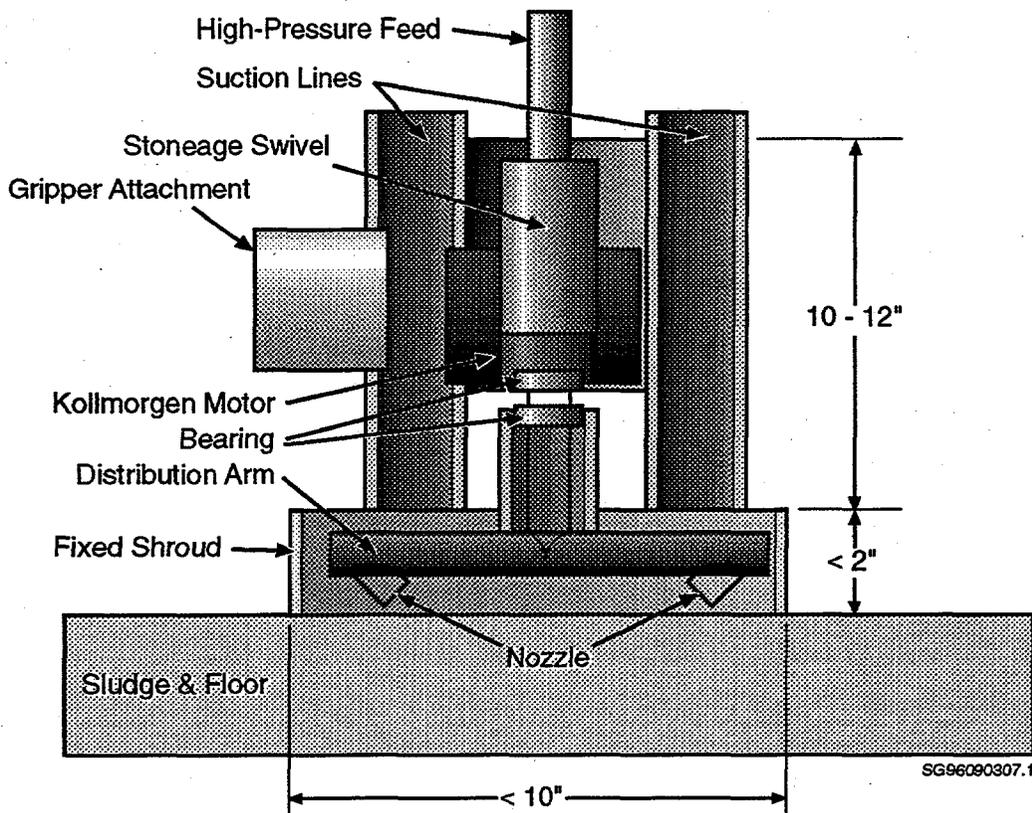


Figure 10. INEL Retrieval End Effector - Test Article Concept

Waste conveyance is accomplished through two small diameter suction hoses positioned in line with the gripper interface. This configuration provides maximum clearance on two sides of the shroud so that it can slide under the cooling coils. The end effector must reach about 8.9-centimeters (3.5-inches) beyond the vertical projection of the coils to fully clean beneath the coils. The design allows adjusting the downward angle of the nozzles to optimize the cleaning performance of the end effector. Allowing a small amount of outward flow from the nozzles may act to mobilize the rim of material just outside the normal zone of influence of the suction, sucking material into the shroud after the nozzle array rotates past it.

### **3.3.2 Application of Other Waste Retrieval Techniques to INEL V-Tanks**

Other waste retrieval techniques being investigated by RPD&E may be well suited for cleaning the INEL V-Tanks. The V-tanks are horizontal cylindrical tanks, compared to the upright cylindrical shape of the HLLW tanks. Tanks V-1, V-2, and V-3 are 5.5-meters (18-feet) long and 3.0-meters (10-feet) in diameter; tanks V-13 and V-14 are 16.8-meters (55-feet) long and 3.8-meters (12.5-feet) in diameter. These tank designs include an access at one end of the tank. Such cleaning technologies as the pulsed-air mixer or the extendible nozzle and borehole miner, may apply under these limited access conditions. Pulsed-air mixing may be effective in suspending the particulate sludge in the supernate to allow pumping from the tanks. The extendible nozzle and borehole miner may be applicable, due to the ease of inserting and positioning the nozzle for cleaning the remote end of the tank and due to the integrated retrieval system.

### **3.4 Support of the Hanford ACTR Project**

During FY96, the ACTR program sponsored retrieval equipment demonstrations to determine the feasibility of candidate technologies for a range of Hanford waste tank simulants. Commercial off-the-shelf equipment was configured at a scale that may be used in a Hanford tank. Surveys of available technologies for waste retrieval have been conducted previously and used to guide some of the retrieval technology development efforts at Hanford. Because some of the requirements have changed, the previous technology surveys were reviewed by ACTR in an effort to identify promising technologies previously not considered because they violated certain operational requirements.

Candidate retrieval technologies were also identified by reviewing vendor responses to open requests for proposals issued by ACTR. Vendors with proposals that were judged favorably received a subcontract from the ACTR program to demonstrate the performance of their proposed retrieval approaches using test materials. During the past year, the RPD&E team has been involved in several activities in support of the ACTR team, including 1) developing a testing strategy for vendor demonstrations, 2) developing test materials for retrieval demonstrations, 3) observing vendor demonstrations, and 4) developing instrumentation to measure impact pressure. Descriptions of these activities follow.

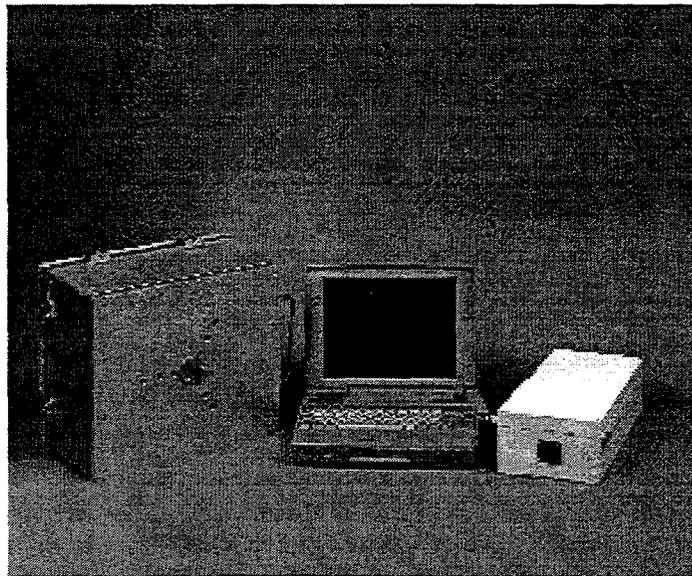
- **Develop Testing Strategy** -To establish a framework for technology evaluation a broad set of retrieval technology test objectives was compiled for the ACTR team to assist in technology demonstration and

test planning. These objectives are the product of a review of past RPD&E test plans, operational test objectives provided by the other retrieval end users (including the GAAT-TS), and a review of the ACTR specific test objectives. These objectives are broad in nature and do not apply to end effectors or other specific devices. The database includes the data requirements for dislodging systems, conveyance systems, mining strategy development, deployment system interface, mechanical cutting, and safety. These test objectives helped the ACTR team to gather critical data required to evaluate candidate retrieval technologies. RPD&E staff also helped write a document for use by ACTR to identify, evaluate, compare, and select commercially developed technologies that could be applied economically at Hanford.

- **Develop and Specify Simulants** - Simulants were needed before the candidate's technologies and processes could be evaluated through testing. The selection process required consideration of the key waste properties for each candidate retrieval method, as well as the expected ranges of these properties. The mechanisms by which the proposed retrieval approach is expected to interact with the waste determine the required chemical and physical properties of the test materials. For example, if the retrieval technique relies upon high-pressure waterjets to break up saltcake into small pieces, the selected test materials should cover the estimated range of properties that are known to influence Waterjet cutting (porosity, tensile strengths, fracture toughness). As part of this activity, the simulant development subtask completed a document entitled *Initial ACTR Retrieval Technology Evaluation Test Material Recommendations (Powell 1996)*. The simulant recipes specified in the document will be used by vendors to represent tank waste during retrieval technology demonstrations. Simulants were specified to cover a wide range of material properties to determine applicability for each technology. The general classes of test materials were limited to the following classes: saltcake, sludge, and hardpan type simulants. Simulant characterization procedures were also included that ensure a suite of simulants consistent for all vendors. This information was furnished to all vendors participating in ACTR demonstrations.
- **Participate in Vendor Demonstrations** - RPD&E staff helped assess the potential of candidate retrieval processes in several ACTR demonstrations and, in some cases, data was collected. The results of this participation are summarized in the following paragraphs.
  - *Crawler with Various Dislodging Devices (ARD Environmental, Inc.)* Two track crawlers were tested against waste simulants using various mechanical dislodging devices and conveyance systems. A rotary cutter, a concrete scabbler, and a jackhammer were used to dislodge the test materials. A positive displacement pump or an air conveyance system was used to retrieve the dislodged material. This testing showed that all simulants could be removed using one or more dislodging techniques. RPD&E staff witnessed the testing and discussed the deployment of EM-50 end effectors on remote crawlers with ARD Environmental.
  - *Medium Pressure Waterjet (MPW Industrial Services Inc.)* Two pieces of medium pressure (10,000 psi) waterjet cleaning equipment was demonstrated: a rotary cleaning head and a water cannon. The cleaning head consists of two rotating nozzles approximately 30-centimeters (12-inches) apart and directed in opposing directions. The head uses 95-liters (25-gallons) per minute of water at 10,000 psi, typically to remove stubborn material inside industrial storage tanks.

The water cannon is a large fixed nozzle mounted to a long lance. The lance is supported by a swivel mount and attached to a protective shield. The cleaning head and water cannon were tested against the matrix of test materials, including saltcake, sludge, and hardpan. To correlate cleaning performance versus stand-off distance, tests were conducted using equipment provided by RPD&E to measure the impact pressure and force of the water cannon at distances from 0 to 2-meters (0 to 6-feet).

- *Sluicing Nozzle (Packer Engineering/Bristol)* A Bristol Equipment tank cleaning system, using a hydraulic sluicing nozzle, was tested against waste simulants at pressures ranging from 20 to 300 psi (140 to 2070 kPa ) and stand-off distances from 0.3 to 19.2-meters (1 to 63-feet). These tests were sponsored by the ACTR program to determine 1) the impact pressure from a sluicing jet at various flow rates, nozzle sizes, and stand-off distances; and 2) the range of applicability of sluicing technology using various test materials, including saltcake, sludge, and hardpan. During this demonstration, tests were conducted using equipment provided by RPD&E to measure the impact pressure and force versus stand-off distance.
- **Impact Pressure Measurement** - To correlate cleaning performance versus stand-off distance, instrumentation was developed by RPD&E to measure the impact pressure and force of waterjets versus stand-off distance. These data are critical, because the maximum effective stand-off distance that can be used to dislodge material will dictate the tank access requirement of candidate Waterjet processes. Two methods were used to measure impact pressure: pressure sensitive film and a pressure sensor array. The pressure sensitive film, developed by the Fuji Film Company, was used to accurately measure the Waterjet pattern (size and shape). It also provided an approximate measure of magnitude of the impact pressure. The pressure sensor and load cell instrumentation shown in Figure 11,



**Figure 11.** Hanford/ACTR Pressure Sensor and Load Cell Instrumentation

consists of three load cells to measure the impact force on a plate 30.5-centimeters wide and 35.6-centimeters high (12-inches wide and 14-inches high) and a pressure array of 10 diaphragm-type pressure sensors to measure impact pressure. The system includes two sets of pressure sensors to measure waterjets from low pressure (0-300 psi) and medium pressure (0-10,000 psi) and a portable data acquisition system. The results of impact pressure testing, using a sluicing nozzle and a 10,000 psi Waterjet, will be reported in a separate document. Figure 12 provides a summary of the impact pressure decay of a sluicing jet and confirms trends reported in published literature.

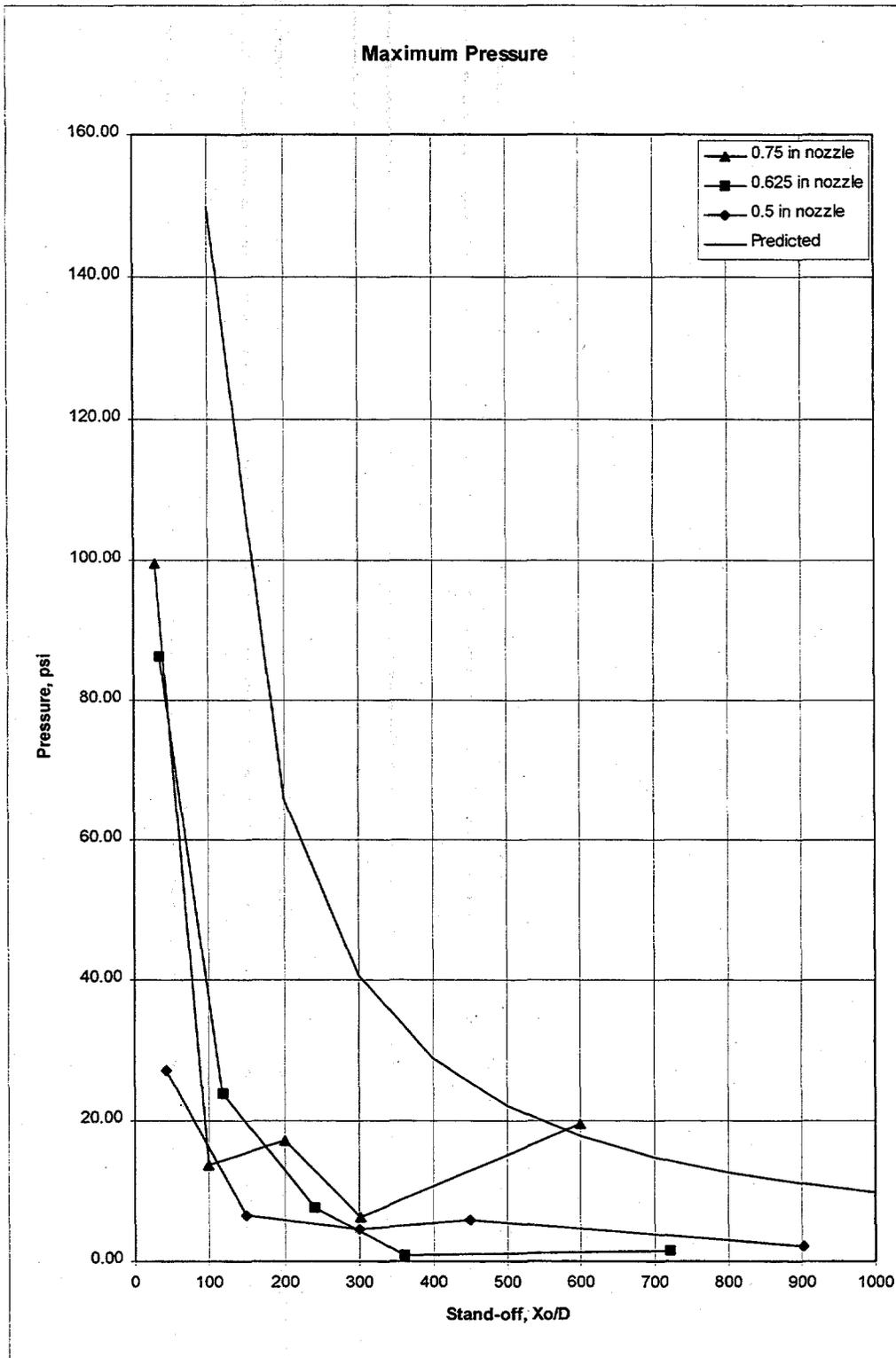
### **3.5 Pulsed-Air Mixing**

This section describes work conducted during FY96 to evaluate the potential application of pulsed-air mixers to the slurry-mixing needs of DOE's waste retrieval programs. Pulsed-air mixers offer considerable cost and operational advantages, compared to the baseline slurry-mixing approach (jet mixer pumps), so pulsed-air mixers are considered preferable wherever their mixing performance is adequate. Pulsed-air mixing equipment has been successfully applied to a number of difficult mixing applications in various chemical process industries. Most previous applications, however, involved the mixing of particle-free viscous fluids. The pulsed-air mixer study described here was performed to improve the understanding of how pulsed-air mixing applies to slurries. A more detailed description of this work is available in Powell and Hymas (1996).

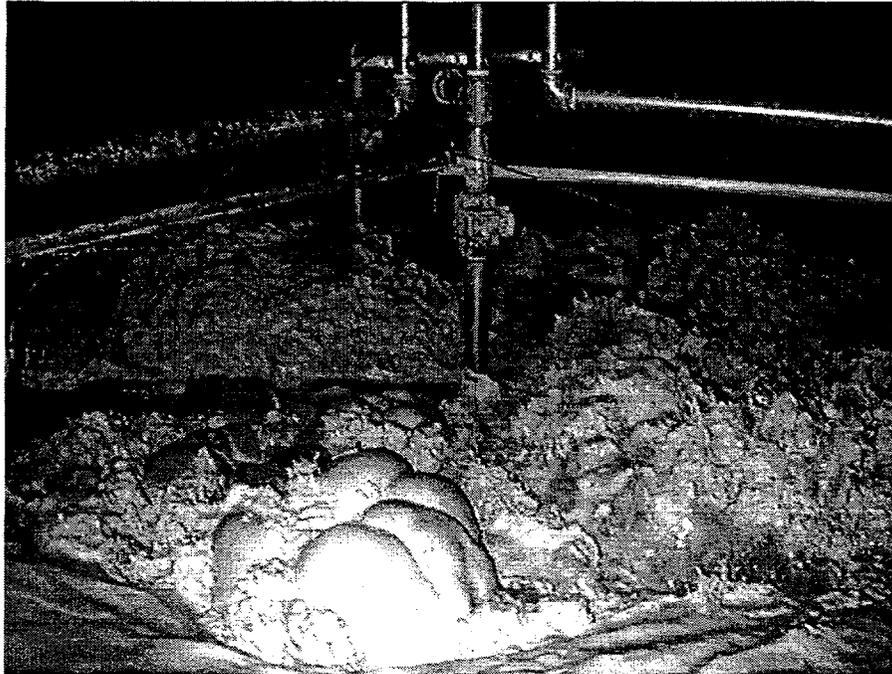
Pulsed-air mixing uses large bubbles introduced near the tank floor to induce slurry mixing. The bubbles are produced by horizontal, circular plates positioned just above the tank floor. Pipes deliver gas to the center of each plate from specially designed gas-pulsing valves, which are commercially available. Pulsed-air mixing differs from conventional air sparging in that single and large bubbles are introduced into the tank fluid periodically (e.g., once every 15 seconds) instead of small bubbles being injected on a continuous basis. The rapid growth of the pulsed-air bubbles near the tank floor and their subsequent rise through the fluid serve to both lift solids from the tank floor and maintain those solids in a uniform suspension.

Measurements of the fluid velocities produced by pulsed-air mixers near the tank floor were made using a hot-film anemometer. The observed peak velocities were correlated with gas pressure, plate diameter, gas-line diameter, and the distance between the plate and the tank floor. These data allow the design of pulsed-air mixing systems using the conservative assumption that the plates operate independently with respect to waste mixing.

The fluid velocity versus mixer design correlations was used to develop a pulsed-air mixer with full-scale mixing plates. This mixer was tested in a 1/4-scale mockup of a Hanford double-shell tank (see Figure 13). This test demonstrated that large-scale circulation patterns induced by the rising bubbles result in better mixing performance than that expected based on the fluid velocity correlations. Resuspension of the settled solids, after a planned mixer outage, was also demonstrated.



**Figure 12. Impact Pressure Decay Summary**



**Figure 13. Pulsed Air Mixer**

Mixer deployment was addressed by the University of Washington Applied Physics Laboratory through a subcontract with PNNL. A feasible concept was developed for deploying the required number of pulsed-air mixing plates into a horizontal underground waste tank, similar to the V-tanks at INEL and the Melton Valley tanks at ORNL. A detailed description of the mixer-deployment process and required equipment is included in this document.

The pulsed-air mixer testing conducted by PNNL, with assistance from Pulsair Systems, Inc., substantially improved the pulsed-air mixer capacity to mobilize tank sludge and maintain solids in suspension. The key findings of the testing:

- Slurry mixing applications, where the goal is to maintain solids in suspension, can be addressed by far fewer plates than are needed for cohesive sludge mobilization. The capability of a single, centrally located mixing plate in the 1/4-scale tank (5.7-meter or 18.75-foot diameter) to maintain approximately 80 percent weight of the solids in suspension demonstrates those large-scale circulation patterns, induced in the slurry by the rising bubbles, effectively maintain solids in suspension.
- The fluid velocities produced by the rapidly expanding gas bubble, near the tank floor are sufficient to stir up cohesive tank sludge. The sludge is mobilized by the pulsed-air bubble to a distance from the center of the plate characterized by the bubble pulse radius ( $R_{pulse}$ ). The bubble pulse radius has been

correlated with mixing plate diameter, gas pressure, gas line diameter, and plate stand-off distance. Thus, pulsed-air mixers can be designed to mobilize sludge by distributing the mixing plates such that the plates are spaced roughly  $2R_{pulse}$  apart.

- Due to the large number of mixing plates required to cover the tank floor in sludge mobilization applications, deployment of pulsed-air mixers in large-diameter, flat-bottomed waste tanks present a challenge. However, sludge mobilization is probably feasible in other tanks where the tank geometry is different. For example, the sludge in the 55-foot long INEL V-tanks can be resuspended by deploying only four mixing plates along the tank bottom. Deployment of four mixing plates into a horizontal tank design is addressed in this document. A similar mixer and deployment design is probably applicable to the Melton Valley tanks at ORNL.

In summary, pulsed-air mixers are best applied to slurry-mixing problems either where the tank is relatively small and the sludge is flocculent and soft, or where mixing will be facilitated by gravity, either through tank design (such as V-tanks and Melton Valley tanks) or through slurry density gradients, e.g., hydrogen mitigation in Hanford tanks 101-SY and 103-SY. Large-diameter tanks require the deployment of an unrealistically high number of mixing plates to achieve sludge mobilization.

Several issues must be addressed before pulsed-air systems can be installed in radioactive waste tanks. First, when the mixing plates are operated using a relatively high gas pressure to generate the bubble (690 kPa or 100 psi), a considerable shock wave can be produced within the waste. The effect of the shock on the structural integrity of the tank must be examined to ensure that the tank is not damaged. Shockwave intensity can be reduced by operating the mixer at a lower pressure, but this decreases the bubble pulse radius. It may be possible to alleviate much of the shockwave by making small changes to the pulse valve and gas line designs.

The second issue to be addressed is aerosol generation. A fine mist of waste slurry is formed when the large bubbles break the waste surface. Whether the rate of aerosol generation is large enough to be of concern, is not yet known. This rate is primarily an operating cost issue; that is, a higher aerosol generation rate requires that the tank ventilation system be designed with greater capacity. The pulsed-air aerosol generation rate is probably similar to or smaller than that for tank sluicing. Thus, it is unlikely for the pulsed air aerosol generation rate to require prohibitively expensive tank ventilation systems.

Pulsed-air mixing is recommended for mobilizing and mixing the solids in Tanks V-3 and V-4 at INEL in preparation for retrieval of the waste slurry. Before deployment, it will be necessary to address tank vibration and aerosol effects, but these issues are expected to be resolvable. An additional application of pulsed-air mixing maybe the flammable-gas mitigation in selected Hanford double-shell waste tanks, such as 101-SY. A single, centrally located mixing plate, pulsed at a low frequency and at low gas pressure (to avoid shockwave effects), may effectively prevent the accumulation of flammable gases within the layer of nonconnective waste. A pulsed-air mixer in Tank 101-SY would not be susceptible to mechanical failure, as is the existing gas-mitigation mixer pump.

## 3.6 In-Line Particle Size and Concentration Measurement

In FY96, the DOE TFA sponsored development of an in-line sensor to measure *in situ* particle size and concentration of slurries in tanks and pipelines. The FY96 goal was to develop an integrated method to demonstrate this technology. A system has been developed to provide particle size and concentration measurements. A patent application has been submitted for this technology.

Radioactive wastes at DOE sites are mainly stored as mixtures of settled solids in the form of sludges. These wastes are transported as slurries with high solid contents. Many sites prefer to dilute these slurries or dissolve the wastes prior to retrieval and transport. Methods of measuring slurry concentration and particle size are not currently available that can be placed in process line, conveyance line, or in tank waste. Therefore, this instrument fills a void and provides sites with methods for real time process monitoring and control. Sites identified for potential radioactive deployment include ORNL waste conditioning module for GAAT waste transfer to the MVST and several of the LLW and HLW transfers at Hanford.

### 3.6.1 Relationship Between Particle Size and Ultrasound

Sound has long been used as an effective means for nondestructive evaluation and characterization of homogeneous and heterogeneous media. Numerous methods have been developed with the common benefits of suitable penetration into complex media, real-time response, and mechanical simplicity and robustness in adverse environments. This combination of attributes is attractive for *in-situ* characterization of radioactive wastes.

A body of knowledge on the spectral attenuation characteristics of suspensions has been developed to describe the multiple regimes of sound propagation in such media. The regimes pertinent to our application are the viscous, the inertial, and the geometric scattering regimes, in ascending order of frequency. This complex collection of regimes has been shown to depend on the size and distribution of particles in a suspension medium through which sound is passing.

Laboratory attenuation spectra were measured at PNNL for four slurry mixtures with particles ranging in size from a sub micron diameter to approximately 100 microns at frequencies ranging from 0.5 to 10-mhz. These spectra were in agreement with theory.

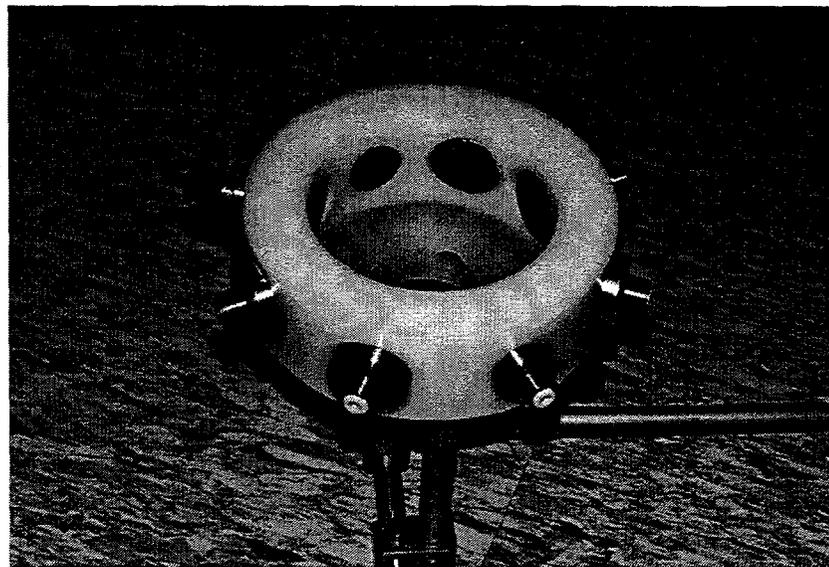
### 3.6.2 Instrument Development

In addressing any inverse problem, the problem must first be shown to have a unique solution. In extracting particle size information from attenuation spectra, only one combination of concentration, mean particle size and distribution width, can result in anyone's attenuation spectrums. The PNNL measurements yielded a unique solution. Furthermore, the solution agreed with independent measurements of size distribution. The degree of agreement depends largely on the accuracy of the model used, and the associated constants of proportion among attenuations, particle size, and frequency. In turn, these constants depend primarily on material properties. For the range of frequencies and particle sizes considered,

the following models were most effective: Atkinson and Kytomaa (1993) for the viscous and inertial regimes and Allegra and Hawley (1971) for the high frequency scattering limit. While the interpretation of the measurement in this method is complex, the effort to date demonstrates that it is widely understood. Furthermore, the associated hardware is simple and mechanically robust, and lends itself well to radioactive environments.

The objective of the present effort was to demonstrate that acoustic attenuation spectra have the necessary attributes to infer mean particle size, a measure of the width of the particle size distribution, particle concentration, and the shape of the size distribution. An equally important objective of this effort was to demonstrate that this information can be obtained non-invasively in a cylindrical device that is part of a slurry transfer pipeline.

On the basis of the measurements that have been made to date and the current state of the associated theory, a working system for sizing has been built and is shown in Figure 14. This instrument aims to quantify particle size distribution; therefore, it should be compared with other methods. The ability to measure size distribution in sizes from sub micron diameters to approximately 100 microns, while quantifying solid concentrations, is unmatched by other existing systems, which tend to be limited in their measuring abilities at the high end of particle size.



**Figure 14.** Immersion Probe for Measuring Particle Size and Concentration

### **3.6.3 In-Line Measurements of Non-Homogeneous Flows**

This sensor provides a true in-line measurement of the process condition without the segregative and other adverse effects of sampling and transporting along a sampling tube that are required by other systems. However two factors, the presence of bubbles and stratified flow, can affect system performance.

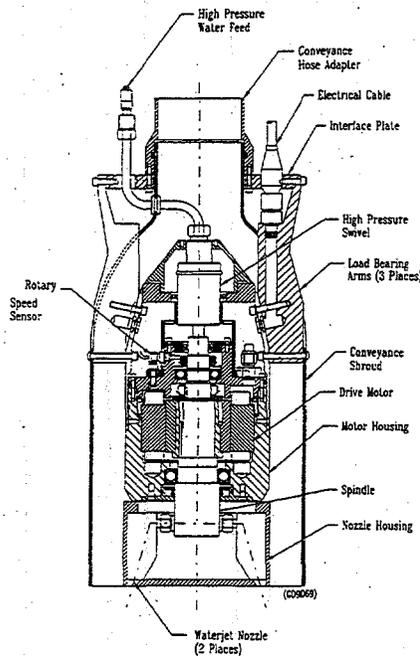
This approach is sensitive to bubbles in the pipe flow. Bubbles will dominate acoustic attenuation, and thereby mask the intended measurement of the instrument. Bubble effects can be minimized by appropriate sensor positioning. The sensor is designed to measure properties of fully mixed, non-stratified homogeneous slurries in which the solids are uniformly distributed over the cross section of the pipe. If the flow is stratified, this technique will only provide size and concentration information over the region occupied by the acoustic beam. With selective transducer placement incipient stratification may be detected. A homogeneous mixture is desired in pipeline applications, and deviations from it may cause plugging of the pipe.

### **3.7 Lightweight Scarifier Development**

The lightweight scarifier (LWS) is being developed for remediation of tanks containing soft to extremely hard wastes, tanks that leak and cannot be safely sluiced, applications where significant waste dilution is not acceptable, and for surface decontamination. The scarifier uses ultra-high pressure waterjets 350,000 kPa (up to 50,000 psi) to fracture and dislodge the waste. The ultra-high pressure waterjets provide extreme power densities to remove material at low water consumption rates. The scarifier is coupled with air conveyance to pneumatically remove the dislodged waste and cutting fluid. Two waterjets are mounted on a manifold and are rotated by an electric motor to mill a channel in the waste as the LWS is moved across the surface. The LWS, weighing 22.7 kilograms (50-pounds) can be deployed inside an underground storage tank by a number of platforms, including an extendible arm, such as the Light Duty Utility Arm or a remote crawler.

During prior years of testing, the performance of the scarifier was evaluated in simulated saltcake and sludge. The target goal for saltcake (200 cubic centimeters/minute) was met and the target goal for sludge was exceeded. Testing was conducted to evaluate retrieval rates, shroud design alternatives, the risk of tank wall damage, Waterjet stand-off sensitivity, various mining strategies, and reaction forces. For this phase of testing, a large prototype scarifier, compatible with a long reach retrieval manipulator, was used. With the development of the LDUA, the need for end effectors that can operate within the envelope of flexible slender arms with limited payloads was created. At the end of FY95, an LWS shown in Figure 15, was designed to incorporate the features of the original scarifier in a smaller and lighter end effector, and maintain the target performance goals.

During FY96, the detailed design of the LWS was completed and two prototypes were fabricated and assembled. A photograph of the LWS is provided in Figure 16. Scarifier testing was initiated in FY96 to provide operational performance data under varying conditions. An objective of the development is to provide a lightweight tool that can retrieve tank wastes ranging from sludge to hard saltcake with minimal water accumulation in the tank. Saltcake recipes were specified by the Simulant Development Subtask to create test material in the 13,800 to 27,580 kPa (2000 to 4000 psi) compressive strength range. The objectives for sludge testing were to minimize water flow and pressure for effective retrieval and to minimize the changes in the LWS configuration needed to switch from saltcake to sludge retrieval. Testing



**Figure 15. Lightweight Scarifier Design**

results are being evaluated and will be reported separately. Testing of the LWS will continue at WTI and also at the RPD&E Hydraulic Testbed in FY97 to correlate Waterjet cutting performance with simulant properties, to evaluate an alternate screen or "discriminator" designs to prevent largely or potentially damaging objects from entering the shroud, and to measure retrieval rates and reaction forces.

Future development of the scarifier will focus on developing alternate uses for the technology, including 1) removal of pumpable components from saltcake fields, 2) cutting boreholes into saltcake for insertion of thermocouple trees, and 3) surface decontamination (such as flat surfaces at close stand-off distances and components or coils at larger stand-off distances). The data generated from these tests are essential to complete the definitive system design of in-tank components.

### **3.8 Retrieval Analysis Tool**

The Retrieval Analysis Tool development was initiated so that data pertaining to retrieval processes across the DOE complex and industry could be collected in a single concise database. Also, waste tank information and waste type data will be collected and decision logic will be incorporated to relate the retrieval processes, tank characteristics, and waste form data. End-users will be able to identify available retrieval technologies and determine the effectiveness, maturity levels, and relative cost information on various alternatives.



**Figure 16.** Lightweight Scarifier - Test Article

The retrieval tool activities were initiated in FY96 using the TFA process for proposals. Six proposals were received and evaluated by a TFA, independent review team. The winning team consisting of Westinghouse Hanford Company, the University of Southern California, and PNNL.

### **3.8.1 FY96 Accomplishments**

1. Developed a conceptual model of the decision tool logic to be implemented next fiscal year.
2. Identified major uses for the tool to define a variety of potential performance parameters and scope.
3. Developed two example decision analyses that further define the decision tool.
4. Identified a strategy that describes a hardware/software approach for the creation of the tool.
5. Developed a template for the evaluation of proposed technology demonstrations that may potentially be incorporated in the final version of the tool.
6. Expanded the EM-30 database to allow for inclusion of tank and technology data from other sites.
7. Held initial contact meetings with teams at ORNL to further define the need for and uses of the tool.

### **3.8.2 FY97 Expectations**

Using available commercial software, primary database information regarding tank conditions and retrieval solutions will be collected from each site. Tank data will be gathered from existing sources currently available for most sites, and additional information will be gathered during site visits. Retrieval technology information will include commercial sources and past studies reviewed to date, and past, current, and projected EM-50 work. Simple queries and data sorts will be implemented using an intuitive user interface. Models of the final decision processes will be available for review and discussion. Ongoing retrieval projects at SRS, ORNL, INEL, Fernald, and Hanford will be included so that validation can begin on cost and performance data.

## 4.0 References

Allegra, J. R., and S. A. Hawley. 1972. *Attenuation of Sound in Suspensions and Emulsions: Theory and Experiments*. Journal of the Acoustical Society of America. 10. Vol 51 No. 5 (Part 2) pp. 1545-1564.

Atkinson, C. M., and H. K. Kytomaa. 1991. *Acoustic properties of solid-liquid mixtures and the limits of ultrasound diagnostics: experiments*. FED Volume 118 Solid liquid flows. American Society of Mechanical Engineers, New York, pp. 145-158.

Jackson, M. K., and T. W. Davies. 1984. *Optimization of Nozzle Flow/Head Requirements for China Clay Mining*. Published in Jet Cutting Technology, 7th International Symposium on Jet Cutting Technology, Sponsored by the BHRA.

Mullen, O. D., Barnes, G. A., Christensen, C., and Potter, J. A. 1996. *Functions and Requirements for a Waste Dislodging and Conveyance System for the Idaho National Engineering Laboratory High Level Waste Tanks*. WHC-SD-WM-FRD-029, Rev 0. Westinghouse Hanford Company, Richland, Washington.

Mullen, O. D. 1996. *Equipment Specification for a Confined Sluicing End Effector, for the Gunite and Associated Tanks Treatability Study*. Westinghouse Hanford Company. WHC-S-04-64, Rev. 0. April 5, 1996. Richland, Washington.

Powell, M. R., and Hymas, C. R. 1996. *Retrieval Process Development and Enhancements FY96 Pulsed-Air Mixing Testing and Deployment Study*. PNNL-11200. Pacific Northwest National Laboratory, Richland, Washington.

Powell, M.R. 1996. *Initial ACTR Retrieval Technology Evaluation Test Material Recommendations*. PNNL-11021. Pacific Northwest National Laboratory, Richland, Washington.

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