INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0492

Borehole Miner

Tanks Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

November 1999

INNOVATIVE TECHNOLOGY
Summary Report

Borehole Miner

OST/TMS ID 1499

Tanks Focus Area

Demonstrated at
Oak Ridge National Laboratory
Oak Ridge, Tennessee

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

TABLE OF CONTENTS

1.	SUMMARY	page 1
2.	TECHNOLOGY DESCRIPTION	page 5
3.	PERFORMANCE	page 9
4.	TECHNOLOGY APPLICABILITY AND ALTERNATIVES	page 11
5.	COST	page 12
6.	REGULATORY AND POLICY ISSUES	page 15
7.	LESSONS LEARNED	page 17

APPENDICES

A.	REFERENCES	page 19
B.	ACRONYMS	page 21

SECTION 1
SUMMARY

Technology Summary

Problem
The U.S. Department of Energy (DOE) has approximately 100 million gallons of tank waste remaining from weapons production. The wastes are stored in underground storage tanks at the Hanford Site, Savannah River Site (SRS), Idaho National Environmental and Engineering Laboratory, Oak Ridge Reservation (ORR), and West Valley Demonstration Project. The wastes have a wide range of chemical properties and physical characteristics that include liquid, sludge, and saltcake. Radiation levels are as high as 10,000 rad/h. DOE plans to remediate the high-level waste by separating the radioactive components from the waste matrix and immobilizing them in glass.

Successful tank waste remediation includes retrieving the waste from the tanks. The liquids are pumped from the tanks, but more aggressive efforts are required to remove the sludges and saltcake without damaging internal tank structures.

How It Works
The Borehole Miner is a waste dislodging and retrieval system demonstrated by Pacific Northwest National Laboratory (PNNL) and Waterjet Technology, Inc. for DOE applications. The design of DOE's Borehole Miner is based on technology used to fracture and remove ore deposits in mines. High-pressure water is pumped through the Borehole Miner's arm, which has an extendible nozzle. The water jet dislodges the waste, and the waste becomes slurry that is pumped from the tank. The solids are allowed to settle, and the water is then pumped through the nozzle again, thus recirculating the Borehole Miner's water supply.

Advantages Over Baseline
Past-practice sluicing is a baseline technology for retrieving tank waste at DOE sites. Past-practice sluicing uses low-pressure water jets to break up and suspend the waste so that it can be pumped out of the tanks. Large quantities of water are added to the tank, increasing the potential for leaks as well as the volume of waste that requires processing. Past-practice sluicing typically requires multiple risers, and many tanks do not have enough risers for conventional sluicing arrangements. Further, this process may have only limited success on difficult waste forms.

Figure 1 shows the Borehole Miner and a tank riser. When compared to past-practice sluicing, the Borehole Miner offers

- increased water jet reach, decreased standoff distance, and a nozzle for precise aim to mobilize waste;
- more sluicing power with less added liquid, including the ability to use recycled slurry;
- the potential for deployment through a single riser;
- lower potential for leaks during sluicing operations;
- the potential for faster waste retrieval rates; and
- reduced risk of radiation exposure to workers and reduced cost of remediation.

Demonstration Summary

The Borehole Miner was used to retrieve waste from the ORR Old Hydrofracture Facility (OHF). Development of the Borehole Miner included the following activities:

Figure 1. The Borehole Miner extendible nozzle, shown oriented 90° from tank riser.

- Beginning in 1996, the Tanks Focus Area (TFA) worked with Waterjet Technology, Inc. (the patent holder) to design and construct the Borehole Miner.
- The Borehole Miner was transferred to ORR in July 1997 to remove sludge from the OHF tanks. The tanks had not been operational since 1980. Removal was made difficult by limited access into tanks.
- Nonradioactive testing began in December 1997 in a tank mock-up facility at ORR. Testing showed the Borehole Miner could successfully dislodge simulated waste even when covered by a deep liquid layer.
- From April 8 through June 28, 1998, the Borehole Miner equipment was moved from the cold-test facility and installed at the OHF site.
- On June 28–29,1998, the Borehole Miner removed 23,000 gal of sludge from Tanks T3 and T9.
- After three previous attempts, the Borehole Miner removed 13,000 gal of waste from Tank T4 on July 13–14, 1998.
- On July 15–16, 1998, the Borehole Miner removed 11,000 gal from Tank T2.
- On July 18–19, 1998, the Borehole Miner removed 13,000 gal of waste from Tank T1.
- In total, approximately 60,000 gal of liquid and sludge low-level and transuranic waste was removed from five tanks.
- On July 29, 1998, a final rinse of the Borehole Miner was performed. Disassembly was initiated on August 6, 1998 and completed on August 28, 1998.

Key Results
The Borehole Miner removed 98% of the waste from the tanks, exceeding its goal of 95% and allowing the State of Tennessee Department of Environment and Conservation to determine that the tanks were cleaned to the maximum extent practicable using pumping technology. At ORR a separate pump was used to remove water and dislodged sludge and heel. Several changes and system features were successfully demonstrated in the OHF Tanks Content Removal Project, including the following:

- The ability to cover the entire area of the tank beneath the nozzle.
- Addition of a visualization system, allowing the operator to see a computer-generated, three-dimensional model of the equipment in the tank.
- A revised design in which the arm actuator was moved from beneath to above the elbow, thereby shortening the lower mast length by approximately 2.5 ft. This modification was made to accommodate a 3-ft-tall obstruction beneath the central riser of one of the OHF tanks but has the added advantage of allowing the nozzle to be operated along the tank horizontal centerline. The new design also simplifies construction and operation.

Participants
Several parties contributed to successful deployment of the Borehole Miner:

- PNNL and Waterjet Technology, Inc. (under contract to PNNL) provided the Borehole Miner and support equipment, as well as on-site support for equipment integration and deployment during testing at the cold-test facility.
- Oak Ridge National Laboratory (ORNL) and Camp Dresser & McKee Federal Programs Company performed nonradioactive testing and deployed the miner in the OHF tanks.
- National Oilwell, Inc. provided on-site support for the high-pressure pump.
- Sandia National Laboratories and PNNL developed a simple operator interface from commercially available software.
- The DOE Oak Ridge Office of Environmental Restoration provided site resources.
- PNNL evaluated data provided by ORNL and issued the report on the system performance and applicability to other tank remediation sites.
- The DOE Office of Science and Technology (OST, EM-50), Waste Management (EM-30) and Environmental Restoration (EM-40) funded the TFA. DOE’s Richland Operations Office leads the TFA. PNNL leads the TFA Technical Team.

Potential Markets
Borehole Miner systems are currently used to mine materials such as oil sands, uranium sands, and phosphates. Potential applications within DOE facilities are horizontal and vertical waste storage tanks, including the large underground waste storage tanks found at Hanford and SRS. In fact, a design for SRS Tank 19, also suited for Hanford’s tanks, is complete through 90% design review. Possible industrial applications include petroleum, chemical processing, and commercial environmental tank remediation.

Commercial Availability
The Borehole Miner is based on a commercially available technology developed in the 1970s and 1980s for the underground mining industry. Waterjet Technology, Inc. has exclusive rights to the technology for environmental cleanup applications.

Contacts

Technical

Judith Bamberger, Principal Investigator, PNNL, (509) 375-3898, ja_bamberger@pnl.gov
Mike Rinker, Principal Investigator, PNNL, (509) 375-6623, mw_rinker@pnl.gov
Cavanaugh Mims, DOE Oak Ridge Operations Office, (423) 576-9481, mimscs@oro.doe.gov

Management

Kurt D. Gerdes, DOE Headquarters Tanks Focus Area Lead, (301) 903-7289, kurt.gerdes@em.doe.gov
Ted P. Pietrok, DOE Richland Tanks Focus Area Lead, (509) 372-4546, theodore_p_pietrok@rl.gov
Pete Gibbons, Tanks Focus Area Technology Integration Manager for Retrieval, Numatec Hanford Co., (509) 372-4926, peter_w_gibbons@rl.gov

Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications." The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for Borehole Miner is 1499.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Demonstration Goals and Objective

Waterjet Technology, Inc. and PNNL cooperatively developed the Borehole Miner system. Cold tests using a variety of simulants evaluated generation of aerosols and dislodging of solids. Variables included jet pressure, nozzle diameter, standoff distance, and jet traverse pattern/mining strategy. The water jets were also tested against a pressure plate to measure their force and against pressure-sensitive film to evaluate jet divergence and coherence.

ORNL selected the Borehole Miner to remove sludge from the OHF tanks. In mining applications, typically both dislodging and retrieval capability are deployed together through one access port. The ORR OHF tanks had multiple risers, and for this demonstration the dislodging system and retrieval pump were deployed in separate risers.

Description of Technology

Figure 2 shows a schematic diagram of the Borehole Miner system. The parts numbered in the diagram are described below.

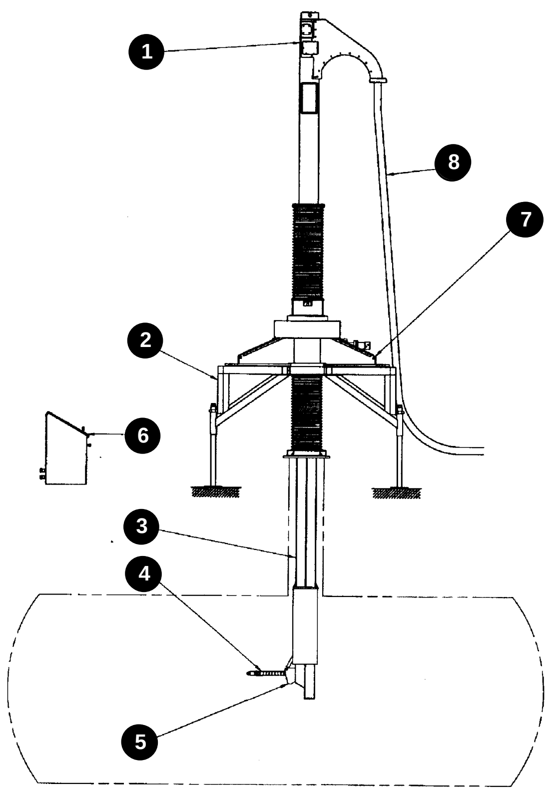

Figure 2. Borehole Miner extendible nozzle sluicing system. Legend: (1) top mast assembly, (2) platform assembly, (3) bottom mast assembly, (4) arm assembly, (5) launch assembly, (6) control console, (7) bridge mount, (8) containment hose assembly. *Source:* Bamberger and Boris 1999.

- *Top and bottom mast assemblies (parts numbered 1 and 3 in Figure 2)*—The mast is approximately 29 ft long and consists of two sections; each section is 14.5 ft long. The top section includes a lifting shackle to carry the weight of the mast and mast mount sections. The arm, arm tensioning assembly, and launch mechanism are contained in the bottom mast. A safety stop is welded to the mast to eliminate the possibility of contaminating the mast from contact with material inside the tank in case the mast is dropped during installation. The axial rotation of the mast is 360°.

- *Platform assembly (2)*—A portable platform over the tank riser is used to support the mast mount assembly. The mast mount assembly includes a bellows-type expanding containment cover to ensure that no radioactive contamination can escape through the riser where the mast is deployed.

- *Arm assembly (4)*—The arm consists of small metallic links that mesh together by bearings and bearing sockets held together with tensioning cables. The 3,000–pound per square inch (-psi) water hose runs through the center of the arm links. The arm is anchored to the tensioning assembly, which incorporates a linear actuator that puts a tensile load on the arm cables, drawing the arm links together and providing a controlled-arm stiffness. The cross section of the semiflexible, extendible, and erectible arm can be varied 2–12 inches in diameter. The precise payload capabilities depend on the cross section of the arm and the distance it is extended. For example, an 8-inch cross section system can support an 800-pound-mass payload at an extension of 200 ft.

- *Launch mechanism (5)*—The arm is extended out of and retracted into the mast by a hydraulic motor–driven chain and tie rod system. The chain moves the tie rod and arm tensioning assembly up and down within the mast tube, moving the arm up and down.

- *Control console (6)*—The arm launch mechanism controls the arm angle by means of linear hydraulic actuators. This system operates with jet arm extensions up to 10 ft. The nozzle angle from the mast can range 30–90°.

- *Bridge mount (7)*—The bridge mount is bolted to the platform over the tank riser and supports the mast assembly at the desired elevation above the tank floor.

- *Containment hose assembly (8)*—Hydraulic hoses serve as conduits between the two mast sections, eliminating the need for hydraulic joints inside the tank.

- *Extendible nozzle*—The extendible nozzle at the end of the water hose is used to sluice the waste into slurry that can be pumped. The sluicing fluid can be pure supernatant, water, or slurry. With adjustments to the mast and arm positions (rotation, elevation, and extension), the extendible nozzle produces a focused stream of liquid to fracture and dislodge solids. The nozzle is not submerged. As waste is dislodged, the nozzle extends to maintain the desired standoff distance between the nozzle and the solids. The 0.38-inch-diameter nozzle was used to sluice the OHF tanks.

Basic Principle of the Technology

The Borehole Miner directs a high-pressure, moderate-flow-rate water jet to retrieve wastes from the walls, floors, and internal equipment of waste storage tanks. The water jet produces pressures of 500–3,000 psi with flow rates of 20–200 gal per minute (gpm). The high-energy water jet is delivered by a nozzle that can be remotely extended 10 ft or more, angled from a horizontal to a nearly vertical position, and rotated about its supporting mast, thus allowing the jet to be directed to any in-tank location. The extendible nozzle is precisely aimed to create a submerged cavity. As material is eroded from the inside of the cavity, it forms slurry that is pumped back to the surface. For tanks with limited riser access, the pump and spray nozzle can be integrated, eliminating a water supply line from the pump, and deployed down a single 12-inch-diameter riser.

Key Elements of the Technology and Support Equipment/Systems

Components of the Borehole Miner system as configured for the OHF tanks are described below. The OHF tanks were the first radioactive application of the Borehole Miner.

- *Transfer pumping system*—A low-pressure transfer pump was used to transfer contents from the sluicing tank to the mixing tank (T9). A mixer and low-pressure feed pump were located in Tank T9 to mix and transfer tank contents to the high-pressure pump.

- *Sluicer pump skid*—The pump skid is used to support a high-pressure pump for the Borehole Miner's water jet, variable-speed drive, valves, and instrument to monitor and control pump pressure. A National Oilwell piston pump provided 1500-psi maximum operating pressure.

- *Visualization system*—The visualization system provided a graphical representation of the system operation in the form of a three-dimensional model. The visualization system provided a variety of views (plan, elevation, section, from the nozzle tip, etc.). Figure 3 is a schematic diagram of the visualization system.

- *Ventilation system*—A high-efficiency particulate air (HEPA) system filtered air discharged from the tank.

- *Associated control systems and connecting piping*—The monitoring system included pressure indicators, switches, flow meters, tank liquid level indicators, video systems, and lead sensors. The nozzle position (elevation, angle from the vertical, and extension length), water pressure, and an operator from a remote control station control flow rate. A collision warning system warned the operator when the Borehole Miner is within a preset distance from an obstacle.

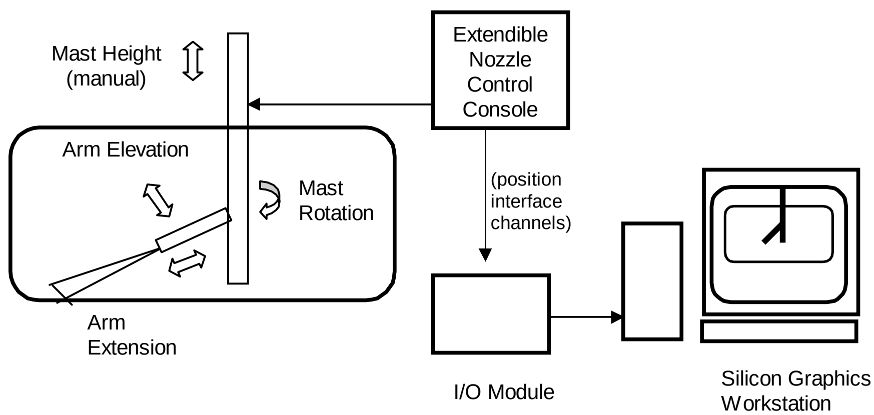

Figure 3. Schematic diagram of the Borehole Miner visualization system.

Specific DOE Application
During the OHF Tanks Content Removal Project, supernatant was used to dislodge and mix settled sludge in the bottom of five ORR OHF tanks. Table 1 shows the specifications for the Borehole Miner system deployed at ORR OHF.

Table 1. Borehole Miner extendible nozzle specifications

Description	Specification
Maximum slurry line working pressure	3000 psi
Design flow rate	150 gpm
Maximum arm extension	10 ft from mast centerline
Arm range of motion Rotation Azimuth	 ±180° 90° (horizontal to vertically downward)
Platform vertical range	30 inches
Weight	6,250 pounds
Maximum arm extension rate	10 inches/second

Description	Specification
Minimum launch angle rate	9°
Mast rotation speed	0.012–1.2 rpm
Maximum arm rinse working pressure	150 psi
Maximum spray ring working pressure	250 psi

Source: Bamberger and Boris 1999.

System Operation

The basic operational requirements for the Borehole Miner that must be considered during deployments are as follows:

- *Special operational parameters*—Although it was possible for the water jet dislodging system and the jet pump retrieval systems to be deployed together through one riser, the retrieval pump was deployed through a separate riser in the ORR OHF tanks. When the dislodging and retrieval functions of the system are installed separately, operators must monitor retrieval activities to optimize the position of both pieces of equipment relative to one another.

- *Materials, energy, other expendable items*—In addition to normal power requirements, Borehole Miner operation requires a source of cutting fluid for the high-pressure jets. This may be water or recycled supernatant.

- *Personnel required*—Using the Borehole Miner requires operators to install the equipment in tanks and conduct and monitor waste retrieval activities. Operations at ORR were conducted with four operators: one instrumentation and controls engineer, two operations technicians, and one operations engineer to oversee and direct the operation but not actively operate the equipment.

- *Secondary waste stream*—Process water is used to flush transfer lines and equipment.

- *Potential operational concerns and risks*—Waste retrieval can be hazardous due to high radiation levels and dangerous chemical constituents. This is not a unique operational concern for the Borehole Miner, but applies to any activity occurring around waste tanks. Radiation levels should be routinely checked.

- There is a potential for leaks and spills during pumping operations. Hydraulic lines should be routinely checked for leaks.

SECTION 3
PERFORMANCE

Demonstration Plan

Demonstration Site Description

The OHF was constructed in 1963 for the permanent disposal of low-level radioactive waste. Until 1980 the waste from the OHF tanks was mixed with grout and injected about 1,000 ft underground. Five underground storage tanks (T1, T2, T3, T4, and T9) remained at the site. The OHF tanks were made of carbon steel without secondary containment. Tanks T3 and T4 had a rubber lining; the remaining three tanks were unlined. Until 1998, they contained about 10,000 gal of transuranic mixed waste sludge and 43,000 gal of radioactive liquid. Analysis of the waste revealed a total activity of around 30,000 curies. The vast majority of the radioactivity (97%) was located in the sludge. Dose rates of up to 130 milliRoentgens per hour were recorded around the tanks.

The Borehole Miner used supernatant to dislodge and mix settled sludge in the bottom of five tanks. Table 2 summarizes the configurations and waste volumes of the OHF tanks emptied in the Borehole Miner deployment.

Table 2. OHF tank configurations and waste volumes

Tank	Diameter (ft)	Length (ft)	Shell thickness (inch)	Distance from riser to end of tank (ft)	Distance below grade (ft)	Sludge (gal)	Supernatant (gal)	Total (gal)
T1	8	44.1	5.46	6.5	4.7	1,497	10,780	12,187
T2	8	44.1	5.62	6.4	5.6	1,556	10,631	12,187
T3	10.5	42.3	2.36	3.4	4.1	3,115	1,962	5,077
T4	10.5	42.3	6.10	3.3	4.1	2,309	14,789	17,098
T9	10	23.8	4.55	4.8	4.1	1,141	4,929	6,070
Total								52,619

Source: Bamberger and Boris 1999.

Major Objectives of the Demonstration

Borehole Miner dislodging and retrieval experiments were initially conducted in a full-diameter, half-length tank at PNNL to define the ability of the nozzle to dislodge difficult wastes. Saltcake simulants were successfully dislodged by a combination of erosion and dilution. The Borehole Miner was transferred to a tank mock-up facility at ORR for cold testing. The objective of Borehole Miner cold testing was to evaluate the components of the system, train the field operators, and to demonstrate the readiness of the system and the operators for the tank removal action. The tests demonstrated that the system components were effective at dislodging dense materials even at relatively low pressures. Supernatant transfers were initiated after cold testing.

The objective of the OHF Tanks Content Removal Project was to remove 95% of the sludge and supernatant from the OHF tanks and transfer it to Melton Valley Storage Tanks (MVSTs). Although sluicing and transfer were successfully completed on five OHF tanks, several problems arose during sluicing. Addressing operation problems provided valuable lessons learned for future Borehole Miner deployments.

Major Elements of the Demonstration

Based on lessons learned in the cold tests, OHF operations were conducted with four operators. Although the water jet can operate at a maximum pressure of 3000 psi, the 1,500-psi pump limited the maximum operating pressure at ORR, and most operations were conducted at 400 psi. Sluicing was executed using a fixed arm angle and extension. When necessary, the arm angle was varied to push a sludge pile towards the retrieval pump. The skid-mounted system was moved from tank to tank at the OHF site. The existing OHF tank liquid waste was recycled through a pump and filter skid and used to scour the interior of the OHF tanks.

The demonstration addressed the following operational problems:

- Operations were conducted at night due to thermal overload in the in-tank submersible pumps.
- A radiation meter malfunction was repaired.
- The strainer on the discharge valve was unclogged.

The Borehole Miner was able to dislodge and retrieve waste despite equipment problems. At the end of the demonstration, the following equipment was not working:

- A mechanical pressure relief valve on the sluicer pump skid failed, leading to spread of contamination inside the skid.
- Light-emitting diodes on the control unit were not functioning.
- The hydraulic control unit shut down due to low hydraulic oil levels from a leak in a hose.
- The cable controlling the extendible nozzle failed, and the arm did not remain straight when extended.

Boundaries of the Demonstration
During cold tests, detailed records of water usage were not maintained. However, water usage was reported during system operation at OHF.

Results

The Borehole Miner was used to dislodge, mix, and suspend radioactive sludge waste in the OHF tanks. Table 3 summarizes the waste removed from each tank and the total waste transferred to the MVSTs.

Table 3: Waste volumes sent to Melton Valley Storage Tanks during OHF sluicing operations

Tank	Volume (gal)
T3-T9	23,014
T4	13,319
T2	10,643
T1	13,150
Total	60,365

Source: Bamberger and Boris 1999.

The total waste volume transferred includes 8,332 gal of water added during sluicing operations. Water use included flushing of systems and lines between transfers and at the conclusion of the campaign.

Retrieval of 98% of the waste from the five ORR OHF tanks was completed in less than three weeks. The goal of the project was to remove 95% of the waste. At the end of the demonstration, the State of Tennessee Department of Environment and Conservation agreed that the tanks were cleaned to the maximum extent practicable using pumping technology.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The Borehole Miner is an alternative to the baseline of sluicing. In comparison with sluicing, the Borehole Miner provides several benefits:

- *Increased waste volumes retrieved*—Conventional sluicing uses water pressures much lower than the water jets employed through the Borehole Miner. The Borehole Miner is able to mobilize more sludge and saltcake than conventional sluicing due to the high water pressures.
- *Focused, positionable liquid stream*—Positioning the high-pressure water jet close to the sludge and saltcake surface delivers the maximum force from the jets to the waste requiring dislodging.
- *Pressurized water jet with more sluicing power*—This feature minimizes the volume of water added to tank and decreases the standing liquid volumes in the tank during retrieval. Recycled supernatant can be used as the jet dislodging fluid, further decreasing the volume of water added to the tank.
- *Decreased standoff distance and greater jet reach*—This feature enables users to mobilize as much waste possible with the smallest amount of water added.
- *Continuous, integrated jet pump retrieval*—This feature enables the added water to be removed as quickly as it is added. The chance that leakage could cause contamination in the soil and groundwater around and below tanks is decreased.

Technology Applicability

In addition to being applicable to other tanks at ORR, the Borehole Miner could be used for waste retrieval activities at Hanford and SRS. The system demonstrated at ORR was originally designed for demonstration at SRS, and site priority changes led to slight redesigns for use in ORR OHF tanks.

In addition to DOE facilities, the system is applicable to any confined space requiring remote operations, both for remediation and routine cleaning and maintenance operations. This might include tanks at petrochemical, chemical, and pharmaceutical facilities, tank cars, and shipping vessel compartments.

Patents/Commercialization/Sponsor

This system is based on existing commercial systems used in the mining industry. It was further optimized by PNNL and Waterjet Technology, Inc. for removing waste from DOE's radioactive waste tanks, many of which have limited access ports and require remote operations. Waterjet Technology, Inc. has exclusive rights to this technology for environmental remediation activities.

SECTION 5
COST

Methodology

The Borehole Miner requires less time and water to retrieve tank waste than does the baseline, past-practice sluicing. A cost comparison between the two is provided, and cost savings are estimated from the difference. Capital costs are based on estimates available from the Site Technology Coordination Group needs statements. Operating costs are calculated estimates.

Cost Analysis

Table 4 compares the cost for retrieving one tank using the Borehole Miner to that using past-practice sluicing. Capital and operating costs are based on removing 20,000 and 250,000 gal/tank of waste. The 20,000-gal/tank estimate approximates the cost savings realized at ORR. The 250,000-gal/tank estimate approximates savings for larger tanks at Hanford and SRS.

Table 4. Cost comparison between the Borehole Miner and past-practice sluicing

Volume retrieved (gal/tank)	Item	Past-practice sluicing	Borehole Miner
20,000	Capital costs[a]	~$3 million/tank (assumed to be the same as for the Borehole Miner)	~$3 million/tank
	Operating costs	2–3 times greater than for the Borehole Miner	~$25,000/tank
250,000	Capital costs[b]	~$35 million/tank	~$35 million/tank (assumed to be the same as for past-practice sluicing)
	Operating costs	~$630,000/tank	~$250,000/tank
Heel	Other	May incur costs for additional sluicing or a follow-on retrieval system to remove the heel	High-pressure water jets can mobilize heel more effectively

[a]Oak Ridge STCG Needs Statement OR TK-03 Sludge Mixing and Mobilization.
[b]Hanford STCG Needs Statement RL-WT064 PHMC Retrieval and Closure—Hanford Past Practice Sluicing Improvements.

Capital Costs
The capital cost for retrieving 250,000 gal/tank is based on Hanford estimates. Past-practice sluicing requires deployment of a sluicer system (driver, arm, and spray nozzle), a vertical pump system, and a visual monitoring system. Hanford estimates the cost of a past-practice sluicing system to be about $35 million. The cost of Borehole Miner is expected to be similar.

The capital cost for the 20,000-gal/tank system for waste removal is based on ORR estimates. The ORR budget for the OHF tank waste retrieval system design, installation, and operation was about $12 million. The cost included capital costs for the pump skids, instrumentation, and support equipment. In addition, the PNNL cost for the Borehole Miner equipment was about $300,000 (Bamberger and Boris 1999). Research and development costs totaled approximately $1.6 million. Assuming a total cost of about $15 million for five tanks, the average cost per tank is approximately $3 million.

Operating Costs
Improved retrieval efficiency can be translated into reduced operating cost for the Borehole Miner. Calculations are shown below for retrieving 250,000 gal/tank. The operating cost for past-practice sluicing is $630,000/tank or approximately 2–3 times the cost for the Borehole Miner because a greater dilution ratio and lower pumping rate are required to mobilize the waste. The operating cost for retrieving a 20,000 gal/tank is assumed to be ten times less than for retrieving 250,000 gal/tank.

Past-practice sluicing—For the purposes of this analysis, approximately 250,000 gal/tank of waste is retrieved. At a dilution ratio of 10:1, the total volume to be pumped is about 2,750,000 gal. Operating costs for past-practice sluicing are estimated as follows:

<u>Time required for sluicing</u>

- Assume 100 gpm, 6 h/day of operation, or 30 h/week.
- Assume 2,750,000 gal pumped at 6,000 gal/h.
- Sluicing would require 458 h, or 15–16 weeks.
- A time period of 16 weeks is selected.

<u>Cost of riser opening crew</u>

- Assume a 22-man crew required to open a riser and sluicing would require crews to open two risers.
- Assume a riser opening crew = 2 pipefitters, 4 riggers, 2 electricians, 2 millwrights, 2 health protection technicians, 2 supervisors, 1 crane operator, 6 tank farm operators, 1 tank farm person in charge.
- Assume risers are opened at beginning of project and closed at the end.
- Cost = 22 crewmen x 4 h/day x 2 risers x $70/h = $12,320/day x 2 days.
- Total cost equals approximately $25,000.

<u>Cost of sluicing operations crew</u>

- Assume a 9-man crew per riser, two risers.
- Assume 2 sluicing operations crews = 2 x (2 health protection technicians, 6 operators, 1 person in charge).
- Cost = 9 crewmen x 6 h/day operating x 2 risers x $70/h = $7,560/day x 5 days/week = $37,800/week, or $604,800 for 16 weeks.
- Total cost is approximately $605,000.

Borehole Miner system—The Borehole Miner system uses a high-pressure (1500-psi), 150-gpm water jet to dislodge wastes. It can operate with water or recycled slurry as the dislodging fluid. Approximately 250,000 gal/tank of waste will be retrieved with a dilution ratio of 5:1. The Borehole Miner can operate at lower dilution ratios; however, a ratio of 5:1 is required for waste transfer.

<u>Time required for sluicing</u>

- Assume 150 gpm, 6 h/day of operation, or 30 h/week.
- Assume 1,500,000 gal pumped at 9,000 gal/h.
- Sluicing would require 167 h, or 5–6 weeks
- A time period of 6 weeks is selected.

<u>Cost of riser opening crew</u>

- Assume $25,000 (the same as for past-practice sluicing).

Cost of sluicing operations crew

- Assume a 9-man crew/riser, two risers.
- Assume 2 sluicing operations crews = 2 x (2 health protection technicians, 6 operators, 1 person in charge).
- Cost = 9 crewmen x 6 h/day operating x 2 risers x $70/h = $7,560/day x 5 days/week = $37,800/week, or $226,800 for 6 weeks.
- Total cost is approximately $227,000.

Technology Scale-Up
PNNL worked with Waterjet Technology, Inc. to design, construct, and test the Borehole Miner equipment for tank remediation. Two extendible nozzle designs have been developed: a bridge mount for large tanks with bridges and a surface-mounted system for deployment in smaller tanks.

Cost Benefit Analysis
The actual amount of savings will depend on a variety of factors. Cost savings are achieved by the following means:

- reduction in water usage,
- reduction in pumping requirements,
- greater ability to retrieve heel,
- increased effectiveness of sluicing,
- minimum liquid levels remaining in tanks, and
- improved pumping capabilities.

Cost Conclusions

The Borehole Miner uses a reduced volume of water at a higher pressure to potentially remove the tank heel sufficiently to meet closure requirements. Past-practice sluicing uses a large volume of low-pressure water to mobilize waste in the tanks, and it may not be able to retrieve the entire heel. A follow retrieval system may be required with past practice sluicing. Avoiding the deployment of a follow-on retrieval system could save several million dollars per tank. In addition, the current baseline of past-practice sluicing has higher operating costs than waste removal using the Borehole Miner.

SECTION 6
REGULATORY AND POLICY ISSUES

The use of any technology for environmental remediation and waste management is constrained by state, federal, and local regulations, which differ at each DOE site. State and local regulations can vary widely, despite some efforts by the U.S. Environmental Protection Agency (EPA) and states to encourage regulatory reciprocity (acceptance of testing from one state or region to another). Regulatory approval and permitting of the Borehole Miner is linked with the rest of the retrieval and closure process. The decision to use retrieval technology will likely be made considering the performance of all retrieval technologies and the specific conditions of each site, tank, and waste stream. No regulatory or permitting issues have been identified with the Borehole Miner. It does not appear to be controversial in terms of public acceptance.

Regulatory Considerations

This technology should meet with favorable regulatory consideration. Regulatory and permitting considerations for the Borehole Miner are comparable to those for other retrieval technologies. Sites and regulators are eager to remove waste from tanks to allow further processing and treatment, and this technology enables more waste to be removed than other sluicing methods.

Secondary Wastes

There is some increase in waste volume due to the water added through the high-pressure jets, but this volume increase is much smaller than would occur to retrieve waste using conventional sluicing systems. Water addition can be minimized or eliminated by the use of recycled supernatant as the jet dislodging fluid.

CERCLA/RCRA Considerations

This technology is currently being considered for wastes regulated by the Resource Conservation and Recovery Act (RCRA). Hazardous and dangerous waste permit(s) will be required to conduct retrieval operations and operate treatment facilities. Treatment of wastes regulated by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) may be considered at a later date. CERCLA considerations are discussed below:

Human Health and Environment—The overall protection of human health and the environment is high because retrieval operations are automated and conducted remotely. In addition, wastes are removed from tanks that are nearing the end of their design life span and subjected to further processing and treatment that enable them to be stored more safely.

Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)—Compliance with ARARs will be met. Vitrified high-level waste sludge will be sent to an off-site repository for disposal. If CERCLA waste has been immobilized, the off-site disposal facilities must be qualified to accept waste from a CERCLA site.

Long-Term Effectiveness and Permanence—Storage of wastes in the underground storage tanks is a temporary condition. Removing wastes from tanks using the Borehole Miner begins the process of waste treatment, which is anticipated to end with the radionuclides permanently immobilized in grout or glass.

Reduction of Volume, Mobility/Toxicity—The technology removes more waste from tanks than would otherwise be possible, minimizing the volumes of material left behind that could potentially leak from the tank and cause future contaminant migration.

Implementability—Full-scale implementability has been demonstrated in a radioactive waste tank at ORR. The remote operations capability and procedures exist, equipment is commercially available, staff have been trained in the process, and regulatory permits can easily be obtained.

Costs—Costs using the Borehole Miner for retrieval of sludge and supernatant are lower than those for retrieval of an equivalent volume of waste using conventional sluicing.

State and Community Acceptance—State and community acceptance is addressed as part of the total remedial action. The state and community have voiced their desire to remove and treat as much of the waste from underground storage tanks as possible, as rapidly as possible, to reduce risks of leaks, contamination, and migration.

Safety, Risks, Benefits, and Community Reaction

Worker Safety
Radiological exposure of personnel must be kept "as low as reasonably achievable" (ALARA), pursuant to DOE regulations.

Community Safety
Operations with the Borehole Miner would be required to comply with safety policies and guidelines of DOE, EPA, and other applicable regulatory agencies. No unusual or significant safety concerns are associated with this technology.

Environmental Impact
The Borehole Miner reduces the volume of waste remaining in tanks. Removing waste from tanks reduces the potential for contaminant migration in the event of leakage. Operating the Borehole Miner creates moderate noise in the immediate vicinity.

Socioeconomic Impacts and Community Reaction
The Borehole Miner has a minimal economic or labor force impact. The general public is unfamiliar with the Borehole Miner; however, the public has firmly stated that it is interested in removing and treating underground storage waste as quickly and efficiently as possible.

Benefits
The Borehole Miner removes wastes from tanks more thoroughly and with less water than conventional sluicing technologies.

SECTION 7
LESSONS LEARNED

Implementation Considerations

As with every technology, the Borehole Miner has situations for which it is ideally suited and conditions in which it provides more retrieval energy than is needed. The variety of tank construction materials and methods combined with the range of physical, chemical, and radiological characteristics of stored wastes requires that DOE have a range of waste retrieval technologies available for its remediation efforts.

Technology Limitations and Needs for Future Development

The radioactive environment and gritty sludges create a difficult environment for mechanical systems. During the ORR deployment, a variety of conventional operational difficulties were observed: the submersible pumps used for supernatant transfer frequently drew more current than expected, strainers clogged and required flushing, and valve alignments failed in transfer lines. Although these were not directly related to the Borehole Miner system, they do illustrate the types of process issues that will be common during full-scale retrieval activities.

Additional optimization might also be required for tanks of different sizes and configurations. Additional demonstration of the capability to deploy dislodging and retrieval capability through a single riser will also give DOE flexibility in planning retrieval campaigns.

Technology Selection Considerations

As mentioned above, DOE waste tanks are made of several different construction materials and styles and contain wastes with a wide range of physical, chemical, and radiological characteristics. A "one-size-fits-all" retrieval strategy will not be effective or efficient and that DOE will need a range of capabilities available for its remediation efforts. For hard or sticky wastes, simple pumping will not be effective, but the Borehole Miner's high-pressure jets can be used very effectively spraying either water or recycled supernatant. The Borehole Miner can be rapidly installed and removed from tanks; it was installed in five tanks at ORR and successfully retrieved 98% of their waste volumes in less than three weeks.

APPENDIX A
REFERENCES

Bamberger, J. A., D. G. Alberts, C. W. Enderlin, and M. White. 1998. *Borehole Miner—Extendible nozzle development for radioactive waste dislodging and retrieval from underground storage tanks.* PNNL-11730. Richland, Wash.: Pacific Northwest National Laboratory.

Bamberger, J. A., and G. F. Boris. 1999. *Oak Ridge National Laboratory Old Hydrofracture Facility waste remediation using the Borehole Miner extendible nozzle sluicer*. PNNL-12225. Richland, Wash.: Pacific Northwest National Laboratory.

Rinker, M. W., D. G. Alberts, J. A. Bamberger, B. K. Hatchell, K. I. Johnson, O. D. Mullen, M. R. Powell, and D. A. Summers. 1996. *Tanks Focus Area retrieval process development and enhancements FY96 technology development summary report*. PNNL-11349. Richland, Wash.: Pacific Northwest National Laboratory.

APPENDIX B
ACRONYMS

ALARA	as-low-as-reasonably-achievable
ARAR	applicable or relevant and appropriate requirements
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
gpm	gallons per minute
HEPA	high-efficiency particulate air
MVST	Melton Valley Storage Tank
OHF	Old Hydrofracture Facility
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OST	Office of Science and Technology
PNNL	Pacific Northwest National Laboratory
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act
SRS	Savannah River Site
TFA	Tanks Focus Area
TMS	Technology Management System