Innovative Technology
Summary Report

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Multipoint Grout Injection System

Tanks Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Multipoint Grout Injection System

Tech ID 2368

Tanks Focus Area

Demonstrated for
Oak Ridge Reservation
Oak Ridge, Tennessee

Savannah River Site
Aiken, South Carolina

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 the U.S. Department of Energy Office of Science and Technology. A report presents the full range of site cleanup problems that a technology, system, or process will address and its advantages to the site 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 Office of Science and Technology Web site at www.em.doe.gov/ost under “Publications.”

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SECTION 1
SUMMARY

Technology Summary

Problem
The United States Department of Energy is remediating underground storage tanks containing hazardous and radioactive waste resulting from over 50 years of production of nuclear materials. After pumpable waste is removed from a tank, residual sludge and incidental liquids may remain. If the residual waste is ruled to be incidental to reprocessing (see Department of Energy Order 435.1) or deemed to be innocuous, it can be blended with grout materials and solidified in place rather than incur significant cost and risk from further efforts to completely empty the tank. Current site baselines call for removal of all waste to a level that is technologically and financially feasible. Once that level of tank retrieval has been accomplished, the risk level associated with the residual waste must be determined, and, if necessary, the residual waste must be retrieved or immobilized in place.

Solution
The patented Multipoint Injection (MPI™) process was used to immobilize simulated residual waste in three test tanks. The MPI™ process is a robust, industrially proven, high-velocity jet-delivery process that injects and mixes chemical agents with residual waste. The homogeneous mixture hardens and immobilizes the residual waste in place, thereby reducing or eliminating the cost of final retrieval operations.

How It Works
The Multipoint Grout Injection System includes four major components: (1) a grout batch plant (water tank, dry cement storage bin, cement mixer), (2) high-pressure pumps, (3) a lifting frame over the top of the tank, and (4) a patented MPI™ process provided by Ground Environmental Services for injecting grout into the residual waste. All components are commercially available.

Dry cement (grout) is mixed with water or chemicals and pumped at high speeds through MPI™ nozzles into residual tank waste. The high-speed jets of grout vigorously blend with residual tank waste to form a homogeneous mixture which hardens and immobilizes residual waste in place.

Potential Markets
Candidate tanks are those where in-tank immobilization of residual waste enables leaving more residual waste in the tank, reducing expensive final retrieval costs. The use of the MPI™ process has potential application in large-diameter tanks such as the Hanford tanks (Kauschinger and Lewis 2000).

Advantages over Baseline

- Turbulent mixing of injected chemical agents with residual tank waste results in a homogeneous waste form with low leach rates.
- Creation of a stable waste form may reduce or eliminate expensive retrieval costs for residual wastes.
- Turbulent injection fills spaces underneath and behind in-tank obstructions which otherwise might remain void.

The baseline closure method used on two radioactive waste tanks at the Department of Energy Savannah River Site was to pour grout into a tank (OST 1999, Savannah River Operations Office 2000). Tanks 17 and 20 were closed by pouring an initial layer of a chemically reducing grout into the bottom of the tanks. The purpose of this layer was to retard the movement of some radionuclides and chemical constituents. A layer of controlled low-strength material was poured on top of the reducing agents to provide sufficient strength to support the overbearing weight. The final layer was high-density grout.

Demonstration Summary

A demonstration of the MPI™ process was performed in December 1997 at the field test facility of Halliburton Energy Services in Duncan, Oklahoma (Kauschinger, Spence, and Lewis 1998). The purpose of the demonstration was to perform a near-full-scale test on a tank representative of Oak Ridge Tank TH-4. Ground Environmental Services provided MPI™, a patented process that included design of the injection pattern, installation of MPI™ tools and operation of the injection equipment. Approximately 45,140 pounds of grout material was injected through eight injection tools into 17,850 pounds of waste surrogate material. A 63,000-pound monolith was created in less than 8 minutes of injection time. The top of the monolith was solid after a consolidation period of about 12 hours. Analytical data showed that the physical surrogates placed into the tank were uniformly mixed within the monolith.

A second demonstration of the MPI™ process was performed in July 1999 at the field offices of Freemyer Enterprises in Odessa, Texas (Kauschinger, Lewis, and Spence 2000). Near-full-scale tests were performed on two tanks representative of those found in the Old Hydrofracture Facility at Oak Ridge and the Old Radioactive Waste Burial Ground solvent tanks at Savannah River. The target tanks were oriented horizontally rather than vertically, creating a need for an innovative mixing campaign. The solvent tanks at Savannah River present further complications in that they have limited access ports through which to insert injection equipment. Ground Environmental Services was able to design, install, and operate innovative and patented MPI™ tools for the horizontal tank configuration.

Key Results
Significant results from the two demonstrations are as follows:

- A grout formulation was successfully developed and demonstrated.
- Homogeneous mixing of chemical agents with waste surrogate material was achieved.
- Limited access ports for horizontal tanks did not pose a problem for MPI™ application.
- Nozzle plugging problems were eliminated by using new, clean lines for the second demonstration.
- The temperature of grout monoliths during the curing phase reached a maximum of 100°F, which made it unnecessary to install cooling equipment to prevent overheating.

Parties Involved in the Demonstration
The following organizations partnered in the demonstrations of the MPI™ process:

- Department of Energy, Office of Science and Technology, Tanks Focus Area
- Oak Ridge National Laboratory
- Halliburton Energy Services (December 1997 demonstration)
- Freemyer Enterprises (July 1999 demonstration)
- Ground Environmental Services

Commercial Availability and Readiness
The high-volume grout-blending systems and high-pressure pumps used in the two demonstrations are commercially available from multiple vendors. The patented MPI™ process includes installation and operation of injection tools by Ground Environmental Services (see Intellectual Property Disclosure Statement in Section 4.)

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Other

All published Innovative Technology Summary Reports are available on the Office of Science and Technology Web site at www.em.doe.gov/ost under “Publications.” The Technology Management System, which is accessible at this Web site, provides information about Office of Science and Technology programs, technologies, and problems. The Tech ID for the Multipoint Grout Injection System is 2368.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

General Features of the Technology
MPI^{TM} is a patented and proven process for the in-place immobilization of chemical and radiological wastes located in underground tanks, shallow trenches, or pits. The MPI^{TM} process relies on the interaction of multiple, high-speed, monodirectional jets to turbulently mix injected chemical agents with waste. Perturbations such as other jet streams, internal structural members, or internal piping in the path of the jet stream help to disperse the jet streams to create more turbulent mixing. The use of multiple nozzles rather than a single nozzle at an injection point eliminates the need for rod rotation. The high speed and turbulence of MPI^{TM} results in a well-blended mix of grout and waste that hardens into a homogeneous monolith.

The complete Multipoint Grout Injection System includes four major components, a grout batch plant, high-pressure pumps, a lifting frame, and the patented MPI^{TM} process. The grout batch plant typically consists of a water tank, dry cement storage bin, and cement mixer. The capacity of the batch plant should be large enough to supply 20 tons of grout in 5–10 minutes. The batch plant feeds into high-pressure pumps, which together can pump 20 tons of grout in 5–10 minutes. The third component is a lifting frame over the top of the tank which is used to lower MPI^{TM} tools through risers into the tank. The last component is the patented injection process, MPI^{TM}, which includes design of the injection pattern, installation of grout injection tools into the waste, and operation of the injection tools. The proper installation and operation of the injection tools are important to ensure a homogeneous monolith.

Installation of Injection Tools
Four installation steps are required as follows: (1) installation of small-diameter holes in tank domes if there are no available openings, and placement of plastic casings through the openings into the waste, (2) installation of a support and lifting frame over the tank, (3) installation of MPI^{TM} tools into each casing, and (4) connection of MPI^{TM} tools to high-speed grout pumps located away from the tank site. Each of these steps is discussed in greater detail below.

1. *Core Drilling and Casing Installation*
   A review of tank dome openings is conducted to determine the location of available openings 4 inches or greater in diameter. In locations where there are no available openings, there may be a need to drill a 4-inch-diameter hole into the top of a tank. The goal is to have enough injection points to ensure the uniform delivery of grout throughout the waste. Significant savings in cost and time could be achieved through the coordination of tank waste retrieval and waste immobilization activities to ensure that the locations of new risers installed for retrieval meet the needs for MPI^{TM} or that risers for MPI^{TM} are installed at the same time as those for retrieval.

   To provide access for MPI^{TM} tools, plastic casings with sealed bottoms are inserted through the tank top and pushed through the waste until the casings touch the tank floor. The sealed casings provide an open space in the waste for placement of injection tools.

2. *Installation of Support and Lifting Frame*
   The lifting frame is used to facilitate remote lifting of MPI^{TM} tools and provide for local containment over the injection area. Once the frame is in place, the injection tools are attached by steel wire cable. The cables are hung from pulleys suspended over each injection point. Winches located outside the boundaries of the support frame are connected to the cable for raising and lowering the in-tank tools.

3. *Installation of MPI™ Tools*

   Each injection tool consists of multiple jet nozzles that are configured around a short piece of steel rod to provide 360° of coverage. The lifting system is used to lower the steel injection tool through openings in the tank top into the previously installed plastic casings. The injection tool is lowered until it rests on the bottom of the plastic casing. The use of nozzles symmetrically configured on a single rod is appropriate for use only when the injection point is located near the central portion of the tank, i.e., away from the walls of the tank. The location of multiple injection points along the rod is designed to develop a net zero jetting force, which creates a very stable injection tool. For instances where the injection point is near a wall or other obstruction, the jetting nozzles on a single rod can be configured to provide coverage for arcs ranging between 45° and 180°.

4. *Equipment and Connections for MPI™ Tools*

   The MPI™ tools are connected to commercially available high-pressure pumps and grout handling equipment through high-pressure hoses. The high-cost pumps and grout handling equipment are located outside of contamination-control areas. These support systems can be brought to a site once lifting frames, casings, and MPI™ tools have been installed in the tank. The remote positioning prevents contamination of high-cost capital equipment and opens the option to reduce the cost of grout injection by renting rather than purchasing support equipment.

   The amount of hydraulic power required for MPI™ can vary between 800 and 2,000 horsepower. For the 1997 Halliburton demonstration, a 2,000-horsepower engine powered four high-pressure pumps. Two sets of four injection rods with eight nozzles per rod were alternately pressurized to a maximum of 6,000 pounds per square inch. The cycle time for each set of injection rods was about 40 seconds, resulting in a calculated grout flow rate of approximately 400 gallons per minute. The cycling continued until a predetermined amount of grout was injected into the tank.

System Operation

Planning and placement design are important to ensure successful waste immobilization. Placement of casings for MPI™ tools and erection of a support structure on the top of the tank are the major manpower-consuming activities. Once the injection tools are in place, the high-pressure pumps and grout handling equipment can be set up and operated. The force from the high-speed jet streams immediately penetrates the plastic casings when grout is injected. The operation of MPI™ takes very little time relative to the preparation work. For the 1997 demonstration, a monolith weighing 63,000 pounds was created in about 8 minutes of MPI™ operation. Total operation time to create the 40-inch-thick monolith was less than 1 hour.

The plastic casings and injection tools are left in place, full of grout, after injection operations are complete. When the grouted mixture hardens, the inexpensive plastic casings and injection tools become an integral part of the final monolith.

Special Operational Parameters

The high-pressure pumps are used in the oil industry and are commercially available. The grout mixers, grout batch plants, and large engines for the pumps are also commercially available, but expensive. Because these systems are located outside of a contamination zone, the potential for contamination is low. Therefore, renting rather than purchasing such equipment is an option to avoid large capital expenditures.

Materials, Energy, and Other Expendable Items

- The plastic casings and injection tools provided by Ground Environmental Services are relatively inexpensive and can be left in place after grouting.
- High-pressure hoses and support systems are reusable.
- Initial testing is required to ensure the resulting monolith will meet tank closure requirements.

- Grout properties need to be checked to ensure compatibility with injection equipment.

Personnel Requirements
Placement of plastic casings in waste tanks is performed by tank farm operators under the direction of Ground Environmental Services. The need for specialized training is not anticipated for the construction of the support platform and installation of lifting systems over the top of the waste tank. An expert from Ground Environmental Services is required to design the operational parameters for the MPI™ process, which consists of injection points, injection duration, and order of injection. After the expert ensures that the equipment is properly assembled and tested, trained operators can operate the high-pressure pumps and grout handling facilities.

Secondary Waste Stream
The potential for creating a secondary waste stream during MPI™ operation is considered to be low. Relatively inexpensive material (e.g., plastic casings and injection tools) is placed in the tank and expected to remain in place as an integral part of the monolith. Equipment located above the tank is anticipated to require limited decontamination, if any. Systems to prevent backflow of potentially contaminated chemical agents are used to protect capital equipment located outside the contamination zone. A site-specific waste control and disposal plan will address potential contamination scenarios.

Immediately on completion of grout injection, the grout lines must be removed from the top of the risers and flushed with water to remove residual grout before it hardens. Flushing of lines and grout handling equipment is required to minimize the formation of solids with the potential of plugging grout injection nozzles during the next grout injection. Provisions must be made to dispose of flush water containing residual grout.

Potential Operational Concerns and Risks
MPI™ equipment has no moving parts other than the support equipment located away from the tank farm, e.g., high-pressure pumps and grout handling facilities. Pressurized grout flows through high-pressure hoses to the top of tanks. A potential operational concern is nozzle plugging. The presence of multiple nozzles and the inherent redundancy of injection locations allows for continued operation without the need for clearing a plugged nozzle. To minimize the potential for plugging, screening systems are employed in the grout handling facility to prevent large solids from entering the injection system. Adjustments to the grout/water ratio can be used to minimize the plugging potential. Grout handling equipment should be flushed with water immediately after use to prevent residual grout from hardening and potentially plugging nozzles during the next grout injection.

Concerns raised prior to the two demonstrations centered on the potential damage that the jet streams might cause to steel tank walls. During the 1997 demonstration, no damage to the steel tank was observed. As part of the 1999 demonstration, an MPI™ tool was suspended in the center of a 55-gallon steel drum and operated at 6,000 pounds per square inch for about 2 minutes. No metal was cut.
(Kauschinger, Lewis, and Spence 2000).

Steel plates can be cut if high enough pressures are applied long enough through a monodirectional jet close to the surface. Steel plates can be cut if sand and bentonite gel are used as the jetting medium. A 1995 test showed that MPI™ jets jetting cement-based grout cannot cut through ¼-inch steel when operated at 11,000 pounds per square inch with a standoff distance of 1 inch for a duration of 300 seconds (Kauschinger, Spence, and Lewis 1998). By reducing pressure to 6,000 pounds per square inch, by keeping injection durations brief, and by maintaining a distance of 20 inches or more from tank walls, the MPI™ process can be applied without damage to tank walls.

SECTION 3
PERFORMANCE

Demonstration Plan

Demonstration Description

A “cold” (nonradioactive) field demonstration of the MPI™ process was performed in December 1997 at the field test facility of Halliburton Energy Services in Duncan, Oklahoma. Halliburton provided the pumps and grout handling equipment and hoses servicing the tank. Ground Environmental Services provided the MPI™ tools placed at eight locations inside the tank. The demonstration used a test tank representative of the smaller Oak Ridge tanks. The vertically oriented test tank measured 15 feet in diameter by 8 feet in height. Table 1 summarizes the physical characteristics of waste tanks in the Gunite and Associated Tanks Operable Unit at Oak Ridge. Fine sand and cohesive clay pods were the physical waste surrogates used to illustrate the mixing capability of the overall system.

Table 1. Physical characteristics of tanks at Oak Ridge

Tank	Construction material	Orientation	Inside diameter (feet)	Length or sidewall height (feet)	Dome height (feet)	Nominal capacity (gallons)
W-1	Gunite	Vertical	12	8	1.6	4,800
W-2	Gunite	Vertical	12	8	1.6	4,800
W-3	Gunite	Vertical	25	12	2.6	42,500
W-4	Gunite	Vertical	25	12	2.6	42,500
W-5	Gunite	Vertical	50	12	6	170,000
W-6	Gunite	Vertical	50	12	6	170,000
W-7	Gunite	Vertical	50	12	6	170,000
W-8	Gunite	Vertical	50	12	6	170,000
W-9	Gunite	Vertical	50	12	6	170,000
W-10	Gunite	Vertical	50	12	6	170,000
W-11	Gunite	Vertical	8	4.6	1	1,500
TH-4	Gunite	Vertical	20	6.5	2.6	14,000
W-1A	Stainless steel	Horizontal	7.5	13.5	Not applicable	4,000
W-13	Stainless steel	Horizontal	6	11	Not applicable	2,000
W-15	Stainless steel	Horizontal	6	11	Not applicable	2,000
W-16	Stainless steel	Horizontal	8	6	Not applicable	2,000

A second cold demonstration of the MPI™ process was performed in July 1999 at the Odessa, Texas field office of Freemyer Enterprises, which provided the high-pressure pumps for the demonstration. Fleet Cementers, a local grouting contractor, performed the bulk blending of the Oak Ridge grout formulation. Ground Environmental Services provided the patented injection tools, installed the tools, determined the operating parameters, collected data and handled the reporting activities. Lockheed Martin Energy Research Corporation, the managing contractor of the Oak Ridge National Laboratory at the time of the demonstrations, provided the in-tank camera, a lighting system, and two nonradioactive test tanks.

The two horizontal tanks used for the 1999 tests were both 8 feet in diameter, 21 feet long, and representative of the Old Hydrofracture Facility tanks at Oak Ridge and a solvent tank at Savannah River. Figure 1 shows the two tanks used for the demonstration. Table 2 provides physical characteristics of the applicable tanks at Oak Ridge and Savannah River. The tanks used for the demonstration were similar in size to Oak Ridge Tank T-9, which is about half the length of the other four Oak Ridge tanks. The same physical tank waste surrogate was used in both test tanks but was laid out differently.

Figure 1. View of horizontal tanks used for 1999 field demonstration.

Table 2. Physical characteristics of horizontal Oak Ridge and Savannah River tanks

Tank	Site	Construction material	Inside diameter (feet)	Length or sidewall height (feet)	Nominal capacity (gallons)	Internal components
T-1	Oak Ridge National Laboratory (ORNL)	Carbon steel	8	44	15,000	Multiple air spargers
T-2	ORNL	Carbon steel	8	44	15,000	Multiple air spargers
T-3	ORNL	Carbon steel, rubber lined	10.5	42.5	25,000	Multiple air spargers and internal connections
T-4	ORNL	Carbon steel, rubber lined	10.5	42.5	25,000	Multiple air spargers and internal connections
T-9	ORNL	Carbon steel	10.5	23	13,000	Multiple air spargers and submersible pumps
S-21	Savannah River Site	Carbon steel	10.5	38.5	24,000	None noted

Major Objectives
The primary objectives for the 1997 MPI™ process demonstration were as follows:

- Demonstrate the ability to pump the specially developed, Oak Ridge–specific grout formulation under high pressure.
- Use the MPI™ tools to mix the grout with a physical surrogate with both cohesive strength (clay pods) and rapid sedimentation properties (uniform sand).
- Create a homogeneous, near-full-scale monolith.

The objectives for the 1999 MPI™ process demonstration were the same as in 1997, with additional objectives associated with horizontal tank orientation and access limitations that exist in the Savannah River solvent tank. These additional objectives were as follows:

- Create a homogeneous monolith for a horizontal tank configuration.
- Demonstrate a deployment technique for a tank with limited access. To meet Savannah River requirements, injection tools were placed inside the test tank through a 4-inch-diameter riser pipe.
- Demonstrate a grout filter to minimize nozzle plugging. The lines were new and clean; therefore, the planned test of a filter was not needed. No nozzle plugging was observed.

Major Elements of the 1997 Demonstration

The grout mixing operation consisted of three pieces of equipment, including a water tank, bulk cement storage, and recirculating cement mixer. The total volume of grout prepared for the demonstration was approximately 4,000 gallons. The grout was prepared prior to injection allowing for very precise control over the density.

The grout flowed from the recirculating cement mixer through a manifold that supplied the intake side of three tractor-mounted, twin HT-400 high-pressure pumps, each driven by a Cummins V-12 diesel engine. The pumps were arranged in parallel so that up to six could be used at the same time to pump grout at 500 gallons per minute and 6,000 pounds per square inch. The pressurized grout was delivered to the test tank via high-pressure, hard-line piping. To simulate deployment conditions at an actual site, the test tank was located about 200 feet away from the pumps. MPI™ tools were placed inside polyvinyl chloride casings and connected to the hard-line piping via high-pressure hoses.

For the demonstration, a 15-foot-diameter by 8-foot-deep tank was used. The bottom of the tank floor was lined with 6 inches of concrete. The field test used two different physical waste surrogates: fine sand and cohesive clay pods. Approximately 17,780 pounds of sand was used for the demonstration. The total mass of clay pods, including red dye, was about 55 pounds.

Major Elements of the 1999 Demonstration

Two major groups of equipment were used for the 1999 demonstration: (a) a grout dry materials storage vehicle and grout mixing plant and (b) high-pressure pumping units. The grout preparation system consisted of a field bin that contained 100,000 pounds of the Oak Ridge–formulation dry blend; a water storage tank that contained 5,000 gallons of a 6% bentonite gel; and the main grout plant, which contained a field batch mixer capable of bulk blending 3,000 gallons of grout at a single time. Figure 2 shows the grout preparation system. The batch mixer is a key component of the grouting plant because the mixer's capacity represents about 10 minutes of MPI™ operation. This volume represented the entire amount of grout injected at one time for the field demonstration. Therefore, the grout plant production capacity was not a limiting factor for this demonstration.

Figure 2. Mobile grout plant used for 1999 field demonstration.

Figure 3. Trailers with high-pressure pumps.

Three triplex oil-field cementing pumps were used in parallel for the demonstration. Figure 3 shows the pump trailers used in the demonstration. The maximum number of nozzles driven at any one time by these pumps was 24. When the Oak Ridge grout formulation was pumped at an injection pressure of 6,000 pounds per square inch, the corresponding grout flow rate was about 400 gallons per minute. The high-pressure grout was pumped through a four-valve manifold. Each valve was attached to a high-pressure flexible hose connected to a MPI™ tool located inside a test tank.

Four MPI™ tools were used inside the tank mocked up to represent an Oak Ridge Old Hydrofracture Facility tank. The plan view of the four MPI™ tools showed two tools at each air sparger location (one air sparger at each end of the tank along the centerline). Pairs of tools (one from each end) were cycled at approximately 1-minute intervals until 3,000 gallons of grout was injected. Physical surrogate waste material (gravel-sand-clay mixture) was piled against the tank wall in all four corners and along the end walls. The total amount of surrogate material used was about 1,000 pounds. A water layer with silt about 4 inches deep was also present in the test tank.

For the test to be representative of the Savannah River solvent tanks, 4-inch-diameter risers were fitted in the existing tank openings at both ends of the tank. To meet Savannah River requirements, all jetting tools had to be deployed through the small riser openings. The adaptation of the injection tools to fit through the small riser opening was accomplished by deploying the tools on very flexible high-pressure hoses with multiple short steel jetting monitors (jet holders). This configuration enabled a horizontal injection tool to be inserted at each end of the tank and placed on the bottom of the tank. The physical surrogate was a gravel-sand-clay mixture mounded against the tank walls at the ends of the tank. A 4-inch-thick, submerged sandbar was placed along the central axis of the tank. Figure 4 shows the deployment of the horizontal injection tool through the sand.*

Figure 4. Deployment of horizontal injection tool through sand in Savannah River tank mock-up.

*All information in Figure 4 is marked as limited rights data under the terms of the subcontracts between Ground Environmental Services, Inc. and Lockheed Martin Energy Research Corporation.

The horizontal MPI™ tool was installed by inserting a composite steel-Lexan™ plastic carrier casing inside the riser. The carrier casing had a gravity-actuated "coal chute," which was machined flush with the outer wall of the carrier casing. The orientation of the coal chute was pointed in the direction in which the string of horizontal injection tools was deployed. The open chute guided the injection tool out of the vertical carrier casing along a very tight radius of curvature, about 4 feet. As the tool was pushed out onto the coal chute, the chute supported the tool until it was nearly horizontal. The tool exited the chute and was manually pushed along the floor of the tank. Even though there were weld bands every 4 feet along the length of the tank, the horizontal injection tool could be manually pushed over them and through the sand layer.

Once a horizontal MPI™ tool was in place, a vertical MPI™ tool was lowered through the annular space left inside the carrier casing. The vertical injection tool was 1.75 inches in diameter and contained 10 injection nozzles. The purpose of the vertical tool was to mobilize the material packed against the end walls of the tank. The flow pattern developed by the interaction of the horizontal jet streams of the floor tools and the vertical tools resulted in turbulent mixing within the tank. The pairs of horizontal and vertical tools were cycled at intervals of approximately 1 minute until 3,000 gallons of grout was injected.

Results

The 1997 cold field demonstration produced a monolith that weighed about 63,000 pounds. This process took about 8 minutes of injection time using the two sets of MPI™ tools. Thus, the grout was injected at about 4 tons per minute. The 15-foot-diameter by 40-inch-thick monolith was created in less than 1 hour of operation, including the time to open and close valves, reorient the MPI™ tools, calculate the amount of the constituents injected into the tank, and inject the grout material.

The monolith was allowed to cure overnight for about 12 hours before sampling and observations were made. After this time period, the monolith was found to be solid enough to walk on. The top of the monolith was level and had no free water on the surface. Although the surface of the monolith was consolidated, the solidification agents in the grout inside the monolith had not achieved an initial set. Because the solidification agents had not set, the sand surrogate could be mechanically separated from the constituents of the grout. Sand particles were thus used as tracer elements to determine how uniformly the surrogate was mixed within the monolith. Data from nine core samples showed that the measured sand density was near the theoretical density value calculated for a homogeneous monolith.

For the 1999 cold field demonstration, MPI™ operation lasted about 10 minutes for each test tank. The two grouted monoliths were allowed to cure overnight for about 12 hours. The grouted mixtures within each tank hardened during this time period with no free water on top of either of the solidified masses. Core samples could not be taken by hand after 12 hours because the monolith was too hard. Unlike the 1997 test, the 12-hour curing period was sufficient for the internal grout solidification agents to initially set. As a result, sand particles could not be separated from the grout components and used as a tracer to determine the distribution of sand within the monoliths. Visual inspection of samples destructively taken from the two monoliths suggested that the physical surrogate was mixed into each monolith. No evidence of free-flowing physical surrogate material was found in either of the test tanks.

Conclusions

Results from the 1997 cold field demonstration showed that the MPI™ process could be performed with relatively inexpensive equipment located in the tank and with the expensive capital equipment located a distance away. The grout formulation developed by Oak Ridge to meet immobilization requirements for waste material contained in Tank TH-4 was shown to be effectively delivered by the MPI™ process. Physical surrogates were uniformly distributed within the resulting monolith.

The Multipoint Injection process, MPI™, is protected under U.S. Patents Nos. 5,860,907 and 5, 645,377 with several other patents pending.

The 1999 cold field tests showed that the injection locations could be configured to produce a homogeneous monolith in horizontal tanks. A deployment method was also demonstrated for tanks with limited access. The successful use of MPI™ tools deployed in a horizontal string along the tank floor provides a basis for the deployment of the technology in large-diameter tanks.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

The MPI™ process is applicable at sites considering in-tank immobilization of residual waste to meet tank closure requirements. Cold field demonstrations showed that the technology is ready for application on vertically oriented tanks 15 feet in diameter and for horizontally oriented tanks 21 feet long. A means for deploying through risers as small as 4 inches in diameter was also demonstrated. Data collected during the two field demonstrations provides a basis for scaling the MPI™ process for larger-diameter vertical tanks and longer horizontal tanks.

Competing Technologies

The baseline closure method for underground storage tanks is to pour grout into a tank without aggressive mixing with the residual waste. For Savannah River Tanks 17 and 20, a reducing grout material was first poured into the tank as an initial layer to retard the movement of some radionuclides and chemical constituents. A layer of controlled low-strength material was poured on top of the reducing grout to provide sufficient strength to support the overbearing weight. The final layer was a strong grout similar to normal cement.

To enhance the baseline closure method, the MPI™ process could be used to inject and mix chemically reducing grout with the residual tank waste to form the bottom layer in a tank. After injection of the reducing grout, the remaining two layers of grout could be applied using previously deployed baseline methods. This enhancement has two advantages relative to the demonstrated closure method: mixing of injected grout with residual waste material for improved immobilization and minimization of void space caused by in-tank obstructions.

Patents/Commercialization/Sponsor

The Office of Science and Technology Tanks Focus Area sponsored the MPI™ demonstrations. Significant involvement of Oak Ridge staff helped to ensure that results from the two demonstrations would be applicable to Oak Ridge site needs. The high-pressure pumps and grout plant equipment are available commercially. Halliburton Energy Services provided support for the first field demonstration. Freemyer Enterprises and Fleet Cementers provided support for the second field demonstration.

INTELLECTUAL PROPERTY DISCLOSURE: The Multipoint Injection (MPI™) process is a patented technology exclusively licensed to Ground Environmental Services, Inc. (GES) by the inventor, Dr. Joseph L. Kauschinger. The technology is covered under U.S. Patents 5,645,377 and 5,860,907 with other patents pending. The practicality of MPI™ technology has been demonstrated using private corporate funding. The 1999 cold demonstration was performed and the document, ORNL/TM-1999/330, was prepared as part of a subcontract for Lockheed Martin Energy Research Corporation (LMER) at Oak Ridge on a no-royalty-fee basis. In consideration of GES' temporarily waving the royalty fees for the work described in ORNL/TM-1999/330, any information presented at meetings or in reports or technical memoranda submitted as part of the subcontract between GES and LMER (1) are limited rights data, as defined in the subcontract terms with respect to the MPI™ tools and procedures used and (2) will not be construed to provide any other license or transfer of technology to LMER or its subsidiaries, the U. S. government, or any other entity. This intellectual property disclosure statement must accompany any reproduction or use of this memorandum. All rights are reserved by GES.

The limited rights data in this Innovative Technology Summary Report includes the descriptions of injection tools, injection tool installations, and injection tool operating parameters that appear primarily in Sections 2 and 3. As used throughout this report, MPI™ refers to a MultiPoint Injection process that has been patented by Dr. Joseph Kauschinger and is available through Ground Environmental Services Inc. This process includes patented injection equipment, patented installation techniques, and patented operating procedures.

The complete Multipoint Grout Injection System includes three support systems for the MPI™ process which are not patented. The support systems include the grout batch plant, the high-pressure grout pumps, and the lifting frame installed on a tank top to lower MPI™ tools through risers into tank waste.

SECTION 5
COST

Methodology

The following estimated costs for the Multipoint Grout Injection System are based on the assumption that the MPI™ process is implemented in a vertically oriented 50-foot-diameter Oak Ridge tank. Cost savings from the integration of retrieval and closure activities have not been estimated. Costs have not been estimated for future grout formulation work required to meet tank closure requirements.

Cost Analysis

Information in Table 3 is taken from Spence and Kauschinger (1997). Site-specific costs for installing additional tank access holes and for working in the tank farms may be different from those presented in Table 3. Additional costs not provided in Table 3 may include potential liability costs incurred by the private vendor doing the work.

Table 3. Estimated cost for grout injection in a 50-foot-diameter tank

Activity	Cost ($)
Manual installation of 15 access holes	10,000
High-density polyethylene plastic casings plus tips	3,000
Disposable high-pressure hoses and injection tools	43,000
Support equipment for hoses and injection tools	10,000
High-pressure pumping services (mobilization and demobilization)	50,190
Dry blend grout material	10,200
Direct cost subtotal	**126,390**
Site management (40% direct cost)	50,500
Direct cost + management subtotal	**176,890**
License fee for MPI™ injection tools	20,000
Engineering support, health physics, training, security	300,000
Total estimated cost for deployment	**496,890**

Cost Benefits

Actual closure costs for Savannah River Tanks 17 and 20 were approximately $5 million for each tank. The closure cost for 24 Oak Ridge tanks was estimated to be between $4.3 and $5.5 million per tank (OST 1999). The cost benefit from the MPI™ process is highly dependent on tank closure requirements. For a tank that requires only filling with grout, there is no cost benefit. The potential for significant cost benefits from the use of the MPI™ process occurs if expensive retrieval operations can be reduced since more residual waste (when immobilized as a monolith) is allowed for tank closure. Cost benefits will be site and tank specific.

Cost Conclusions

Relative to the baseline tank closure method of pouring grout into residual tank waste, the application of the MPI™ process may be a higher-cost closure alternative. The MPI™ process provides the greatest potential cost benefit when expensive retrieval operations can be reduced.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

The MPI™ process will enhance tank closure methods by providing intimate mixing of grout with residual tank waste. The MPI™ process may not be necessary if simply pouring grout into the tank without aggressive mixing satisfies regulatory requirements. The use of multiple layers of grout poured on top of residual waste material is the preferred alternative contained in the draft Environmental Impact Statement for Savannah River High-Level Waste Tank Closure (Savannah River Operations Office 2000). Tank stabilization and residual waste immobilization through the use of the MPI™ process is an option proposed for tanks at Oak Ridge, Idaho National Engineering and Environmental Laboratory, and the West Valley Demonstration Project.

Secondary Wastes
Injection equipment is left inside the tank after grout injection has been completed. Water is used to flush residual grout out of nonradioactive lines and grout handling equipment.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Evaluation
This section summarizes the nine CERCLA evaluation criteria which apply to the MPI™ process. Note that only Oak Ridge is filling tanks with grout under CERCLA. Hanford and Idaho are satisfying Resource Conservation and Recovery Act (RCRA) requirements, while Savannah River is satisfying state wastewater requirements.

1. *Overall Protection of Human Health and the Environment*

   - The MPI™ process results in a solid monolith which more effectively reduces the mobility of waste constituents of concern, providing for effective long-term protection of the environment.

2. *Compliance with Applicable or Relevant and Appropriate Requirements*

   - The MPI™ process results in a solid monolith which immobilizes residual tank waste as a stable waste form. The MPI™ process is an enhancement to the baseline tank closure method where grout is poured into tanks. Therefore, no compliance issues are anticipated for the MPI™ process where grout is the preferred method for immobilization of residual tank waste.

3. *Long-Term Effectiveness and Permanence*

   - Mixing grout with residual tank waste results in a final waste form that has superior immobilization properties than the layering of grout over residual waste. Long-term effectiveness is expected to be enhanced, thus reducing the long-term risk.

4. *Reduction of Toxicity, Mobility, or Volume Through Treatment*

   - MPI™ will immobilize radiological and chemical contaminants of concern. Bench-scale tests were conducted by mixing sludge from Oak Ridge Tank TH-4 with the grout formulation used in the 1997 field demonstration. The resulting final waste form exhibited excellent leach resistance and physical strength characteristics. Results from the Toxicity Characteristic Leach Procedure for all RCRA metals were below the Universal Treatment Standard for the treated sludge at a 35% waste loading. Tests with surrogate sludge containing strontium-85 and cesium-137 showed the final grouted waste form had leachability indexes greater than 10. The Nuclear Regulatory Commission performance criteria recommend leachability indexes greater than 6, meaning that the leach resistance of the waste form from bench-scale tests exceeded the Nuclear Regulatory Commission criteria by four orders of magnitude.

5. *Implementability*

- The MPI™ process was successfully demonstrated in two cold field demonstrations.
- Deployment of the MPI™ process was planned for fiscal year 2000 in the Oak Ridge Tank TH-4. Tank closure requirements for this tank ultimately did not require the immobilization of the residual waste; therefore, the deployment in Tank TH-4 did not proceed past the planning stage.
- Use of existing worker training and worker qualification programs is envisioned for the installation of the platform required for the MPI™ process.
- Design of the patented MPI™ layout and patented operational parameters is provided by GES. GES provides, installs, and operates the patented injector tools.
- With the exception of site-specific training, no additional training is envisioned for the operators of the high-pressure pumps and grout production equipment used to support the MPI™ process.

6. *Cost*

- Relative to the baseline tank closure method, which involves the placement of grout layers on top of residual tank waste, the application of the MPI™ process is a higher-cost closure alternative. However, relative to baseline tank closure, the MPI™ process may enable a greater amount of tank waste to be classified as residual thus reducing costs in the areas of retrieval, pretreatment, waste treatment, transportation and final disposal.

7. *State and Community Acceptance*

- Tanks 17 and 20 have been closed at Savannah River using layers of grout poured on top of tank residual waste.
- Experience gained from the closure of Tanks 17 and 20 forms the basis for the preferred alternative contained in the draft environmental impact statement for the Savannah River high-level waste tank closure document.
- Use of grout for the in-tank immobilization of residual tank waste is an option being pursued at Department of Energy sites in Oak Ridge, Tennessee; Idaho Falls, Idaho; and West Valley, New York.

Safety, Risks, Benefits, and Community Reaction

Topics for this area are covered above in “Regulatory Considerations.” The primary benefit of the MPI™ process is to produce a more stable waste form compared to the baseline of grout pumped on top of residual tank waste. The MPI™ process reduces or eliminates potential concerns associated with the quality of the final baseline waste form achieved with passive grout application. The MPI™ process results in a solid monolith, which immobilizes the residual waste and has excellent leach resistance. The MPI™ process forces grout into all areas of a tank and thereby eliminates potential concerns associated with void spaces.

SECTION 7
LESSONS LEARNED

Design and Implementation Considerations

For storage tanks of a size similar to those used for the two field demonstrations, sufficient information has been obtained for the design of a MPI™ implementation plan with a high probability of success. The following design and implementation considerations must be addressed for successful application of the MPI™ process to tanks significantly greater in size than those used for the field demonstrations:

- The support system must be evaluated for the use of carrier casings more than 20 feet in length. These longer casings may require additional support to remain in place during high-pressure MPI™.
- MPI™ nozzle modifications may be required to increase the sphere of influence for a vertically placed jetting tool so that the number of tank penetrations can be minimized.
- Limits for horizontally placed MPI™ tools need to be identified to determine practical length limit for this tool configuration. The horizontal injection tools have the potential for addressing the area limitations associated with vertically placed injection tools.
- The MPI™ process utilizes a high-pressure system to deliver grout in a short amount of time. For the application of the MPI™ process to larger tanks, the limiting factor may be the grout supply system, i.e., grout mixing plant. Methods and procedures to address this issue need to be identified.
- The MPI™ process relies on a high-pressure delivery system. As with all high-pressure systems, the potential impact on site-specific safety requirements will need to be addressed.
- Analysis of the 1997 demonstration monolith revealed that a number of nozzles had plugged. The source of the plugging may have been small pieces of hardened grout left in the lines from previous grouting work. The 1999 demonstration used new lines and did not experience nozzle plugging. Grout handling equipment must be immediately flushed with water to remove residual grout before the grout hardens.

Technology Limitations and Needs for Future Development

The MPI™ process is ready for deployment in vertically oriented tanks similar to Oak Ridge Tank TH-4. The MPI™ process is ready for deployment in horizontally oriented tanks similar to the Oak Ridge Old Hydrofracture Facility tanks and the Savannah River Old Radioactive Waste Burial Ground solvent tanks. Application of the MPI™ process in tanks that are significantly larger in size than used for the two cold field demonstrations may require further development and demonstration.

Technology Selection Considerations

As tank closure requirements are developed and agreed to by stakeholders, regulators, and the Department of Energy, the criteria for selecting a closure method will be better defined. The MPI™ process is capable of providing enhanced immobilization of residual waste compared with the baseline. The versatility of the MPI™ process results in a process that can be used to address variability in tank waste and variability in internal tank configuration which exist across the Department of Energy complex.

APPENDIX A
REFERENCES

Ground Environmental Services. 1996. *Multi-Point Injection Demonstration for Solidification of Shallow Buried Waste at Oak Ridge Reservation, Oak Ridge, Tennessee*. ORNL/ER-378. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Kauschinger, J. L. 1999. *Method for In Situ Remediation of Waste Through Multi-Point Injection*. U.S. Patent #5,860,907.

Kauschinger, J. L., and S. T. Evans. 1997. *Apparatus for In Situ Remediation of Waste Through Multi-Point* Injection. U.S. Patent #5,645,3777.

Kauschinger, J. L., and B. E. Lewis. 2000. *Utilization of the MPI™ Process for In-Tank Solidification of Heel Material in Large-Diameter Cylindrical Tanks*. ORNL/TM-2000/8. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Kauschinger, J. L., B. E. Lewis, and R. D. Spence. 2000. *Fiscal Year 1999 Cold Demonstration of the Multi-Point Injection (MPI™) Process for Stabilizing Contaminated Sludge in Buried Horizontal Tanks with Limited Access at the Oak Ridge National Laboratory and Savannah River Site*. ORNL/TM-1999/330. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Kauschinger, J. L., R. D. Spence, and B. E. Lewis. 1998. *In Situ Grouting Technology Demonstration and Field Specifications Overview for Hot Deployment of the Multi-Point Injection™ System in Gunite and Associated Tank TH-4*. ORNL/TM-13710. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Lewis, B. E., R. D. Spence, J. V. Draper, R. E. Norman, and J. L. Kauschinger. 2000. *Oak Ridge National Laboratory Old Hydrofracture Facility Tank-Closure Plan and Grout-Development Status Report for FY 1999*. ORNL/TM-2000/7. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

OST (Office of Science and Technology). 1998. *Innovative Grouting and Retrieval.* DOE/EM-0380. Washington, D.C.: U.S. Department of Energy, Office of Environmental Management.

OST (Office of Science and Technology). 1999. *SRS Tank Closure.* DOE/EM-0449. Washington, D.C.: U.S. Department of Energy, Office of Environmental Management.

Savannah River Operations Office. 2000. *Savannah River Site High-Level Waste Tank Closure: Draft Environmental Impact Statement.* DOE/EIS-0303D. Aiken, S.C.: U.S. Department of Energy.

Spence, R. D., and J. L. Kauschinger. 1997. *Grout Performance in Support of In Situ Stabilization/ Solidification of the GAAT Tank Sludges*. ORNL/TM-13389. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

APPENDIX B
ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
GES	Ground Environmental Services, Inc.
LMER	Lockheed Martin Energy Research (Corporation)
MPI^{TM}	MultiPoint Injection (patented process)
RCRA	Resource Conservation and Recovery Act