ORNL/TM-2000/8

Utilization of the MPI™ Process For In-Tank Solidification of Heel Material in Large-Diameter Cylindrical Tanks

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January 2000

Prepared by the
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Oak Ridge, Tennessee 37831
Managed by
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
For the
U.S. DEPARTMENT OF ENERGY
Under contract DE-AC05-96OR22464

INTELLECTUAL PROPERTY DISCLOSURE STATEMENT

The multi-point injection (MPI™) system is a patented technology exclusively licensed to Ground Environmental Services, Inc. (GES), by the inventor, Dr. Joseph L. Kauschinger. It is covered under U.S. Patents 5,645,377 and 5,860,907, with other patents pending. The MPI system has been reduced to practice using private corporate funding for demonstrating the practicability of the MPI system. The cold demonstration was performed and this report was prepared as part of a subcontract for Lockheed Martin Energy Research Corporation (LMER) on a no-royalty-fee basis. In consideration of GES's temporarily waving the royalty fees for this subcontract, any information presented at meetings or in reports or technical memorandum submitted as part of this subcontract will be considered (1) as limited rights data, as defined in the subcontract terms with respect to the MPI tools and procedures used, and (2) not construed to provide any other license or transfer of technology to Lockheed Martin, its subsidiaries, the U. S. Government, or any other entity reviewing this report.

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EXECUTIVE SUMMARY

A major problem faced by the U.S. Department of Energy is remediation of sludge and supernatant waste in underground storage tanks. Exhumation of the waste is currently the preferred remediation method. However, exhumation cannot completely remove all of the contaminated materials from the tanks. For large-diameter tanks, amounts of highly contaminated "heel" material approaching 20,000 gal can remain. Often sludge containing zeolite particles leaves "sand bars" of locally contaminated material across the floor of the tank. The best management practices for in-tank treatment (stabilization and immobilization) of wastes require an integrated approach to develop appropriate treatment agents that can be safely delivered and mixed uniformly with sludge. Ground Environmental Services has developed and demonstrated a remotely controlled, high-velocity jet delivery system termed, Multi-Point-Injection (MPI™). This robust jet delivery system has been field-deployed to create homogeneous monoliths containing shallow buried miscellaneous waste in trenches [fiscal year (FY) 1995] and surrogate sludge in cylindrical (FY 1998) and long, horizontal tanks (FY 1999). During the FY 1998 demonstration, the MPI process successfully formed a 32-ton uniform monolith of grout and waste surrogates in ~8-min. Analytical data indicated that 10 tons of zeolite-type physical surrogate were uniformly mixed within a 40-in.-thick monolith without lifting the MPI jetting tools off the tank floor. Over 1,000 lb of cohesive surrogates, with consistencies similar to Gunite and Associated Tank (GAAT) TH-4 and Hanford tank sludges, were easily intermixed into the monolith without exceeding a core temperature of 100^0 F during curing.

The treatment agents used during the MPI demonstrations in FY 1998 and 1999 had chemical properties that were shown to be effective in treating GAAT surrogate sludge and actual "hot" sludge taken from GAAT TH-4. The Resource Conservation and Recovery Act metals (mercuric chloride salts, lead oxide, and sodium di-chromate) in the sludge surrogate were immobilized to below their respective universal treatment standards at sludge loadings of 35 to 60%. The radioactive components, predominately ^{85}Sr and ^{137}Cs, typically exhibited excellent leach resistance with leachability indices of ~9 to 10, as measured in American Nuclear Society (ANS) test procedure, ANSI/ANS-16.1, Leach Test.

During FY 1999 a cold demonstration was successfully performed in which the MPI process was used to support hot closure activities at ORNL for the Old Hydrofracture Facility waste tanks, and the Savannah River Site (SRS) Old Radioactive Waste Burial Ground solvent tanks. The unique aspects of the cold demonstration were related to the long horizontal tank geometry and severely restricted access into the SRS tanks, (4-in.-diam riser). The challenges presented by the long geometry and limited access were overcome by adapting the MPI tooling so that multiple jets could be deployed along a horizontal string. This technical memorandum presents photographic documentation of the horizontal MPI tool string deployed during the FY 1999 cold demonstration. Since a long, horizontal tank is analogous to a segment of a large, circular tank, the activities demonstrated for SRS in FY 1999 need only to be repeated several times to provide mixing and mobilization across the entire floor of an 85-ft-diam tank.

The report describes in detail the deployment of multiple horizontal MPI tools through a single riser in an 85-ft-diam tank. The discussion focuses on deployment through either a single 28-in.-diam riser at the center of the tank or a single 34-in.-diam riser near the outer diameter of the tank.

An MPI super tool is also described that integrates the elements of directional drilling into the currently demonstrated horizontal tool. Directional drilling not only allows the MPI horizontal tool to be deployed over 100 ft, but also allows the tool to be drilled into the sludge for depths up to ~10 ft. This adaptation of MPI jetting and directional drilling could be used to initially exhume thick sludge and then, using the same tools, treat any residual heel material that remains behind. Currently, DOE does not have an integrated technology that can perform both exhumation and in-situ treatment of residual heel material.

The report supports the conclusion that all the pumping and mixing equipment required to drive the MPI tools in a large-diameter tank are readily available. The site logistics and material-handling requirements are within manageable limits such that the MPI injection can likely be completed within a 24-h period.

1. INTRODUCTION

A major problem facing the U.S. Department of Energy (DOE) buried-tank remediation program is the dispositioning of the "heel" material remaining at the bottom of the tanks after an exhumation campaign. In cases where the sludge contains rapidly settling particles (zeolites), the heel material may resemble a "sand bar" across the floor of the tank. Although these residual heel materials are often only a few inches or less thick and the tank is essentially empty, the heel material can still be highly contaminated. For large-diameter tanks, the volume of heel material may be on the order of 20,000 gal. This "empty tank" could be filled with concrete to entomb the heel material and thus provide structural integrity to the tank. However, concrete flow studies have shown that the concrete placement tends to "sweep" residual material across the tank floor, away from the point of placement, and outward toward the edge of the tank. The scouring process during concrete placement not only concentrates the heel material but also deposits the contamination at the least attractive location for long-term disposal, (i.e., at the outer edge of the tank). A "better management" practice would be to homogeneously mix the heel material with a treatment agent. This would tend to redistribute the treated waste uniformly throughout the buried tank. Furthermore, the in-tank treatment process would tend to decrease the concentration of the heel contamination within a larger uniform monolithic structure.

The full potential of in-tank treatment processes can be realized only if the appropriate solidification agents are chosen and delivered using a robust injection system. During fiscal year (FY) 1998, Lockheed Martin Energy Research Corporation (LMER), in cooperation with Ground Environmental Services (GES), performed an integrated demonstration in which a slag/cement/fly-ash/red-clay grout was developed for in-tank treatment of Gunite and Associated Tank (GAAT) sludge, especially tank TH-4. The general results from the FY 1998 demonstration indicate:

- Laboratory bench-scale work on surrogate and hot sludges from GAAT tank TH-4 could be effectively treated at sludge concentrations of 35 to 65% of the monolith total weight. The Resource Conservation Recovery Act (RCRA) metals (mercuric chloride salts, lead oxide, and sodium di-chromate) in the sludge surrogate were immobilized to below their respective universal treatment standards. The radioactive components, predominately ^{85}Sr and ^{137}Cs, typically exhibited excellent leach resistance with leachability indices of ~9 to 10 as measured according to the American Nuclear Society (ANS) test procedure, ANSI/ANS-16.1, Leach Test.

- The cold-field component of the demonstration proved that the Multi-Point-Injection™ (MPI) process was a robust jet delivery system capable of forming a 32-ton uniform monolith in ~8 min. Analytical data indicated that 10 tons of a zeolite-type physical surrogate (quartz sand 0.5 to 0.8 mm) was uniformly mixed within a 40-in.-thick monolith without lifting the MPI jetting tools off the tank floor. Over 1,000-lb of cohesive surrogates, with consistency similar to GAAT TH-4 and Hanford sludge, were also placed within the test tank. These cohesive surrogates were easily intermixed into the monolith. Review of the data from the cold field demonstration indicates that the MPI process successfully delivered the correct gross amount of treatment agents specified from the Oak Ridge National Laboratory (ORNL) bench-scale studies. Exhumation of the monolith provided visual evidence that a 15-ft-diam by 40-in.-thick uniform monolith was created. The maximum internal core temperature of the monolith reached only 100^0F during curing.

The simplicity of the injection process allowed the treatment of the physical surrogates to be accomplished remotely with all capital equipment and workers in the safety of a work zone about 200 ft away from the test tank. Only low-cost, disposable equipment (e.g., plastic pipe and steel tubes) came in contact with the sludge surrogate. The field quality controls implemented during the demonstration showed that the required level of treatment could be reproduced accurately in the field. The bulk-blended grout used during the cold-field demonstration had chemical properties that were shown to be effective in treating GAAT surrogate sludge and "hot" sludge taken from GAAT TH-4. The data show that there was excellent quality assurance— quality control in the field and that the correct amount of grout was injected to form a mixture with the required gross amount of constituents. A more nearly complete description of the FY 1998 demonstration program can be found in Kauschinger et al.[1]

The success of the MPI demonstration in FY 1998 encouraged further demonstration of the applicability of the MPI process for applications in long, horizontal tanks (40 ft long) with limited access (riser pipe opening of 4-in.-diam). The results from this successful cold demonstration are to be covered in detail in a separate technical memorandum.[2] One of the most important results from the long, horizontal tank demonstration was the successful horizontal deployment of multiple MPI tools along a single string of flexible hose. Horizontal deployment of the MPI tools makes it feasible to perform the MPI process through a single, large-diameter riser (28- to 34-in.-diam) to treat residual heel material inside large 85-ft-diam tanks.

The remaining sections of this technical memorandum will present information about using the MPI process to treat heel material in large-diameter tanks. Details concerning the injection strategy are presented, including the grouting and pumping requirements to activate the MPI tools. An outline is provided which covers the use of an MPI super tool, which can be deployed across the entire 85-ft-diam of a buried tank. The directional drilling aspects of the MPI super tool has been demonstrated in a radioactive landfill to drill a 150-ft-horizontal hole down to depths of ~10 ft.

Currently, DOE has no unified techniques that can be used to both exhume and treat tank heel material using the exact same tools. This report will close with a discussion of how to implement the MPI system for the dual purpose of exhumation and in-tank treatment of residual heel material.

2. GENERAL FEATURES OF MPI™ TECHNOLOGY

MPI technology is a general-purpose, jet delivery system for the in-situ treatment of wastes deposited into buried tanks, shallow trenches, or pits. The MPI system relies upon the interaction of multiple, high-speed mono-directional jets to turbulently mix the waste with various treatment agents. The turbulence created by an MPI injection tool is illustrated in the photograph, shown as Fig. 1. The photograph shows a vertical injection tool lying on the ground during a training session for the FY 1998 MPI demonstration in Duncan, Oklahoma. Use of mono-directional jetting tools greatly simplifies the equipment used for in-situ waste treatment because rotation of the jetting tools is not needed. Instead of tool rotation, the mixing of the waste occurs as a result of the turbulence that is produced from multiple jet streams that expand as they travel through the waste. This process leads to very turbulent jet action, which is used to uniformly mix the waste with the treatment agents. Perturbations in the path of the jet stream, such as other jet streams or obstructions (piping in a tank), help to disperse all the jet streams for more efficient mixing. The MPI jets are located in the best possible position with respect to the geometry of the tank sludge, which is usually thin and spread out along the entire tank bottom. The multi-point injections are performed over a limited thickness to incrementally form thin plates of treatment. The jet nozzles used during the cold-field demonstration conducted in FY 1998 were placed within 1.5-in. of the tank bottom and projected the jet streams horizontally. For shallow-tank sludge (2–3 ft), the injection tools need not be lifted. For relatively thick sludge (above 5-ft), vertical jetting tools can be remotely lifted since they can be suspended from hoses that are attached to electrical winches.

The MPI techniques were devised to protect construction workers and capital equipment from becoming contaminated in an As Low As Reasonably Achievable (ALARA) manner. Once this safety requirement was satisfied, emphasis was redirected at making the delivery system as robust and broadly applicable as possible. The constraints of safety and robustness drove the delivery system to be based upon jetting technology. The major capital investment for jetting is related to the cost of the high-pressure pumps and surface piping, which are conventional oil field rental equipment. During the MPI process, this expensive equipment is located in the support zone, and the power generated by the pumps is brought to bear upon treating contamination via very inexpensive and disposable equipment (e.g., plastic pipe, hoses, carbide jet nozzles). Therefore, the cost of the remediation can be better predicted since any loss of expensive capital equipment resulting from contamination is highly unlikely.

ORNL-Photo-401-2000

Fig. 1. Photograph of MPI vertical tool lying on the ground during a training session for the FY 1998 MPI demonstration in Duncan, Oklahoma.

Two major placement options are available for deploying the MPI jetting tools inside large-diameter tanks. The simplest and potentially least expensive option is to drill small-diameter holes through the dome of the tank and deploy vertical jetting tools. The location of the eight injection tools and orientation of the jet streams used during the FY 1998 demonstration are illustrated in the plan view sketch shown in Fig. 2. The central four MPI jetting tools were used to scour the bottom of the tank, while the four tools along the outer edge of the tank were used to create a large vortic flow. This injection strategy was successfully demonstrated during FY 1998 on a 15-ft-diam cylindrical tank in which a 40-in.-thick, 32-ton uniform monolith was formed in about 8 min.

Another option to perform the MPI process is to attach multiple jetting tools to a single high-pressure hose and then horizontally drill the multiple string in the sludge. This deployment strategy was successfully used during the FY 1999 cold demonstration, which supported closure activities at ORNL and the Savannah River Site (SRS). SRS placed access constraints upon the installation of the MPI tools in which all tooling had to be fed through a 4-in.-diam riser pipe. The MPI tools were designed to install vertical and horizontal jetting tools through the same 4-in-diam opening. The jetstream pattern of the vertical tool resembles a starburst pattern, as illustrated in the vector diagram in Fig. 2. The jetting pattern for the MPI floor tools also resembles a starburst. Both vertical and horizontal tools project a jet stream about 1.5-in. off the tank floor.

ORNL-Dwg-2000-2706

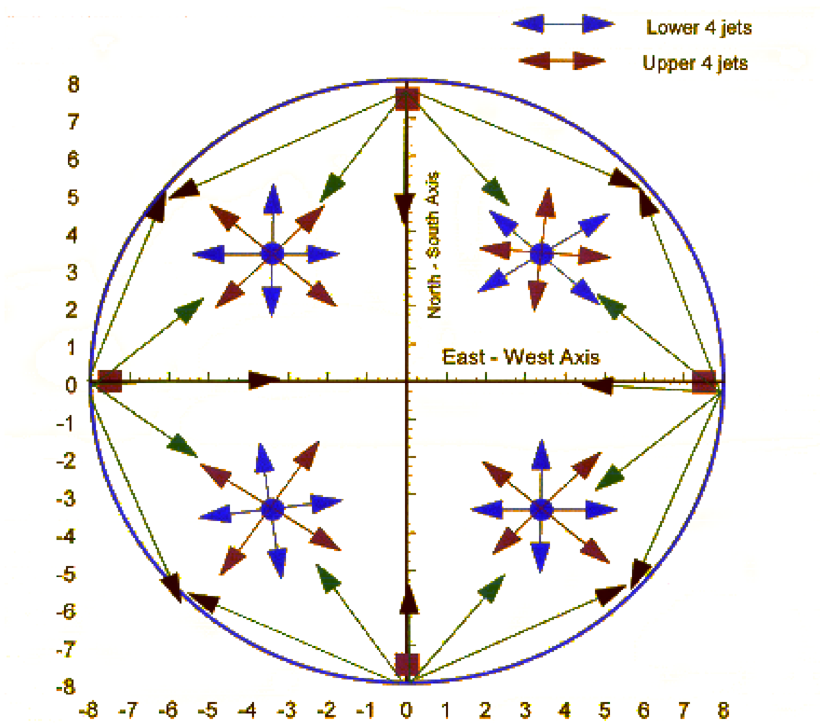


Fig. 2. Schematic plan view of MPI injection pattern used during the FY 1998 cold demonstration in Duncan, Oklahoma. Note: All information in this Figure is marked as limited rights data under the terms of the subcontracts between Ground Environmental Services and Lockheed Martin Energy Research. MPI is protected under U. S. Patents Nos. 5,860,907 and 5,645,377 with several other patents pending.

2.1 INSTALLATION OF MULTIPLE VERTICAL MPI™ Tools

Large-diameter waste tanks can vary in diameter from 50 up to 85 ft. They typically have a hemispherical dome (see schematic in Fig. 3) constructed of either reinforced concrete or steel and an overburden of soil covering each tank. Near-surface pipelines are often buried within the soil overburden. Since the jetting tools and associated casing only require a 4-in.-diam hole for emplacement, the shallow soil overburden can be probed to locate obstructions using hand tools. A non-intrusive probing technique is used that will allow clearance of utilities as the hole is dug. If a utility line is encountered, then the hole can be back-filled and the location moved to avoid the obstruction. The actual locations of the boreholes for the MPI injection points are not critical. A typical MPI injector can influence sludge (turbulent mixing) for a distance of ~14-ft in all directions (starting from a 4-in.diam hole).

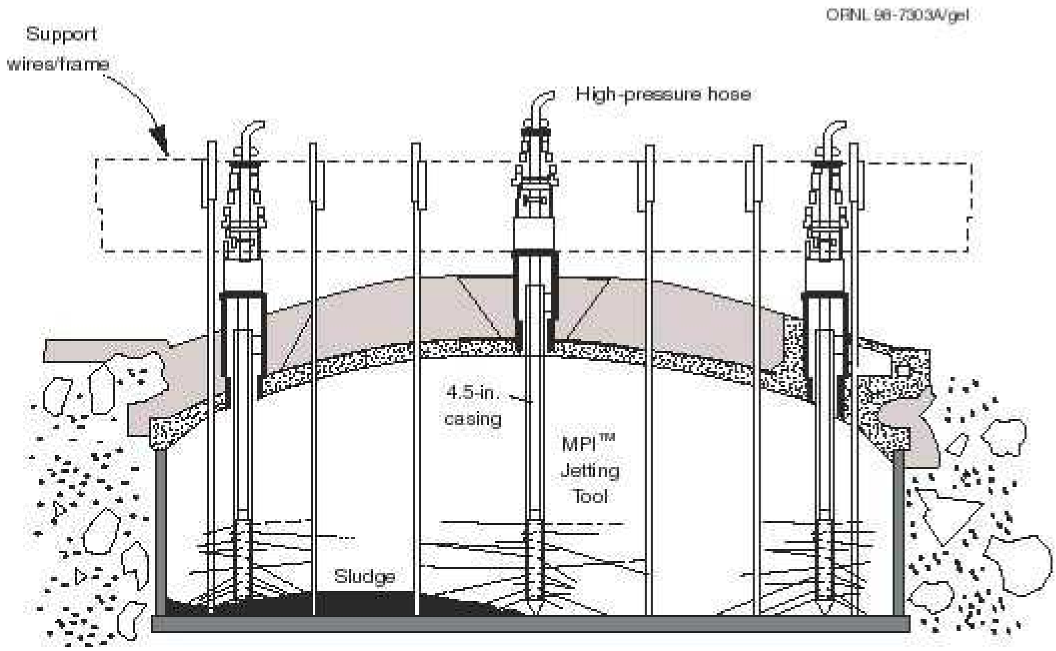


Fig. 3. Elevation view of large-diameter GAAT tank at ORNL Waste Area Grouping (WAG) 1 with vertically inserted MPI jetting tools.

The following are two major types of vertical jetting tools that are parts of the MPI process:

- tools with jets that are arranged symmetrically; such as the starburst jet pattern, as illustrated in Fig. 2, and
- high-eccentricity jetting tools used along the perimeter of the cylindrical tank, as illustrated in Fig. 2.

The combination of linear jet turbulence created by the starburst tools and circular vortic flow formed by the eccentric tools helps ensure intimate mixing of sludge and solidification agents.

The vertical deployment method used during the FY 1998 cold demonstration has been criticized because of the need for eight vertical holes (Fig. 2 and Fig. 3) through the dome of the proposed hot demonstration tank—GAAT tank TH-4. The eight small-diameter holes (4-in.-diam) were acceptable at ORNL because of the relatively low radioactivity levels in the tanks and the operations being conducted with the robotic tank waste retrieval systems. Insertion of the robotic systems into the GAAT required the installation of large-diameter holes (36-in.) through the dome of the tank. When examining an 85-ft-diam tank, the MPI injection pattern would require many more holes if vertical tools were exclusively used, typically around fifty 4-in.-diam holes. This requirement was considered unacceptable at Hanford and SRS.

To reduce the number of holes in the dome of a large-diameter tank needed to implement the MPI process, several new vertical tool deployment concepts have been developed. The basis of one of the new deployment systems is pneumatically inflated membranes that are used as inflatable arms to position the jetting tools. These arms are grouped together in an "octopus arm" array with the tentacles representing the carrier casing currently used for the vertical tools. The main advantage of the octopus-arm deployment is that the arms can be installed through small-diameter risers on large tanks and inflated into position for distributing multiple MPI tools across the floor of the tank. The tools inside the arms can be drilled and inserted through thick layers of sludge (soft sludge, hardpan, and salt cake). Furthermore, the arm allows the tools to be repositioned at any location across the floor of a large-diameter tank. This vertical deployment system is analogous to the creation of a disposable "non-robotic" arm. Several aspects of this tool have been demonstrated, but the entire tool is not ready for actual demonstration. Since the inflatable arm is disposable, it will be manufactured for installation and remediation of a specific, large-diameter tank.

One of the major considerations for the implementation of the MPI process in a large-diameter tank is to use the minimum number of holes through the dome of the tank. In the extreme case, if it were possible to deploy the MPI tools through existing riser pipes in the tank, then there should be little objection to using the MPI system to treat at least residual heel material in large-diameter tanks. The cold demonstrations have already proven that the MPI process can form large, uniform monoliths (32 tons). Furthermore, the 40-in.-thick monolith created in FY 1998 was formed without lifting the jetting tools off the tank floor. Therefore, if jetting tools could be dispersed horizontally across the floor of a large tank, then these tools would operate in an equivalent fashion as vertically installed tools. This is especially valid for heel material, which may be less than a foot thick. For thicker sludges, simple directional drilling methods are available which can be used to install a horizontal string of MPI jetting tools.

The following sections describe the deployment of multiple horizontal MPI tools for treating heel material in large-diameter tanks. In the extreme case, all the MPI tools required for treating heel material in an 85-ft-diam tank can be deployed through a single 34-in.-diam riser. The discussion focuses upon a single riser being located either at the center or outer edge of the large tank. The photographic documentation of the multiple horizontal MPI tool string deployed during the FY 1999 cold demonstration is used to illustrate the types of tooling which currently can be used in large-diameter tank closure actions.

2.2 MULTIPLE HORIZONTAL TOOL STRING

The MPI system was used during FY 1999 in a cold demonstration to support the closure activities at the SRS for the Old Radioactive Waste Burial Ground (ORWBG) solvent tanks, which are about 40 ft long and 10 ft in diam. Much of the residual heel material in these tanks is about 4-in. thick. The most significant complexity related to the access into the SRS tanks is that most of the tanks have only one or two 4-in.-diam riser pipes at either end of the tank. These long, horizontal tanks with severe access restrictions are representative of a single segment taken from a larger-diameter tank. Therefore, the activities for a single long, horizontal tank needs only be repeated several times to cover the entire cross section of larger-diameter tanks, say 85-ft in diam.

The adaptation of the MPI tools to fit through a 4-in.-diam opening was accomplished by deploying the tools on flexible, high-pressure hoses with short, steel, jetting monitors (jet holders). The simplicity of the horizontal deployment of multiple MPI tools is supported by the series of photographs taken during the deployment of the horizontal tool string for treating a sand surrogate inside a 22-ft long test tank. A 4- to 6-in. layer of white sand was used as a physical surrogate for a zeolite "sand bar" deposited across the floor of the test tank. The end walls of the tank were packed with a mound of cohesive clay to simulate the more viscous sludge, which can accumulate around the intake of a pump.

A horizontal MPI tool is initially installed by inserting a composite steel-Lexan™ plastic carrier casing inside of the 4-in.-diam-riser pipe. The photograph in Fig. 4a shows a 4-in.-diam tube (carrier casing) placed inside of a 4-in.-diam schedule 40 piece of pipe. This is the diameter of the riser pipe measured on the old solvent tanks at SRS. The carrier casing has a gravity-actuated "coal chute," which is machined flush with the outer wall of the carrier casing. The orientation of the coal chute is pointed in the direction in which the horizontal string of MPI tools are to be deployed (Fig. 4b). The open chute guides the MPI tool out of the vertical carrier casing along a very tight radius of curvature (~4 ft). As the tool is pushed out onto the coal chute, the chute provides support to the tool until it is nearly in a horizontal position, (Fig. 5a). Thereafter, the tool exits off the chute and is manually pushed along the floor of the test tank, (Fig. 5b). Even though there were weld bands every 4 ft along the length of the test tank, the horizontal MPI tool could be manually pushed over the weld bands and through the 4- to 6-in. of sand surrogate. Ultimately, the tool was pushed up against the back wall of the test tank (Fig. 5c). This was about 20 ft from the point at which the carrier casing contacted the tank floor. During other phases of the cold demonstration, the multiple string of MPI tools could be manually pushed along the ground surface for a maximum distance of ~35 ft. This was the full length of push rods attached to the tool. However, this may represent a practical maximum distance for manual installation of the string of MPI floor tools.

Once the MPI floor tools were in place, a vertical tool was lowered through the annular space left inside of the carrier casing. The photograph in Fig. 5d reveals the vertical tool through the Lexan plastic at the tip of the steel carrier casing. The photograph also shows the relationship between the vertical tool and two horizontal tools deployed inside the SRS tank. The vertical tool in the photograph is only 1.75-in. in diameter and is mounted with ten jets. The vertical tool was used to mobilize and mix the mound of cohesive surrogate that was packed against the back wall of the test tank.

The flow pattern developed by the interaction of the horizontal jetstreams of the MPI floor tools and the vertical 1.75-in.-diam tool is illustrated by the series of photographs in Fig. 6a to 6c. The photograph in Fig. 6a is an overall view of the vertical and floor tool simultaneously operating at 6,000 psi. It is noted that the left side of the photograph depicts a large amount of turbulent mixing and interaction as the jets from the vertical and floor tool impact each other. Conversely, on the right side of the photograph, distinct horizontal jet patterns can be observed as shown in the close-up photograph in Fig. 6b. The photograph in Fig. 6c shows the condition of the hoses and tools after about 5 min of jetting at 6,000 psi and 400 gal/min.

ORNL-Photo-402-2000

(a)

(b)

Fig. 4. Close-up photographs of MPI tool: (a) Insertion into 4-in.-diam riser pipe and (b) lowering through carrier casing inside SRS tank. Note: All information in this Figure is marked as limited rights data under the terms of the subcontracts between Ground Environmental Services and Lockheed Martin Energy Research. MPI is protected under U. S. Patents Nos. 5,860,907 and 5,645,377 with several other patents pending.

(a)

(b)

(c)

(d)

Fig. 5. Series of photographs showing: (a) MPI tool whipstock and coal chute, (b) tool pushed along tank floor, (C) tool hitting tank end wall, and (d) vertical tool inserted to bottom of Lexan plastic, and relationship to two MPI floor tools. Note: All information in this Figure is marked as limited rights data under the terms of the subcontracts between Ground Environmental Services and Lockheed Martin Energy Research. MPI is protected under U. S. Patents Nos. 5,860,907 and 5,645,377 with several other patents pending.

ORNL-Photo-404-2000

(a)

(b)

(c)

Fig. 6. Series of photographs showing MPI floor tool being activated at surface: (a) overall view, (b) close-up of MPI jetting tool, and (c) tool and hose after 5 min of jetting at 400 gal/min and 6,000 psi. Note: All information in this Figure is marked as limited rights data under the terms of the subcontracts between Ground Environmental Services and Lockheed Martin Energy Research. MPI is protected under U. S. Patents Nos. 5,860,907 and 5,645,377 with several other patents pending.

The coherent jet stream shown in Fig. 6b develops because there are no perturbations in the path of the jet to cause dispersion (energy loss) of the jet. When the MPI tools are operated in an actual tank, they start from a submerged condition, which is typical for a tank containing supernatant above the actual sludge. Operating the tools from a submerged condition ensures the dispersion of the jetstream and the creation of turbulent jet mixing. The submergence also ensures that no aerosols are created. This process helps to keep all the sludge within the mixing action of the MPI jet streams.

Subsequent sections of this report will discuss an MPI super tool, which integrates the elements of directional drilling into the currently demonstrated tool. The directional drilling will not only allow the MPI horizontal tool to be deployed over 100 ft, but it will also allow the MPI tool to be drilled into sludge for depths up to ~10 ft. This adaptation of MPI jetting and directional drilling could be used to mobilize and retrieve thick sludges and then use the same tools to treat any residual heel material that remains behind. Currently, DOE does not have such an integrated technology that can be used to perform both exhumation and in-situ treatment of residual heel material.

2.2.1 Limitations of Current Multiple Horizontal Tool String

Hydraulic flow limitations are associated with the multiple MPI floor tools string used during the SRS old solvent tank demonstration. The 1-in. high-pressure hoses (Fig. 6c) used in the demonstration have a flow rate limitation typically on the order of 250 gal/min. Although higher flow rates are possible, the head losses for the types of treatment agents injected (Sect. 2.4.1) start to cause the friction losses to be on the order of 5 to 10 psi/ft of hose. Therefore, there is a practical limitation on the currently used 1-in.-diam hose in that the 250-gal/min delivery rate can be used to drive a maximum of ~20 jets. The 20 jets allow about 3 or 4 MPI tools to be deployed in the horizontal tool string. Since the typical spacing of the MPI tools on the string is from 5 to 15 ft; the maximum tool string length would be ~20 to 40 ft. This tool string length also corresponds to the practical limit of manually pushing the tool string into the tank and along the floor.

An important implication of the 40-ft long horizontal tool string is that this distance will cover about one-half the diameter of a large 85-ft tank. Therefore, if the tank has a centrally located riser pipe, then the currently demonstrated horizontal tool (shown in Figs. 4, 5, and 6 could be deployed through a single central hole to cover the floor of the tank. The injection strategy for deploying the MPI system through a single central riser is discussed in Sect. 3.1.

In order to reduce the deployment costs and minimize tank penetrations, it is desirable to adapt the MPI floor tools so that they can be deployed across the entire diameter of a large-diameter tank (85 ft) through a single penetration. A concept for an MPI super tool has been developed and is described in Sect. 2.2.2.

2.2.2 MPI™ Super Tool String

Conceptual designs for two different MPI super tool strings that can be installed horizontally through tank sludge have been developed. Both designs overcome the hydraulic limitations of a single high-pressure hose. It is estimated that it will require ~6 to 8 MPI tools to cover a linear distance of 85 ft, (a large-diameter tank). The two main strategies for the manufacture of an MPI super tool would take either of the following routes:

- Fabrication of a high flow, flexible hose that can carry upwards of 500 gal/min at 6,000 psi. This will allow doubling the number of jets and tools that can be deployed on a single tool string, (40 MPI jets contained on ~8 tools).

- The other super tool would be to use the current high-pressure hose and redesign the MPI jetting monitor so two horizontal tools can be deployed through a single carrier casing. This change would correspond to essentially converting the 1.75-in.-diam vertical tool (see Fig. 5d) into a string of multiple floor tools. The two hoses in the single carrier casing would allow about 500 gal/min to be supplied through that particular casing. This approach can be implemented immediately since all aspects of this tool design have already been successfully demonstrated.

Installation of a horizontal tool over a length of 85 ft would be accomplished using both manual and percussion drilling methods. The integration of pneumatic impact hammers is easily assured since these percussion tools can be activated via the same hoses used to perform the MPI injection. Most impact hammers require air pressure at ~100 psi and a flow rate of 100 ft^3/min. The MPI hoses are rated at nearly 20,000 psi. The impact hammers under consideration have been used to install 150-ft-long horizontal directional holes to depths of about 10 ft. This directional bore was demonstrated in a radiological controlled zone at WAG 6 on the Oak Ridge Reservation.

The development of MPI super tools must be considered in light of the availability of pumping and grouting equipment to supply the tool. A survey of pumping services contractors and suppliers has been done to ensure the availability of the required equipment. Some of the findings from these discussions are outlined in the Sect. 2.3.

2.3 MPI™ PUMPING-EQUIPMENT REQUIREMENTS

The amount of hydraulic horsepower required for conducting the MPI process can vary from about 800 upwards to 2000 hp. A single MPI super tool string containing 40 jets would require about 1,800 hp to perform the injection. Several high-pressure pump suppliers offer equipment for rental that can be used to perform the MPI process. The following suppliers have indicated that they have sufficient equipment available for rental such as to drive at least 4 MPI super tools (7,000 hp):

- Freemyer Enterprises, Odessa, Texas
- B. J. Services, Houston, Texas
- Chalmers Equipment Corporation, Tulsa, Oklahoma

The U. S. DOE currently has at the Hanford Reservation two Casagrande™ high-pressure cement pumps, which could also be used for performing the MPI injection, if the pumps can be made available.

The equipment usage for the MPI process has been modeled after oil well stimulation services, in which a large amount of equipment can be mobilized to an oil field site for a short duration to perform stimulation services. This concept is the key to making the MPI process cost competitive. It is also the main reason why the primary equipment suppliers for the technology are from the oil industry.

2.4 TREATMENT AGENT AND MIXING EQUIPMENT REQUIREMENTS

The critical path for performing the MPI process is not related to the pumping equipment, because the oil field services industries have many such pumps. Rather, the key for a successful MPI deployment in a large-diameter tank is linked to the material-handling requirements for forming a uniform monolith of treated sludge. The first step is to ensure that a robust treatment agent is available that can immobilize the contaminants of concern. Once the treatment agent is selected, then the issues are related to the field logistics of transporting and mixing the material at the site. For a large-diameter tank, it is preferable to perform the MPI process in a continuous manner. This method allows the treatment agents to be uniformly intermixed with the sludge prior to the monolith setting.

The following sections show that ORNL has extensively tested a slag-cement reducing grout that can be used to treat a wide variety of RCRA metals and radioactively contaminated sludges. This is followed by a presentation of the material-handling issues at the site. It will also be shown that the injection phase of the MPI process can be accomplished in a single 10–12-h shift. This capability results in a significant cost-containment strategy since the major costs of the MPI process are for pumps and grouting equipment, which are rented at a high rate for only 24 h.

2.4.1 ORNL Grout Formulation

The grout formulation preferred for MPI injection into radioactively contaminated sludge is a recipe that was originally developed at ORNL. Modifications were made to the blend to enhance the thixotropic properties of the formulation. Improved thixotropy helps ensure the formation of a homogeneous monolith of sludge and treatment agents, especially when the sludge contains sand-sized particles, such as zeolite. The basic ORNL formulation consists of the following ingredients:

40%	Granulated blast furnace slag
40%	Class F fly ash
10%	Cement
7%	Red clay
3%	Bentonite

The bentonite is prehydrated with the mix water to make a gel, which is used as the liquid phase of the treatment agent. The grout is usually prepared by adding the dry components to the bentonite gel until the grout has a unit weight of about 13 to 14.5 lb/gal, which corresponds to 7.5 lb to 10 lb of ORNL dry blend in each gal of grout mixed, respectively.

Laboratory bench-scale work on hot surrogates and actual sludges taken from the GAAT TH-4, proved that the ORNL formulation could effectively treat contaminated sludge at concentrations of 35 to 65% of the monolith's total weight. The RCRA metals (mercuric chloride salts, lead oxide, and sodium di-chromate) in the sludge were immobilized to below their respective universal treatment standards. The radioactive components, predominantly ^{85}Sr and ^{137}Cs, typically had leachability indices of about 9 to 10, as measured in ANS 16.1 leach tests. The details of the bench-scale tests along with the results from the FY 1998 field demonstration are discussed in greater detail in the technical memorandum published by Kauschinger, Spence and Lewis in 1998.[1]

The other advantage of the formulation is that the set time of the grout can be adjusted by changing the percentage of the portland cement in the recipe. The 10% portland in the current recipe has a pot time of about 4 to 5 h and achieves an initial set in about 10 h. The pot time of the grout is not an issue since a large volume of grout can be injected within a few minutes, (15,000 gal). However, the initial set of the ORNL formulation is an important consideration for creating a large-diameter monolith. It is desirable for the ORNL formulation to remain in a weak consistency for at least 24 h. This 24-h initial set time can be achieved by lowering the percentage of portland cement in the dry blend, but must be verified in the laboratory with an actual mixture of the sludge to be treated. The 24-h set time will be used in the following discussion involving sizing the material-handling equipment needed at the site of the large-diameter tank.

2.4.2 Material-Handling and -Mixing Equipment Requirements

The other major consideration in the performance of the MPI process is associated with the size of the grouting plant and bulk storage equipment. In the extreme case, if multiple MPI super tools are simultaneously activated, they may require upwards of 2,000 gal/min of treatment agent to drive 4 MPI super tools. This is the estimated maximum number of tools, which must be simultaneously activated (see Sect. 3). If this flow rate were required for continuous injection, then the grout plant would be very large. However, the advantage of using the MPI process is related to running the tools at high flow rates in short bursts of ~60 s. Therefore, the 2,000 gal of treatment agent are only required in an incremental manner. The grout plants, which have been used, can blend 4,000 gal of grout in about 15 min. Therefore, using a conventional oil field batch mixer, approximately 15,000 gal of treatment agent can be mixed and pumped per hour of operation. This corresponds to placement of about 60 tons of the ORNL dry blend material, (2 tanker trucks). If a larger volume of grout per hour is needed, then a second batch mixer can be added to produce 30,000 gal/h (120 tons of ORNL dry blend). An associated consideration is the onsite storage and transport of material. To better understand the material handling requirements for implementation of the MPI process for large-diameter tanks, it is necessary to examine the total amount of ORNL dry blend formulation that must be processed in a 24-h period.

An 85-ft-diam tank requires ~42,000 gal to raise the liquid level 1 ft. During a 24-h production cycle a maximum of 350,000 gal of grout can be prepared and injected. This volume of grout corresponds to raising the liquid level in an 85-ft-diam tank by ~8 ft. This increase in liquid-level depth is much more than that required to mobilize and uniformly mix a wide variety of tank heel materials. Typically, a 1-ft-thick layer of surrogate requires about 2.5 ft of ORNL grout to allow sufficient mixing such as to form a homogeneous monolith. The 2.5-ft increase in tank depth corresponds to ~105,000 gal of grout, which require nearly 420 tons of ORNL dry blend (17 tanker trucks). A single oil field batch mixer would take ~8 h to prepare this amount of grout. The amount of time to batch the ORNL formulation and the number of trucks (17) necessary to transport the dry blend into the site can be easily accommodated with a few oil field storage bins.

The previous discussions indicate that the pumping equipment required to drive the MPI tools for a large-diameter tank application is readily available. The site logistics and material handling requirements are within manageable limits such that the entire injection can be done within a 24-h time period. Furthermore, an effective treatment agent (ORNL formulation) has been devised and extensively tested in the field for construction-related issues and in the laboratory for verifying efficacy as a treatment for RCRA metals and radionuclides. The final aspect of the in-tank treatment for large-diameter tanks is related to presenting the layout of the MPI tools.

3. MPI™ INJECTION LAYOUT AND SEQUENCE FOR LARGE-DIAMETER TANKS

A central philosophy in developing the injection strategy for the MPI process is to develop tools and a layout that are specific for a particular tank. Since no candidate tank has been identified, the only driving force in this discussion is to demonstrate that the system can be deployed through the fewest number of openings as possible. The extreme case is deployment through a single riser pipe. For purposes of discussion, two deployment scenarios are examined. The first is associated with a single, large riser pipe (28-in.-diam) near the center of the tank and the second considers a larger riser pipe (34-in.-diam) near the edge of an 85-ft-diam tank. Existing access at any other locations in the tank would merely make it easier to deploy the tools across the floor of a large-diameter tank.

For the two cases under consideration, it is assumed that the residual sludge is a foot or less in thickness and uniformly distributed across the floor of the tank. It is further assumed that a final monolithic volume of ~3.5 times the original waste volume will be sufficient to chemically treat the one-foot of sludge. This level of treatment would require injection of 105,000 gal of the ORNL grout. The monolith would have a final thickness of ~42-in., with a waste loading of ~30%. The total injection stage would be accomplished in a single 10- to 12-h work shift. The delivery of the ORNL dry blend material would be done before mobilizing the high-pressure pumps. Furthermore, all the tooling required for insertion in the tank would be done before any other site mobilization of the grouting equipment. Sections 3.1 and 3.2 discuss the two proposed tooling arrangements, respectively, which would allow the MPI process to be deployed through a single riser pipe.

3.1 MPI™ TOOL LAYOUT FROM A SINGLE CENTRAL RISER

The schematic of the jetting tools deployed through a central riser on top of an 85-ft-diam tank (depicted in Fig. 7Fig. *7*) resembles a wagon wheel, with the spokes corresponding to MPI injection hoses. The maximum lateral distance, along which a string of tools needs to be deployed, is half a tank diameter, 42.5-ft. It is estimated that it will require ~18 tool strings to make up the spokes of the wheel depicted in Fig. 7. Each tool would contain ~20 jets on 4 tools and require about 270 gal/min of grout at 6,000 psi. The engine horsepower required to drive this tool is about 900. Depending upon the local conditions of the tank floor and type of sludge to be treated, the multiple tool string demonstrated during the SRS FY 1999 cold test would be the prime candidate for use (see Fig. 4 and 5 for the actual tool used in the SRS tests). For some areas of installation across the tank floor, the use of both manual and percussion drilling installation may be required. The discussion of incorporating an impact hammer into the MPI horizontal tool has already been presented in Sect.2.2.2.

It is estimated that 8 tools would be simultaneously activated for a total flow rate of 2,000 gal/min, which would require ~7,200 hp of pumping capacity. Four 1,800-hp pumps or six 1,200-hp pumps could provide this horsepower. It would depend upon the equipment availability at the time of the project. Each of the eight tools would be activated for ~1 min. The turbulent mixing developed during this time would cover about one-half the cross section of the tank. Thereafter, eight different tools would be used to cover the other half of the tank. During each MPI injection, there would be an increment of ~2,000 gal of grout injected. This would mean that about fifty 1-min cycles of injection would be required to introduce a total of 105,000 gal. Obviously, the 50 cycles of injection allows for a very large combination of injection patterns from the 18 tools placed within the tank. Cameras mounted in the dome of the tank would be used to visually monitor the mixing process. These observations would be used to optimize the mixing process and assist in deciding which combination of MPI tools would be best to operate.

The insert at the bottom of Fig. 7 is representative of the carrier casing arrangement and canister, which would be located at the central riser of the tank. Each of the 18 carrier casings shown in Fig. 7b has a corresponding tool in the upper sketch. The large canister is ~28-in. in diam. A "coal chute" is attached to each of the carrier casing and will be pointed in a outward radial direction, (see Fig. 4 and 5 for photographs of the coal chute used in FY 1999 SRS cold tests). Each of the carrier casings, as shown drawn in Fig. 7b, has an offset angle of 20º from the adjacent casing.

Any injection that must be done around the central hole and canister would be accomplished with vertical injection tools. These vertical injection tools would be merely lowered through the center of the 28-in.-diam canister.

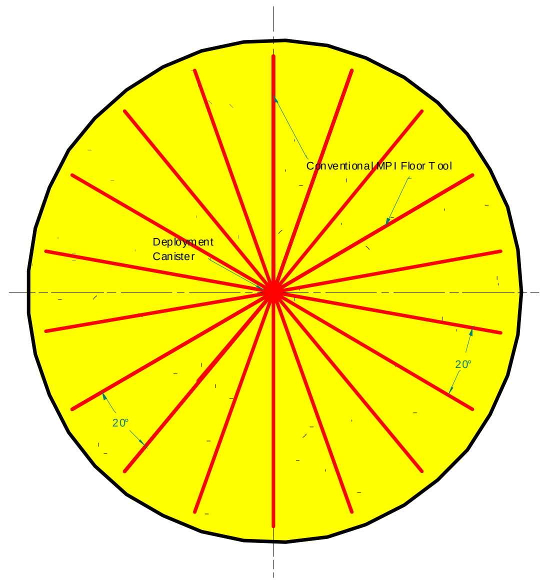
3.2 MPI™ TOOL LAYOUT FROM A SINGLE RISER AT THE EDGE OF TANK

A logical extension to a central wagon wheel tool arrangement is to shift the center of the entire wagon wheel off to the outer edge of the tank, as depicted in the schematic in Fig. 8a. Of the 17 tools depicted in the sketch in Fig. 8a, ~50% of them are longer than 40 ft. The maximum lateral distance, which a string of tools needs to be deployed, is across the entire diameter of the tank and is ~85 ft. Therefore, half the tools required would be of the type used during the FY 1999 SRS cold demonstration, while the other half would correspond to the MPI super tools described in Sect. 2.2.2. The insert at the bottom of Fig. 8 is representative of the carrier casing arrangement used to insert the tools in the tank. All 17-carrier casings can be fitted within a half-moon circle of a 34-in.-diam-riser pipe.

It is estimated that 4–6 of the injection tools could be simultaneously activated. The injection scheme would be to try and limit the total required horsepower to ~7,200. Each of the 4–6 tools would be activated for ~1 min. The turbulent mixing developed during this time would cover about one-third the floor of the tank. Thereafter, 4–6 different tools would be used to cover one-third of the tank floor. The process would be repeated until a total of 105,000 gal of grout are injected. As previously described, this would require about fifty 1-min injection cycles.

ORNL-Dwg-2000-2707

(a) Plan view schematic of MPI tool arrangement around single central riser of 85-ft--diam tank



(b) Close-up schematic of deployment canister attached to central tank riser

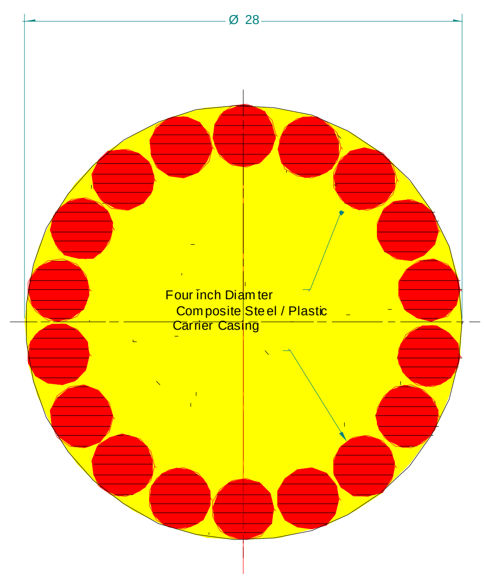
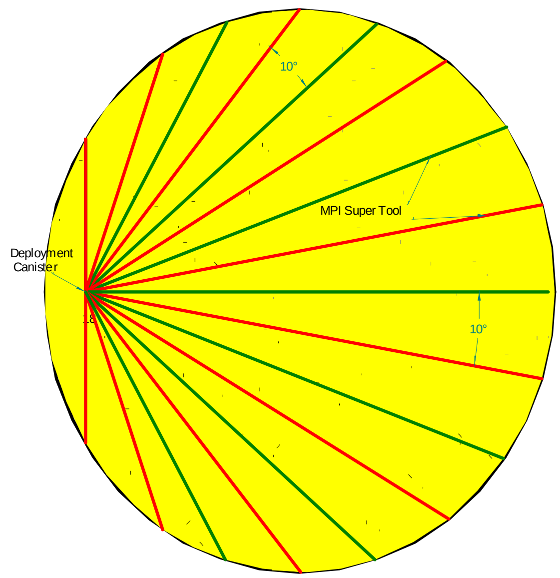


Fig. 7. Schematic layout of MPI horizontal tools for in-tank treatment of heel sludge: (a) plan view and (b) close-up of canister holding MPI carrier casing for attachment to central riser. Note: All information in this Figure is marked as limited rights data under the terms of the subcontracts between Ground Environmental Services and Lockheed Martin Energy Research. MPI is protected under U. S. Patents Nos. 5,860,907 and 5,645,377 with several other patents pending.

ORNL-Dwg-2000-2708

(a) Plan view schematic of MPI super tool arranged around single riser at edge of 85-ft-diam tank



(b) Close-up schematic of deployment canister illustrating arrangement of carrier casing

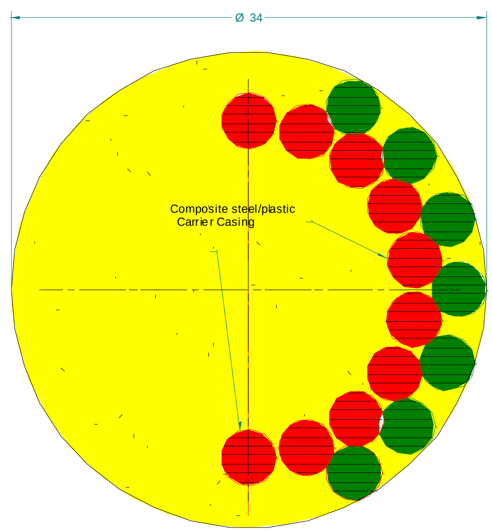


Fig. 8. Schematic illustration showing general arrangement of MPI super tools deployed through 34-in.-diam riser at edge of 85-ft-diam tank: (a) plan view of floor tools and (b) close-up of deployment canister and arrangement of carrier casing. Note: All information in this Figure is marked as limited rights data under the terms of the subcontracts between Ground Environmental Services and Lockheed Martin Energy Research. MPI is protected under U. S. Patents Nos. 5,860,907 and 5,645,377 with several other patents pending.

The major advantage of deploying all the MPI tools through a single riser at the edge of the tank is related to health and safety issues. All construction activities would be confined to a single location-off the top of the tank. Opening and closing the valve manifold, which controls grout flow into each tool, is simplified since all the MPI hoses would be grouped at a central location near the canister. This procedure is also an advantage of deploying all the MPI tools through a single central riser.

It should be noted that the vector diagram, which defines the initial orientation of the MPI jets, was not superimposed upon any of the tool layouts that are shown in Fig. 7 or 8. The jet orientation is done in relationship to the location and amount of actual sludge at the bottom of the tank. Uniformly placed sludge infers uniformly placed jets along the hose paths, as depicted in Figs. 7 and 8.

3.3 INTEGRATION OF EXHUMATION AND IN-TANK TREATMENT VIA MPI™ PROCESS

Currently, the baseline remediation technique for buried tanks, which is used by DOE, is exhumation of sludge via sluicing using high-pressure water jetting. The approach taken is to use a few small-diameter jets and a robotic arm to deploy the water cutting tools. For a large-diameter tank, the robotic arm has a severe payload restriction because of the external forces applied to the extension cylinders of the arm. Furthermore, most of the funds and effort are directed at fabricating an expensive deployment system (robotic arm) with little applied to the water-jetting tools that actually perform the work.

The development of the MPI process has taken a totally different route in that all the tooling placed in the tank is simple and disposable. This approach allows the design of the tooling layout to be done for a specific tank—unlike the robotic arm, which is too costly to be abandoned in a tank after a single use. However, the exhumation methods preferred by DOE and currently incorporated into the MPI process are both identical. Each relies upon jetting technology. Additionally, the MPI process has been successfully demonstrated as a means to treat heel material in-situ and form a homogeneous monolith, which is both advective flow and leach resistant. The fabrication of all the MPI tooling and mobilization of the pumps and grouting plant to a large tank site can be used more effectively (at lower cost) if multiple of activities are performed with the tools and equipment. These activities would encompass the following steps:

(1) The MPI process would initially be used to break apart and mobilize the sludge to allow submersible pumps to transfer the waste from the tank.
(2) Once the bulk waste has been retrieved from the tank, the same tooling can be used to treat any heel material that remains inside the tank after the exhumation campaign.

Currently, DOE does not have an integrated technology that can perform both sludge exhumation, followed by in-situ stabilization and immobilization of the heel material left behind. The discussions presented here provide an integrated approach for using the MPI process to facilitate meeting these needs.

4. REFERENCES

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