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Demonstration of Close-Coupled Barriers for Subsurface Containment of Buried Waste

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DEMONSTRATION OF CLOSE-COUPLED BARRIERS FOR SUBSURFACE CONTAINMENT OF BURIED WASTE

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Abstract

The primary objective of this project was to develop and demonstrate a close-coupled barrier for the containment of subsurface waste or contaminant migration. A close-coupled barrier is produced by first installing a conventional cement grout curtain followed by a thin inner lining of a polymer grout. The resultant barrier is a cement polymer composite that has economic benefits derived from the cement and performance benefits from the durable and resistant polymer layer. Close-coupled barrier technology is applicable for final, interim, or emergency containment of subsurface waste forms. Consequently, when considering the diversity of technology application, the construction emplacement and material technology maturity, general site operational requirements, and regulatory compliance incentives, the close-coupled barrier system provides an alternative for any hazardous or mixed waste remediation plan.

This paper discusses the installation of a close-coupled barrier and the subsequent integrity verification. The demonstration was installed at a benign site at the Hanford Geotechnical Test Facility, 400 Area, Hanford, Washington. The composite barrier was emplaced beneath a 7,500 liter tank. The tank was chosen to simulate a typical DOE Complex waste form. The stresses induced on the waste form were evaluated during barrier construction. The barrier was constructed using conventional jet grouting techniques. Drilling was completed at a 45^0 angle to the ground, forming a conical shaped barrier with the waste form inside the cone. Two

overlapping rows of cylindrical cement columns were grouted in a honeycomb fashion to form the secondary backdrop barrier layer. The primary barrier, a high molecular weight polymer manufactured by 3M Company, was then installed providing a relatively thin inner liner for the secondary barrier. The primary barrier was emplaced by panel jet grouting with a dual wall drill stem, two phase jet grouting system.

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I. Introduction

Over the past five decades, many US Department of Energy (DOE) Complex sites have experienced numerous loss of confinement failures from underground storage tanks, piping systems, vaults, landfills, and other structures containing hazardous and mixed wastes. Consequently, efforts are being made to devise technologies that provide containment of waste sites either as a safety net to "catch" future contaminant leakage/migration or as an interim step while final remediation alternatives are developed. A subterranean barrier increases the performance of the waste site and reduces the possibility of contaminant migration into local geologic media or groundwater. Failure to treat contamination in situ may result in exorbitant restoration costs at a later date. In addition, the legal ramifications for not treating many of these waste sites could be detrimental to the responsible parties.

The primary objective of this project was to develop and demonstrate an economical subsurface barrier technology capable of containing virtually any waste form(s) within the existing subsurface media, disposal, or storage structures. More specifically, the barrier was designed to cost substantially less than any known alternative remedial action such as: cryogenic, soil-saw, or circulating air barriers; excavation and treatment; vapor extraction, etc. In addition the barrier design provides interim, or permanent containment or can enhance other remedial options such as stabilization and removal.

The close-coupled barrier is built by first installing a conventional cement grout curtain followed by a thin lining of a polymer grout. The resultant barrier is a cement polymer composite that has economic benefits derived from the cement and performance benefits from the durable and resistant polymer layer. It is essential that materials (grouts) and emplacement techniques are compatible; therefore, they were developed and demonstrated simultaneously. This is not a trivial issue. Barrier materials must simultaneously be emplaceable; i.e., compatible with emplacement equipment and site geology; withstand a wide variety of chemical; thermal, physical and radiological conditions; and meet acceptable longevity requirements. The concept of close-coupled barrier technology is the combination the two technologies being developed at Sandia National Laboratories (SNL) and Brookhaven National Laboratory (BNL). The demonstration was further expanded by incorporating non intrusive barrier continuity verification technologies into the demonstration. These included a non intrusive ground penetrating radar (GPR) geophysical surface survey conducted by Allied Signal and a gas tracer study by BNL.

SNL has been investigating placement methods and cementitious grouts for subsurface barriers (Dwyer, 1994). During the summer of FY94 SNL placed several pilot scale jet-grouted cement columns at a clean site near the Chemical Waste Landfill at Sandia. At the same time BNL was invited to demonstrate a polymer grout using the same placement equipment.

BNL has been developing improved polymer-grout barrier materials for applications where impermeability and long-term durability are required (Siskind and Heiser, 1993). These materials have been used extensively in many commercial applications such as sewage and brine handling systems and electrolytic baths. Polymer grouts are candidates for high quality barrier materials due to their impermeability to gases and liquids, tremendous resistance to radiation, acidic, and alkaline environments (Heiser and Xfilian, 1994). However, these tremendous properties do have their cost. Polymer grouts are relatively expensive when compared with cementitious materials; consequently, a close-coupled or composite barrier combining polymers and cement materials offers the optimum combination of high performance and low cost in a barrier.

For a barrier where zero tolerance in leak rate is required it would be nearly impossible to achieve this goal using a cementitious grout. Large castings of hydraulic cements result invariably in cracking due to shrinkage, thermal stresses induced by the hydration reactions, and wet-dry cycling prevalent at arid sites. The improved, low permeability, high integrity polymer materials under investigation by BNL achieve the permeability and durability goals, but are relatively costly. A team composed of Brian Dwyer of SNL, John Heiser of BNL, and Steve Phillips (grouting contractor) of Westinghouse Hanford Company (WHC) was assembled to complete the design, installation, and integrity validation of the subsurface barrier. SNL designed an economical cement grout curtain that served as a backdrop for the polymer liner. A cementitious "bath tub" was formed and the inside coated with a polymer binder. The final containment is a composite barrier having the cost savings associated with using relatively inexpensive neat cement grout to form the structural backdrop; thereby, minimizing the volume of the more expensive polymer grout required to attain the desired containment objectives.

Close-coupled barrier technology is applicable for final, interim, or emergency containment of subsurface waste forms. Consequently, when considering the diversity of technology application, the construction emplacement and material technology maturity, general site operational requirements, and regulatory compliance incentives, the close-coupled barrier system provides an alternative for any hazardous or mixed waste remediation plan.

This demonstration was jointly funded by the Landfill Stabilization Focus Area (LSFA) and the Plumes Focus Area (PFA). For the LSFA close-coupled barriers have many applications. They can be used to contain buried waste providing a lower permeability, more durable and chemically resistant barrier than cement grout alone. The polymers are not expected to crack as easily as cement (wet-dry cycling) or slurry walls (solvent or organics). Close-coupled barriers are also useful in hot spot retrieval for containing mobile contaminants while excavation and removal take place and may serve as shoring reducing the amount of contaminated soil. Utilization by PFA related projects include isolating a source term (e.g., sealing a leaking UST or containing a subsurface spill of solvent) and preventing continued spread of a plume; thereby, fixing the volume of waste. A data subset of the technology developed from the close-coupled barrier demonstration will include grouting with polymers. The use of polymers alone will also prove useful to the DOE complex. Plumes or source terms can be surrounded by an inexpensive polymer(e.g., AC-400 acrylate grout) to improve remediation efficiency for such technologies as in-situ air stripping of VOCs.

II. Background

During FY94 small scale configurations (v-trough, cone, and 7x7 vertical column matrix) using cementitious grouts were installed via jet grouting. A single column was installed using a polymer grout. The FY95 demonstration installed a conical configuration barrier that is representative of many DOE sites. Figure 1 is a conceptual profile of the close-coupled cement/polymer barrier installation. FY94 testing consisted of infiltration testing and lab analysis of core samples. FY95 testing (evaluation) was expanded to include more rigorous infiltration testing (leak test with TDR and soil moisture block probes strategically located), gas tracer evaluation and also stress/strain monitoring of the waste form during grouting. The barrier was constructed to surround a simulated waste site (tank) configured in a landfill excavation. A buried tank was chosen to simulate a typical waste form that exists within the DOE Complex. It was not intended to imply that this technology is only applicable for buried tanks.

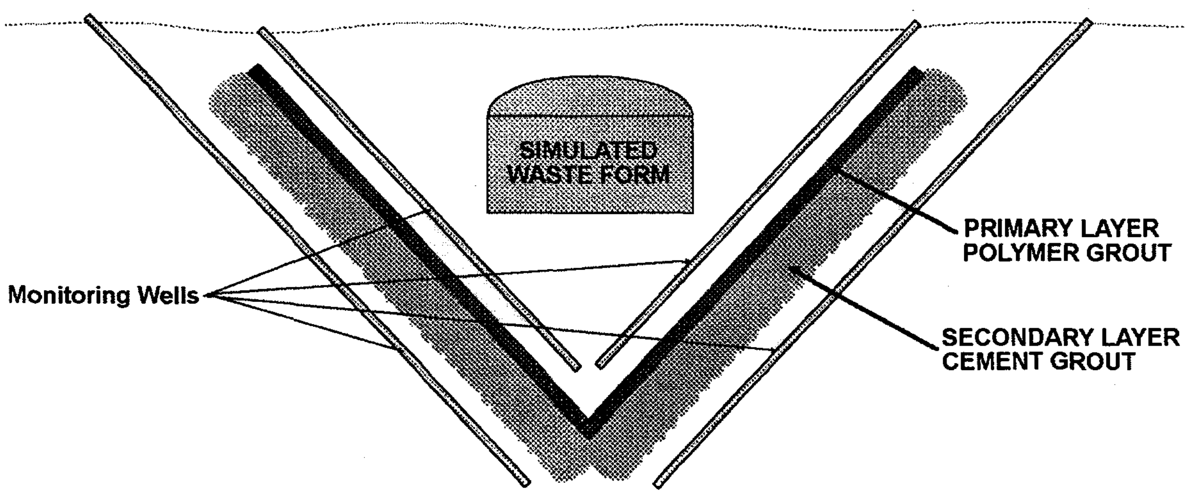

Figure 1. Schematic of Close-Coupled Barrier Demonstration.

III. Test Site

The site selected for the field-scale demonstration was the Geotechnical Test Facility (GTF), 400 Area at the Hanford Site near Richland, Washington. This site was selected for several reasons: in geotechnical terms it represents many DOE facilities, the GTF is fully characterized and permitted for such a demonstration, the grouting contractor and required instrumentation and equipment (e.g., accelerometers, steel tank, etc.) is located nearby (eliminating mobilization/de-mobilization costs).

The GTF was completed in FY '82. It was originally designed to test and demonstrate burial ground subsidence control methods. The site is NEPA approved and well characterized and is described in a report Construction and Preliminary Description of a Geotechnical Test Facility at the Hanford Site, Richland, Washington by Phillips and Fischer (Rockwell Hanford Operations SD-RETI-048). Potential end users were identified and include BNL (chemical and glass pit remediation), INEL (hot spot retrieval) and Hanford (close-coupled barriers for UST leak repair). The GTF (Hanford) soil is a coarse sand to gravel; BNL is a coarse sand, free of clay lenses or cobble, and INEL is an alluvial/eolian deposit consisting of fine clay sized silts to coarse gravels of carbonaceous origin overlying basalt.

Jet grouting is a technique first developed in Japan in the 1970s. This technique injects grout at high pressure and velocity; thereby, completely destroying the soil's structure. The grout and soil are intimately mixed, forming a homogeneous columnar mass. Jet grouting is feasible in virtually all soil conditions ranging from clays to gravels (Kauschinger et al, 1992). However the soil type affects the effective diameter of the grout column, i.e., the efficiency of the process. For example, the diameter of a grouted column in clay soil is less than in sandy soil due the energy absorbing characteristics of the clay vs. the sand. This effect will be minimal and in the worst case will require slightly reduced spacing of the installation bore holes (columns), increased jetting pressures, and decreasing withdrawal rates. The worst impediment soil type could impose to jet grouting would be large cobble that could block the jetting pathway, potentially resulting in a gap (shadow) in the barrier. It is anticipated that with a close-coupled approach the cobble will become part of one or both of the barrier layers (since the jetting would occur parallel and perpendicular to the cobble; column jetting followed by panel jetting). Therefore the success of the technology is virtually independent of the test site soil type.

Prior to the demonstration the subcontractor prepared the site by burying a 7500 liter tank and simultaneously installing verification and monitoring equipment. Monitoring wells were located inside and outside the area to be enclosed by the barrier. The monitoring wells were used for verification of the barrier integrity using perfluorocarbon tracers and for moisture determinations during water infiltration testing.

IV. Barrier Installation

This project demonstrated a "Systems Approach" to construction of a subsurface barrier. This includes the integration of barrier materials, emplacement equipment, verification techniques, and monitoring instrumentation to produce a close-coupled engineered barrier. The barrier materials and engineering placement systems portion of this technology were sufficiently mature to produce and demonstrate functionality.

A full scale subsurface barrier consisting of two different materials was emplaced around and beneath a 7500 liter tank. The tank was chosen to represent typical waste forms that exist within the DOE Complex. The stresses induced on the waste form were evaluated during barrier construction. This is an important part of a barrier emplacement because a miscalculation of the forces exerted on the waste form or structure could result in an unplanned release. After installation of each barrier layer the integrity of the barrier was verified using PFT technology. After the tracer gas verification was completed a static hydraulic head test was conducted. This involved flooding the internals of the barrier with water. Soil moisture and TDR (Time Domain Reflectometry) probes were used to follow the wetting front during saturation and for subsequent performance monitoring. This test will last approximately 3 to 4 months, consequently results are not incorporated in this report. Results will be applicable to construction of subsurface barriers throughout the DOE Complex and will have direct applicability to other government and private sector waste confinement actions. The technology will be applicable to construction of final, interim, and emergency barriers for a wide variety of waste/storage disposal sites.

The barrier was constructed using conventional jet grouting techniques. Conceptually jet grouting is a process in which grout is injected at high pressure orthogonal to the drill string through a small orifice(s) just above the drill bit. When the grout travels through the small nozzle orifice(s) the high pressure is converted to velocity which in turn masticates and intimately mixes the soil and grout forming a column approximately 1 meter in diameter that resembles a pancake stack (Figure 2). After the grout pumped into the primary holes has gelled, secondary boreholes are drilled (in a honeycomb fashion) and grout is injected to fill gaps in the primary grout injection. This results in a barrier 1 1/2 to 2 meters thick. Typically, the technique requires a pumpable grout that can be injected at pressures of 400 to 500 bars through a small orifice(s), typically 1 to 2.5 mm. Generally the grout is a low viscosity material (-5 cps) that uses the soil as the bonding aggregate providing relatively high compressive strengths when fully cured. Jet grout curtains can be vertical using conventional drilling, or may be angled, or horizontal, using directional drilling.

Panel jet grouting is simply jet grouting without rotating the drill string during withdrawal. Instead, the drill rod/ nozzle jet orifice(s) is oscillated back and forth only a few degrees or simply withdrawn with no rotation. This results in a thin panel, typically 30-40 centimeters wide. Panels are laid side by side with a slight overlap in order to form a continuous barrier. The result is a significant reduction in the volume of grout required to form a continuous barrier layer.

The barrier was emplaced using a Casa Grande C6S, owned by Westinghouse Hanford Company, track mounted drill/grouting rig. The unit is depicted in Figure 3. The grouting assemble includes the following components: 1) a track mounted drill rig capable of conventional rotary/percussion drilling any direction conceivable; 2) a sub-assemble that connects up to three pressure lines to the drill string; 3) pump systems

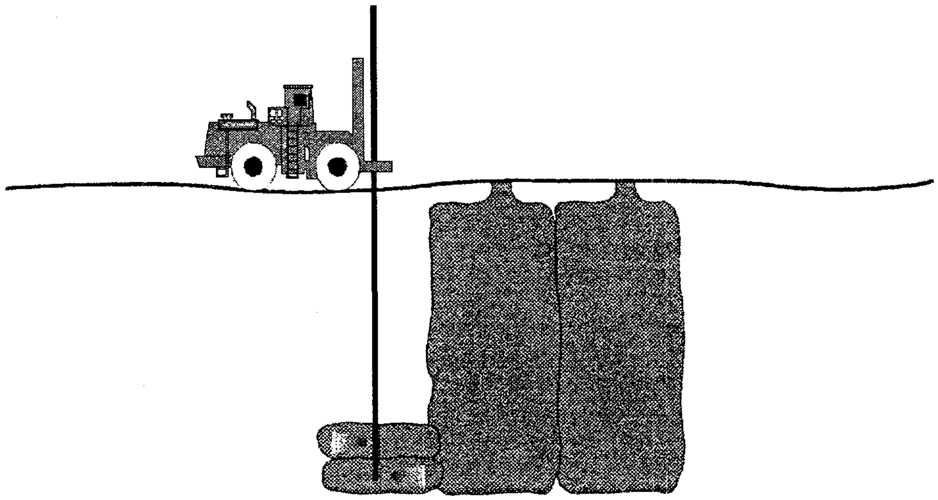

Figure 2. Conventional column jet grouting.

Figure 3. Casa Grande Jet Grouting Rig used at Hanford Demonstration.

capable of delivering a single or multiple grouts to the drill string at pressures ranging from 10 to 600 bars complete with volume and pressure measurement.

The secondary (cementitious) barrier layer was installed first during the summer of 1995. Installation was completed in seven days. This layer serves primarily as a backdrop for the polymer layer and secondly as a redundant, albeit less durable, barrier. The following steps summarize the secondary barrier installation activities: 1) optimize jet grouting process by installing a series of individual columns, varying the applicable parameters, in a test pit adjacent to the test site; 2) excavate/observe the test column results and choose optimum grout injection parameters; 3) barrier location and corresponding drill holes are mapped on the surface, including drilling sequence; thereby, avoiding cross communication between grout holes; 4) drill rig geometry/alignment determination for each drill hole; 5) drill to desired depth; 6) grout during drill string withdrawal. The following grout injection parameters (optimized parameters) were used: 1) injection pressure = 400 bars; 2) number of nozzles = 2; 3) nozzle orifice diameter = 2.2 mm; 4) extraction length/step = 5 cm; and 5) rotation/step = 2. Figure 4 exhibits an optimized individual column, which was approximately 38 inches in diameter.

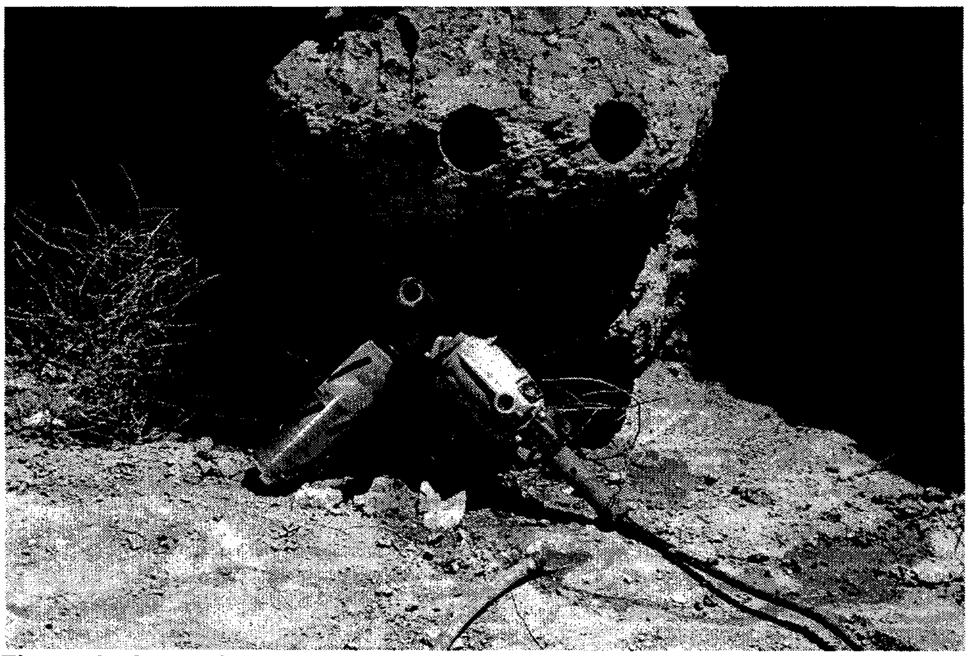

Figure 4. Secondary Barrier Test Column.

The secondary layer, a relatively thin layer of polymer (0. 15 to 0.3 meters) was applied to the inside of the cementitious barrier using panel grouting. This reduces the required volume of relatively expensive polymer grout used to create the primary barrier. The secondary cementitious grout backdrop is durable enough to withstand the jetting action during the polymer injection.

The primary barrier installation was completed in December, 1995. Installation procedures were similar to the secondary barrier installation with a few exceptions: 1) injection pressure = 100 bars; 2) panel grouting was used instead of full rotation; and 3) a two part polymer was injected instead of a single neat cement material. Injection of the two part polymer was accomplished using a two-phase injection system. More specifically this required the use of two injection pumps, one high pressure, and one low pressure, and corresponding metering equipment;, a subassembly connecting the high and low pressure pump hoses to the drill string, and a dual wall drill string capable of injecting and mixing the two grout parts downhole external to the drill string ensuring that no grout polymerizes inside the pumping or drilling equipment. Grout injection optimization parameters were again determined using individual test panels. The grout injection parameters used were: 1) injection pressure = 100 bars; 2) number of nozzles = 2; 3) nozzle orifice diameter = 2.2 mm 3) withdrawal rate = 6 seconds/m. Figure 5 exhibits the optimized individual panel, which was approximately 30 inches in width and 6 inches thick.

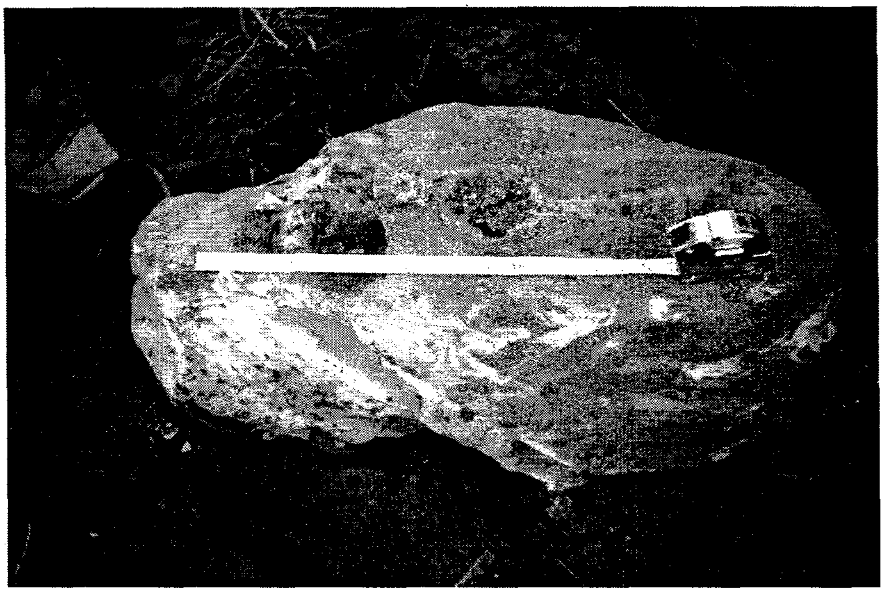

Figure 5. Primary Barrier Test Panel.

The polymer used as the primary barrier is a high molecular weight acrylic manufactured by 3M Company. The resin is polymerized using a catalyst in combination with a promoter. The promoter is mixed in with half the monomer resins(Part A) and the catalyst is mixed into the other half (Part B). The polymerization reaction begins when parts A and B mix together downhole. The mixing occurs as part of the soil mastication/mixing that occurs from the high pressure jetting. The polymer layer was installed in December, 1995, following baseline verification activities on the cement curtain.

Successful demonstration of close-coupled barrier technology will be verified by operational testing, post operational monitoring, and destructive examination of the tank and geologic system. Specific criterion for measuring technology success include: formation hydraulic conductivity reduction of greater than two orders of magnitude, emplacement of primary and secondary barriers without compromising the integrity of the waste form (tank), and smooth integration of emplacement, barrier materials, verification, and post monitoring technologies, providing a comprehensive subsurface barrier program.

V. Integrity Verification

Currently there is no suitable methodology for validating the containment integrity of an emplaced barrier.(Heiser, 1994) Because of the large size and deep placement of subsurface barriers detection of leaks is challenging. At present, nonintrusive geophysical techniques appear inadequate for this task. These techniques identify/image anomalies in the subsurface but cannot distinguish small variations, such as cracks or gaps because the resolution is insufficient. Consequently, detection of discontinuities (small cracks or gaps) on the order of inches at relatively shallow depths (< 100 ft.) has not been possible using existing geophysical techniques. In addition to problems with nonintrusive viewing of the subsurface, the emplacement techniques such as jet, compaction, or permeation grouting have potential flaws. Permeation and compaction grouting for instance, results in very unpredictable grout placement in the majority of soil types, i.e., most soils are heterogeneous in nature. Consequently preferential grout flowpaths result in no guarantees of barrier location. Conversely, during a jet grouting emplacement soil heterogeneity has a much less negative impact. Although problems can occur when a borehole becomes misaligned or a jet nozzle is partially obstructed by cobble or varying soil types/densities, leaving a gap in the final barrier. Panel jet grouting may leave gaps between panels and/or at the junctions of horizontal and vertical barrier walls and may be thinner, and thus more prone to cracking. Additionally at the time of gel formation separations or "tears" may occur if localized settling takes place. In this experiment, two overlapping rows of jet grouted columns were placed; thereby, substantially decreasing the likelihood of barrier flaws.

As a subtask to the barrier emplacement, two novel approaches for verifying the continuity of the barrier were simultaneously demonstrated: 1) Brookhaven National Laboratory used perfluorocarbon tracers (PFT) to locate breaches in the barrier; and 2) Allied Signal Federal Manufacturing & Technologies New Mexico conducted a nonintrusive surface geophysical survey using Ground Penetrating Radar (GPR) to characterize the extent (volume, depth, etc.) of the barrier and to detect any voids in the barrier. Although the final results of subtask 1 have not been interpreted yet, the demonstration has provided a proof-of-concept for gaseous tracer verification of barrier integrity. Feasibility of the PFT technology was established, and final results will give an estimate of the resolution of the technology. According to Allied Signal personnel the data collected using GPR clearly showed each individual grout injection, tight connection between all injections, and in their estimation no voids exist. (Baumgart, Pounds, et al., 1996)

A. PFT Technology Description

The equipment and materials required for PFT technology includes: the tracer gases, injection equipment, samplers and analyzers. Negligible background concentrations of PFTs occur naturally in our environment; consequently, very small quantities of PFTs are needed to conduct a verification test. PFTs are nontoxic, nonreactive, nonflammable, environmentally safe (contain no chlorine), and commercially available. PFT technology is the most sensitive of all non-radioactive tracer technologies and concentrations in the range of 10 parts per quadrillion of air (ppq) can be routinely measured. The PFT technology is a multi-tracer technology permitting up to six PFTs to be simultaneously deployed, sampled, and analyzed with the same instrumentation. This increases flexibility and lowers the cost of experimental design and data interpretation. All six PFTs can be analyzed in 15 minutes on a laboratory based gas chromatograph.

Low detection limits allow detection of very small breaches in a barrier. Breaches are located by injecting a series of PFTs on one side of a barrier wall and monitoring for those tracers on the other side. The injection and monitoring of the PFTs was accomplished through slotted wells as shown in Figure 1. The location, quantity and type of tracer detected on the monitoring side of the barrier indicates the size and location of a breach. Obviously, the larger the opening in a barrier the greater the amount of tracer transport across the barrier. Precise location of a breach requires more sophistication in the tracer methodology. Multiple tracer types can be injected at different points along the barrier (both vertical and horizontal). Investigation of the spectra of tracers coming through a breach then gives a location relative to the various tracer injection points.

The concentration of PFTs in the gas innoculation mixture was determined using computer codes to make first approximations of expected dilutions during subsurface transport. Because the required gas detection concentration outside the barrier is known, a back calculation determines the required source concentration (assuming gas permeability constants for the soil and barrier layers). These assumptions and model predictions determine the initial sampling numbers and duration. The process was refined substantially during this experiment.

B. GPR Technology Description

Geophysical Survey Systems, Inc. (GSSI) ground penetrating radar was used to characterize the barrier installation. Both 100 and 300 Mhz antennas, with a Model SIR-10A system were used. The survey of GPR data was collected by pulling the antennas in an X-Y grid fashion. Data was collected at approximately one A-scan/cm along each grid line (B-scan line). Data was taken at 1/2 the width of the RADAR antenna between B-scan lines.

In addition, an EM-31 conductivity probe was tested at the barrier site, but results yielded no useful data. Details of the nonintrusive geophysical survey conducted by Allied Signal personnel can be found in separate reports. (Baumgart, et.al.,1996)

VI. Monitoring

Forces exerted on the simulated waste form (buried tank) were monitored to determine changes in stress due to grout injection. Four vertical and four horizontal strain gages (one in each quadrant of the tank) were mounted on the inside of the tank , ten inches from the bottom. These gages measure strain on the tank wall. Also three modules were mounted on the outside of the tank-two inches from the tank bottom and evenly spaced around the tank (120^0 between each module). Each module contained three earth pressure cell monitors mounted orthogonally to monitor soil pressure outside the tank. Finally an inclinometer/extensiometer tube was mounted in each quadrant outside of the tank next to the outside wall of the tank to measure lateral and horizontal soil displacements.

Monitoring instruments were recorded prior to barrier installation (baseline), after secondary barrier installation and again after primary barrier installation. Results were as follows:

- horizontal and vertical strains measured on the tank wall showed no significant changes throughout the entire experiment;
- the earth pressure cells showed no significant changes throughout the experiment;
- and the extensiometer readings indicated no vertical soil displacements, but inclinometer readings indicated a maximum of 0.5 inches displacement in one tank quadrant.

VII. Costs

Table 1 exhibits an estimate of the relative costs of this close-coupled barrier installation to competitive technologies.

IMPERMEABLE SUBSURFACE BARRIERS

$$$ RELATIVE COSTS $$$

CORRECTIVE ACTION	$/M^3	COST FOR 2 ACRE x 20' DEEP HAZARDOUS WASTE SITE
CLOSE-COUPLED BARRIER	$24	$1.7 MILLION
CRYOGENIC BARRIER	$90	$6.4 MILLION
TEVES	$150	$10.7 MILLION
EXCAVATE & TREAT	$590	$41.9 MILLION

Table 1. Subsurface Barrier Costs.

VIII. Conclusions

Close-coupled barriers demonstrated by this task are applicable to final, interim, and emergency loss of confinement conditions. The technology is applicable to any buried or surface waste form that has the potential to release mobile contaminants. Unlike many other subsurface barrier technologies, close-coupled barriers are applicable to a wide range of waste materials and geohydrologic conditions. This is extremely advantageous because nearly every subsurface barrier has site specific conditions that require the flexibility offered by this technology, more specifically this technology offers an ability to place barrier materials that are compatible with virtually any waste form in almost any geologic setting.

End users for this technology include any DOE, state or commercial facility that has waste that may release contaminants to the environment. Specific end users have been identified and include Idaho National Engineering Laboratory (INEL), Brookhaven National Laboratory (BNL) and the Hanford reservation. INEL and BNL are interested in the full subsurface close-coupled barrier technology. Letters of support of the demonstration have been obtained from Lockheed Idaho for INEL and the DOE area office for BNL. Hanford has expressed interest in the use of polymers to form a close-coupled barrier. This technology could be used to seal leaks in the underground storage tanks at Hanford.

PFTs may potentially assist in locating and sizing breaches in a subsurface containment system. The technology has regulatory acceptance and is used commercially for non-waste management practices (e.g. detecting leaks in underground power cables, radon intrusion into basements). This technology has been used in a variety of soils and locals and will be applicable to the entire DOE complex as well as commercial waste sites. Gas tracers may be used to validate barrier continuity after emplacement, to re-check corrective actions that may be used to seal or repair a breach, and may also be useful to periodically check a barrier to determine the long term integrity.

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