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DEVELOPMENT OF A CEMENT-POLYMER CLOSE-COUPLED SUBSURFACE BARRIER TECHNOLOGY

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ABSTRACT

The primary objective of this project was to further develop close-coupled barrier technology 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 chemically resistant polymer layer. The technology has matured from a regulatory investigation of issues concerning barriers and barrier materials to a pilot-scale, multiple individual column injections at Sandia National Labs (SNL) to full scale demonstration. The feasibility of this barrier concept was successfully proven in a full scale "cold site" demonstration at Hanford, WA. Consequently, a full scale deployment of the technology was conducted at an actual environmental restoration site at Brookhaven National Lab (BNL), Long Island, NY. This paper discusses the installation and performance of a technology deployment implemented at OU-1 an Environmental Restoration Site located at BNL.

INTRODUCTION

U.S. 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 fixes the volume of waste and reduces the possibility of contaminant migration into local geologic media or groundwater. Failure to treat contamination in situ will also 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 at a field scale an economical subsurface barrier technology capable of containing virtually any waste form(s) within the existing subsurface media, disposal, or storage structures. 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. A secondary objective of this project was providing a demonstration barrier for integrity verification. The technology of choice was perfluorocarbon gas tracers. BNL provided the expertise in this area.

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Conceptually a 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 chemically 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.

BACKGROUND

SNL has been investigating placement methods and cementitious grouts for subsurface barriers. During the summer of FY'94 SNL placed several pilot scale individual jet-grouted cement columns, conical and v-trough shaped configurations, and a 7 X 7 matrix of 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. FY94 barrier evaluation testing consisted of infiltration testing and lab analysis of core samples. In FY'95, a team composed of Brian Dwyer of SNL, John Heiser of BNL, and Applied Geotechnical Engineering Construction, Inc. (grouting contractor) was assembled to complete the design, installation, and integrity validation of a full scale subsurface barrier. The test was conducted at a benign (cold) site in Hanford, WA. A cone shaped cementitious "bath tub" was constructed and the inside lined with a polymer binder that BNL has been developing for applications where impermeability and long-term durability are required (Siskind and Heiser, 1993) (Heiser and Columbo, 1994). The final containment product 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. FY'95 testing (barrier integrity validation) was expanded to include more rigorous infiltration testing (falling head test with TDR and soil moisture block probes strategically located), gas tracer evaluation and also stress/strain monitoring of the waste form during grouting. Figure 1 is a conceptual profile of the close-coupled cement/polymer barrier installation at BNL.

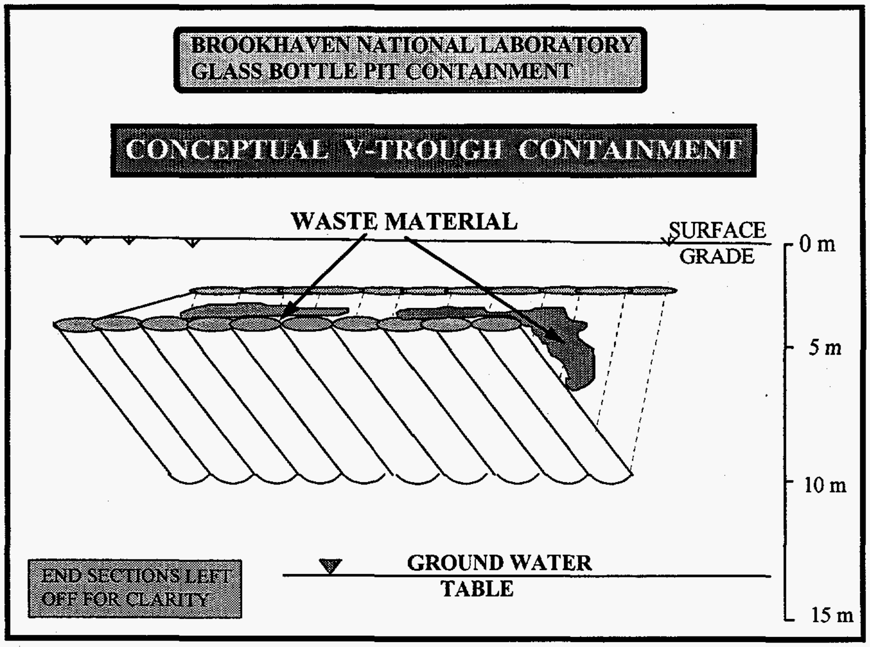

Figure 1. Schematic of Close-Coupled Barrier Demonstration.

TEST SITE

The deployment test site selected for the field-scale demonstration is noted as the AOC 2C Glass Holes location. The Glass Holes area is located inside OU-IV, BNL, and the Glass Hole pit chosen was G-11 (1 of 17 Glass Hole pits in OU-IV). BNL is located in central Long Island, New York state. The geologic media consists of unconsolidated glacial deposited sediments primarily composed of fine to coarse grained quartzose sand with lessor amounts of gravel. Groundwater beneath Pit G-11 is approximately 13 meters below grade. Groundwater sampling in the OU-IV area has shown the presence of volatile organics, heavy metals, and fission products. Historical records indicate that the Glass Hole pits were typically excavated with a clam-shell to depths of 6 to 7 meters. Waste materials and backfill were placed into the individual unlined pits in lifts with final backfill to grade. Most of the constituents in Pit G-11 are unknown.

TECHNOLOGY DESCRIPTION

Jet grouting is a technique first developed in Japan in the 1970s. This technique injects grout at high pressure (~400 bars) 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, Perry and Hankour, 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.

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 post monitoring instrumentation to produce a close-coupled engineered barrier. More specifically, during this project the first step was construction of a tertiary barrier consisting of two rows (honeycombed) of interconnected vertical and inclined portland based grout columns installed adjacent to and below Pit G-11 forming a v-shaped trough with the waste pit contents undisturbed on the inside. Figure 1 exhibits a conceptual view and Figures 2 and 3 are plan and cross sectional views. Next, the inside of the cement v-trough was lined with a low viscosity, chemically resistant polymer (AC-400) to form a secondary barrier to contaminant movement. The composite cement-polymer barrier provides isolation of the pit contents from the underlying groundwater. Next, the primary barrier was formed by injecting cementitious grout material at relatively low pressure into the waste form; thereby, stabilizing/solidifying the entire waste form. Prior to hardening of the grouted waste form, concrete demolition tubes (dewy-dags), and steel retrieval picking eyes were strategically placed to enable controlled fracturing of the monolithic waste form into smaller retrievable monoliths (~ 4 ft. X 4 ft. X 9 ft. deep) once the large monolith was fully cured. After complete curing of the concrete monolith, an expansive demolition grout placed in the dewy-dags facilitated cracking the large monolith into the smaller more manageable stabilized cells or monoliths. Each cell can now be containerized, transported and stored, disposed to other facilities, or other actions taken in accordance with BNL closure plans.

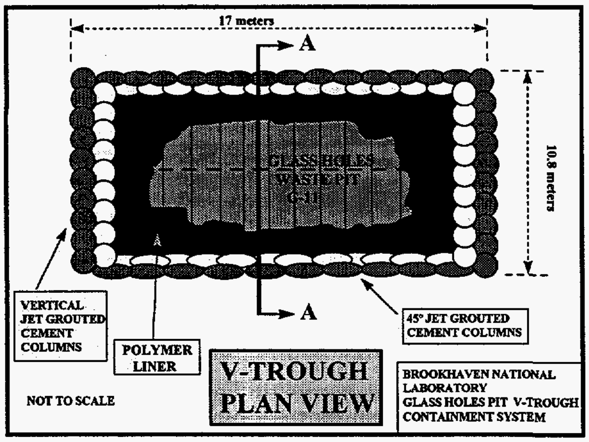

Figure 2. Plan view of glass holes pit G-11.

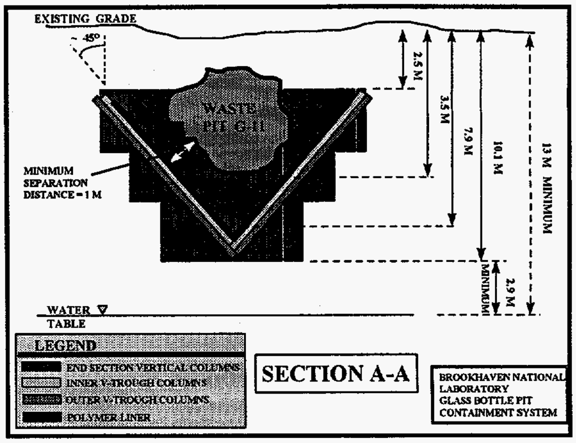

Figure 3. Cross Section A-A of glass hole pit G-11.

EQUIPMENT AND MATERIALS

The barrier was emplaced using a Casa Grande C6S, track mounted drill/grouting rig. The unit is depicted in Figure 4. The grouting assembly 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 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.

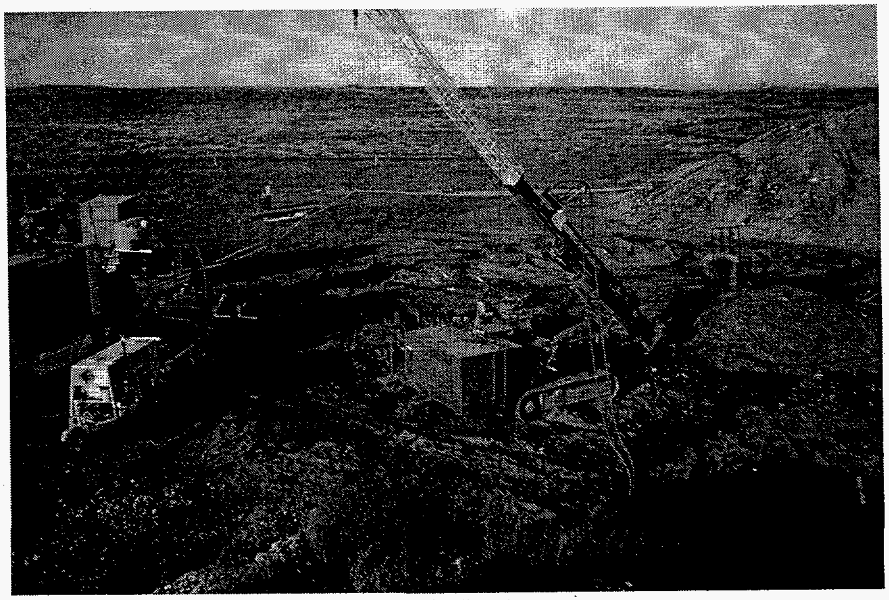

Figure 4. Casa Grande C6S Jet Grouting Rig.

The polymer used as the secondary barrier is a conventional acrylic polymer manufactured by Geochemical Corp. known as AC-400. 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 external to the drill string. The mixing occurs as part of the soil mastication/mixing that occurs from the high pressure jetting. The tertiary barrier and the primary stabilizing barrier material was neat cement, a 0.9: 1 mixture of water to portland cement.

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. Nonintrusive geophysical techniques appear inherently inept 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 or thin diaphragm wall 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 the demonstrations at BNL and Hanford, two overlapping rows of jet grouted columns were placed (honeycomb configuration); thereby, substantially decreasing the likelihood of barrier flaws.

Validating the integrity of the barrier at BNL was achieved in two ways: (1) adherence to Test Plan QA/QC barrier construction procedures; and (2) use of a novel approach developed at BNL. QA/QC procedures included rigid specifications for grout mixtures, injection pressures, and drilling geometries to ensure barrier continuity by emplacement of multiple or redundant barrier walls. The second verification technique utilizes perfluorocarbon tracers (PFTs) to locate breaches in the barrier. The feasibility of the PFT technology was established during the demonstration at Hanford, WA.

The equipment and materials required for PFT technology includes: the tracers 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 are 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 geoprobe wells strategically place inside and around the subsurface barrier. 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 certain gas permeability constants for the soil and barrier layers). These assumptions and model predictions determines the initial sampling numbers and duration.

PFTs will 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.

MONITORING

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.

CONCLUSIONS

The successful deployment of a multiple material close-coupled barrier at BNL indicates the technology can be used for remediation of subsurface waste sites with: (1) current loss of containment; (2) high probability of near term loss of containment; and/or (3) loss of containment caused by retrieval or in situ remedial actions. Furthermore, this technology is applicable to any 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.

Demonstration of this technology in a very difficult geologic setting is the next step toward final development of: (1) the subsurface barrier equipment and materials, and (2) the cost data to allow potential end users a method to estimate the cost of implementation of this technology at their site.

In the area of barrier verification, it appears that QA/QC procedures during barrier construction in conjunction with tracer gas validation and post emplacement monitoring are the most effective candidates available at this time.

ACKNOWLEDGMENTS

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