COLLOIDAL SILICA BARRIER DEPLOYMENT AT BROOKHAVEN NATIONAL LABORATORY

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ABSTRACT

MSE Technology Applications, Inc. (MSE) has deployed the first colloidal silica barrier at a radioactive contaminated site, the Brookhaven Linear Accelerator (LINAC) Isotope Producer (BLIP) at Brookhaven National Laboratory (BNL) on Long Island, New York. Routine groundwater monitoring detected contamination including tritium (^{3}H) and sodium-22 (^{22}Na) downgradient from the BLIP. Site characterization studies were performed to confirm the BLIP was the source of the contamination, as well as to determine the levels and extent of the contamination (1). ^{3}H and ^{22}Na are the primary contaminants of concern due to their longer half-lives; and both can be easily transported down to the groundwater with precipitation that infiltrates the contaminated soils.

While several actions were taken to improve surface water management at the BLIP in response to the contamination detected, BNL proposed that a colloidal silica (CS) barrier be emplaced to encapsulate the activated soil beneath the BLIP building. This barrier would prevent further migration of the contaminants to the groundwater. The expected life span of the barrier is 25 years (2).

The CS grout was injected in spring 2000 using the low-energy delivery method, so destruction to the subsurface infrastructure did not occur and spoils/contaminants were not brought to the surface. Grout was injected from between 6 and 7 meters below ground level down to approximately 10 meters below ground level, where the BLIP footing was located. The barrier was emplaced within two and half weeks and encapsulated the approximately 73 cubic meters (m^3) of activated soil.

A test panel was emplaced in close proximity to the barrier, so in situ hydraulic conductivity testing could be performed without compromising the integrity of the barrier. Using the field hydraulic conductivity measurements and correlations developed from lab sand tank testing and modeling, it was determined that the flux through the test panel met the BNL requirement (3).

INTRODUCTION

The BLIP facility, located at BNL on Long Island, New York, is an accelerator facility, which produces radioisotopes that are crucial to nuclear medicine for both research and clinical use. During operation, the LINAC generates a proton beam that impinges a target to produce the required isotopes. This proton beam is absorbed prior to reaching the soils surrounding the target shaft. However, high-energy secondary neutrons created in the process pass through the target cooling water and into the surrounding soils. This bombardment of high-energy neutrons on the soil has resulted in the activation of several radionuclides including ^{3}H and ^{22}Na, both of which have been detected in groundwater samples collected from monitoring wells downgradient of the BLIP facility. The groundwater contamination is a result of contaminant transport from the activated soil zone via infiltrating water. BNL has implemented several storm water management actions to decrease the infiltration of water through the activated soil zone; however, further action was required to prevent future contamination of the groundwater. (4)

The emplacement of a CS barrier was selected to encapsulate the activated soils and prevent further migration of activation products to the groundwater table. This containment method would not only prevent the leaching of ^{3}H and ^{22}Na from the activated soils surrounding the BLIP target area into the groundwater; it would also allow the continued operation of the BLIP facility. Conversely, the option of excavation and removal of the contaminated soils would require a shutdown and potential dismantling of the facility. The containment technology will allow time for development of new technologies that can treat the isolated activated soils and time for radioactive material to degrade to a level in which the risk to human health and the environment is acceptable (if contaminated soils are removed at a future date). Figure 1 is a conceptual drawing of the BLIP facility during the CS barrier emplacement.

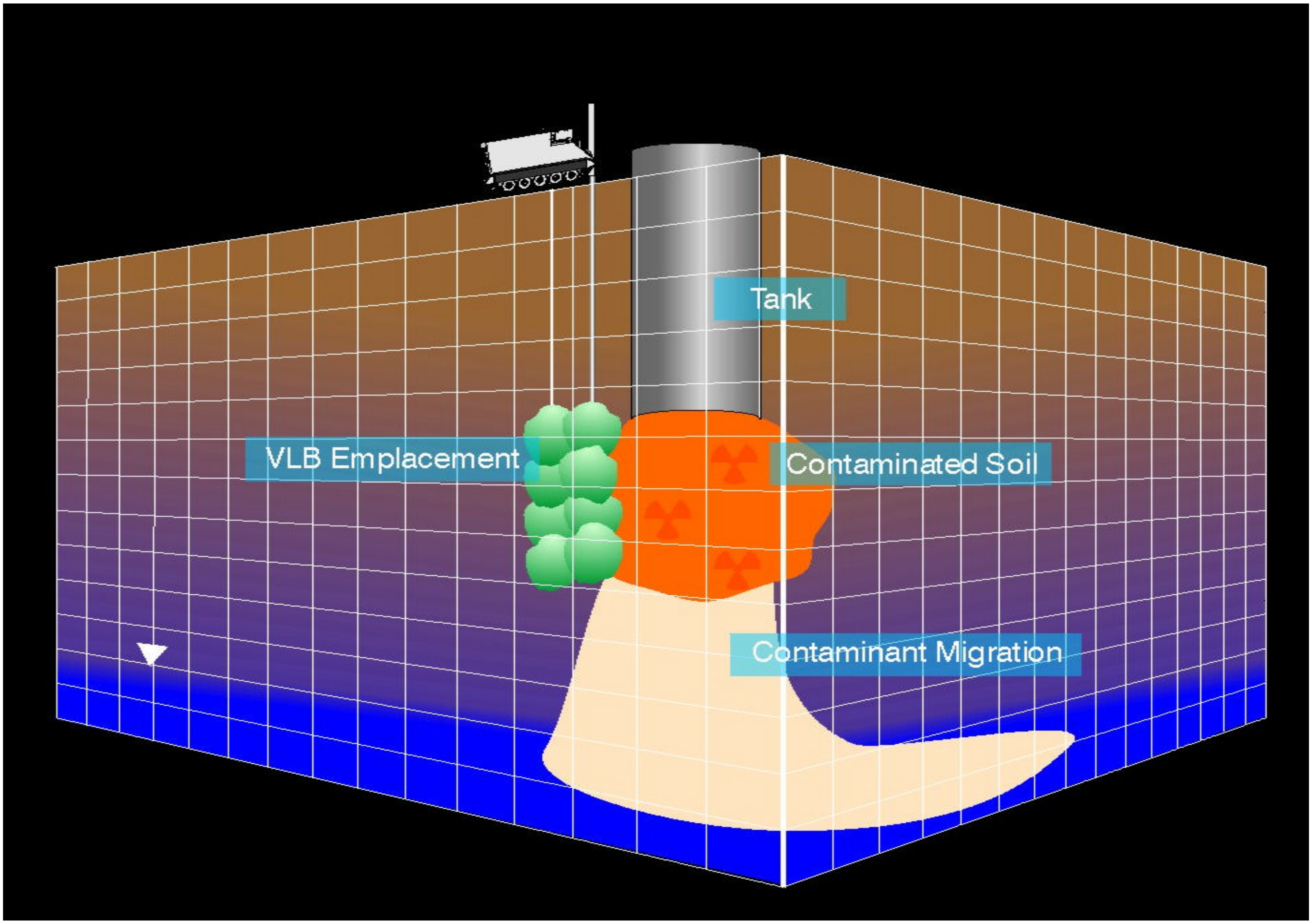

Fig. 1. Conceptual drawing of the BLIP Site at BNL

The overall goal of the CS barrier emplacement is to construct and verify the performance of a subsurface hydraulic barrier emplaced using a viscous liquid chemical grout material (i.e. colloidal silica) and downstage permeation grouting methods at the BNL BLIP site.

Technology Description

The colloidal silica grout used for the barrier is a silica-based chemical grout that has excellent durability characteristics in the subsurface (especially in radioactive environments), poses no health hazards, and is chemically and biologically inert. The colloidal silica gels when mixed with a calcium chloride ($CaCl_2$) electrolyte; the amount and strength of the electrolyte solution control the gel time. The grout gel time, CS colloid particle size, CS solids content, and injection spacing control the performance of the barrier. This grout mixture is injected via permeation grouting into the subsurface where it permeates the soil matrix, displaces the pore water and air, and seals the pore voids.

The CS barrier technology has the ability to provide either long-term or interim containment of waste in the unsaturated soil zone. Since the emplacement uses a low-energy delivery system, few contaminants are brought to the surface during grouting, and destruction to fragile infrastructure does not occur.

Benefits of the VLB technology include:

- The VLB provides reduced worker exposure at hazardous/radioactive sites;
- It provides interim or long-term isolation of waste;
- The VLB has the ability to contain waste material in situ, decreasing the mobility of waste through the
- unsaturated soils and preventing the waste from entering the groundwater;
- VLB is a cost-effective technology compared to excavation and disposal;
- The viscous liquid is compatible with multiple waste forms (i.e., radioactive waste, organics, and inorganics) and is not degraded biologically or chemically, resulting in a long-term containment system; and
- The viscous liquid containment system can be emplaced around areas of a sensitive nature (i.e., around piping, under storage tanks and infrastructure) for source control purposes because the low-energy emplacement method allows nondestructive emplacement, limiting surface disruption.

CS Barrier Deployment Objective

The primary driving mechanism for the contaminant flux is water moving through the unsaturated zone, carrying the isotopes downward to the water table. The objective of the CS barrier emplacement is to cause a reduction in the rate at which water moves through the soils, thereby reducing the amount of contaminants transported to the water table. The performance goal set by BNL was to reduce the flux through the contaminated soils from 30 centimeters per year (cm/yr) to a maximum of 4 cm/yr.

CS BARRIER EMPLACEMENT

The equipment required for the CS barrier emplacement was selected or designed specifically for the project to provide a robust, efficient grout delivery and grout quality testing system. The components of the grout delivery/testing systems included: direct-push rig, direct-push injection rod, grout mixing/delivery system, grout flow control stations, hole deviation tool, digital level, field computer, grout laboratory equipment, and an electric concrete coring tool. The emplacement equipment and tote bins containing CS and electrolyte were shipped to the project site at BNL and arranged in preparation for grouting operations.

Field Testing and Test Panel Installation

Once the equipment was setup and injection and equipment performance testing were complete, the test panel was installed. Three different grout bulb strings of three bulbs each were injected into the subsurface; the injection horizons ranged from 3.6 meters below ground surface (bgs) to 5 meters bgs. The test panel maintained the 30% vertical and horizontal bulb overlap to mimic the design for the BLIP CS barrier. The volumes of the test panel bulbs ranged from 340 to 568 liters of grout each.

Maintaining verticality was a primary goal during the pilot hole drilling and while advancing the injection rods. Once at the injection horizon, the design volume of grout was injected; the injection rod string was then driven down to the next horizon and the process repeated until all three horizons were injected. Once complete, the rods were pulled and the holes backfilled. The procedures were then repeated for the second and third injection locations of the test panel. During grout injection, flow rates were monitored and recorded at the flow control rack, along with grout specific conductivity measurements for quality control (QC).

GROUT FIELD TESTING

Quality Assurance/Quality Control Testing

A field laboratory for CS grout testing was set up to allow on-going testing of the grout quality to determine if there were any irregularities in the grout mixture, as determined by the laboratory tests. Material acceptance testing, electrolyte molarity testing, grout gel time testing, and viscometer testing were conducted during the test panel and barrier emplacement.

Acceptance Testing – The specific gravity was measured for colloidal silica and calcium chloride ($CaCl_2$); both were within the specified parameters. The CS viscosity and pH were also within the accepted range. Gel time testing was also performed. The CS was made to gel by adding electrolyte solution. A 90-minute State 2 gel time was determined using viscometer and jar tests. State 2 gel time viscometer readings correspond to a viscosity between 10 and 12 centipoise (cP). State 2 gel time is defined as a highly flowing gel that appears to be only slightly more viscous than the initial solution. After an additional 90 minutes, the grout obtains a State 9 gel, where it becomes a rigid gel with no gel-surface deformation upon inversion of the sample jar. The process of gelation for the jar tests was recorded by assigning gel states according to gel time states modified by Lawrence Berkeley National Laboratory (5). All grout materials were accepted.

Electrolyte Solution Molarity Testing – The proper electrolyte solution molarity was determined to produce the desired gel time test for the CS grout, then batches of the electrolyte solution were mixed for the deployment. Baseline viscometer and jar tests were conducted using samples from the larger batches of electrolyte solution to confirm the gel times. The same $CaCl_2$ concentration was used throughout the barrier emplacement.

Grout Gel Time Testing – The desired gel time range for the grout was from 70 minutes to 110 minutes. Grout samples were collected from the flow control racks throughout the emplacement of the test panel and barrier. A sample was collected and tested for each of the emplaced grout bulbs. Nine grout bulbs were injected to form the test panel, and 99 grout bulbs were injected to form the barrier. Out of a total of 108 grout bulbs emplaced during the emplacement, only 3 grout bulbs did not have gel times within the desired range. However, all neat grout samples collected did completely gel and then cure to form a rigid material. The three (out of specification) samples were all collected at times when the pump seals were leaking due to excessive wear. Once the seals were replaced, the desired gel time was again achieved.

Radiological Work Preparation

The BLIP target handling room was cleared out to make room for the grout injection operations. Plastic sheeting was laid out to cover the painted concrete floor and the seams were joined together and sealed with duct tape to prevent radiological contamination from getting under the protective cover. The rig was painted with a special strip-coat material, which allowed the coating to be removed along with radiological contamination once the project was completed. Plastic sheeting and duct tape were used to cover movable parts such as hydraulic lines and control levers. A rod decontamination rack was built for the storage and decontamination of injection rods and tips. In addition, the pipe-vise tripod was also covered with plastic and duct tape, protecting it from contamination.

Once the equipment was inside the BLIP building, radiological control zones were set up to control access and potential contamination. A radiological buffer zone was located inside the large garage door to provide a space for grout hoses and the rig exhaust hose. In order to operate the rig inside the building, a hose was attached to the exhaust of the rig and ducted outside the building. To prevent potential airborne contamination in the air cleaner and engine, an air duct was brought from outside and attached to the air-cleaner intake manifold to supply clean air. In addition, sheets of aluminum were placed on the floor to prevent the rig from ripping the plastic sheeting as it was moved around in the building.

Once the preparations inside and outside the BLIP building were completed and the injection hole locations were measured and marked on the floor covering, the area was designated as a radiological controlled area (RCA) or rad zone and access was limited to necessary personnel. Personnel were permitted entry per the BNL Radiological Work Permit (RWP). The designated safety level was modified Level D, based on respiratory protection; the Radiological Control Technician (RCT) would upgrade if conditions existed to change the posted area to "Airborne Radioactivity Area."

All tasks performed throughout the project were coordinated with BNL personnel to minimize exposure and reduce radioactive waste, as well as to comply with BNL's pollution prevention objectives.

Barrier Installation

Installation of the barrier began in late May. Procedures established for working in the rad zone and used for the first injection were used throughout the emplacement process. Therefore, the same general procedure described for the first injection was used on all injection locations, the only differences being the number and depths of injections. A 7.6-cm diameter hole was cored through the concrete, using the approved standard operating procedure for coring concrete in a radiological contamination zone. The procedure used water to mitigate dust during coring operations with the water being removed by a wet/dry vacuum.

Fig. 2. CS injection at the BLIP

Once the concrete was cored, the rig was moved over the hole in preparation for grouting. A pilot hole was pushed down to 4.5 meters below floor level using the pilot rod with the slightly oversized tip, checking for verticality periodically. The injection rod string was placed down the hole, the injection drive cap and grout supply hose from the flow control rack were attached, grout flow was established, and the injection sequence was initiated at the first injection horizon. Figure 2 shows the push rig during CS injection. The grout injection progressed as previously described in the test panel installation section. Once the designed volumes of grout were injected, the rods were advanced to the next horizon; when the grout string was completed the rig was moved to the next location. A deviation survey was conducted to measure the verticality of the injection string, once total depth was reached at each injection location. The deviation survey was completed using the injection rig crew to lower the probe down the rod and a person to run the data logger/recorder outside the rad zone. The survey was completed by repeating the measurement procedure at 0.5-meter increments until reaching the bottom of the injection rod. The injection rods were pulled immediately after completion of the deviation survey. The deviation rods and injection rods were swiped to monitor for contamination as they were retracted from the injection hole. Once the swipes determined that the rods were not contaminated, they were placed on the rack for cleaning. Any rods or injection tips that were contaminated were placed in plastic sleeves and sealed for later decontamination. At the end of each grouting session, grout lines were drained and flushed with clean water to wash out any activated grout from the in-line mixing system and supply hoses.

The injection holes were backfilled with a mixture of silica sand and CS grout to within 4.5 meters of the surface. After the grout gelled, neat cement grout was poured down the hole to seal the remaining portion of the injection hole to within 15 cm of the surface.

Injection Sequence

The injection sequence was designed to optimize the grout injection process in terms of pore water management in the subsurface. By starting in back of the activated zone area on one side and working towards the front, pore water in the soils would effectively be pushed out rather than trapped within the grouted area. However, for radiological contamination control purposes, the sequence of injection was modified in order to work on the area furthest to the back so that if contamination was encountered, it would be confined to areas previously grouted and would not be spread due to further work in the area. To achieve the two objectives, the injection pattern was changed to allow work to progress outward to keep contamination in check while taking into consideration pore water management. The injections next to the BLIP tank were completed first, and then the outer injections were completed, keeping at least one inner injection ahead of the outside injections.

Several injection locations were modified due to the facility equipment interfering with maneuvering the rig and to optimize the grout placement in the subsurface. One injection location was omitted from the injection pattern due to other injection locations being moved and the grout bulb volumes increased.

Where possible, two grout injections were completed simultaneously to maximize productivity. When grouting two locations at once, one would typically be started first to get two or three injection horizons ahead of the second injection location to avoid cross-hole interference.

As-Built Representations

Near-time as-built drawings were constructed in the field during the emplacement using injection data and grout string locations, as well as the deviation data to determine the actual grout bulb placement in the subsurface. The construction of the as-builts provided a QC check of the constructed barrier. The drawings helped determine when modifications were necessary, including redesign of grout string locations and addition of grout to fill any void spaces to compensate for injection rod deviation that had occurred.

The final as-built representation of the CS barrier shown in Figure 3 represents the barrier as emplaced. The drawing was constructed using the grout string locations, including those that deviated from the design, and the actual injected volumes of grout for each of the bulbs.

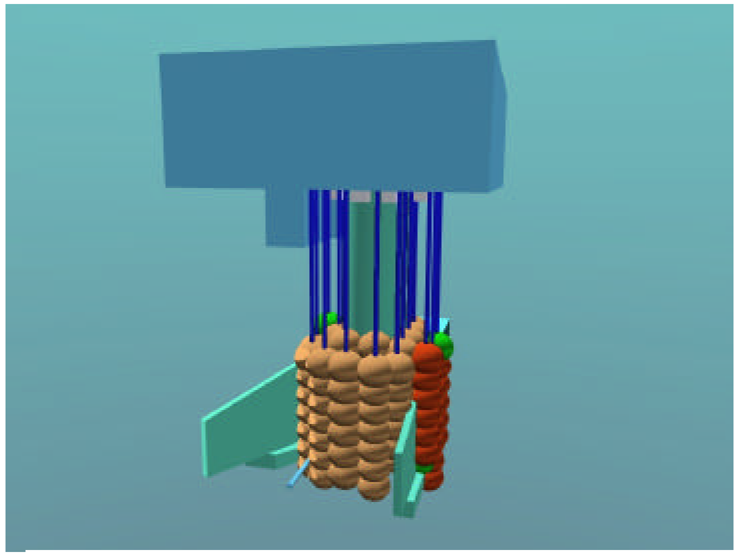

Fig. 3. As-built representation of the CS barrier

Equipment Decontamination and Radiological Surveys

Once the grout injections were complete, clean up, survey and removal of equipment and tools from the RCA were initiated. The injection rods were cleaned, and the outer surfaces were surveyed for radiological contamination. Although the rods surveyed clean on the outer surfaces, they could not be released due to the inability to survey the inner surfaces. The rods and injection tips were then stored in a rad zone for eventual disposal as rad waste. The protective covering was removed from the rig; it was surveyed clean and released from the RCA. The remaining equipment was surveyed out of the area, leaving only the radiological waste to be bagged, labeled, and stored for eventual monitoring and disposal. The floor covering was also removed, bagged, and stored for later monitoring to determine if rad waste disposal was necessary. The RCT then removed the RCA control, allowing easier access in and out of the BLIP Building. All equipment and personnel were demobilized.

BARRIER INTEGRITY VERIFICATION

Prior to the CS barrier emplacement, boreholes were installed at an angle beneath the BLIP facility to aid in the barrier integrity verification. Borehole logging was performed prior to the emplacement as a baseline and after emplacement to monitor changes in soil moisture and isotope concentrations. Any changes would most likely be a result of the barrier emplacement. The boreholes were about 60 feet in length and installed at an angle of approximately 20 degrees from vertical. With these boreholes in place, it was possible to monitor the isotope concentrations in the pore water and soil moisture beneath the BLIP.

Geophysical Borehole Logging

A suite of geophysical logs was acquired in boreholes on four occasions. Data were acquired twice prior to the CS barrier installation to establish a baseline, once within a few days after completing the installation and once approximately 60 days after the installation. The data acquired during these logging events included borehole deviation (first logging event only), electromagnetic (EM) conductivity, neutron–soil moisture, and spectral gamma (including total gamma). From the spectral gamma logs, the gamma ray energies associated with the ^{7}Be and ^{22}Na

isotopes were extracted and plotted. Two sets of logs were acquired in each borehole during each logging event to provide independent data sets for QC.

Baseline Data

The neutron, electrical conductivity, and total gamma logs from the two baseline data acquisitions are almost identical; and the ^{7}Be and ^{22}Na energies show no significant change. The baseline total gamma and spectral data show an area between 6.1 meters and 9.1 meters down the boreholes (corresponding to about 5.8 meters to 8.5 meters vertical depth) with a significant increase in counts per second. This indicates an increase in concentration of gamma-emitting isotopes. The neutron logs indicate the soil moisture is fairly constant from the surface to a borehole depth of about 9.1 meters. From 9.1 meters to about 13.7 meters the soil moisture decreases steadily before leveling off. The electrical conductivity remains fairly constant along the length of the borehole. This indicates the subsurface material is most likely consistent from the surface down to depth.

Post-Barrier Installation Analysis

Following the CS barrier emplacement, two more sets of logging data were acquired. The first sets of post-installation data were acquired within a few days of completing the CS injections. The second geophysical borehole logging event was completed approximately 60 days later.

Post-installation logging data acquired within a few days of completion of injections show common responses in both boreholes; the logs show changes in the formation responses from approximately 6.1 meters to 12.2 meters (vertical depth of 5.8 meters to 12.2 meters bgs). These depths correspond to the zone in which the CS barrier was installed. The neutron logs indicate that soil moisture increased slightly. Conductivity and gamma logs (including the ^{7}Be and ^{22}Na energies) from the first post-installation logs also increased compared to the baseline data. These variations are most likely a result of the CS injection; the CS grout is extremely conductive. As it is pumped into the formation, the grout pushes the occupying pore fluid out, closer to the geophysical boreholes. In addition, the pore fluid most likely contains some amount of contamination (gamma-emitting isotopes) from the activated zone.

The 60-day post-installation logging results indicated there was little change in the subsurface since the first set of post-installation measurements. In both boreholes, the two post-injection data sets are very similar in magnitude and shape, showing the same trends when compared to the pre-injection data. Additional borehole logging after an extended period of time may provide different results that could aid in monitoring the barrier's performance effectively.

Guelph Permeameter Testing

The hydraulic conductivity of the BLIP test panel was determined in situ using Guelph permeameters. The Guelph permeameter is a constant head device that provides a method to measure saturated in situ hydraulic conductivity. The Guelph permeameter data were analyzed by the single-head analysis method (6), which uses steady-state flow rates from one constant head setting. Guelph permeameter testing was conducted in August 2000 and again in December 2000. The results are summarized below.

Permeameter Test Results – August 2000

Thirteen possible test locations for the Guelph permeameters were identified, both within the grout bulbs and where the grout bulbs overlap. During the early permeameter testing conducted approximately 60 days after the barrier emplacement, the permeability of the test panel was measured in four different boreholes at three different horizons, at 3 meters, 3.9 meters, and 4.7 meters bgs. This resulted in a total of 12 different permeability tests performed at 7 different locations, both within and outside of the grout bulb overlap zone.

Table I displays the permeameter test results determined using the single-head analysis method. While the hydraulic conductivity values ranged from $3.09x10^{-6}$ cm/sec to $1.50x10^{-3}$ cm/sec, the geometric mean hydraulic conductivity of the BLIP test panel was calculated at $7.63x10^{-5}$ cm/sec. (The in situ hydraulic conductivity of the native sands at BNL is approximately $1x10^{-3}$ cm/sec.)

Table I. BLIP test panel permeability values for August 2000.

Horizon	Borehole ID	Hydraulic Conductivity (cm/sec)
3 m	A	$3.09x10^{-6}$
	7	$5.06x10^{-5}$
	3	$4.21x10^{-6}$
	2	$8.88x10^{-6}$
3.9 m	C	$3.07x10^{-4}$
	9	$6.01x10^{-4}$
	5	$3.07x10^{-5}$
	2	$2.53x10^{-4}$
4.7 m	A	$1.50x10^{-3}$
	7	$1.35x10^{-5}$
	5	$1.14x10^{-3}$
	3	$1.84x10^{-4}$
Geometric mean of hydraulic conductivity values = 7.63x10^{-5} cm/sec		

Permeameter Test Results – December 2000

As a consequence of the earlier Guelph permeameter testing, space for additional boreholes was limited. Boreholes for the December testing were placed where interference from the completed boreholes and simultaneous permeameter tests would be minimized. Again, the permeability of the test panel was measured at three different horizons, at 3 meters, 3.9 meters, and 4.7 meters bgs. This resulted in a total of 11 different permeability tests performed at 7 different borehole locations, both within the grout bulbs and where the grout bulbs overlap.

Table II displays the permeameter test results determined using the single-head analysis method. While the hydraulic conductivity values ranged from $5.25x10^{-7}$ cm/sec to $1.68x10^{-3}$ cm/sec, the mean hydraulic conductivity of the BLIP test panel was calculated at $7.54x10^{-5}$ cm/sec.

Table II. BLIP test panel permeability values for December 2000.

Horizon	Borehole ID	Hydraulic Conductivity (cm/sec)
3 m	12	$2.17x10^{-5}$
	13	$1.39x10^{-6}$
	16	$5.25x10^{-7}$
	10	$5.91x10^{-6}$
3.9 m	10	$5.30x10^{-4}$
	17	$1.95x10^{-4}$
	D	$5.17x10^{-4}$
	12	$4.54x10^{-4}$
4.7 m	11	$1.68x10^{-3}$
	16	$1.70x10^{-4}$
	13	$6.88x10^{-4}$
Geometric mean of hydraulic conductivity values = 7.54x10^{-5} cm/sec		

The results from the permeameter testing conducted in August and December were combined and a geometric mean was calculated for each of the test horizons. The geometric mean hydraulic conductivities are $5.28x10^{-6}$ cm/sec, $2.77x10^{-4}$ cm/sec, and $3.63x10^{-4}$ cm/sec for 3 meters, 3.9 meters, and 4.7 meters bgs, respectively.

PERFORMANCE VERIFICATION

In advance of and in preparation for the barrier deployment, sand tank testing was conducted in the laboratory using native BLIP sands. During this phase of the investigation, grout was injected into sand tanks under simulated subsurface conditions. Grouted sand tank samples were collected and analyzed; and hydraulic conductivity data and soil moisture characteristic curves were developed for the grouted materials. Data/fitting parameters from the soil moisture characteristic curves and field parameters from the site were inputted into PORFLOW™ modeling software to simulate the flux through a 1-radian portion of the barrier. The results of the flow simulation were analyzed with respect to the barrier performance goal, to reduce the flux through the barrier from 30 cm/yr to 4 cm/yr. Considering that the cross-sectional area of a 1-radian portion of the barrier is 5.61 m^2, the flux of 4 cm/yr corresponds to an outflow from the modeled region of 0.22 m^3/yr.

Total outflow from the solidified medium predicted by the model ranges from 0.00005 m^3/year to 0.5 m^3/year depending on the soil moisture characteristic curve used for the modeling. Modeled outflow appears to be related to the values of saturated hydraulic conductivity (Figure 4). This power-function relation needs to be considered site specific as the magnitude of the outflow from the solidified region depends on the mutual relationship of water retention curves for the native and the silica solidified sand. The outflow from the solidified region, if calculated using the power function relationship shown in Figure 4, is 0.15 m^3/year, 0.12 m^3/year and 0.0077 m^3/year for the hydraulic conductivities of 3.6×10^{-4} cm/s, 2.8×10^{-4} cm/s and 5.3×10^{-6} cm/s, respectively. This calculation indicates that the test panel (and thus the colloidal silica barrier) meets the BNL performance goal, i.e., flux through the barrier will be less than 4 cm a year or 0.22 m^3/year.

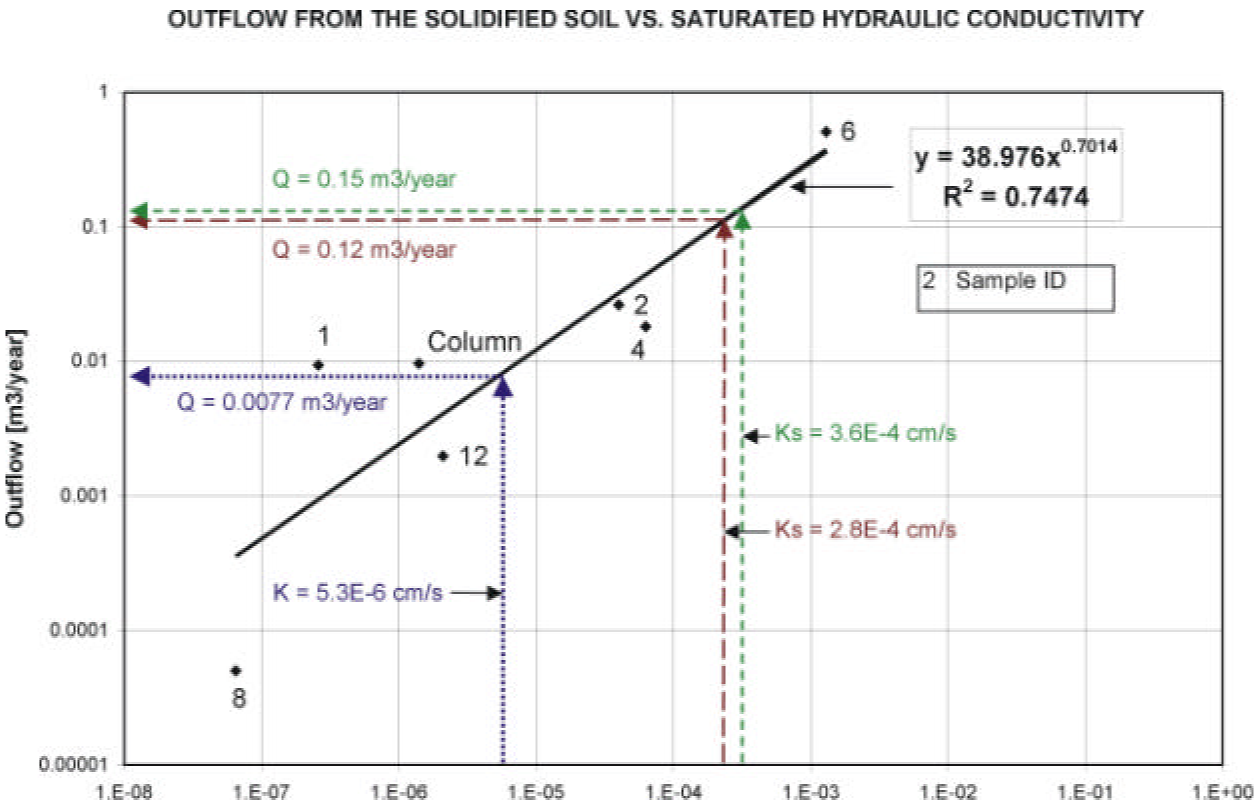

Fig. 4. Plot of Saturated Hydraulic Conductivity (cm/sec) vs. Outflow (m^3/yr).

SUMMARY

The objective of the CS barrier deployment was to reduce the contaminant flux originating at the activated zone below the BLIP to the groundwater (i.e., to cause a reduction in the rate at which water moves through the soils, thereby reducing the amount of contaminants transported to the water table). The performance requirement set by BNL was to reduce the fluxthrough the contaminated soils from 30 centimeters per year (cm/yr) to a maximum of 4 cm/yr.

Many tasks that were not discussed in this report were accomplished to support the overall completion of the CS barrier emplacement and integrity verification. Once the site was selected, the site characterization followed to provide necessary data for the laboratory work. Once the laboratory grout selection and optimization testing were completed, the results were used as input to the model that simulated the subsurface response to the grout injections in a soil similar to BNL. The model predictions were favorable with respect to the performance goal developed by BNL (3), and all documentation to support the emplacement was reviewed and approved by the necessary regulatory agencies and the end user; consequently, the project advanced to the field implementation. The field preparations, the CS barrier emplacement, and the associated health and safety and QA/QC activities were accomplished at the site. DOE's Brookhaven Area office was responsible for the successful regulator approval and also funded the site management activities, while BNL's Environmental and Waste Technology Center coordinated the site logistical support, accomplished all permitting, and managed the radiological testing. The actual deployment progressed smoothly and was accomplished earlier than anticipated due to the combined efforts of BNL and MSE.

In situ permeameter testing was conducted on the VLB test panel in August and December. The geometric means of the hydraulic conductivity results for the three different horizons (3 meters, 3.9 meters, and 4.7 meters bgs) are 5.28×10^{-6} cm/sec, 2.77×10^{-4} cm/sec, and 3.63×10^{-4} cm/sec. From past modeling of hydraulic conductivity values from BNL sands solidified with colloidal silica, a power-function relationship between the outflow and the saturated hydraulic conductivity was defined. Using the geometric means of the field measured hydraulic conductivities, the total outflow/flux from the barrier was calculated as 0.0077m^3/yr, 0.12m^3/yr, and 0.15m^3/yr, respectively. These results indicate that the test panel, and thus the colloidal silica barrier, meets the BNL performance goal of less than 4 cm/yr or 0.22 m^3/yr of flux through the barrier.

ACKNOWLEDGMENT

Work was conducted through the DOE-National Energy Technology Laboratory at the Western Environmental Technology Office under DOE Contract Number DE-AC22-96EW96405.

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