Deployment of a Colloidal Silica Barrier at Brookhaven National Laboratory

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Abstract: A colloidal silica (CS) barrier was deployed at Brookhaven National Laboratory (BNL) on Long Island, New York. Contamination including tritium (^3H) and sodium-22 (^{22}Na) was detected downgradient of the Brookhaven Linear Accelerator Isotope Producer (BLIP) during routine groundwater monitoring. An investigation was performed to confirm the BLIP was the source of the groundwater contamination and to determine the extent of the contamination. (CDM 1999) BNL then completed an Engineering Evaluation and Cost Analysis for the remediation/containment of the contaminated soils. The analysis recommended the emplacement of a CS barrier to encapsulate the contaminated soils beneath the BLIP building to prevent further migration of the contaminants to the groundwater.

The CS barrier was emplaced in 2000 via downstage permeation grouting. The grout was injected from approximately 6 meters below ground surface (bgs) down to 10 meters bgs, encapsulating approximately 73 cubic meters of contaminated soil. In situ permeameter testing was conducted on a test panel adjacent to the barrier, so the integrity of the barrier would not be compromised. Using the measurements from the field permeameter testing and correlations previously developed from modeling and laboratory sand tank testing, it was determined that the flux through the test panel (and thus the barrier) met the BNL requirement.

Introduction: The BLIP deployment site is radioactive contaminated. The facility produces radioisotopes that are essential to nuclear medicine for research and clinical use. During operation, a proton beam is generated and impinges a target to produce the required isotopes. This 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 resulted in the activation of several radionuclides including ^3H and ^{22}Na, 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 implemented several storm water management actions to decrease the infiltration through the activated soil zone; however, further action was required to prevent future contamination of the groundwater. (Heiser 2000) Figure 1 is a conceptual drawing of the BLIP during the barrier emplacement.

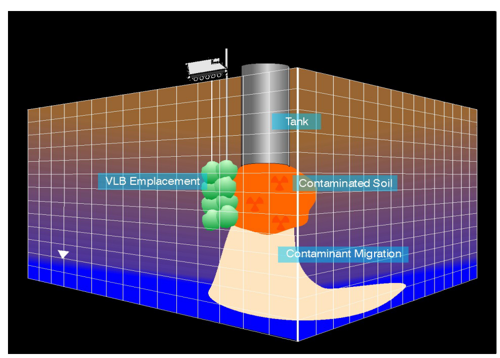

Figure 1 - Conceptual drawing of the BLIP Site.

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The deployment goal is to encapsulate or contain the contaminated soils to prevent further contaminant migration to groundwater, while allowing continued operation of the BLIP facility. The expected life of the CS barrier is 25 years (Mitchell et. al 1997), which is beyond the anticipated operational life of the facility.

Technology Description and Benefits: The colloidal silica grout used for the barrier is a silica-based chemical grout that has excellent durability characteristics in the subsurface, poses no health hazards, and is chemically and biologically inert. The colloidal silica gels when mixed with a calcium chloride ($CaCl_2$) electrolyte, the gel time is controlled by the amount and strength of the electrolyte solution. 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.

Because the CS barrier technology uses a low-energy delivery system and few contaminants are brought to the surface during grouting, it provides reduced worker exposure at hazardous sites and destruction to fragile infrastructure does not occur. The barrier 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. It is a cost-effective technology compared to excavation and disposal and it is compatible with multiple waste forms.

Barrier Deployment: The objective of the CS barrier emplacement was 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.

The barrier was emplaced using a direct-push rig, a specially designed grout mixing and delivery system, flow control stations, a deviation tool, levels, laboratory grout testing equipment, and a computer. A test panel consisting of three grout bulb strings of three bulbs each was emplaced in an uncontaminated area, to avoid comprising the barrier during performance verification testing. The procedures for the test panel and the barrier were consistent. At each injection horizon, the design volume was injected then the rods were advanced to the next horizon and the process repeated. When the grout string was completed, the rig was moved to the next injection location. Deviation surveys were conducted to measure the verticality of each injection string. During the injection of the grout, flow rates were monitored and samples were collected for grout quality testing in the field laboratory during barrier and test panel emplacement, including material acceptance, electrolyte molarity, grout gel time, and viscometer testing.

The injection sequence was designed to optimize the grout injection process in terms of pore water management in the subsurface and for radiological contamination control purposes. 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. In addition, the back of the activated zone had lower contamination levels and the injection sequence would proceed from the “cleaner” to the more contaminated soils. To achieve the two objectives, the injection pattern was designed to progress outward to keep contamination in check while taking into consideration pore water management.

As-built representations were constructed in the field using injection data and grout string locations, and deviation data to determine the actual grout bulb placement in the subsurface. The drawings helped determine whether modifications were necessary, including redesign of subsequent grout string locations and addition of grout to compensate for any void spaces.

Barrier Integrity & Performance Verification: Permeameter tests were conducted on the test panel to determine hydraulic conductivity values. The geometric means for the 3-meter, 3.9-meter, and 4.7-meter bgs horizons are 5.28×10^{-6}, 2.77×10^{-4}, and 3.63×10^{-4} cm/sec, respectively.

Laboratory sand tank testing was conducted prior to the barrier deployment using native BLIP sands injected with grout under simulated subsurface conditions. Samples were collected, analyzed, and hydraulic conductivity data and soil moisture characteristic curves were developed. With this information, PORFLOW™ modeling software simulated 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 of reducing flux through the barrier from 30 to 4 cm/yr. The cross-sectional area of a 1-radian portion of the barrier is 5.61 m^2, so the 4 cm/yr flux corresponds to an outflow from the modeled region of 0.22 m^3/yr.

The model predicted outflow from the solidified region ranging from 0.00005 to 0.5 m^3/yr, depending on the soil moisture curve used. Modeled outflow appears to be related to the values of saturated hydraulic conductivity. This power-function relation is site specific, as the magnitude of the outflow from the solidified region depends on the mutual relationship of water retention curves for the native sand and the silica solidified sand. The outflow from the solidified region, if calculated using the power function relationship shown in Figure 2, is 0.15, 0.12, and 0.0077 m^3/year for the hydraulic conductivities of 3.6×10^{-4}, 2.8×10^{-4}, 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 of less than 4 cm/yr or 0.22 m^3/yr flux through the barrier.

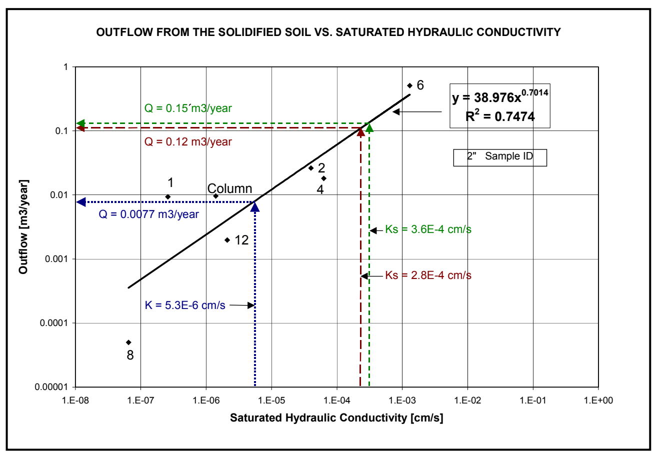

Figure 2 - Saturated Hydraulic Conductivity vs. Outflow.

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