AN INNOVATIVE SOLUTION FOR MGP RESIDUAL SLUDGE STABILIZATION WITHIN A FORMER QUARRY

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ABSTRACT

In-situ stabilization/solidification was utilized as a component of a remedy for sludge in a former quarry that had been used for the historic disposal of MGP-related wastes. Remedial investigations conducted at the Site under Pennsylvania's Land Recycling Program (Act 2) confirmed that sludge and impacted sediment beneath the quarry contained certain volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) at concentrations exceeding Act 2 direct contact Medium Specific Concentrations (MSCs). The quarry also posed a physical hazard due to its steep-sided slopes and standing water.

A treatability study was conducted for solidification/stabilization (S/S) design and product testing for the quarry sludge. The treatability program evaluated possible additives for in-situ stabilization (ISS) of composite samples of the quarry sludge in order to: 1) identify reagents that facilitate rapid solidification of the sediments while providing stabilized materials that can be used as engineered fill within the quarry; and 2) control leaching to allow the stabilized sediments to remain in place while reducing the potential for groundwater impact. The reagents tested were: 1) Type I portland cement (PC); 2) Type III PC; 3) $MgSO_3$ scrubber by-product; and 4) coal fired power plant fly ash. Based on an evaluation of the initial screening data, it was determined that confirmatory testing would be done using Type III PC.

Based on the confirmatory evaluation, the recommended dosages were as follows: 1) Upper Sludge-20 to 22.5% Type III PC; and 2) Lower Sludge – 15 to 17.5% Type III PC. Physical and chemical testing of the stabilized material proved that Type III PC achieved the project goals.

Full-scale implementation of the quarry sludge ISS occurred in January of 2003. During a five-day period, an estimated 1,900 yd^3 of sludge was stabilized using an in-situ mixing device, an ALLU Power Mix Model 300 attached to a tracked excavator. A total of 340 tons of Type III PC was injected and mixed with the sludge and underlying sediment. The calculated full-scale application rate of PC was approximately 18%, confirming the results of the treatability testing. The results of field testing (temperature, penetration resistance) confirmed the efficacy of the sludge stabilization process. As expected, the sludge was solidified and able to support the construction equipment within 24 hours or less of being treated, even under ambient weather conditions in the 10 to 15° F temperature range experienced during the work.

INTRODUCTION

In-situ stabilization/solidification (ISS) is gaining acceptance as an effective remedial alternative to traditional ex-situ remedies for MGP sites. The applicability of S/S remedies depends in large part upon three site-specific considerations: 1) treated material composition; 2) regulatory endpoints; and 3) future land use. The first of these, treated material composition depends upon the findings of bench-scale treatability tests that help answer three basic questions: 1) will S/S be effective at meeting regulatory endpoints; 2) what are the optimal reagent(s) and mix ratios needed to meet performance objectives; and 3) will the ISS process be cost-effective when compared to other remedial technologies?

The treatability tests were conducted on sludge from a former quarry located in Southeastern Pennsylvania. The Site consists of a partially wooded, 5-acre parcel of land in an area with light industrial and commercial properties. Prior to 1940 and until 1972, the Site was used for the disposal of spent filter media (purifier box waste), tank bottoms and residuals from a nearby coal coking plant. Since 1964 a portion of the property has been used as an electrical substation.

Remedial investigations (RI) were conducted between 1999 and 2002 to support closure of the property using Pennsylvania's Land Recycling and Remediation Standards Act (Act 2). The attainment demonstration under Act 2 involved the development of site-specific MSCs for both soils and groundwater. The findings from the RI and an exposure assessment supported the use of pathway elimination in combination with institutional and engineering controls as the final remedy.

SITE CONCEPTUAL MODEL

Figure 1 illustrates a site conceptual model (SCM) developed for the Site. The SCM combines information from the exposure assessment, remedial investigation and other sources into a simplified framework as an aid in understanding site conditions. The key elements of the model include:

- Site geology characterized by a thick overburden of heavily weathered schist bedrock. The weathered bedrock extends approximately 100 feet below ground surface and then transitions gradually to a deeper, more competent bedrock zone.
- Groundwater is present under unconfined conditions in the weathered bedrock and artesian conditions in the underlying competent bedrock. Groundwater in the vicinity of the property is not used for potable water supplies.
- Fill material (spent coke gas filter media) and construction debris is confined to the central portion of the Site. The fill material extends to a maximum depth of approximately 38 feet below ground surface. The western portion of the fill area is isolated by a soil and clay cover that inhibits the infiltration of precipitation and/or stormwater runoff. The eastern portion of the fill area is heavily vegetated.
- Adjacent to and east of, the fill material is the unfilled portion of the former quarry. Standing water is approximately 3 feet deep and is underlain by waste sludge.
- Infiltrating precipitation migrates vertically through the fill material, desorbing contaminants and transporting them to the underlying bedrock and to the groundwater.
- Site contaminants, principally benzene and naphthalene, are present in groundwater beneath the Site at concentrations in excess of the used aquifer MSCs. The groundwater impacts are limited to the Site, and do not extend to downgradient areas at concentrations above the Statewide health MSCs.

Based on the SCM, it was concluded that ISS of the quarry sludge, when combined with placement of cover material and institutional controls, would provide an effective remedy for the Site.

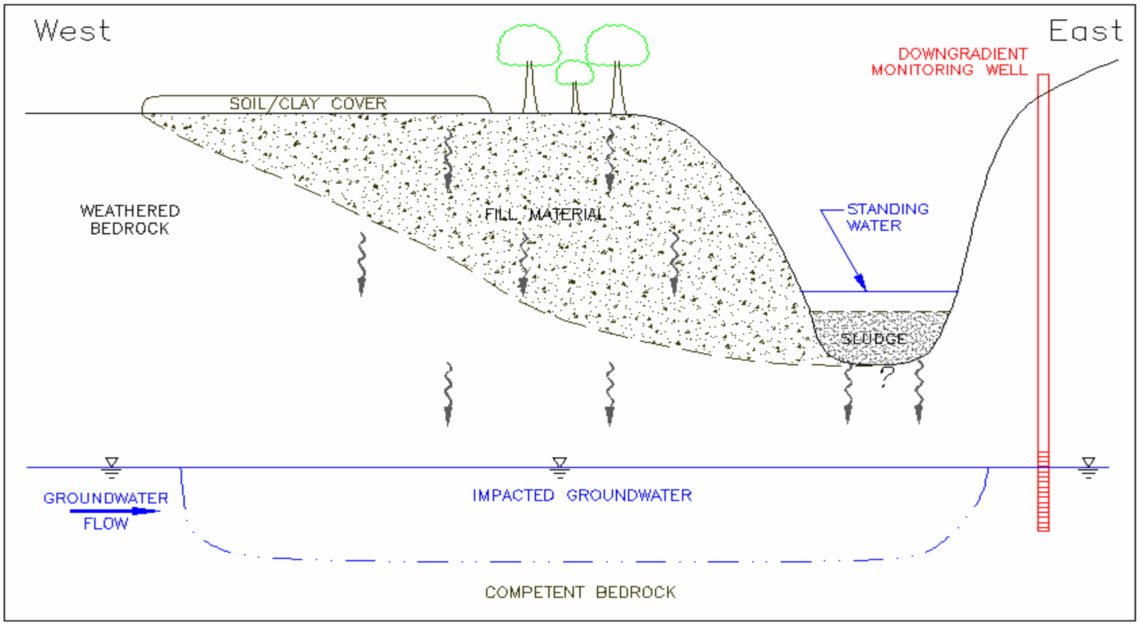

Figure 1. Site Conceptual Model

FIELD INVESTIGATIONS

Field investigations were conducted to obtain estimates of sludge volumes, geotechnical measurements and bulk samples for treatability testing. Because the quarry was water-covered and the underlying sludge unstable (non-load bearing), a pontoon-boat was constructed on-site to provide a safe working platform for the field team. A sampling grid for the quarry was established by placing survey flags at 10 and 20-foot centers along the shoreline on North-South and East-West transects.

Field measurements were obtained at 20 grid locations across the quarry. At each location the following measurements were made: 1) the water column depth; 2) the thickness of the sludge layers; and 3) the depth to competent loading bearing soils. The water-column depth and thickness of the sludge layers were determined using a 2-inch diameter PVC pipe marked in 1/2 foot increments. The PVC pipe acted as simple pressure plate. The depth to competent soils was determined using a Proving Ring penetrometer that provided a soil resistance reading in tons/ft^2 (tsf). The following table summarizes the findings of the grid sludge thickness measurements.

Sludge Thickness Measurements

Media	Thickness Range (ft)	Average Thickness (ft)
Upper Sludge (US)	0.4-4.3	3.4
Lower Sludge (LS)	0.1-6.6	1.8

Following completion of the grid measurements, confirmation of the depth to native soils was achieved by advancing a hand-driven core barrel to refusal at five of the sample points. The core-barrel was equipped with a retractable end-plug and inner lexan sleeve. Core samples of native soils were successful at two locations where a red silty-clay was recovered from depths of 9.5 and 11.3 feet. The silty-clay was discolored from contact with the overlying sludge.

Samples of quarry sludge were collected for treatability testing from three separate grid locations. Selection of these locations was based on the ease with which the sampling platform could be maneuvered into position and secured, the overall depth to competent soil, and the desire to obtain samples representative of the central quarry area. Samples of the upper, water-saturated sludge and the deeper, more consolidated sludge were collected at each location. Six sludge samples (two samples at each of three locations) were obtained for treatability testing purposes. All of these sludge samples were collected in 5-gallon plastic buckets with locking lids.

TREATABILITY TESTING

A treatability study was conducted for ISS design to evaluate the feasibility of in-situ stabilization as a component of the remedy for the quarry area sludge. The treatability program evaluated several solidification agents as possible additives for stabilization of the quarry sludge.

The purpose of the bench-scale testing program was to evaluate ISS reagents mixes, with the following goals:

1) Identification of reagent systems that, when admixed with the quarry sludge, will facilitate rapid solidification of the sediments while providing stabilized materials that can be used as engineered fill within the quarry. Specific physical goals for the stabilized sediment included: 1) Unconfined Compressive Strength (UCS) $\geq$ 50 psi (3.6 tsf); and 2) Permeability < 1 x 10^{-5} cm/sec.

2) Control of sludge leaching to allow the stabilized sediments to remain in place with reduced potential for impacting current or expected future groundwater conditions at the site.

Once the six samples of sludge were delivered to the treatability laboratory representative material from the US sample containers was combined to prepare an “US Composite Sample”; likewise, representative material from the three LS sample containers was combined to prepare a “LS Composite Sample”. Free liquid that accumulated on top of the containers was not decanted. These mixtures were homogenized with a submerged mixer (to reduce the loss of volatiles) to ensure sample moisture contents and analytical results typical of the quarry sludge. Small stones and oversized debris were removed to facilitate mixing. A summary of pre-treatment chemical and physical analyses were performed on the two composite samples as follows:

Parameter	Method
Volatile Organics (VOC)	EPA Method 8260B
Semivolatiles Organics (SVOC)	EPA Method 8270C
TAL Metals	EPA Method 6010B/7471
SPLP VOC, SVOC and TAL Metals	EPA Methods 1312, 8260, 8270 and 6010/7471
Total Cyanide	EPA Method 335.2
Material pH	EPA Method 9045C
Bulk Density	ASTM D 5057
Moisture Content	ASTM D 2216
Loss on Ignition	ASTM D 2974
Grain Size Distribution	ASTM D 4241
Total Petroleum Hydrocarbons	EPA Method 418.1

The compounds detected most frequently and at the highest concentrations in the sludge included BTEX, naphthalene and various polycyclic aromatic hydrocarbons (PAHs).

Four reagents were selected for testing based on previous experience on similar projects, relative cost effectiveness, and their availability in the project area. The reagents used in the treatability study were:

Portland Cement (Type I and Type III) - Each of the mixes in the testing program contained cementitious reagents, these have been shown to provide consistent results (i.e., good quality control) at full-scale when in-situ mixing techniques are employed. Cement-based reagents are typically fast acting thereby allowing projects to proceed at a rapid pace, and are available in abundance.

Fly Ash / $MgSO_3$ Scrubber Residue - Portland cement/pozzolan by-product or portland cement/alkaline (e.g., $MgSO_3$) by-product admixture combinations can be used to absorb free liquids while providing the fast-reacting solidification properties associated with cementitious agents. In addition, the use of byproducts from utility operations is favorable from a materials reuse/ recycling perspective.

Once untreated sludge characterization tests were complete, preliminary stabilization/solidification mix designs were evaluated. The initial screening tests involved hand mixing homogenized US and LS sludge samples with selected additives to create a plastic (pasty) mix. Immediately following mixture development, the treated material was placed into a cylindrical mold for curing.

Initial test batch preparation involved twelve (12) mixtures per sludge source (four selected solidifying agents/ combinations at two, three, or four pre-determined dosages, depending on the mix). These initial mix design tests provided the necessary information to assess solidifying agent combinations and identify dosage rates that achieved the performance standards. The relative hardening rates for all 24 batches were tracked using a pocket penetrometer, with penetration resistances (PR) recorded (in tsf) after 1, 2, 3, 5, and 7 days of curing. Mixture consistency and workability were also documented.

The PR target for the bench-scale program was ≥ 2 tsf after 7 days of curing. While it was expected that many acceptable mixes would meet this resistance requirement after curing, it was also necessary to place a constraint on the hardening rates. This was necessary as there is limited access to the quarry and full-scale field operations require that large machinery be placed on stabilized materials as soon as possible. Hence, a 1-day PR target of 3 tsf was used to evaluate the initial mix designs. This value is a conservative choice, based on the generally acceptable PR value of 2 tsf for support of construction equipment and accounts for differences between laboratory test results and full-scale results.

The 1-day PR values for all mixes were plotted against the dosage rates used in the mix as shown in Figure 2. Only the subset of mixes whose 1-day PR values exceeded the 3 tsf goal were considered for preliminary economic assessment. These dosage rates were used in economic calculations to select cost-effective treatment alternatives. Based on these preliminary cost evaluations, two dosage rates were selected for both the US and LS composite samples. Four formulations were retained for confirmatory testing. The retained mixes (on a weight/weight basis) were as follows: 1)Upper Sludge (US), 20% and 22.5% Type III portland cement; and 2) Lower Sludge (LS),15% and 17.5 % Type III portland cement.

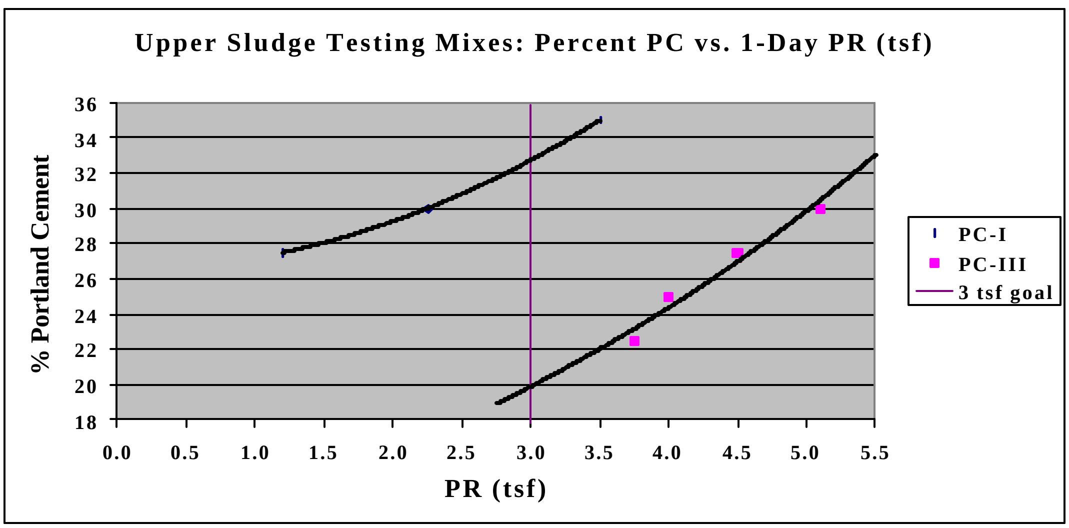

Figure 2. Penetration Resistance versus Portland Cement Addition

Based on the initial screening results, four mix designs were prepared for confirmatory testing using Type III PC. Stabilization treatment began by placing a pre-weighed aliquot of untreated material into a mixing bowl. Dry reagents were then added to the untreated sludge material, and blended slowly to mimic full-scale subsurface mixing techniques. The resultant material was then placed in test molds. The molds were placed in sealed plastic bags for curing at room temperature. The cured samples were tested at 7, 14 and 28-day intervals for USC. After 28 days of curing, the samples were subjected to the following additional tests: Synthetic Precipitation Leaching Procedure (SPLP) VOC, SVOC and TAL Metals; Liquid Release (EPA Method 9096); and Permeability (ASTM D 5084).

The confirmatory testing program resulted in treated samples that achieved the defined project goals and generated suitable mix designs for full-scale implementation at the site. None of the samples released liquid when subjected to the liquid release test. This result is expected as the PC reacts with water contained in the sludge matrix. The bulk density of the treated material was in the range of 86-88 lbs/ft^3, typical of a stabilized sludge material. All samples achieved the minimum acceptable 28-day Unconfined Compressive Strength (UCS) of 50 psi. As expected, the UCS readings were lower than the PR readings (typically by a factor of 2). The UCS reading at 28-days ranged from a low of 69 psi (US @ 20% PC) to a high of 159 psi (LS @ 17.5% PC). In all cases the treated samples were cohesive materials of a monolithic nature suitable for leaving in-place. A plot of compressive strength versus time is shown in Figure 3.

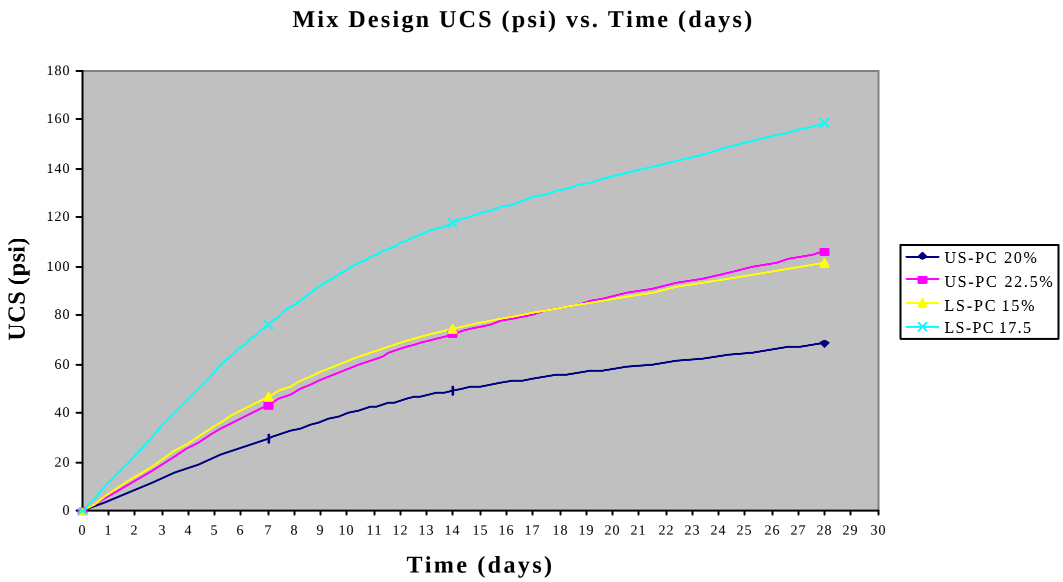

Figure 3. Compressive Strength Versus Time for Confirmatory Mix Design

The treated samples after 28-days of curing had very low resultant permeability, ranging from approximately 1x10^{-6} to 7x10^{-9} cm/sec. These results were all significantly lower than the project goal of 10^{-5} cm/sec. The S/S material following the 28-day cure time was subjected to a Synthetic Precipitation Leaching Procedure. These results were compared to the SPLP results on the untreated sludge samples. The following general conclusions can be reported based on an analysis of the data: 1) The stabilized samples with the higher PC additive ratios did in both cases significantly better in reducing the leachable constituents. The improvement in performance was significantly better than could be associated with the small additional dilution that can be associated with increased reagent addition; 2) Within the accuracy of the testing, the stabilized material had improved leachate testing results. For VOCs (benzene was the only constituent detected), reductions of 40% to greater than 90% were achieved. For SVOCs concentrations tended to remain the same for several analytes (2-methylnaphthalene, acenaphthylene, fluorene), however, naphthalene showed a reduction of 15-50%; and 3) The data for heavy metals showed little change as both samples had low levels of heavy metals.

Given the combination of low permeability and similar or reduced concentrations of leachable constituents, the project goal of reducing the mobility of the constituents in the sludge matrix was achieved.

FIELD IMPLEMENTATION

Given the water content of the quarry sludge, additional water was unnecessary to mix with the dry PC. Therefore, excess water above the sludge layer was removed from the quarry prior to the commencement of ISS. Since a sample of the quarry water analyzed indicated no exceedances of PADEP Water Quality Criteria, the cover water was pumped from the quarry to vegetated areas of the Site, where it was allowed to infiltrate. Between January 14 and 15, 2003, approximately 24 inches or 110,000 gallons of the water was removed from the top of the quarry. A 3-5 inch deep layer of water was left on top of the sludge to act as a barrier to odors and dust.

Prior to commencing ISS activities, the existing access roadway that crossed the Site and terminated at the quarry area was improved as this was the main access to the quarry for all trucks and equipment. The road was improved by the addition of approximately 6 inches of Type 2A modified stone compacted on top of a woven geotextile fabric. As a best management practice, the access roadway was improved with the addition of a turnaround. The turnaround, of construction similar to the access road, allowed trucks and equipment to backup to the quarry area or be staged on-site while limiting damage to grassy areas thereby limiting soil and sediment tracking off-site.

In-situ solidification/stabilization of the quarry sludge began on January 20, 2003, and was completed on January 24, 2003. The first truck of Type III portland cement was delivered via bulk pneumatic cement trailer on Monday, January 20, 2003. The dry cement was pneumatically transferred to the quarry area for direct mixing with the quarry sludge. A track-mounted excavator with an ALLU Power Mix Model PM300 mixing head attachment was used to perform the in-situ mixing of the Type III portland cement and the sludge. The ALLU Power Mix is a Finnish invention that can effectively mix different types of soils, peat, clay and sludge with dry reagents resulting in a well-mixed product. The PM300 utilizes a hydraulically driven drum with flights to mix the material in-situ. The mixing drum can rotate both forward and backward, and given the movement of the excavator arm, mixing can be accomplished in all three axes simultaneously. Reagents are pneumatically conveyed the length of the mixing arm to the mixing drum where they are “injected” into the sludge mass and immediately mixed with the sludge.

The ISS process began in the northwest corner of the quarry and the mixing head proceeded to mix the PC and sludge into a relatively homogeneous mixture. The portland cement was added pneumatically at approximately 20% by weight of the sludge volume calculated to be within the swing radius of the excavator. The average thickness of sludge being treated was approximately 8-9, with a maximum recorded depth of 10.5 feet. Care was taken to thoroughly mix the sludge and cement within the quarry. To ensure that the entire column of sludge was treated, the operator of the excavator pushed the mixing head down into underlying soils until the front end of the excavator lifted off the ground. This technique demonstrated that the entire depth of sludge was mixed with PC and that competent material (underlying soil) was reached.

Field measurements were generally taken after 18 hours of cure time. Temperature and pocket penetrometer readings were taken at several locations 6 inches below the surface. The average treated material temperature was between 70 and 80 degrees Fahrenheit, and the penetration resistance was greater then 4.5 tons per square foot. Based on these measurements, the ambient weather conditions (10°F to 15°F), and the ability to drive the excavator on material that was stabilized the pervious day, the field results were consistent with the treatability study. The total mass of Type III PC used was 340 tons, and approximately 1,900 yd3 of sludge were solidified and stabilized. Based on the measured bulk density of sludge, the calculated average PC addition rate was 18%, a number consistent with the treatability studies.

All solidification and stabilization activities were concluded by January 24, 2003. A woven geotextile and a minimum 3-inch layer of stone was then placed on top of the solidified/stabilized sludge on January 29, 2003. All equipment was decontaminated between January 27 and 29, 2003 and demobilized from the Site.

Real-time air monitoring was conducted during the ISS activities in accordance with the project Health and Safety Plan. The following air monitoring equipment was utilized during the ISS work: 1) Photoionization detector (MiniRAE PID) for volatile organic compounds (VOC’s); 2) Photoionization detector (Ultra RAE PID) for compound specific benzene; 3) Combustible gas indicator (Q-RAE CGI) for gas level in excavations; and 4) Dust monitor (MiniRam) to evaluate the need for dust suppression or modification to operations.

Three ambient air-sampling events were conducted at the Site during ISS activities. The objective of the sampling events was to determine the background air quality and then compare background air quality to air quality during ISS activities. This was particularly important as the adjacent properties were occupied by a large research and development facility. Each sampling event included time weighted average (TWA) determinations using 6-liter Summa Canisters, and polyurethane foam (PUF)/XAD resin tubes, mercury tubes, and particulate cartridges. A Universal Personal Sampling Pump (PCXR4) was used to pull air through each device. During each event, sampling was performed at 5-locations around the Site, selected based on the wind direction during the activities being monitored. A meteorological station was set up at the sampling stations to monitor the ambient temperature, wind speed, and wind direction. Barometric pressure data was obtained from the National Weather Service via the Internet.

The 8-hour background event took place on January 16, 2003, prior to the commencement of ISS activities. The first 8-hour air-sampling event during ISS activities occurred on January 21, 2003. The second 8-hour air-sampling event occurred on January 24, 2003.

Based on the real time air monitoring results, there was no exposure of on-site or off-site personnel to concentrations above the OSHA/NIOSH Permissible Exposure Limits (PELs). The ambient concentrations determined during the three sampling events were orders of magnitude below the published PELs. Hence, the ISS work was completed in a manner that was protective of human health and the environment.

CONCLUSIONS

Based on the treatability-testing program, Type III portland cement was selected as a suitable reagent for use in ISS of sludge in the former quarry. At rates necessary to achieve unconfined compressive strengths of 3 tsf after one day, the Type III portland cement mixes greatly surpassed the ultimate physical goals set for UCS and permeability prior to commencement of the bench-scale testing program.

The chemical effectiveness of the ISS remedy was determined by SPLP Method 1312. This procedure is "designed to determine the mobility of both organic and inorganic analytes in liquids, solids, and wastes", and was performed on the quarry sludge before and after treatment with Type III portland cement. The results of these tests demonstrated that the ISS process would be successful at reducing the leachability of all constituents via cement chemistry. In addition, the resultant low permeability of the stabilized matrix further reduces constituent mobility.

A small range (15 to 22.5%) of appropriate addition rates was defined for both the upper and lower sludge. Because the sludge layers are mixed during project execution, it was expected that the operational addition rate will fall somewhere between these ranges (around 20% PC).

During January 2003, full-scale implementation of the ISS of the quarry sludge was completed. Approximately 340 tons of Type III PC was used to stabilize 1,900 yd^3 of sludge, a calculated addition rate of 18% cement to sludge on a weight to weight basis. The work was completed in a timely and safe manner, and the resultant solidified materials achieved the desired physical characteristics. Following ISS activities, the former quarry was filled with over 20 feet of fill and capped. The balance of site-closure activities (backfill, grading, lower permeability cover and drainage improvements) were completed during the summer of 2003.

For the Site discussed in this paper, ISS proved to be a cost-effective process for management of the residual quarry sludge material. The results of the treatability studies were borne out in the field, as reagent addition rates and resultant material properties were consistent with laboratory testing. The successful completion of the work resulted in significant cost savings compared to other potential alternatives for sludge treatment and disposal while meeting all requirements of local and state regulatory agencies.