United States
Environmental Protection
Agency

SITE Technology Capsule

Demonstration of Rocky Mountain Remediation Services Soil Amendment Process

Abstract

RMRS developed the Envirobond™ process to treat heavy metals in soil. This phosphate-based technology consists of a proprietary powder and solution that binds with metals in contaminated waste. RMRS claims that the Envirobond™ process converts metal contaminants from their leachable form to a stable, nonhazardous one.

The EPA SITE Program evaluated a pilot-scale application of the Envirobond™ process at two locations in September 1998. The Envirobond™ process was applied to the soil surface and tilled 6 inches into the lead-contaminated soil.

Personnel used the Toxicity Characteristic Leaching Procedure (TCLP) to analyze treated and untreated soil samples for lead and a method for bioavailable lead to support two primary objectives. Primary objective 1 (P1) evaluated whether Envirobond™ can treat lead-contaminated soil to meet the Resource Conservation and Recovery Act (RCRA)/Hazardous and Solid Waste Amendments (HSWA) alternative universal treatment standards (UTS) for land disposal of lead-contaminated soils. The alternative UTS for soil contaminated with lead is determined from the results of the TCLP. The alternative UTS is met if the concentration of lead in the TCLP extract is no higher than one of these: (1) 7.5 milligrams per liter (mg/L), or (2) 10 percent of the lead concentration in the TCLP extract from the untreated soil. Contaminated soils with TCLP lead concentrations below the alternative UTS meet the RCRA land disposal restrictions (LDR), and are eligible for disposal in a land-based RCRA hazardous waste disposal unit. The alternative UTS is defined further under Title 40 of the Code of Federal Regulations (CFR), Chapter I, part 268.49 (40 CFR 268.49). To meet that objective, soil samples were collected before and after the application of Envirobond™. The soil samples were analyzed for TCLP lead concentrations to judge whether the technology met objective P1. Analysis of the data showed Envirobond™ reduced the mean TCLP lead concentration at the inactive pottery factory from 382 mg/L to 1.4 mg/L. The treated soil meets the alternative UTS for soil at the inactive pottery factory. Data from the trailer park were not used to evaluate P1 because TCLP lead concentrations in all treated and untreated soil samples from this location were either at or slightly higher than the detection limit of 0.05 mg/L.

In primary objective 2 (P2), staff evaluated whether Envirobond™ decreased soil lead bioaccessibility by 25 percent or more, as defined by the Solubility/Bioaccessibility Research Consortium's (SBRC) Simplified In-Vitro Test Method for Determining Soil Lead and Arsenic Bioaccessibility (simplified in vitro method [SIVM]). EPA Lead Sites Workgroup (LSW) and Technical Review Workgroup for lead (TRW) do not endorse an in-vitro test for finding soil lead bioaccessibility (Interstate Technology and Regulatory Cooperation [ITRC] 1997). To meet objective P2, personnel collected soil samples before and after applying Envirobond™. They analyzed soil samples for soil lead bioaccessibility to find whether the technology met objective P2. Analyzing data showed that Envirobond™ reduced the soil lead bioaccessibility by about 12.1 percent, which is less than the project goal of at least a 25 percent reduction in soil lead bioaccessibility.

The staff examined 12 cost categories for a plan in which the Envirobond™ process was applied at full scale to treat lead-contaminated soil at a Superfund site. The cost estimate assumed the size of the site was 1 acre, and that the treatment was applied to a depth of 6 inches, which results in an estimated treated volume of about 807 cubic yards. The estimate assumes the site's soil characteristics and lead concentrations were similar to those of the CRPAC evaluation. Based on these assumptions, the total costs would be $33,220, which is $41.16 per cubic yard of soil treated. Costs for applying the Envirobond™ process may vary.

The Envirobond™ process evaluation was based on the nine decision-making criteria used in the Superfund feasibility study process. Results are summarized in Table 1.

Introduction

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, which is committed to protecting human health and the environment from uncontrolled hazardous waste sites. CERCLA was amended by the

Table 1. Evaluation of Envirobond™ Compared to the Nine Criteria for Superfund Feasibility Studies		
	Criterion	Discussion
1.	Overall Protection of Human Health and the Environment	The technology is expected to significantly lower the leachability of lead from soils as indicated by the TCLP results, thereby reducing the migration of lead to groundwater and the potential for exposure of all receptors to lead; however, the technology did not significantly reduce soil lead bioaccessibility, as determined by the SIVM.
2.	Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)	During the SITE demonstration, Envirobond™ reduced the mean TCLP lead concentration from 382 mg/L to 1.4 mg/L, a reduction of more than 99 percent. Further, the treated TCLP lead concentrations were less than the alternative UTS for lead in soil. Therefore, the treated soil met the land disposal restrictions (LDR) for lead-contaminated soil, as specified in 40 CFR 268.49. However, the technology's ability to comply with existing federal, state, or local ARARs should be determined on a site-specific basis.
3.	Long-term Effectiveness and Permanence	The analytical results of procedures for the multiple extraction procedure (MEP), the procedure for lead speciation by sequential extraction, the test for cation exchange capacity (CEC), and leachable lead by the simulated precipitation leaching procedure (SPLP) suggest long-term chemical stability of the treated soil. The analytical results of a number of other procedures do not suggest long-term chemical stability of the treated soil. Those procedures included pH analyses, Eh analyses, separate analyses for total lead by nitric and hydrofluoric acids; total phosphates; and SPLP phosphates. The results related to long-term effectiveness from the test for lead speciation by scanning electron microscopy and acid neutralization were inconclusive.
4.	Short-term Effectiveness	Short-term effectiveness is high; measures for dust control and surface runoff controls may be required at some sites.
5.	Reduction of Toxicity, Mobility, or Volume through Treatment	The mean TCLP lead concentration was reduced from 382 mg/L to 1.4 mg/L, reducing the mobility of the lead in the soil.
6.	Implementability	The technology is relatively easy to apply. Large areas can be treated using common farm equipment, and small areas can be treated using readily available home gardening tools (sod cutter, tiller, fertilizer sprayer)
7.	Cost	For full-scale application of the technology at a 1-acre site contaminated with lead in the top 6 inches of soil, estimated costs are $33,220, which is $41.16 per cubic yard.
8.	Community Acceptance	Community acceptance of Envirobond™ likely will be a site-specific issue.
9.	State Acceptance	State acceptance of Envirobond™ likely will be a site-specific issue.

Superfund Amendments and Reauthorization Act (SARA) in 1986. SARA mandates implementing permanent solutions and using alternative, innovative treatment or resource recovery technologies to the maximum extent possible.

State and federal agencies and private organizations are exploring a growing number of innovative technologies for treating hazardous wastes. These new technologies are needed to remediate the more than 1,200 sites on the National Priorities List. The sites involve a broad spectrum of physical, chemical, and environmental conditions requiring diverse remedial approaches.

The U.S. Environmental Protection Agency (EPA) is engaged in a number of activities that are focused on exploring and applying innovative technologies to Superfund site remediation. One EPA initiative to accelerate the development, evaluation, and use of innovative site remediation technologies is the Superfund Innovative Technology Evaluation (SITE) Program. One of the goals of the SITE Program is to disseminate information about innovative technologies to the user community. This Technology Capsule is one of the documents the SITE Program uses to meet this goal.

EPA SITE Technology Capsules summarize the latest information available on innovative technologies. The technology capsules assist EPA remedial project managers, EPA on-site coordinators, contractors, and other remedial managers in evaluating site-specific information to determine a technology's applicability for site remediation.

This technology capsule provides information on the Rocky Mountain Remediation Services, L.L.C. (RMRS), Envirobond™ process. RMRS developed the Envirobond™ process for treating heavy metals and radionuclides in soil by reducing the contaminants' ability to leach from the soil. The Envirobond™ process was evaluated in September 1998, at a site in southeastern Ohio. The Envirobond™ process was applied *in situ* to residential and industrial soils contaminated with lead from pottery factory waste.

This technology capsule describes Envirobond™ and summarizes results from the SITE evaluation. The capsule includes the following information:

- Abstract
- Site Background

- Technology Description
- Evaluation Activities
- Technology Applicability
- Performance Data
- Technology Status
- Sources of Further Information

Site Background

The villages of Crooksville and Roseville, located along the Muskingum/Perry County line in southeastern Ohio, are famous for a long history of pottery production. Lead compounds were used in pottery glazes until they were replaced by low-lead or no-lead compounds in the last 20 years.

In 1996, the Ohio Environmental Protection Agency (OEPA) entered into a cooperative agreement with the EPA to conduct a Geographic Initiative (GI) of the Crooksville/Roseville Pottery Area of Concern (CRPAC). The purpose of the investigation was to determine if the pottery operations in the CRPAC resulted in heavy metal contamination of the soil, groundwater, surface water, and ambient air.

Analytical results from samples collected for the GI investigation in mid-1997 identified 14 pottery waste disposal sites with significant lead contamination in shallow soil. OEPA is seeking innovative technologies that will remediate the lead in the soil in the CRPAC.

SITE Program personnel collected soil samples from four sites throughout the CRPAC in May, June, and August 1998. These samples were analyzed for TCLP lead concentrations and relative percent bioavailable lead concentrations. The analytical results and visual observations were used to characterize soil to enable selection of the evaluation sites.

The two locations selected for the SITE demonstration were an inactive pottery factory in Roseville, Ohio, and a trailer park, also in Roseville. The principal reasons for the selection of the inactive pottery factory in Roseville were that it appeared to have higher concentrations of lead than any of the other locations and it was more readily accessible than the other pottery factories under consideration. The trailer park was selected for the SITE demonstration primarily because use of that site would allow evaluation of the Envirobond™ technology at sites at which concentrations of lead in soil were lower than those at the other sites under consideration. At the time the selection was made, there was some concern that the concentrations of lead at the trailer park might be too low because they did not exceed 400 mg/kg, the residential preliminary remediation goal (PRG) for lead established by EPA (EPA 2000). However, previous field sampling conducted by OEPA with X-ray fluorescence (XRF) analyzers had indicated that total concentrations of lead in the soil at the trailer park were well above 400 mg/kg.

Technology Description

The Envirobond™ process is a combination of a proprietary powder and solution that binds with metals in contaminated soils, sludges, mine tailings and process residues, and other solid wastes.

The Envirobond™ process consists of a mixture of additives containing oxygen, nitrogen, and phosphorous; each additive has an affinity for a specific class of metals. RMRS claims that the Envirobond™ process converts each metal contaminant from its leachable form to an insoluble, stable, nonhazardous metallic complex. The Envirobond™ process is essentially a mixture of ligands that act as chelating agents. In the chelation reaction, coordinate bonds attach the metal ion to at least two ligand nonmetal ions to form a heterocyclic ring. The resulting ring structure is inherently more stable than simpler structures formed in many binding processes. RMRS claims that, by effectively binding the metals, the Envirobond™ process reduces the waste stream's leachable metal concentrations to less than regulated levels, and thereby reduces the risks posed to human health and the environment.

The Envirobond™ process can be deployed as an *in situ* or *ex situ* treatment process. RMRS reports that the Envirobond™ process is capable of achieving processing rates of 20 to 40 tons per hour for *ex situ* treatment and can be used with contaminated media containing as much as 10 percent debris.

Evaluation Activities

SITE Program personnel prepared the evaluation sites by removing the sod, tilling the soil, and collecting samples of untreated soil. Evaluation activities began on September 21, 1998. SITE Program personnel located several experimental units in the trailer park and at the inactive pottery factory. The sod was removed from the experimental units, and the units in the trailer park were tilled to a depth of 6 inches using a garden tiller. The units at the inactive pottery factory were tilled using a backhoe to a depth of 6 inches. SITE Program personnel screened the experimental units with a field XRF analyzer for total lead concentrations. The screening results were used to select the units with high lead concentrations. The Envirobond™ process was then applied to 10 experimental units in the trailer park and one experimental unit at the inactive pottery factory. The experimental units at the trailer park measured 5 feet wide by 5 feet long, and the unit at the inactive pottery factory measured 3 feet wide by 6 feet long. Although RMRS injected the remediation fluid to a depth of 2 feet, the depth evaluated during this evaluation was limited to 6 inches.

Sampling of untreated soil in the trailer park consisted of collecting composite soil samples from each experimental unit. The composite soil samples were formed by collecting approximately 1900 cubic centimeters of soil from five locations (each corner and the middle) of the experimental unit. The soil was collected using a stainless steel spoon or trowel and placed into a stainless steel bowl. The samples were sieved through a brass, 0.375-inch sieve into a plastic, 5-gallon bucket. All particles larger than 0.375 inch were returned to the stainless steel bowl. The percentage of the particles that did not pass through the sieve was estimated and recorded in the logbook. The composite sample was mixed in the bucket for 1 minute before the sample containers were filled.

Sampling of untreated soil at the inactive pottery factory consisted of collecting five grab samples from one experimental unit. Approximately 1900 cubic centimeters of soil was collected for each grab sample (one sample was collected from each corner and from the middle) within the unit. The soil was collected using a stainless steel spoon or trowel and placed into a stainless steel bowl. The soil sample was sieved through a brass, 0.375-inch sieve into a plastic, 5-gallon bucket. All particles larger than 0.375 inch were returned to the stainless steel bowl. The percentage of the particles that did not pass through the sieve was estimated and recorded in the logbook. Each grab sample was mixed in the bucket for 1 minute before the sample containers were filled. The individual grab samples were not composited.

RMRS applied the Envirobond™ process after the sampling of the untreated soil was completed at each experimental unit. The Envirobond™ process powder was applied to the surface of the experimental unit using a fertilizer drop spreader. The Envirobond™ process liquid was applied over the powder using a watering can. The Envirobond™ process powder and liquid were mixed into the soil using a garden tiller. Flyash was used to adjust the soil pH of each experimental unit to approximately 7.0. A thin layer was distributed over the surface of the experimental unit and tilled into the experimental unit.

SITE Program personnel collected samples of treated soil from the experimental units a minimum of 24 hours after treatment with Envirobond™. Samples of treated soil were collected from the trailer park using the same techniques as the untreated soil samples; at the pottery factory, however, four additional grab samples were collected from the midpoints between the corners on each side.

Technology Applicability

RMRS claims that The Envirobond™ process can treat heavy metals in soils, sludges, mine tailings and process residues, and other solid waste. RMRS states the following heavy metals can be stabilized with the Envirobond™ process: arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and zinc (RMRS 1999). According to RMRS, the Envirobond™ process can also stabilize wastes contaminated with various radionuclides, including thorium, uranium, radium, and cesium.

Technology Limitations

According to RMRS, metals such as aluminum, magnesium, calcium, and manganese at concentrations greater than 30 percent by weight can reduce the bonding capability of the Envirobond™ process. RMRS reports that the Envirobond™ process is not effective in treating soil with leachable lead concentrations greater than 30 percent by weight.

Site Requirements

RMRS determines an appropriate site-specific concentration of the Envirobond™ solution and powder through bench-scale studies on soil samples. The site must be evaluated to determine the contaminant concentration throughout the site, and the concentration of other metals that may be present at the site. The site conditions, such as soil type, depth of contamination, and moisture content, must be evaluated to determine the application procedure and equipment requirements.

The technology may be applied with standard construction and farming equipment. The site should be accessible to wheeled or tracked vehicles and have sufficient storage space for the equipment. Potable water is required for applying the technology and for equipment and personnel decontamination.

Process Residuals

Based on existing data, it appears that application of the Envirobond™ process generates limited residual waste. The chemicals in the Envirobond™process bond with the lead to form an insoluble metallic complex. However, personal protective equipment and decontamination fluids that contact lead-contaminated soil may require management as potentially hazardous waste.

Performance Data

Primary and secondary objectives were established for this SITE evaluation to provide criteria for evaluating technology performance. To achieve the evaluation objectives, SITE Program personnel collected untreated and treated soil samples from the experimental units.

Primary Objectives

Primary objective 1 (P1) was to evaluate whether Envirobond™ can treat soil contaminated with lead to meet the Resource Conservation and Recovery Act (RCRA)/Hazardous and Solid Waste Amendments (HSWA) alternative universal treatment standards (UTS) for land disposal of soils contaminated with lead. The alternative UTS for soil contaminated with lead is determined from the results of the toxicity characteristic leaching procedure (TCLP). The alternative UTS is met if the concentration of lead in the TCLP extract is no higher than one of the following: (1) 7.5 milligrams per liter (mg/L), or (2) 10 percent of the lead concentration in the TCLP extract from the untreated soil. Contaminated soils with TCLP lead concentrations below the alternative UTS meet the RCRA land disposal restrictions (LDR), and thus are eligible for disposal in a land-based RCRA hazardous waste disposal unit. The alternative UTS is defined further under Title 40 of the Code of Federal Regulations (CRF), Chapter I, part 268.49 (40 CFR 268.49). To meet that objective, soil samples were collected before and after the application of Envirobond™. The untreated and treated soil samples were analyzed for TCLP lead concentrations to evaluate whether the technology met objective P1. Analysis of the data demonstrated Envirobond™ reduced the mean TCLP lead concentration at the inactive pottery factory from 382 mg/L to 1.4 mg/L, a reduction of more than 99 percent. Therefore, the treated soil meets the alternative UTS for soil.

Primary objective 2 (P2) was to evaluate whether Envirobond™ could decrease the soil lead bioaccessibility by 25 percent or more, as defined by the Solubility/Bioaccessibility Research Consortium's (SBRC) Simplified In-Vitro Method for Determining Soil Lead and Arsenic

Bioaccessibility (simplified in vitro method [SIVM]). However, EPA Lead Sites Workgroup (LSW) and Technical Review Workgroup for lead (TRW) at this time, do not endorse an in-vitro test for determining soil lead bioaccessibility (Interstate Technology and Regulatory Cooperation [ITRC] 1997). To meet objective P2, soil samples were collected before and after the application of Envirobond™. The soil samples were analyzed for soil lead bioaccessibility to evaluate whether the technology met objective P2. Analysis of the data demonstrates that Envirobond™ reduced the soil lead bioaccessibility by approximately 12.1 percent, which is less than the project goal of at least a 25 percent reduction in soil lead bioaccessibility. However, it was recognized early on that meeting this goal would be difficult because the SIVM test procedure used in the demonstration involves a highly acidic sample digestion process, which may be revised in the future, because it may exceed the acid concentrations that would be expected in a human stomach.

Secondary Objectives

The secondary objectives of the demonstration were:

S1 - Evaluate the long-term chemical stability of the treated soil.

S2 - Demonstrate that the application of Envirobond™ did not increase the public health risk of exposure to lead.

S3 - Document baseline geophysical and chemical conditions in the soil before the application of Envirobond™.

S4 - Document the operating and design parameters of Envirobond™.

S1 was evaluated primarily by analyzing soil samples using the following analytical procedures: the multiple extraction procedure (MEP), lead speciation using a scanning electron microscope (SEM), lead speciation with a sequential extraction procedure, oxidation-reduction potential (Eh), pH, cation exchange capacity (CEC), acid neutralization capacity, total lead (as determined by two methods), leachable lead by the synthetic precipitation leaching procedure (SPLP), total phosphates, and SPLP-leachable phosphates. The evaluation was accomplished by comparing the results of the analytical procedures on soil samples collected from both sites before and after application of Envirobond™. Secondary objective S2 was evaluated by collecting air samples during the sod removal, tilling, and soil sampling operations and calculating exposure based on the total lead analysis of the air sample filters. Air samples were collected during the collection of untreated and treated soil samples. Secondary objective S3 was evaluated by analyzing soil samples from the experimental units at both demonstration sites for plasticity, moisture content, predominant clay type of the soil, the presence of volatile organic carbons (VOCs), semivolatile organic compounds (SVOCs), oil and grease content, and humic and fulvic acid concentrations. Secondary objective S4 was established to provide data for estimating costs associated with use of the Envirobond™, and was based on observations during the evaluation, and data to be provided by RMRS.

Site Evaluation Results

This section summarizes the results of the SITE evaluation and includes an evaluation of the primary and secondary objectives.

Evaluation of Objective P1

The TCLP lead concentrations from the inactive pottery factory were used to evaluate objective P1. The TCLP extraction was performed according to SW-846 Method 1311. The extracts were digested by SW-846 Method 3010A, and the lead concentration was determined using ICP-AES according to SW-846 Method 6010B. Soil samples from the inactive pottery factory were collected before and after application of the technology. The results from analyses of the treated soil were evaluated to determine if the lead in the soil was leaching at levels above the alternative UTS of 7.5 mg/L TCLP lead.

The data analysis shows that the Envirobond™ process reduced the TCLP lead concentration to below the alternative UTS of 7.5 mg/L at the inactive pottery factory site. The technology reduced the mean TCLP lead concentration from 382 mg/L to 1.4 mg/L. Therefore, the TCLP lead concentrations were reduced by at least 90 percent. Table 2 summarizes the TCLP lead data from five sampling locations within the experimental unit at the inactive pottery factory site.

Evaluation of Objective P2

Objective P2 requires using an in-vitro test to evaluate the relative percentages of bioavailable lead in untreated and treated soils from the trailer park site. For this demonstration, the simplified in vitro method (SIVM) developed by the Solubility/Bioavailability Research Consortium (SBRC) was selected to evaluate the relative percent bioavailability of lead in soil. The SBRC consists of representatives from the federal and state regulatory agencies, academia and other research organizations, and the regulated community. The SIVM determines the relative percent of bioavailability of lead in soil by calculating the ratio of the lead in the sample before extraction to the amount of lead that leached using an extraction solution that simulates gastric fluid. However, the EPA Lead Sites Workgroup (LSW) and the EPA Technical Review Workgroup (TRW) for lead, at this time, do not endorse an in-vitro test for determining lead bioavailability.

The relative percent bioavailable data is used to determine if the technology would reduce the risk of exposure to the bioavailable lead in the soil. The risk of exposure is determined by calculating the percent reduction in the relative percent bioavailable lead, which is calculated by dividing the relative percent bioavailable lead after the application of the technology to the relative percent bioavailable lead before the application of the technology and multiplying by 100.

The data are not intended to be used to support a risk-based cleanup level for the soil, such as a level that is determined using EPA's Integrated Exposure Uptake Biokinetic model (IEUBK). IEUBK is used to determine if the lead exposure (from various sources) on a residential property has no more than a 5 percent probability that a child's blood lead level will exceed 10 micrograms per deciliter.

Table 2. TCLP Lead Results from the Envirobond™ Process Evaluation			
Experimental Unit	Sampling Location	Untreated Soil TCLP Lead Concentration (mg/L)	Treated Soil TCLP Lead Concentration (mg/L)
U	1	421	2.0
U	2	563	1.5
U	3	320	1.4
U	4	247	<0.50
U	5	358	1.5
U	6	n/s	2.1
U	7	n/s	0.94
U	8	n/s	1.7
U	9	n/s	1.5

Note: n/s = Statistical experimental design only required five pretreatment samples for TCLP analysis. Nine grab post-treatment samples were collected instead of five to obtain a more precise estimate of the post-treatment mean.

The technology decreased the relative percent bioavailable lead by approximately 12.1 percent. Although the technology did not achieve the goal of objective P2, which is reducing the relative percent bioavailable lead by 25 percent, it was recognized early on that meeting this goal would be difficult because the SIVM test procedure used in the demonstration involves a highly acidic sample digestion process. The SIVM may be revised in the future, because it may be exceeding the acid concentrations that would be expected in a human stomach. Table 3 summarizes the bioavailable lead data.

Evaluation of Objective S1

Objective S2 was evaluated using the results of 11 analytical procedures that were conducted to predict the long-term chemical stability of the treated soil. Soil treated with Envirobond™ appears to exhibit overall long-term chemical stability. However, the results of some of the analytical procedures suggest that Envirobond™ does not appear to exhibit long-term chemical stability. In summary:

— Long-term soil chemical stability was indicated for soils treated by Envirobond™ at both test locations, as indicated by the analytical results of the multiple extraction procedure (MEP), the procedure for lead speciation by sequential extraction, the test for cation exchange capacity (CEC), and leachable lead by the simulated precipitation leaching procedure (SPLP). The CEC results are considered to be qualitative, because this test was conducted on only a single sample from each location.

— Long-term chemical stability was indicated at one site, but not at the other, by the analytical results of procedures for evaluating acid neutralization capacity. The results of tests on acid neutralization capacity are considered to be qualitative, because this test was conducted on only a single sample from each location.

— The analytical results from the lead speciation test by scanning electron microscopy (conducted only on soils from the trailer park) were mixed, in that the silica phosphate phase (low solubility) of lead was increased and some soluble phases of lead were reduced, while other low-solubility phases of lead were also reduced.

— At both locations, long-term chemical stability was not indicated for soils treated by Envirobond™by the results of the pH analyses, Eh analyses, separate analyses for total lead by nitric and hydrofluoric acids; total phosphates; and SPLP phosphates (The tests involving two types of total lead analysis were extremely aggressive tests; thus, meeting the acceptance criteria established for these tests was not as important as meeting the acceptance criteria of other tests involving long-term chemical stability).

Evaluation of Objective S2

SITE Program personnel collected air samples during the sod removal, tilling and soil sampling operations and calculated exposure based on the total lead analysis of the air sampling filters. Ten out of 11 samples did not indicate the presence of lead above the detection limit of 0.004 mg/m^3. The result above the detection limit, 0.024 mg/m^3, was found to be within applicable exposure guidelines, which include the Occupational Health and Safety Administration Permissible Exposure Limits (OSHA PELs), the American Conference of Governmental Industrial Hygiene Threshold Limit Values (ACGIH TLVs), the National Institute for Occupational Safety and Health Recommended Exposure Limits (NIOSH RELs), and the National Ambient Air Quality Standards Program (NAAQS) limits. Based on these results, the risk to public health and worker exposure was not increased due to the demonstration activities.

Table 3. Relative Percent Bioavailable Lead Results from the Envirobond™ Process Evaluation		
Experimental Unit	Untreated Soil Percent Bioavailable Lead	Treated Soil Percent Bioavailable Lead
A	51.2	37.6
B	50.4	33.7
D	63.3	48.1
E	62.4	46.8
F	58.8	45.6
H	45.0	41.6
I	41.5	55.6
J	47.4	45.8
P	48.7	41.0
S	37.5	38.6
Note: Negative values equal an increase in the soil lead bioaccessibility.		

Evaluation of Objective S3

Soil samples from the experimental units at both demonstration sites were analyzed for plasticity, moisture content, predominant clay type of the soil, the presence of volatile organic carbons (VOCs), semivolatile organic compounds (SVOCs), oil and grease content, and humic and fulvic acid concentrations.

Table 4 lists the plastic index, liquid limit, and soil type from the analyses of the soil samples from both sites using the American Society for Testing and Materials (ASTM) Method D 2487-93, Standard Classification of Soils for Engineering Purposes.

The VOC analytical results did not indicate the presence of any volatile organics in the soils at either site. The SVOC analysis indicated the presence of the following SVOCS in the soils at the inactive pottery factory site: benz(a)anthacene (0.82 mg/kg), benzo(b)fluoranthene (0.91 mg/kg), benzo(k)fluoranthene (0.77 mg/kg), benzo(a)pyrene (0.69 mg/kg), chrysene (1.0 mg/kg) fluoranthene (1.9 mg/kg), and pyrene (1.9 mg/kg). These SVOCs are typically found in crude oil, gasoline, or used motor oil. The soil in this area did show signs of staining that may be the result the disposal of a small quantity of waste oil. Based on these concentrations and the current state regulations for petroleum releases, it does not appear that the SVOCs present at the site require remediation. Also, the technology developer indicated that these SVOCs will not interfere with the Envirobond™ process. The analytical results for the inactive pottery factory indicate the presence of oil and grease at a concentration of 3,680 mg/kg. The analytical results for the trailer park site did not indicate the presence of oil and grease.

The concentration of humic acid at the trailer park site was 2,400 mg/L, and the mean concentration of humic acid at the inactive pottery factory site is 1,400 mg/L. The concentration of fulvic acid at the trailer park site was 600 mg/L, and the mean concentration of fulvic acid at the inactive pottery factory site was less than 500 mg/L.

Evaluation of Objective S4

Using information obtained from the SITE evaluation, RMRS, and other sources, an economic analysis examined 12 cost categories for a scenario in which the Envirobond™ process

Table 4. Soil Classification information			
Site	Plastic Index	Liquid Limit	Soil Type
Trailer Park	8	42	Sandy Silt
Inactive Pottery Factory	11	46	Sandy Silt

was applied at full scale to treat lead-contaminated soil at a Superfund site. The cost estimate assumed the site was 1 acre in size, and the treatment was applied to a depth of 6 inches, which is approximately 807 cubic yards (yd^3). The estimate assumes the site's soil characteristics and lead concentrations were the same as those encountered during the CRPAC evaluation. Based on these assumptions, the total costs were estimated to be $33,220 per acre or $41.16 per yd^3. Costs for application of the Envirobond™ process may vary significantly from this estimate, depending on site-specific factors.

Technology Status

RMRS has completed several bench-scale studies and pilot-scale tests on soil and debris contaminated with heavy metals and radionuclides. The Envirobond™ process has been used on several full-scale commercial sites contaminated with metals, and is currently being used to stabilize waste and debris contaminated with radionuclides at two government facilities.

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