East Coast Engineering, INC.

P. O. Box 745 156A Front Street Marion, MA 02738
Tel: (508) 748-2460 Fax: (508) 748-2553

SCANNED

LETTER OF TRANSMITTAL

DATE 2/1/99
JOB NO.
ATTENTION Mr. Hector LaGuette
RE

TO Dept. of Environmental Protection
205 Lowell Street
Wilmington, MA 01887

WE ARE SENDING YOU ☐ Attached ☐ Under separate cover via ____________ the following items:

☐ Shop drawings ☐ Prints ☐ Plans ☐ Samples ☐ Specifications
☐ Copy of letter ☐ Change order ☐ ____________

COPIES	DATE	NO.	DESCRIPTION

THESE ARE TRANSMITTED as checked below:

☐ For approval ☐ Approved as submitted ☐ Resubmit ____ copies for approval
☐ For your use ☐ Approved as noted ☐ Submit ____ copies for distribution
☐ As requested ☐ Returned for corrections ☐ Return ____ corrected prints
☐ For review and comment ☐ ____________
☐ FOR BIDS DUE ____________ 19____ ☐ PRINTS RETURNED AFTER LOAN TO US

REMARKS Hector,

Attached are copies of requested information. I have enclosed your fax of requested information. The highlighted items are not included in this package either because we don't have copies (i.e., we don't have memos from teleconferences), the item was already sent, or the item requested is not available to me at this time. Chris will be out of the office until Thursday, but if there is anything else I can help you with, please let me know.

COPY TO File

SIGNED: Lynn M. Southworth

AN MPC FORM
NO. 3502

If enclosures are not as noted, kindly notify us at once.

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Teleconference. Bob Sharkley, Sun Chemical, Cincinnatti, Ohio, January 1998.

Teleconference. Jack Frost, Phytotech, Monmouth Junction, New Jersey, December 1998.

Teleconference. Jerald Schnoor, University of Iowa, Iowa City, Iowa, December 1998.

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Phytotech

Phytotech

One Deer Park Drive
Monmouth Jct, NJ 08852
(732) 438-0900

Jack Frost

(724)935-2270

Upper 12" — ok
>12" iffy.
Sometimes done ex-situ

This is an US EPA Bulletin

IT Reports & Tech Eval Rpt referenced. Get these? Cost is low. T Holdsworth ~~again~~! @ EPA mentioned. & call him!

Demonstration Bulletin

Molecular Bonding System® for Heavy Metals Stabilization

Solucorp® Industries Ltd.

Technology Description: The patent-pending Solucorp® Molecular Bonding System (MBS®) utilizes a solid-phase chemical stabilization process to reduce the leachability of heavy metals in soils, slags, and other solid wastes. Arsenic (As), cadmium (Cd), chromium, copper, lead (Pb), mercury, and zinc are rapidly converted to less-soluble metallic sulfides. The technology was applied ex situ during the demonstration but may be utilized with standard in situ mixing equipment; this bulletin discusses only ex situ applications.

Soil is excavated, then pretreated by screening to remove debris larger than two inches in diameter. As with other ex situ technologies, wet or clayey soils may need to be dried to improve material handling characteristics. The MBS agent, a proprietary chemical mixture, is added to the pugmill where it is blended with the soil (Figure 1). Moisture also may be added at the pugmill, to increase the moisture content of the soil to 15 to 25 percent to promote uniform mixing. Treated soil exits on a conveyor and is stockpiled.

Leachability of target metals in the treated soil is determined using the Toxicity Characteristic Leaching Procedure (TCLP) or other appropriate test, such as the Synthetic Precipitation Leaching Procedure (SPLP). Depending on chemical feed and water requirements, the volume expansion of the treated soil may range from 3 to 16 percent. The total metal concentrations in and the physical characteristics of the soil are not significantly changed by treatment. Hydrogen sulfide gas formed during the process is collected and vented through drums of specially-coated carbon; a packed tower scrubber, which is more efficient, may replace the carbon if air emission standards are more stringent.

Waste Applicability: The MBS process is designed to reduce leachable heavy metals concentrations from soils or solid wastes. Certain metals present in reduced forms (e.g., As) may require treatment with an oxidizing agent to improve treatment effectiveness. As with other ex situ processes, this technology is most cost-effective for treatment of contaminants in shallow soils because the soils are readily accessible. However, excavation to greater depths, or use of in situ mixing may provide cost-effective applications of the MBS technology at certain sites. Soils or wastes with high chloride content (in excess of 15 to 20 percent) cannot be effectively treated with this technology.

Demonstration Results: The U.S. EPA National Risk Management Research Laboratory (NRMRL) Superfund Innovative Technology Evaluation (SITE) Program conducted a demonstration of the Solucorp MBS process at the Midvale Slag Superfund Site in Midvale, Utah during the Spring of 1997. Three waste streams, contaminated with As, Cd, and Pb, were treated: Soil/Fill (SF), Slag Pile B (SB), and Miscellaneous Smelter Waste Without Brick (SW). Approximately 900 tons of each waste/soil was treated. A second test of 500 tons of SW was performed independently by Solucorp using a

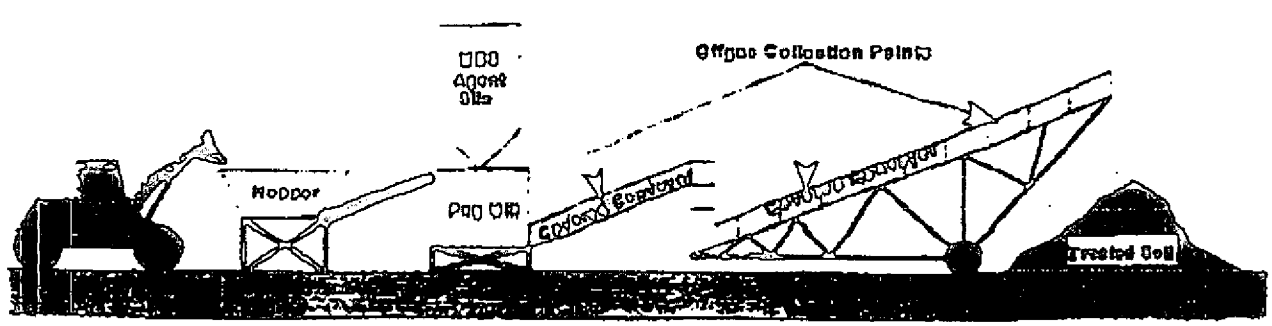

Figure 1. MBS® Soil Remediation Process

higher purity sulfide component in the MBS formula, after the initial demonstration of SW resulted in TCLP leachable Cd concentrations exceeding the regulatory limit of 1 mg/L. For the SW retest, Science Applications International Corporation (SAIC) performed sampling and provided oversight and analytical support under contract to Solucorp. All procedures were identical to those used by SAIC during the initial demonstration that was performed for EPA-NRMRL. EPA-NRMRL provided independent oversight and review of the SW retest results.

Because EPA NRMRL's Quality Assurance Program has not yet reviewed the demonstration results, this bulletin presents preliminary results only. The key finding from the Solucorp MBS demonstration is that the mean TCLP leachable Pb concentration in each of the three wastes/soils was reduced to less than the TCLP regulatory limit of 5 mg/L. Table 1 presents the mean TCLP leachable Pb concentrations in the untreated and treated wastes/soils.

Table 1. Mean TCLP Leachable Pb Concentrations, mg/L.

WASTE/SOIL	UNTREATED	TREATED
SF	20	0.18
SB	17	0.70
SW	36	2.60
SW (Retest)	15	0.33

Other demonstration results include:

- The mean TCLP leachable As concentrations increased slightly with treatment, but were below the TCLP regulatory limit of 5 mg/L in each of the untreated and treated wastes/soils.
- The mean TCLP leachable Cd concentrations were below the TCLP regulatory limits of 1 mg/L in both the untreated and treated SF and SB; the mean TCLP Cd concentrations in the untreated and treated SW were 2.1 and 1.1 mg/L, respectively. In the SW retest, mean TCLP Cd values decreased from 0.3 to 0.01 mg/L.
- SPLP As, Cd, and Pb concentrations were below their respective regulatory limits in the treated and untreated SF, SB, SW, and SW retest.
- The mean volume increases in the treated SF, SB, SW, and SW retest were 16, 4, 13, and 14 percent, respectively, as compared to the excavated, untreated waste/soil.
- Other than dilution effects, total metals concentrations were not affected by the treatment process.
- Process throughput of untreated waste/soil averaged 52, 59, 56, and 61 tons/hour for the SF, SB, SW, and SW retest, respectively.
- Treated wastes/soils passed EPA's Multiple Extraction Procedure (As, Cd, and Pb); however, no conclusion could be drawn regarding the effect of treatment on long-term stability because there was no change in the measured leachable metal concentrations from the treated to the untreated wastes/soils.

Total costs for treatment of approximately 2 million tons of SF, SB, and SW were estimated assuming a system capacity of 10,000 tons per day. Based on scale-up from the demonstration and information from Solucorp and other sources, costs were estimated at approximately $16/ton of waste/soil at the Midvale Slag Site.

The EPA will publish an Innovative Technology Evaluation Report (ITER) and a Technology Evaluation Report (TER) in the fall of 1997. These reports will address final test results in detail, including a complete analysis of analytical and geophysical results, estimated processing costs, and observations on process reliability and operating conditions made during the demonstration.

For Further Information Contact:

Thomas J. Holdsworth, SITE Project Manager
U.S. Environmental Protection Agency
National Risk Management Research Laboratory
26 W. Martin Luther King Dr.
Cincinnati, OH 45268
(513) 569-7675

Peter Montia, President
Solucorp Industries Ltd.
250 W. Nyack Rd.
West Nyack, NY 10994
(914) 623-2333

2/10/99 – Spoke w/ Tom H.
He will send me copy of the ITER; the TER is actually the whole file which was the basis for the ITER. The ITER is available to the public and will send me a copy. Cost-effective; He favours the Technology, got good results for various metals, passing the TCLP test for As, Cr + Cd. He did not deal with Pb, but says the vendor has info on Pb treatment, and he would expect it to also be effective for this metal. OK to call him back w/ more questions.

United States Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

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EPA / -97/

Was Cr in +3 or +6 state?
Have they had any experience/success ... metals in pigments

FROM: MARTIN E. JANIS & COMPANY, INC.
PUBLIC RELATIONS
919 North Michigan Avenue
Chicago, IL 60611

CONTACT: Hal Schweig
312-943-1100

FOR: SOLUCORP INDUSTRIES LTD

CORPORATE CONTACT:
Brian Binckes
913-685-4530

SOLUCORP UNVEILS MBS^{3000} TECHNOLOGY AT CONTRACTED SITE IN CANADA

West Nyack, N.Y., August 22, 1997 - Solucorp Industries Ltd. "The Company" (OTCBB:SLUP) announced today that its newly formulated and patent pending MBS^{3000} Soil Remediation Process is being unveiled for the first time ever.

Under the terms of an agreement signed with Mid Canada Soil Treatment Ltd., Winnipeg, Canada, Solucorp will commence a full scale remediation of chromium contaminated soil. In addition to the MBS^{3000} "milestone", this clean-up is the company's first full-scale commercial clean-up in Canada.

The MBS^{3000} process is applied directly (in-situ) to contaminated soils and sludges, eliminating costly excavation and processing associated with soil removal from the ground prior to treatment. This, of course, is highly cost effective and enables the company to compete for the first time in a $600 million "in-situ" annual remediation market.

The MBS^{3000} Technology adds to Solucorp's hazardous soil remediation arsenal which already includes the Superfund Innovative Technology Evaluation ("SITE") proven MBS® "ex-situ" hazardous soil remediation process (News Release 8/11/97) and the MBS^{2000} "In-Line" remediation process(News Release 8/5/96).

Headquartered in West Nyack, NY, Solucorp Industries develops products for environmental markets, with specific focus on solving the problem of heavy metals contamination. The Company's patent-pending MBS process has been acknowledged as an innovative and cost-efficient solution for remediating heavy metals in soil and industrial slag, sludge and ash.

The foregoing discussion contains forward-looking statements which are based on current expectations. Actual results, including the timing and amount of revenues recognized, contracts awarded and performed and net income may differ due to such factors as: delays in payment on contracts due to dealings with governmental and foreign entities; fluctuations in operating costs associated with changes in project specifications; economic and other conditions affecting the ability of prospective clients to finance projects; and other risks generally affecting the financing of projects.

OFFICIAL

EPA

REPORT ENCLOSED

Tom Holdsworth
[illegible] a [illegible]
* Ask Cincinnati
EPA for help in
pigment treatment
what about Cr?
(this is Duplicate
of other "Demonstration
Bulletin")

OFFICIAL EPA REPORT ENCLOSED

SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Breakthrough Heavy Metals Technology Acknowledged

ENVIRONMENTAL SOLUTIONS

EPA ACKNOWLEDGES SOLUCORP TECHNOLOGY...

MBS® Sets New Standard In Heavy Metals Remediation

The results are in...U.S. Environmental Protection Agency confirms the cost efficiency, effectiveness and safety of Solucorp's MBS Technology. Now you can effectively treat contaminated heavy metal wastes at your site or production facility and begin saving money immediately.

MBS is the newest of a select group of technologies evaluated by the U.S. Environmental Protection Agency. From thousands of applicants over the past 10 years, only 124 technologies were selected for final evaluation by the EPA - and of the nine selected for heavy metals, MBS was the only sulfide based treatment process.

MBS reduces the leachability of all heavy metals by rapidly converting them into insoluble metallic sulfides. At the Midvale Slag Superfund Site, MBS surpassed TCLP, SPLP, and MEP test standards for arsenic, lead and cadmium, the EPA's three highest priority metals. MBS treated six waste streams in all, with results exceeding proposed UTS requirements and most reaching non-detectable levels.

For additional information on MBS, please call Solucorp at **(914) 623-2333** or visit our website at **www.solucorpltd.com**.

NEWSWIRE

ENVIRONMENTAL SOLUTIONS
Solucorp Industries Ltd.
250 West Nyack Road
West Nyack, NY 10994

DEP FEB 2 1999

Results: The U.S. k Management Research NRMRL) Superfund nology Evaluation (SITE) cted a demonstration of the process at the Midvale Slag in Midvale, Utah during the 7. Three waste streams, con- th As, Cd, and Pb, were Fill (SF), Slag Pile B (SB), neous Smelter Waste Without Approximately 500 tons of oil was treated. A second test of SW was performed indepen- olucorp using a higher purity nponent in the MBS formula, initial demonstration of SW TCLP leachable Cd concentra- eding the regulatory limit of For the SW retest, Science ons International Corporation erformed sampling and provided and analytical support under o Solucorp. All procedures were o those used by SAIC during the nonstration that was performed NRMRL. EPA-NRMRL provided ent oversight and review of the results.

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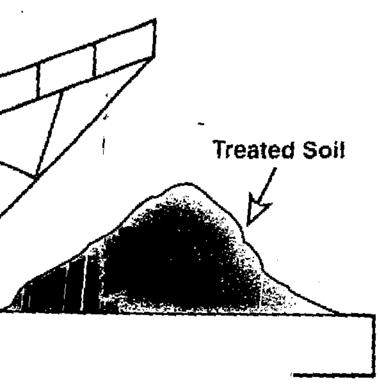

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- Process throughput of untreated waste/soil averaged 52, 59, 56, and 61 tons/hour for the SF, SB, SW, and SW retest, respectively.
- Treated wastes/soils passed EPA's Multiple Extraction Procedure (As, Cd, and Pb); however, no conclusion could be drawn regarding the effect of treatment on long-term stability because there was no change in the measured leachable metal concentrations from the treated to the untreated wastes/soils.

Total costs for treatment of approximately 2 million tons of SF, SB, and SW were estimated assuming a system capacity of 10,000 tons per day. Based on scale-up from the demonstration and information from Solucorp and other sources, costs were estimated at approximately $16/ton of waste/soil at the Midvale Slag Site.

The EPA will publish an Innovative Technology Evaluation Report (ITER) and a Technology Evaluation Report (TER) in the fall of 1997. These reports will address final test results in detail, including a complete analysis of analytical and geophysical results, estimated processing costs, and observations on process reliability and operating conditions made during the demonstration.

For Further Information Contact:

Thomas J. Holdsworth, SITE Project Manager
U.S. Environmental Protection Agency
National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7675

Peter Mantia, President
Solucorp Industries Ltd.
250 W. Nyack Road
West Nyack, NY 10994
(914) 623-2333

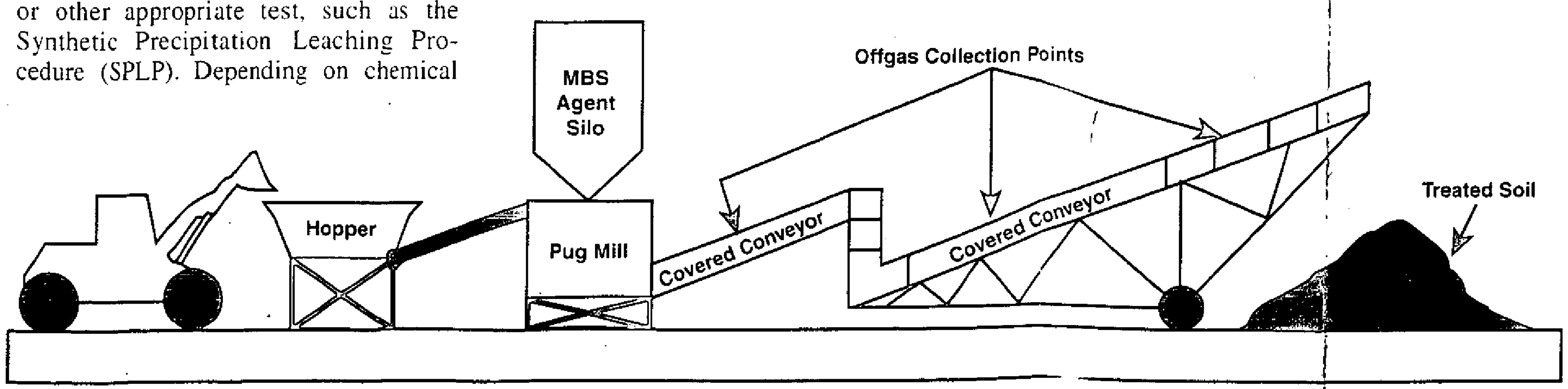


Figure 1. MBS® Soil Remediation Process

[illegible]ations

[illegible] maintains several mobile treatment systems that can be brought to your [illegible] set up within a matter of hours or days, depending on project size. [illegible] rates range from 25 tons per hour to more than 250 tons per hour. [illegible] material is screened and crushed to 2" or less diameter. The waste is then [illegible] with MBS powdered reagents in a closed hopper pugmill system. Water [illegible] be added at the pugmill to increase moisture content to 15% to 20 % and [illegible] uniform mixing. Treated soil exits the pugmill on a conveyor and is [illegible]

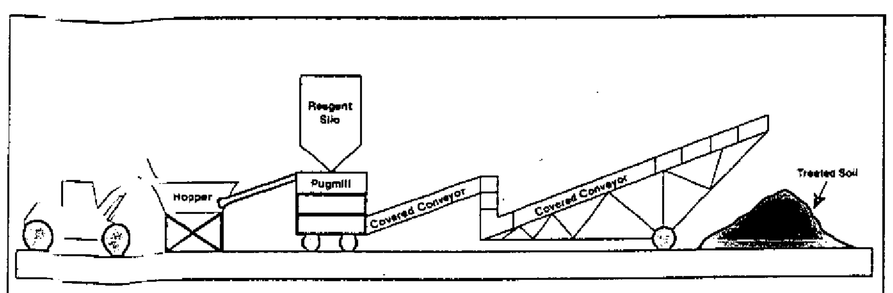
[illegible]tions

MBS [illegible] reagents can be applied using traditional tilling methods by blend[illegible] into the soil with appropriate equipment. Powdered reagents are [illegible] bags or various sized silos with variable off loading augers. Water may be [illegible] to enhance dispersion of reagents throughout the matrix being [illegible] After the reagents and water have been applied to the surface and per[illegible] the ground, soils are mixed to homogeneity to a depth of up to two feet with [illegible] a backhoe, rototiller or other tilling/discing equipment without any [illegible] of material. MBS can also be applied in a slurry form.

[illegible] Treatment

The MBS process can easily be integrated into a manufacturing line to stabilize a heavy [illegible] waste so it can be classified as non-hazardous. This means a safer facil[illegible] [illegible]surance, compliance, training and disposal costs. The MBS in-line treat[illegible] [illegible] design is typically a simple mixing system, such as a pugmill. This system can be [illegible] in various locations on the production line, with the optimal location based [illegible] such as: regulatory compliance issues, feed rate, material handling requirements and others. Solucorp's engineering staff will customize a system to best [illegible] on the specific conditions present at your facility.

MBS On-Site Soil Remediation Process



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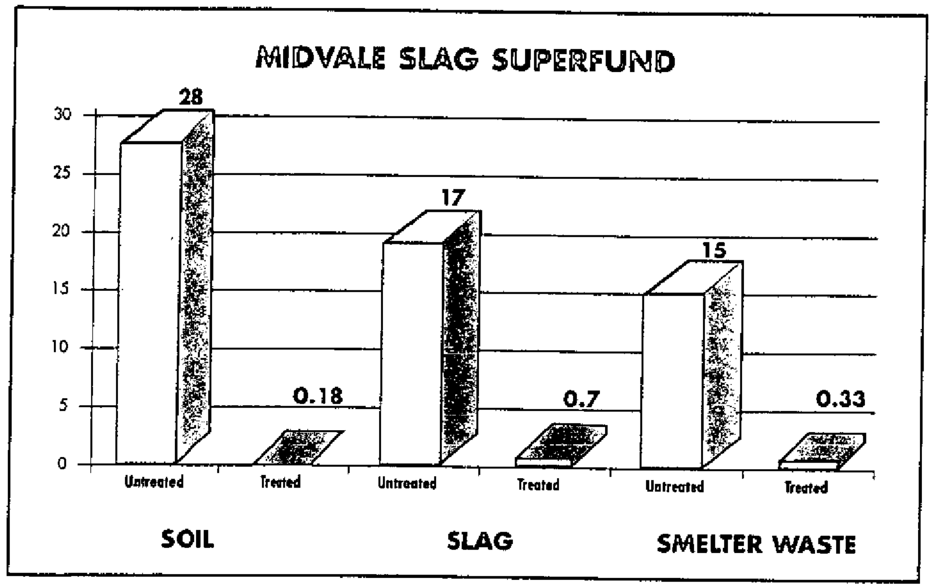
INTRODUCTION

MBS is an EPA "SITE" (Superfund Innovative Technology Evaluation) program technology, proven successful at the Midvale Slag Superfund site and on dozens of other commercial applications. It provides simple, environmentally sound and cost effective stabilization of heavy metals contamination. MBS effectively stabilizes all RCRA and UTS metals and, with minimal reagent addition will permanently reduce the leachability of metals in soil, sludge, slag, baghouse dust and ash to levels significantly below regulatory limits. Heavy metals are chemically transformed into their metallic sulfides (a metal's most insoluble form). The processed material is pH balanced, non-hazardous, and unchanged in physical characteristics. In addition to the TCLP test, MBS has been subjected to and passed other regulatory methods such as SPLP, SWEP, CAL WET and the Humidity Cell and MEP long term stability tests.

EPA Site Program Results – Lead (mg/l)



MBS APPLICATIONS

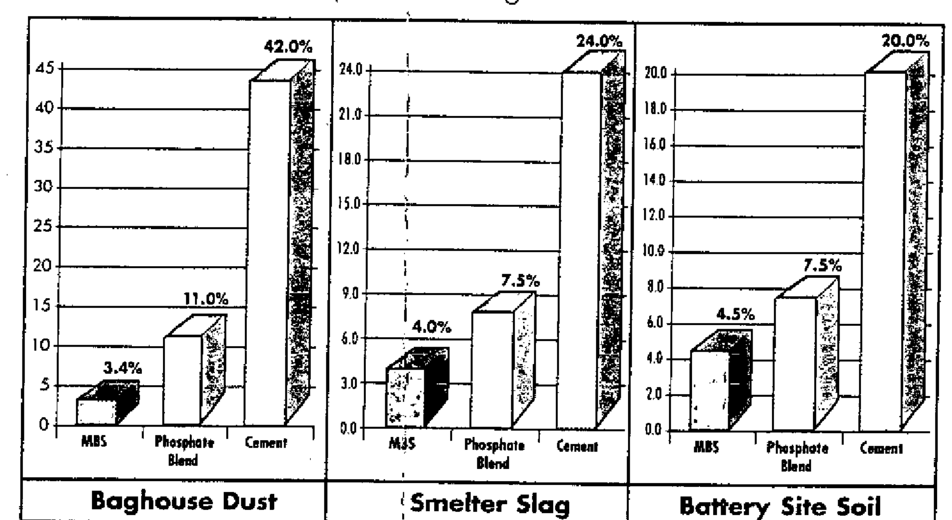
MBS on-site operations may be completed either ex-situ or in-situ using standard mixing equipment. MBS is proven for wastes classified as D004 through D011, as well as K-listed wastes. MBS has effectively treated sludges, filter cake, slag, paint chips, auto fluff and various types of clay, soil, gravel, and sand.

MBS PROCESS CHEMISTRY

In the MBS process, an inorganic sulfide reacts with the metal compounds in the waste, converting leachable metallic ions into non-leaching molecules. A proprietary reagent is used to minimize or completely eliminate hydrogen sulfide off-gassing, and to provide long-term buffering capacity. An additional reagent is utilized to inhibit long-term oxidation.

MBS is composed of three or four reagents which are utilized in proportions established by Solucorp's benchscale treatability study. These reagents are normally provided as a single dry blend. The benefits and superiority of the MBS stabilization system, as compared to cement, lime, phosphate and other mineralization systems, are seen in the fact that metal sulfides are known to be much more stable and to exhibit much lower solubilities. Reagent additions are very low, usually in the range of 2% to 5% by weight of waste, and the increase in volume of the waste attributable to stabilization is usually less than 3%. In some cases, a volume reduction will occur.

Comparative Reagent Addition %



PHYSICAL CHARACTERISTICS

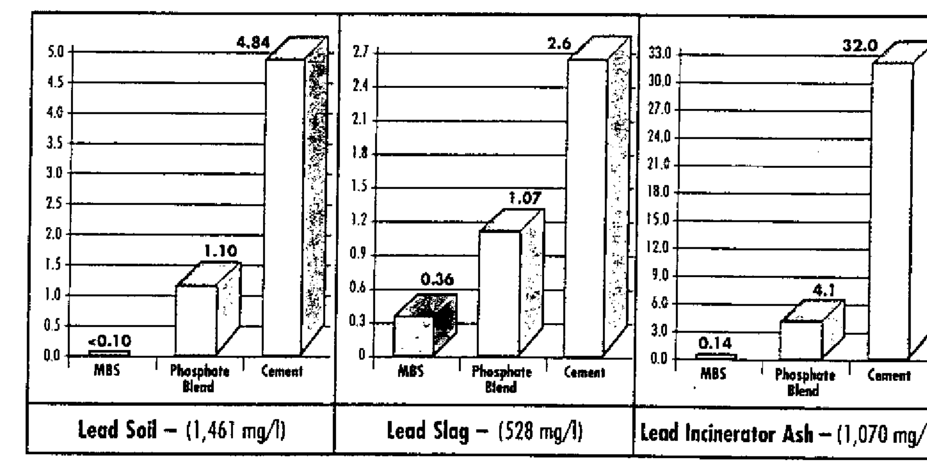
The physical characteristics of MBS treated wastes are not changed by the process. The treated wastes appearance will be basically unchanged. Additionally, there is no curing time, as the MBS chemical reaction occurs immediately. Unconfined compressive strength may be slightly increased and permeability may be slightly reduced. Moisture content should be near optimum, yielding a treated soil which is ideal for use as contour or fill. Unlike other technologies, since physical characteristics are unchanged, material handling is easier.

TECHNICAL CONSIDERATIONS

Conventional cementitious stabilization systems rely heavily on pH control, and these systems are usually evaluated using EPA's TCLP as the criterion for measuring the success of the process. TCLP analysis is conducted using a buffered acid as the leaching medium to evaluate the potential for leaching under worst case acid conditions. Cement-based systems are strongly alkaline, so they can overpower the acid used in a TCLP test and complete the leaching process in a mildly alkaline environment.

The MBS process has been developed to avoid the potential leaching problem of cement-based systems. The leaching characteristics of the metal sulfides that are formed are not pH sensitive. Final pH values in the TCLP extract, of MBS treated wastes are often in the 5 to 6 range. This condition would result in failure of cement-based system. The tolerance of the MBS process to low pH has been demonstrated by its resistance to leaching in the repetitive acid environment of the Multiple Extraction Procedure (MEP) test. Examples of the excellent results MBS provides versus phosphate and cement-based systems are shown below.

Comparative TCLP Results



SUMMARY / CONCLUSIONS

MBS is the most effective system to chemically alter the form of heavy metal contaminants into a non-hazardous, stable compound. The simplicity of the MBS process combined with its modular / transportable design and fully enclosed operational system (preventing the release of contaminants or secondary wastes), provides lower operating costs, enhanced safety and reduced emissions / secondary wastes.

The inherent ability of MBS to transform hazardous contaminates into non-hazardous, insoluble compounds can facilitate on-site disposal of a variety of wastes. The MBS process can also be easily integrated into a manufacturing line. The result is a safer site or facility and significantly reduced liability.

When off-site disposal is necessary, MBS requires much less reagent by weight than conventional processes resulting in a waste with minimal volume increases. This significantly reduces storage, off-site transport and disposal costs.

NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH AND QUALITY ASSURANCE

Office of Research and Development
U.S. Environmental Protection Agency

The Bioaccumulation of Heavy Metals From Soil and Groundwater by Phreatophytic Trees

Awarding Agency: Department of Defense
SBIR Contract Number:
Title: The Bioaccumulation of Heavy Metals From Soil and Groundwater by Phreatophytic Trees
Principal Investigator: Edward Gatliff
Company Name:
Applied Natural Sciences, Inc.
7225 C Dixie Highway
Fairfield, OH 45014
Telephone Number: 513-942-6061
Business Representative:
Project Period:
Project Amount:
Research Category: Remediation

Description:

The extensive use of heavy metals in prior industrial/military operations has resulted in numerous sites with soil/groundwater contamination. Phytoremediation research has shown that plants can successfully uptake heavy metals from contaminated sites. Recent research on phytoremediation of heavy metals has focused on vegetation such as Eastern Gamagrass (Tripsacum dactiloides) and Indian Mustard (Brassica juncea), both of which are typically limited by relatively shallow root systems. The proposed research will focus on aggressively growing phreatophytic (water-loving plants) trees that have the potential to impact deeper contaminated soil and groundwater and thereby expand the role of phytoremediation for deep soil and ground contaminants. The proposed project will continue work conducted by the Applied Natural Sciences and Argonne National Laboratory investigating in-field findings that hybrid poplars and willows (Salix sp.) will be evaluated to determine their ability to remove arsenic and lead from the soil solution. Partitioning of heavy metals in the roots, stems, and leaves will be a primary focus. Commercial application of phytoremediation approaches for treatment of heavy metal contaminants using deeper rooted plants will extend this low-cost alternative for in-place treatment to a substantially greater number of sites. Additional verification of this technology for selected contaminants will permit their implementation at site characterization with these problems. Identification of a cost-effective method for the immobilization of heavy metal contaminants from soil will be made.

Supplemental Keywords: small business, SBIR, remediation, DOD

Soil Paper (2b)

[Home] [Up]

Parameter	% Removal from Sediment
Total Organic Carbon	**72**
Total Oil/Grease	**87**
Total polyaromatic hydrocarbons	**88**

This approach could provide an effective pre-treatment wherein the recovered organic concentrate could be then subjected to biological, chemical or thermal destruction of the contaminants (as discussed below).

3.C.2. Destruction of Organic Contaminants

3.C.2.1. Biological Destruction

Biological destruction is useful for certain of the organic but not for inorganic contaminants. The process depends on the abilities of microorganisms to utilize organic contaminants as sources of carbon and nitrogen for their growth thereby destroying these by assimilation into the bio-mass. Biological treatment of soils contaminated with volatile and semi-volatile light hydrocarbons has been quite successful.

However, the utility of biological treatment of sediments is much less certain. Sediments generally contain the more recalcitrant and higher molecular weight organic contaminants such as PAH's, PCB's and dioxins and these are quite resistant to biological attack. Approaches involving pre-oxidation of organics in slurry phase bio-reactors are interesting but relatively short treatment times are essential for the treatment of large quantities of sediments. At present, biological treatment of sediment materials appears to have limited potential for commercial scale usage.

3.C.2.2. Chemical Destruction

Chemical destruction of organic contaminants has particular importance in the case of chlorinated organic contaminants such as PCB's and dioxins, where extremely low residual levels are required in the treated materials.

A patented process (ADOX) has been developed by ADI Limited (ADI) for the low temperature destruction of organo-chlorines, including PCB's, pentachlorophenol and dioxins as shown in Figure 4.

The ADOX process can be used to destroy any organo-chlorines at up to 100% concentrations in a wide variety of matrices including soils and sediments.

For sediments, the ADOX process typically involves two stages. The first stage involves the addition of low cost inorganic additives to the sediment and the application of indirect heat to about 300 to 400 degrees C. This initial stage totally decomposes some organo-chlorines in situ, partially dechlorinates others and desorbs the remaining organo-chlorines and any partially dechlorinated decomposition products into a high boiling paraffinic hydrocarbon oil. The desorbed sediments are recovered for re-use with low residual organo-chlorine contaminant residuals.

The second stage of the ADOX process treats the oil containing the organo-chlorine condensate, with sodium hydroxide and small quantities of proprietary low cost chemical accelerants at a temperature of around 300 degrees C. This ADOX process initiates a unique free radical decomposition reaction that very rapidly converts any organo-chlorine directly into carbon and sodium chloride. The only other products of the reaction are water and hydrocarbon gases.

The overall ADOX reaction can be viewed as:

ADOX Accelerants

R-Cl + NaOH + R'-CH3 ———→ C + NaCl + H2O + R'=CH2

300oC

The principle advantage of the ADOX process over other thermal or chemical destruction technologies is that the organo-chlorine contaminant decomposition is initiated in the sediment matrix. The process uses only medium temperature and thus ensures retention of sediment-soil physical properties. The ADOX process also uses only small quantities of low cost accelerants and the hydrocarbon carrier oil can be recovered and recycled.

The ADOX reaction does not proceed via sequential dechlorination and can provide proven destruction of dioxins. The ADOX reaction time at 320 degrees C to decompose 25% (250,000 mg/kg) PCB's to less than 1 mg/kg is about 2 hours while for more reactive organo-chlorines such as hexachlorobenzene the reaction times can be as short as a few minutes.

Application of this technology to a sediment containing very high levels of pentachlorophenol, chloro-dibenzo dioxin's and chloro-dibenzo furan's produced results as shown in Table 8.

Table 8 Destruction of Chlorinated Organic Contaminants in Sediments by the ADOX Process

Contaminant	ng/g (ppb) dry weight	
	Sediment before treatment	Sediment after treatment
2378 TCDD[a]	0.19	0.04
2378 TCDF	0.12	<0.01
12378 PeCDD	0.68	0.06
12378 PeCDF	1.9	0.001
123478 HxCDD	4.6	0.018
123678 HxCDD	9.8	0.046
123789 HxCDD	111	0.036
123478 HxCDF	131	0.004
123678 HxCDF	107	0.003
234678 HxCDF	52.2	0.001
123789 HxCDF	<0.2	<0.001
1234678 HpCDD	2450	0.15
1234678 HpCDF	311	0.011
1234789 HpCDF	3.5	0.001
OCDD	11800	0.273
OCDF	36.1	0.011
Pentachlorophenol	2470000	<0.1

[a] T =Tetra
Pe = Penta
Hx = Hexa
Hp = Hepta
O = Octa
CDD = chloro-dibenzo dioxin
CDF = chloro-dibenzo furan

3.C.2.3. Thermal Destruction

Treatment of dredged sediments or the classified fines portion of sediments to destroy organic contaminants to stringent cleanup levels for reuse or re-deposition is achievable using thermal treatment methods. Incineration and low temperature thermal desorption have demonstrated their capabilities to produce treated solids from soil and sediment that meet the cleanup requirements for the more difficult-to-treat organic contaminants. Thermal treatment, if properly designed and operated, can achieve residual levels of <1 ppm for PCB's and PAH's and less than <1 ppb for dioxins and furans.

Thermal treatment systems are also capable of treating volatile metal contamination, principally mercury, to low cleanup levels, provided the volatilized mercury is recovered in a secondary treatment system.

Incineration systems involve a primary combustion chamber such as a refractory-lined rotary kiln, a secondary combustion chamber operating at 800-1200C, and an elaborate air pollution control system to clean up the flue gas for atmospheric discharge. A schematic diagram of one such system, the IT Corp hybrid thermal treatment system, is presented in Figure 5.

Low temperature thermal desorption, as recently clarified by the U.S. EPA, is defined as the indirect-heating of solids (no contact of solids with hot combustion gas) to separate organics by volatilization. A variety of devices have been developed as the primary heating chamber for thermal desorption. Variations of the rotary calciner are the most prevalent. The organic contaminants are volatilized at temperatures in the range of 250-550C in a low oxygen purge gas and conveyed as gases to a condensation/scrubbing system that removes the contaminants from the purge gas. The condensed contaminants are collected as concentrates for recovery or further treatment. Further treatment by thermal destruction or chemical destruction can be either on-site or off-site. A schematic of low temperature thermal desorption with condensate collection is shown in Figure 6.

The commercial literature frequently includes references to low temperature thermal desorption systems that utilize an afterburner to destroy the volatilized organics, rather than a condensing system to collect these as a condensate. This type of system is in reality an

incinerator, and in the future such systems will be required to meet Resource Conservation Recovery Act (RCRA) incinerator standards when treating sediments or soils contaminated with hazardous waste constituents.

The performance of an incinerator or a low temperature thermal desorber in treating sediments or soils will be dependent on the time-temperature conditions achieved in the primary chamber. In general, the higher the temperature, the shorter the time that the solids have to be at that temperature to achieve cleanup standards. Lower temperatures require longer residence time in the primary chamber and therefore reduce throughput. For contaminants such as polychlorinated aromatics (e.g., PCB's) and polycyclic aromatic hydrocarbons (PAH's), processing temperatures at or below the normal boiling point of the contaminant will not meet stringent cleanup standards with practically useful residence times.

The key factors affecting the cost of thermal treatment by either incineration or thermal desorption are throughput requirements, quantity of sediment/soil to be treated, water content of feed, on-stream reliability, and disposal of residuals.

Hundreds of thousands of tons of contaminated soils have been successfully treated by incineration in the USA. IT Corporation recently completed the remediation of over one hundred thousand tons of creosote-contaminated sediment at the Bayou Bonfuca Superfund site in Slidell, LA, using its Hybrid Thermal Treatment System®. The sediment was first dewatered in filter presses to minimize the water in the solids fed to the incinerator. A unique feature of this incineration project was the cost-effectiveness of the use of oxygen instead of air for the incinerator.

The remediation of contaminated sediments or soils by low temperature thermal desorption has not been as widely used as thermal treatment by incineration. Extensive pilot plant development testing in engineering-scale equipment has shown the ability of thermal desorption to provide cleanup performance equivalent to incineration. Representative pilot- and full-scale performance data are presented in Table 9.

Table 9 Thermal Desorption Treatment Performance Data Summary

Contaminant	Matrix	Scale	Treated Soil Analysis Results
TCD Dioxin	Soil, Coral	Pilot	<1 ppb
PCB	Soil	Full	<2 ppm
PCB	Soil	Pilot	<2 ppm
PAH	Soil	Pilot	<1 ppm
Pesticides	Soil	Full	<1 ppm
Chlorinated Solvents	Soil	Full	<50 ppb

To date, full-scale applications of thermal desorption/condensation are few. The Resolve, Inc. Superfund site in Massachusetts was successfully remediated by Chemical Waste Management (CWM) using their X*TRAX thermal desorption/condensation system. The primary thermal chamber of this unit is an indirectly-fired rotary calciner. Thirty-five thousand tons of PCB-contaminated soil were treated to <2 ppm PCB's at an average rate of 6.6 tons/hr (13). Prior to full-scale operation, the X*TRAX system was fully tested in the U.S. EPA's Superfund Innovative Technology Evaluation (SITE) program. The results of that test (13) enabled CWM to proceed with full-scale remediation.

A hybrid thermal desorption system was used to remediate 12,700 tons of PCB-contaminated sediment from the Waukegan Harbour. This hybrid unit used the transportable Anaerobic Thermal Processor (ATP) System of SoilTech ATP Systems, Inc. Prior to this application, this unit had also remediated ~25,000 tons of PCB-contaminated sandy soil at Wide Beach, NY. The PCB concentrations in the dredged sediments at Waukegan Harbour averaged 10,400 ppm. Treated solids were <2 ppm. This unit was also tested in the U.S. EPA SITE program (14).

The central element of the ATP technology is the processor itself, which resembles a rotary kiln. However, inside the processor are three physically distinct zones and 4 zones characterized by different physical processes (15). These include zones for preheat, retort (anaerobic desorption chamber), combustion, and cooling.

In the combustion chamber, the desorbed solids are exposed to hot combustion gases to burn out residual organics. This feature causes the ATP to not qualify as a strictly thermal desorber, even though it is equipped with a condensation system for the desorbed organics.

The ADI ADOX System employs thermal desorption and condensation as components of the chemical destruction system (see Figure 4).

In summary, thermal treatment, using either incineration or thermal desorption, is a proven and effective remediation technology to achieve stringent cleanup standards in treating organically-contaminated sediments and soils. When large quantities of material are involved, the cost of using these thermal technologies in on-site remediation drops to the range of $200-300/ton. A volume-reduced feed of organic concentrate from sediment treatment can therefore be treated economically by thermal treatment (see below).

3.D. Removal of Heavy Metal Inorganic Contaminants

3.D.1. Chemical Extraction of Heavy Metals

A number of attempts to provide heavy metal extraction to soil and sediment materials have been made. Generally these procedures have relied on solubilizing the metals usually in an acid solution and then separating these metals with the solution from the solids. This approach has proved to be difficult in terms of solids/metal liquor separation and associated costs.

Tallon has developed chelation-based hydrometallurgical extraction procedures which provide for metal solubilization and recovery without separation of the aqueous phase from the solid phase as shown diagrammatically in Figure 7.

Vitrokele™ adsorbents of particulate size >0.6mm, i.e. much larger than the sediment solids are intermixed with the sediments and the metal mobilizing agents, generally mineral acid and mono-, di- or tiricarboxylic acids (e.g. acetic acid or citric acid) at a moderately low pH, pH 1.0 to pH 4.0.

The Vitrokele™ with its high affinity metal chelating groups adsorbs various heavy metals with high efficiency. The metals are recovered with the Vitrokele™, as shown in Figure 7 and then eluted from the Vitrokele™ and recovered. The Vitrokele™ is continuously re-used in a counter-current leach/adsorption circuit, similar to that used in the mining industry, and as shown schematically in Figure 8. The process has been described in detail elsewhere (11,12) and applied to the full-scale treatment of heavy metal contaminated soils.

Preliminary testing of the fines, <0.06mm, from the partial treatment (classification, see Figure 1) of Hamburg Harbour Sediments has produced encouraging results. A single in-pulp contacting with Vitrokele™ at pH 2.0 resulted in substantial recovery of various heavy metals from these sediments as shown in Table 10. Optimization of process conditions and additional contacting with Vitrokele™ would be expected to further reduce these residual metal levels.

Table 10 Removal of Heavy Metal Contaminants from the Silt/Clay Fraction (<0.06mm) of Hamburg Harbour Sediments

Metal	Metal Level ppm (mg/kg dry weight)		
	Before Treatment	After Single Contact with Vitrokele™ [a]	% Removal
Pb	212	53	75
Cu	235	70	70
Ni	103	32	70
Zn	1306	266	80
Cd	10.3	2.2	79
Cr	156	78	50

[a] Sediments were contacted once with Vitrokele™ at pH 2.0, separated from the Vitrokele™, dried and analyzed.

The technology has the ability to produce very low metal levels even with substantial initial metal values as can be seen for various materials contaminated with Pb as shown in Table 11.

Table 11 Removal of Pb by Vitrokele™ from Various Contaminated Materials

Material	Pb ppm (ug/g)		
	Initial	Treated	% Removal
Catchment Sediment	338	11	97
Soil from Pb-pigment manufacturing site	12,329	243	98
Soil from Pb-smelting site	5,704	573	90
Harbour Sediment	200	10	95

Another variation of Vitrokele™ technology involves the use of initially water soluble chelators which become water insoluble and recoverable with the metal from the soil slurry as also shown in Figure 7. This approach has been found useful for Pb and other metals where initial metal levels are moderate and extremely low treated residuals are not required.

4. Integrated Total Treatment and Recycling of Decontaminated Dredged Sediment Materials

The various treatment options discussed above and the ability to successfully perform high rate treatment for fine soil matrices indicate that integrated full treatment of dredged sediments is now technically feasible.

We have presented a conceptual approach to the total treatment and recycling of dredged sediments as shown in Figure 9. The materials handling aspects of this treatment have been essentially proven at Tallon's Longue Pointe project in Canada where 115,000 tonnes of soil containing 50-60% clay are being treated. This soil has striking similarities to sediments, being 40% sand/gravel and up to 60% fines (<0.06mm).

In the case of this soil, water has to be added to prepare it for treatment whereas dredged sediments are already 50% water. Figure 10 shows the pre-treatment section of a 800 ton per day treatment plant (equivalent to approximately 1400 m3 of sediments per day). Figure 11 shows physical removal of organic material by flotation and Figure 12 shows final recovery of metal depleted fines (clay).

The approach shown in Figure 9 integrates a principle treatment train providing recovery of both organic contaminants and metal contaminants. The recovered organics are then available for appropriate destruction, on or off-site, using appropriate chemical or thermal approaches as detailed above. Metal recovery is achieved by Vitrokele™ to produce residual treated sediments meeting regulatory limits and being available for potential re-use, e.g. as landfill cover. The cleaned coarse fraction (sand/gravel) is immediately re-utilizable for construction purposes.

Given the magnitude of the problem of contaminated sediments and the limited options for their disposal, integrated treatment has an important role in their treatment. This can maximize the removal of contaminants and maximize the recovery of re-usable materials from the dredged materials.

Integrated treatment costs, competitive with the costs for conventional alternative approaches (disposal) are achievable for the full-scale remediation and recycling of dredged sediment materials..

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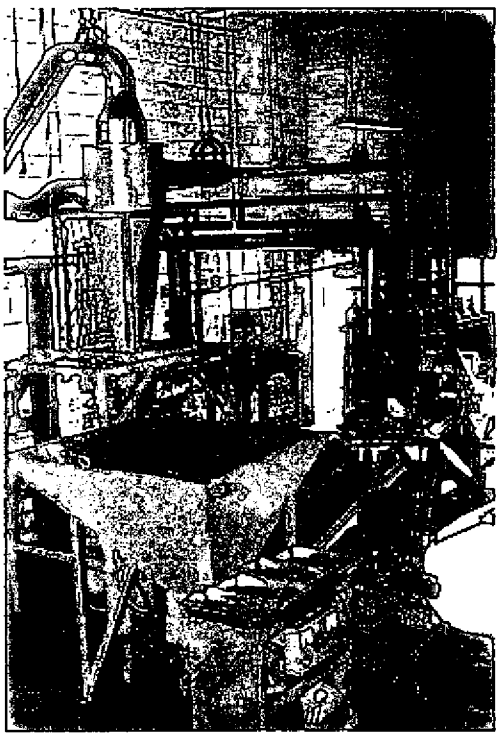
The alpha prototype MagMill shown in the photo is available for testing and demonstration at ETCi. Go to **Request for Information** to inquire.



Alpha Prototype MagMill

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Phytoremediation Bibliography

[A] [B] [C] [D] [E] [F] [G] [H] [I] [J] [K] [L] [M] [N] [O] [P] [Q] [R] [S] [T] [U] [V] [W] [X] [Y] [Z]

This bibliography is the work of the EPA Phytoremediation Handbook Team in conjunction with the RTDF Phytoremediation Action Team. This is a combination of reference lists compiled by several individuals, especially Bruce Pivetz (of ManTech Environmental Research Services Corp., with extensive assistance from Stacy Cejka), working at various EPA Labs. The Handbook Team consists of Steve Rock, Bruce Pivetz, Tom Wilson, Nancy Adams, Phil Sayre, Kelly Madalinski, Dawn Carroll and Scott Huling. Todd Anderson, Jon Chappell, and Jessica Palmiotti also contributed to the Handbook and Bibliography.

This list is as comprehensive as we can make it. It includes peer-reviewed journal articles, presentations and posters from conferences, book chapters, and articles from newspapers and magazines. This update of the bibliography has 1171 citations on phytoremediation or closely related subjects. Inevitably some of the information is redundant, and some literature might have been missed. This list will be updated quarterly to add new information and to make corrections. Corrections, deletions, and additions may be sent to Steve Rock (rock.steven@epamail.epa.gov), Bruce Pivetz (pivetz.bruce@epamail.epa.gov), or by leaving a Comment for the RTDF Webmaster.

The bibliography is presented alphabetically by author. It may be searched on-line or downloaded. In the future this list will be sortable, with links to other information, and your suggestions as to how to make the bibliography more usable are welcome. The information referenced may be obtained from libraries, as reprints available from the journals, or from the authors. Articles are not available from EPA staff. A printed list will take about 65 pages depending on font and printer settings.

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ABSTRACT BOOK

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Edward J. Calabrese, Ph.D.
Environmental Health Sciences Program
School of Public Health
University of Massachusetts
Amherst, MA 01003

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ARSENIC SESSION

Sources of Environmental Arsenic Contamination. Edward J. Zillioux, Florida Power and Light Company. Arsenic occurs naturally in a wide variety of mineral compounds and associations. Some of the most common arsenic-bearing minerals include lead, tin, antimony, silver, gold, platinum, nickel, cobalt, copper, iron, sulfur, zinc, and aluminum. Thus the most common source of arsenic for its many uses, both current and historic, and ultimately as an environmental contaminant, has been as a byproduct of mineral smelting, particularly of copper, lead, cobalt and gold ores. However, naturally-occurring arsenic is sometimes present at concentrations that challenge the concept of "natural" as being safe for human habitation. Taking the reported world-wide average natural content of arsenic in soil of 5 to 6 ppm as a baseline, sources of elevated arsenic in soil from geophysical processes include, for example, recent volcanism (avg. 20 ppm), shales (about 13 ppm) and soil derived from certain sedimentary rocks (20-30 ppm), with much higher concentrations in limited areas.

To fully understanding the sources of environmental arsenic contamination, therefore, knowledge is required of both its natural associations as well as the history of production at smelting operations and pathways to the many end uses mankind has devised since the earliest discoveries of orpiment (As^2S^3; yellow arsenic) and realgar (AsS, As^4S^4; red arsenic) in ancient Arabia. There is evidence of arsenic compounds being in common use in all the ancient centers of civilization. During the brief Copper Age, arsenic was alloyed with copper so commonly that it has been suggested that the period which preceded the bronze age (about 3500 B.C.) should properly be renamed the Arsenical-Copper Age. There is evidence of common use of arsenic in ancient Mesopotamia and Persia, from the beginning of Egyptian civilization, throughout the Greco-Roman period and the Middle Ages in Europe, as well as in the pre-Columbian Andean Civilization. Besides extensive use by metalsmiths in the production of tools and ornaments, arsenic was a fascination among alchemists, was used to make numerous pigments, cosmetics, the silvery backing of mirrors, as a fluxing ingredient in glass manufacture, in tanning of hides, and a plethora of medicinal uses, which claimed to cure everything from leprosy to the fear of ghosts. There are no precise records of arsenic production during these early periods, but since there were no controls over its use for over 4000 years, there is little doubt that past civilizations must have had a major influence on the redistribution of arsenic in today's environment.

In recent history, world production of arsenic trioxide (As^2O^3; white arsenic), the parent material for manufacture of all arsenic compounds, has increased in production from 10,000 tons prior to World War I to 62,000 tons in 1960. Production has decreased since the 1960s owing to a sharp decline in its most common use as arsenical pesticides. Arsenicals are still used in pharmaceuticals, particularly in veterinary medicine in this country, although clinical trials using daily infusions of arsenic trioxide have recently shown very promising results in achieving remission of acute promyelocytic leukemia. The primary industrial sources of release today include metal and metal alloy manufacturing, petroleum refining, coal combustion, and various agricultural, wood and waste incinerations. Both past and current uses of inorganic arsenical pesticides are still a major source of environmental contamination with at least 11 registered uses prior to 1988. Organic arsenical herbicides also are used extensively, particularly in cotton production in southern states, where the combined use of cacodylic acid, MSMA and DSMA in 1992 was over 7 million pounds of active ingredient. Despite the major uses in industry and agriculture, the largest single source of both inorganic and organic arsenic for most people is food. In 1988, EPA estimated average daily arsenic ingestion from food to be about 50 µg, of which 13 µg was inorganic.

Edward J. Zillioux
Florida Power & Light Company
700 Universe Boulevard
Junl Beach, FL 33408
Tel: 561-691-7063
Fax: 561-691-7049

The Bioavailability of Arsenic in Soil. Stephen M. Roberts, Center for Environmental & Human Toxicology, University of Florida, Gainesville, Florida, 32611.

When evaluating the potential risks posed by arsenic-contaminated soil, an important consideration is the extent to which arsenic in soil is absorbed - i.e., its bioavailability. The absorption of soil arsenic via the inhalation route (e.g., from contaminated soil-derived dusts) is often assumed to be complete, although there are virtually no experimental data which address this. Existing data on dermal absorption of arsenic from soils are also extremely limited, but studies in monkeys suggest that dermal arsenic bioavailability may be >5%, surprisingly high for a metalloid. The dominant exposure pathway for arsenic in most risk assessments of contaminated soil is incidental ingestion, and several studies have measured arsenic GI bioavailability from soils using animal models. Bioavailability estimates in various studies have ranged from non-detectable to about 80%. The reason for the differences in these estimates is unclear, but there are several possible sources of variability, including: 1) animal species used in the studies [experiments measuring absorption of soluble arsenic suggest that there can be substantial differences in arsenic absorption among species]; 2) the soil type; 3) the type of arsenic introduced into the environment; 4) treatment group size and inter-individual variability in arsenic absorption; and 5) arsenic dose [dose dependence or independence of absorption has not been well characterized in any of the animal models]. Unfortunately, systematic studies of arsenic bioavailability from soils with which to sort out the relative contributions of these potential variables are not yet available. Inexpensive in vitro methods to predict arsenic GI bioavailability from soils have been proposed, and studies to validate these methods are being conducted.

Arsenic and Chromium in Unsaturated Soils: Evaluating Potential Groundwater Impact. Jeffrey R. Hale and James S. Zubrow, Key Environmental, Inc. Protection of groundwater is an important consideration when developing soil remedial criteria. At an active chemical-manufacturing facility, regulator emphasized the protection of groundwater from the leaching and infiltration of arsenic and chromium from soils, as well as risk-based remediation standards facility-wide soils investigation provided the necessary data for evaluating the degree to which arsenic and chromium may leach to shallow groundwater. Shallow facility soils are believed to be associated with local Iredell fine sandy loam (IrC) and Wilkes sandy loam (WkC). Background data indicate naturally occurring chromium concentrations ranging from. 45.3 to 539 mg/Kg, which is attributed to chromium-rich mafic bedrock from which the soils formed. Selective extraction analyses suggest that arsenic and chromium in these soils may be strongly bound to soil constituents such as iron hydroxides and organic material. Maximum arsenic and chromium concentrations of 6750 and 9930 mg/Kg, respectively, were detected in facility soils; however, typical concentrations are more than an order of magnitude less. Hexavalent chromium concentrations up to 4610 mg/Kg were also measured. The Summers Model Equation was identified as an appropriate method for developing groundwater-protective remedial goals for vadose. zone soils. Input data consist of the volumetric infiltration rate, the volumetric groundwater flow rate, and the estimated contaminant concentration of infiltrating water. The model was setup to estimate minimum soil concentrations that would cause established groundwater standards to be exceeded. The results of this analysis yielded proposed soil remedial criteria of 200 mg/Kg arsenic and 652 mg/Kg chromium.

Jeffrey R. Hale
Key Environmental, Inc.
1200 Arch Street, Suite 200
Carnegie, PA 15106
Tel: 412-279 3363
Fax:412-279-4332

James S. Zubrow
Key Environmental, Inc.
1200 Arch Street, Suite 200
Carnegie, PA15106
Tel:412-279-3363
Fax:412-279-4332

Methodology For Evaluating Health Claims From Exposure To Arsenic In Soil Near A Superfund Site. Glenn C. Millner, Ph.D.[1,2], Alan C. Nye, Ph.D.[1,2], Phillip T. Goad, Ph.D.[1,2], [1]Center for Toxicology and Environmental Health, L.L.C. and 2University of Arkansas for Medical Sciences. A total of 42 individuals reported health effects from exposure to arsenic in soil near a Superfund site. Soil arsenic concentrations ranged between 2 and 350 ppm with a mean concentration of about 42 mg/kg. The number of years of exposure ranged from 1 to 22 years. The primary exposure routes were inhalation or ingestion of arsenic-containing dusts. Although individuals reported a wide range of health symptoms, a review indicated that many of the health effects claimed by these individuals were not consistent with arsenic exposure. After reviewing medical records, some of the reported symptoms were more readily explained by alternate causes. Further, the onset of other symptoms was not consistent with the reported period of arsenic exposure. Other reported symptoms that may be linked with arsenic exposure were critically evaluated in terms of whether the symptom occurs with acute poisoning or chronic low-dose exposure to arsenic. Threshold doses for these various symptoms were determined through review of the literature. Standard EPA risk assessment methods were used to estimate near worst case arsenic exposures through inhalation and ingestion based on known arsenic soil concentrations in the area. These calculations indicated that unrealistically high soil exposures would need to occur for individuals to receive arsenic doses known to produce systemic symptoms. Further, the reported health effects were not consistent with biomonitoring studies that indicate low arsenic exposure despite the presence of elevated levels of arsenic in soil.

Glenn C. Millner, Ph.D.
Alan C. Nye, Ph.D.
Phillip T. Goad, Ph.D.
Center for Toxicology & Environmental Health
Hendrix Hall, Ste. 100A
4301 W. Markham St. – Slot 767
Little Rock, AR 72205
501-614-2834 –Tel
501-614-2835 – Fax
MillnerGlenn@exchange.uams.edu
NyeAlan@exchange.uams.edu
GoadPhillip@exchange.uams.edu

The Trace Analysis of Arsenic in Soil and Water, Thomas L. Potter, [1], Hakan Gurleyuk [2], Julian Tyson [2] and Peter Uden [2] The distribution and forms of arsenic in soil and water is being intensively investigated throughout the United States and the world. The interest in arsenic is related to classification of certain inorganic forms as human carcinogens by the U.S. Environmental Protection Agency (EPA) and other agencies. In light of its toxic potential, the regulation of arsenic in soil and water has become increasingly stringent. Within EPA there is an on-going review of the arsenic maximum contaminant level (MCL) in drinking water with proposals to reduce the regulatory threshold form 50 to 2 ug L^{-1}. Since arsenic is recognized as a carcinogen, its MCL Goal (MCLG) is by regulation zero ug L^{-1} Establishment of regulatory levels in soils is being addressed at the state level. Acceptable levels span a broad range. For example, in Massachusetts, the reporting limit is 30 mg kg^{-1}. In the State of Florida, the Tier I Soil Screening Level (SSL) for Residential Areas is 0.7 mg kg^{-1}. These values are for total arsenic in soil and do not take in account variation in toxicity depending on form.

Some of the proposed and established regulatory levels for arsenic in soil and water present an enforcement problem in the sense that the levels are below Practical Limits of Quantitation (PQL). Studies conducted by the American Water Works Association support a PQL of 4 ug L^{-1} in drinking water. This is nearly twice the proposed MCL. In soil, PQL's in the 2 to 10 mg kg^{-1} range have been reported. The is above the SSL used in the State of Florida. It should be noted that there are few studies in which PQL's for any analyte has been systematically determined. In most cases, PQL's are estimated by multiplying the Method Detection Limit (MDL) by a factor of 2.5 to 10. This adds considerable uncertainty to PQL values, in particular for soils. The bottom-line is that arsenic PQL's are not well defined and some states may be regulating below the PQL. This is the aforementioned enforcement problem. In this presentation, the analytical chemistry of arsenic in soil and water will be reviewed with special emphasis placed on Method Detection Limits (MDL) and PQL's. The development and application of an extremely sensitive GC-GFAA procedure for the separation and quantitation of arsenite, arsensate and various organic arsenic species will be will also discussed.

[1] USDA-ARS, Southeast Watershed Environmental Research Laboratory P.O. Box 946, Tifton, GA, 31793. Tpotter@tifton.cpes.peachnet.edu
[2] Department of Chemistry, Analytical Chemistry Division, University for Massachusetts, Amherst, MA, 01003.

Strategic Sampling Approach to Support Risk Assessment at the U. S. Army Sudbury Annex, Massachusetts. Thomas Eschner, John Peters, Andrea Fogg, Norman Richardson, Harding Lawson Associates (formerly ABB Environmental Services, Inc.), and Thomas Strunk, Sudbury Annex BRAC Environmental Coordinator. HLA designed and implemented an innovative statistically-based soil sampling program to characterize arsenic distribution and concentration along more than 26 miles of road/former railroad corridors at the U. S. Army Sudbury Annex. The program was designed to meet data quality objectives (DQOs), which included characterizing the nature and extent of contamination, identifying hot spots, and establishing exposure point concentrations for human health and ecological risk assessments. By designing the program to meet these DQOs, ABB reduced the number of samples required to characterize the facility and associated costs by more than 70 percent. The statistically-based soil sampling program was performed in three stages. In the first stage, we used transect sampling across transportation corridors to verify our hypothesis that arsenical herbicides may have been applied along the corridors for vegetation control, resulting in arsenic distribution as a function of distance from the corridors. In the second phase, HLA conducted systematic composite sampling to identify possible hot spots and to establish the sampling locations for the third phase of the program. In the third phase, HLA used a stratified random sampling program to establish exposure point concentrations for risk assessment. The strata and sampling units were selected based on human and ecological receptor exposure considerations, and results of the transect and composite sampling programs. The sampling program achieved its objectives and its results were accepted by the regulatory community as valid.

Thomas Eschner
Harding Lawson Associates
511 Congress Street
Portland, ME 04101
Tel: 207-775-5401
Fax: 207-772-4762

John Peters
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: 781-245-6606
Fax: 781-246-5060

Andrea Fogg
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: 781-245-6606
Fax: 781-246-5060

Norman Richardson
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: 781-245-6606
Fax: 781-246-5060

Thomas Strunk
Sudbury Annex BRAC Environmental Coordinator
30 Quebec Street, Building 666
P.O. Box 100
Devens, MA 01432-4429
Tel: 508-796-3839
Fax: 508-796-3133

BIOREMEDIATION/SEDIMENTS SESSION

Passively Enhanced in-Situ Anaerobic Biodegradation of Chlorinated Solvents Maureen Dooley, Willard Murray, harding Lawson Associates, Andrea Dogon, TGG Environmental, and Stephen Koenigsberg, Regenesis. The results of a pilot-testing program developed to demonstrate enhanced in-situ chlorinated solvent bioremediation using a new product, Hydrogen Release Compound (HRC), will be presented. The HRC product, which was placed in an existing well, was continually released unto the groundwater contaminated primarily with trichloroethene (TCE), but tetrachloroethene, dichloroethene (DCE), and vinyl chloride (VC) were also present. Groundwater was extracted from wells and reinjected into upgradient injection wells (which contained the HRC) located approximately 17 feet away The concentration of VOCs, redox conditions and HRC product conditions were monitored over a six month period. These data will be compared with the results from a pilot-test conducted at the same location by HLA using the Two-Zone Plume-Interception Treatment Technology. This technology was designed to operate by establishing two subsurface zones through which a contaminated plume flows and is treated. The first zone is anaerobic and provides conditions suitable for the dechlorination of highly chlorinated contaminants such as tetrachloroethylene. The second zone is aerobic and provides conditions suitable for biological oxidation of the partially dechlorinated products from the first zone as well as other contaminants. An evaluation and comparison of both technical performance under pilot-scale test conditions and estimated full-scale costs will be presented.

Evaluation of Aromatic Pathway Induction for Creosote Contaminated Soils. John A. Glaser, Paul T. McCauley, Carl L. Potter, and Ron Herrmann, U.S. EPA, ORD, NRMRL, Cincinnati, OH and Majid Dosani, IT Corp. Cincinnati, OH Creosote, a major soil contaminant at wood treating facilities, contains polyaromatic hydrocarbon contaminants (PAHs) which are among the most difficult components of the residue to effectively treat by many technologies. Biodegradation of this set of organic compounds has been found to be difficult since the compounds in this class have low water solubilities and reactivities in soil systems. Liquid culture studies have shown that certain inducer chemicals affect the biochemical control of an organism's ability to degrade this set of contaminants. This type of strategy may be very useful to the biotreatment of PAH contaminated soils. A set of designed experimental treatments were conducted to evaluate the incorporation of potential inducer compounds. The inducers chosen for evaluation were 2-hydroxybenzoic acid and phthalic acid with treatment controls of 3-hydroxybenzoic acid and terephthalic acid at three concentrations in slurried creosote-contaminated soil. An abiotic treatment control of formaldehyde was used for contrast. The designed treatment evaluation used 250mL Erlenmeyer flask slurry reaction vessels. The flask study used an orbital shaker to maintain slurry suspension. At selected time points throughout the study individual flask reactors were sacrificed and the contents were analyzed for PAH concentration, nutrients, and biomass(FAME Analysis). Depletion of individual PAHs, total PAHs, 2&3-ring, and 4&6-ring PAHs was correlated with the biomass quantity and fatty acid composition. The effect of selected surfactant addition was also evaluated. Rates of PAH depletion and applications to larger scale investigations will be discussed.

John A. Glaser
U.S. Environmental Protection Agency, ORD
National Risk Management Research Laboratory, LRPCD
26 W. M. L. King Dr.
Cincinnati, OH 45268
Tel: 513/569-7568
Fax: 513/569-7105
email glaser.john@epamail.epa.gov

Paul T. McCauley
U.S. Environmental Protection Agency, ORD
National Risk Management Research Laboratory, LRPCD
26 W. M. L. King Dr.
Cincinnati, OH 45268
Tel: 513/569-7444
Fax: 513/569-7105

Carl L. Potter, Ph.D.
U.S. Environmental Protection Agency, ORD
National Risk Management Research Laboratory, LRPCD
26 W. M. L. King Dr.
Cincinnati, OH 45268
Tel: 513/569-7231
Fax: 513/569-7105

Ron Herrmann
U.S. Environmental Protection Agency, ORISE Fellow
National Risk Management Research Laboratory, LRPCD
26 W. M. L. King Dr.
Cincinnati, OH 45268
Tel: 513/569-7741
Fax: 513/569-7105

Majid Dosani
IT Corp.
11499 Chester Rd.
Cincinnati, OH 45246
Tel: 513/782-4700
Fax: 513/782-4807

Bioremediation of PCP Contaminated Soil by Composting. Ning H. Tang, Arturo Massol, and Nancy Cavallaro, University of Puerto Rico. Jaime Graulau, Greg Morris and Associates. A composting process was used to bioremediate pentachlorophenol (PCP) contaminated soil. Operational parameters such as temperature, moisture content, and organic content were evaluated. It was found that a 30 ^{o}C was adequate and no additional carbon source was needed for the process. Several bacteria populations with known PCP degrading ability were inoculated into different composters. The composter inoculated with Arthrobacter spp. (ATCC 33790) and Flavobacterium spp. (ATCC 53874) was specially capable of degrading PCP from an initial concentration of 250 mg PCP/kg of soil to a level below 50 mg/kg after two weeks of operation. The indigenous microorganisms were also capable of using PCP as their carbon and energy source. The composter with only indigenous microorganisms degraded PCP from 250 to less than 50 mg/kg after 42 days of operation. The toxicity level for the ATCC microorganisms was estimated at 750 mg/kg. The toxic level for the indigenous bacteria was 500 mg/kg. We conclude that PCP in soil will be biodegraded if conditions are favorable. These conditions are near neutral pH, sufficient nutrients, suitable moisture content, and aerobic environment.

Ning H. Tang
Civil Engineering Department
University of Puerto Rico
P.O. Box 9041
Mayaguez, PR 00681-9041
Tel: 787-832-4040 ext 2115
Fax: 787-833-8260
Email: n_tang@rumac.upr.clu.edu

Jaime Graulau
Greg Morris and Associates
265 San Francisco St
Old San Juan, PR 00902
Tel: 787-723-8005
Fax: 787-721-3196
Email: jgraulau@prtc.net

Arturo Massol-Deya
Biology Department
University of Puerto Rico
P.O. Box 9012
Mayaguez, PR 00681-9012
Tel: 787-832-4040 ext 5425
Fax: 787-265-3837
Email: a_massol@rumac.upr.clu.edu

Nancy Cavallaro
Department of Agronomy and Soils
University of Puerto Rico
P.O. Box 5000
Mayaguez, PR 00681-5000
Tel: 787-832-4040 ext 2146
Fax: 787-832-4220
Email: n_cavallaro@rumac.upr.clu.edu

Deep In-Situ Respiration Testing at the Powerhouse Facility, Badger Army Ammunition Plant. Jeffrey A. Havlena and Joel Janssen, Vierbicher Associates, Mark Maxwell, Olin Corporation. An in-situ bioremediation pilot test was conducted at the Powerhouse Facility to support the design of an in-situ soil biovent remediation system. Soil investigations showed that approximately 40,000 cubic yards of unsaturated, silty sands were contaminated with #2 and #6 fuel oil to depths as great as 85 feet below ground surface. In-situ bioventing was selected as the preferred remedial alternative. Design of the biovent system required determination of the in-situ rates of air delivery, oxygen consumption and carbon dioxide production. A pilot testing program was conducted using in-situ extraction and respiration tests in a series of biovent wells completed within the intermediate and deep soil profile. Initial monitoring showed that the ambient rate of biodegradation and the population of hydrocarbon-degrading bacteria were limited by the absence of available oxygen. Oxygen was depleted throughout the soil profile, and only 102 to 103 hydrocarbon degrading bacteria were found to be present in each gram of soil. During the pilot test, oxygen was injected into the subsurface and the in-situ rates of oxygen depletion and carbon dioxide production were monitored. The observed oxygen respiration and carbon dioxide production rates showed a distinct lag during the first two days of testing, apparently reflecting the time required to develop a healthy population of hydrocarbon degrading bacteria. Starting with the third day, the oxygen utilization and carbon dioxide production rates increased, and followed a linear trend indicating the degradation of 2.05 mg of hydrocarbon per kilogram of soil per day. The results of the pilot test were used to support the design of a flexible remediation system where individual biovent wells can be used in either injection or extraction mode. The system is scheduled for installation and startup during late 1998.

Jeffrey A. Havlena
Vierbicher Associates, Inc
6200 Mineral Point Road
Madison, WI 53705
Tel: 608-233-5800
Fax: 608-233-4131

Joel Janssen
Vierbicher Associates, Inc
6200 Mineral Point Road
Madison, WI 53705
Tel: 608-233-5800
Fax: 608-233-413

Mark Maxwell
Olin Corporation
Badger Army Ammunition Plan
One Badger Road
Baraboo, WI 53913-5000
Tel: 608-643-3361
Fax: 608-643-2674

A Monte-Carlo Analysis of Risks Associated with PCBs in Sediment: A Case Study. Brent L. Finley, Ph.D., Chris R. Kirman, Paul K. Scott, and Timothy R. Barber, Ph.D., McLaren/Hart-ChemRisk. Health-based sediment criteria for PCBs are often based on estimates of fish consumption risks. Because of the complexity of the analysis, there are several areas where significant uncertainty may be introduced when attempting to establish a relationship between human health risk and PCBs in sediment, including: bioaccumulative factors that govern PCB uptake into the food web, fish consumption rates, and the toxicity equivalency factors (TEFs) for coplanar PCB congeners. In this case study, a Monte-Carlo analysis of human health risk associated with fish consumption is conducted using sediment data from a PCB-contaminated waterway. A bioenergetics food web model is used to estimate fish tissue concentrations of coplanar PCB congeners. Probability density functions are developed for each factor in the analysis, and site-specific factors are used wherever possible. The resulting range of risk estimates is compared to the standard point estimates (most likely and reasonably maximally exposed), and a sensitivity analysis is conducted to assess the degree to which each exposure factor introduces uncertainty into the results. We conclude with suggestions regarding research topics that should serve to increase the accuracy of PCB risk assessments for contaminated waterways.

Brent L. Finley, Ph.D
McLaren/Hart-ChemRisk
5800 Landerbrook Drive
Suite 100
Cleveland, Ohio 44124
Tel: 440-684-8300
Fax:440-684-8320

Chris R. Kirman
McLaren/Hart-ChemRisk
5800 Landerbrook Drive
Suite 100
Cleveland, Ohio 44124
Tel: 440-684-8300
Fax:440-684-8320

Paul K. Scott
McLaren/Hart-ChemRisk
Two North Shore Center
Suite 100
Pittsburgh, PA 15212
Tel: 412-395-1400
Fax: 412-395-1410

Timothy R. Barber, Ph.D.
McLaren/Hart-ChemRisk
5800 Landerbrook Drive
Suite 100
Cleveland, Ohio 44124
Tel: 440-684-8300
Fax:440-684-8320

Biota to Sediment Accumulation Factors for PAH in a Tidal Marsh in Delaware. P. Anderson, Allison Nightingale, William Alsop, Ogden Environmental Energy Services; J. Patarcity. Typical practice at Superfund Sites is to conduct a preliminary screening ecological risk assessment to determine whether more detailed evaluation is required. Assumptions used in such an assessment are conservative defaults. The results of such a screening assessment identified that assumptions about the accumulation of chemicals from sediments to biota was critical to refinement of potential risks. Data on the concentration of several individual PAH and total PAH in sediments and mummichogs were collected at six locations. Biota to sediment accumulation factors BSAFs were calculated for individual PAH and total PAH at each location. Two sets of BSAFs were developed. One set was normalized for lipid content of fish and organic carbon of sediment. The other set was not normalized. The resulting BSAFs for total PAH range from 0.0068 to 0.000067. These values are substantially lower than the default BSAF of 1.0 recommended by U.S. EPA.

Paul Anderson, Ph.D
Allison Nightingale
William Alsop
Ogden Environmental Energy Service
239 Littleton Road, Suite 1B
Westford, MA 01886
Tel: 580-692-9090
Fax: 508-692-6633
email:pdanderson@oees.com
ainightingale@oees.com
wralsop@oees.com

Jane Patarcity
Beazer East, Inc.
One Oxford Centre
Suite 3000
Pittsburgh, PA 15219

Practical Issues Associated with Management of Contaminated Sediment. Paul Doody and Stuart D. Messur, Blasland. Bouck & Lee. Inc. Aquatic sites with contaminated sediment possess many characteristics that are not necessarily associated with typical hazardous waste site. As such, we will focus on the unique aspects of aquatic sites. More specifically, practical issues associated with the management and remediation of contaminated sediment will be discussed. A discussion of the unique issues associated with contaminated aquatic sites will be followed by more specific discussions of sediment remediation issues using actual case study examples. Many related issues will be discussed, including human health/ecological risks, public perception, current Agency perspectives, fish/wildlife consumption advisories, and sediment/contaminant transport modeling. The practical issues to be presented will include, but not be limited to, the following:

1. Importance of understanding the extent of natural processes (e.g., natural biodegradation, sedimentation, etc.)
2. Effectiveness of current sediment containment techniques;
3. Effectiveness of current sediment removal technologies;
4. Effectiveness of sediment treatment technologies; and
5. Potential risks associated with remediation;

Where possible, actual information from contaminated aquatic sites in the United States will be discussed to demonstrate how these issues have been addressed at certain sites.

J. Paul Doody, P.E.
Blasland, Bouck Lee, Inc.
6723 Towpath Road, Box 66
Syracuse, NY 13214 0066
Tel: (315) 446-9120
Fax: (315) 445-9161
Email: jpd@bbl-inc.com

Stuart D. Messur
Blasland Bouck & Lee, Inc.
6723 Towpath Road, Box 66
Syracuse, NY 13214-0066
Tel: (315) 446-9120
Fax: (315) 445-9161
Email: sdm@bbl-inc.com

ENVIROMENTAL FATE/ANALYSIS SESSION

Fate of Benzo (a) Pyrene in Petroleum-Contaminated Soils. Samuel Fogel and Margaret Findlay. Bioremediation Consulting Inc. Robert Kanaly and Richard Bartha. Rutgers University. The fate of benzo(a)pyrene (BaP) in soil will be discussed in terms of biodegradation. humification. binding and bioavailability to soil microorganisms. BaP is a carcinogenic PAH which has been reported as slowly or non- biodegradable by ordinary soil microortanisms. Research conducted by the authors has demonstrated that BaP is readily biodegradable in soil under aerobic conditions when dissolved in petroleum. Evidence will be presented which suggests that the microorganisms capable of biodegrading BaP are present in soil that has not previously been exposed to petroleum or other types of contaminants. The presence of a readily degradable petroleum food source appears to be necessary for biodegradation of BaP. The components of petroleum which serve as co-metabolic substrates will be discussed. BaP has also been reported to bind both reversibly and irreversibly to soil organic matter. Information about the chemical nature of the binding. as well as the type of chemical procedures required to demonstrate the nature of the binding will be presented. The implications of our research findings for remediation of petrolleum and for exposure assessments will be discussed.

Samuel Fogel
Bioremediation Consulting Inc.
55 Halcyon Rd
Newton MA 02459
ph 617-969-5913
fx 617-969-5968

Margaret Findlay
Bioremediation Consulting Inc.
55 Halcyon Rd
Newton MA 02459
ph 617-969-5913
fx 617-969-5968

Robert Kanaly
Dept. of Biochemistry and Microbiology
Cook College. Rutgers University
New Brunswick. NJ 08903
ph 908-932-9763
fax 908-932-8965

Richard Bartha
c/o Dept. of Biochemistry and Microbiology:
Cook College. Rutgers University
New Brunswick. NJ 08903
ph 908-932-9763
fax 908-932-8965

Imploding Chlorinated Plumes by Core Removal and NaturalAttenuation. William B. Kerfoot, Ph.D., K-V Associates Inc. The growth and extent of groundwater plumes of dissolved chlorinated solvents are based upon a set of reversible adsorbed/dissolved equilibria maintained by core sources. With the use of a unique reaction which removes the adsorbed fraction. as well as dissolved species. the central regions become adsorbers instead of emitters. resulting in a collapse of concentration which radiates outwards. dropping levels across the outer plume regions.

The direction. rate. and mixing potential of the aquifer region is characterized by direct groundwater flow measurement. Modeling is performed to determine the extent of the core region which has to be treated to initiate the process. The final equilibrium is given with time to be able to monitor time course.

During removal of the core region. the groundwater column is set in motion similar to mixing observed in deeper lakes during destratification. The parallel circulatorpatterns transport peripheral concentrations back into central areas which are now low in background level. Two examples of sites are used to illustrate the phenomenon.

William B. Kerfoot. Ph.D.
K-V Associates. Inc.
766 Falmouth Road. #B-12
Mashpee. Massachusetts 02649
Phone: (508) 539-3000
Fax: (508) 539-3566

Modeling Pesticide Transport in Support of Monitored Natural Attenuation at theMarzone Superfund Site, Tifton, Georgia. Andy Davis and Jeffrey Anderson, Geomega; Curt Peck and Karl Hoenke, ChevronRemediation of pesticide-contaminated soils at the subject site was guided by modeling contaminant impacts on groundwater. It was next necessary to incorporate the effects of this source removal in implementation of the groundwater remedy. Numerical groundwater modeling of post-remedial pesticide fate and transport incorporated site-specific lindane and atrazine biodegradation rates obtained from a laboratory study to evaluate the efficacy of groundwater treatment technologies. It demonstrated that a funnel & gate system would be preferable to the pump & treat remedy in the Record of Decision.

Flow modeling was simulated with MODFLOW (McDonald and Harbaugh 1988). Advective particle tracking was completed with MODPATH (Pollack 1989) to compare possible flow-through treatment wall alternatives to pump & treat. MT3D96 (Zheng 1996) was employed to estimate temporal aqueous-phase solute concentration distributions. It was determined, after completing the preliminary treatment wall design, that a modified funnel & gate system consisting of a barrier wall, treatment cell, and trenches afforded the most robust design.

During the final remedial design, simulation results showed that the orientation and areal extent of the downgradient distribution gallery were crucial to effective system operation. The preferred configuration provides for complete capture and containment of the existing upgradient groundwater plume, while precluding bypassing around the ends of the wall and minimizing groundwater mounding on the downgradient side of the treatment wall. Adding pesticide degradation rates in the model structure demonstrated that even recalcitrant compounds such as lindane may reasonably be expected to degrade within 30 years, facilitating US EPA acceptance, on a pilot basis, of a more cost-effective, equally protective, and passive treatment system than a lengthy pump and treat alternative.

Andy Davis
Jeffrey Anderson
Geomega
2995 Baseline Road
Suite 202
Boulder, Colorado 80303

Curt Peck cpec@chevron.com
Karl Hoenke khoe@chevron.com
Chevron Chemical Company
6001 Bollinger Canyon Road
San Ramon, California 94583

The Use of Energy Dispersive X-Ray Fluorescence in Rapid Site Characterization. John B. Hankins CPG, Kevin W. Miller, Ph.D., Robert R. Kovach, II, CPG, Paul B. Smart. Energy Dispersive X-Ray Fluorescence (EDXRF) is a technique that is capable of qualitative and quantitative composition determinations of selected elements. Although the technique was developed nearly 30 years ago, it has only recently been applied as a field screening technique for soil remediation projects. The detection limit of each element is dependent on matrix, the EDXRF source and detector. The method provides rapid turn around of analytical results (usually a few minutes) that allows project managers to make critical judgements in the field during site characterization. The interpretation of X-Ray emission spectra is straight forward and can easily be accomplished by professional field staff. Because the method is non-destructive, the EDXRF samples can then be forwarded to a fixed based laboratory for independent verification using standard methods. We present a case study of using EDXRF during a rapid site investigation for lead at a shooting range site. Preliminary lead data was available from a fixed-based laboratory to develop a response factor between EDXRF and fixed-based laboratory analyses. EDXRF was then used to analyze approximately 200 soil samples in two days. comparison of EDXRF results and fixed-based laboratory results were evaluated by linear regression analysis. The comparison of the analytical results were excellent. Statistical analysis of these results and a cost comparison of fixed-based laboratory analysis and EDXRF analysis are discussed.

John B. Hankins, LEP, CPG
Kevin W. Miller, Ph.D.
Robert R. Kovach, II, CPG
146 Hartford Road
Manchewster, CT 06040
Tel: 860-646-2469
Fax: 860-643-6313
e-mail: jhankins@fando.com
kmiller@fando.com
rkovach@fando.com

Paul B. Smart
Strum, Ruger and Company, Inc.
411 Sunapee Street
Newport, NH 03773
Tel: 603-863-3300
Fax: 603-863-9470

Application Of Basic Chemical Field Screening Techniques To Support Remediation Of Petroleum Release Sites. Lewis Horzempa, David Peterson, and Lawrence Kahrs, Foster Wheeler Environmental Corporation. Chemical field screening techniques are a potentially valuable tool in ongoing efforts to expedite and economize the cleanup of petroleum release sites. When used as an integral part of field efforts, screening techniques can provide dramatic savings to remediation cleanup schedules and budgets while simultaneously enhancing the flexibility of field programs. A growing variety of commercially available screening techniques can be used to support petroleum related remediation efforts. However, effective selection and application of screening techniques at individual sites require a clear understanding of the analytical principles upon which the individual screening methods are based, the chemical nature of site related petroleum contaminants, and the chemical implications of site specific regulatory cleanup requirements. This becomes increasingly important as risk based target cleanup levels gain greater acceptance. Equally important is the careful consideration of practical and engineering factors such as the cost benefit of on-site screening versus off-site laboratory analyses and implementability constraints to screening method field use. This evaluation process is demonstrated by examining the application of certain basic commercially available screening techniques at several petroleum remediation sites. Specifically, the effectiveness of immunoassay, turbidimetric (PetroFlag), and organic vapor screening methods to support remediation efforts at several commercial and Federal facilities in New England is examined. The strengths and weaknesses of each method including its applicability and specificity for site petroleum releases, detection limits, and interferences are discussed in terms of its practical utility to support remediation efforts. Also considered are approaches to correlating screening results with risk based target cleanup levels such as the Massachusetts DEP VPH/EPH approach.

Lewis Horzempa
David Peterson
Lawrence Kahrs
Foster Wheeler Environmental Corporation
470 Atlantic Avenue
Boston, MA 02210
Tel: 617-457-8200
Fax: 617-457-8498

Incorporation of Petroleum Carbon into Soil Organic Matter. Margaret Findlay and Sam Fogel, Bioremediation Consulting Inc., Newton MA, Sara McMillen, Chevron Research and Technology, Richmond CA, Jill Kerr, Exxon Production Research, Houston TX. A procedure based on measurement of the stable carbon isotope 13C, has been developed for determining the extent to which petroleum carbon is incorporated into soil organic matter (SOM) by humification of biomass produced during biodegradation of the petroleum in soil. We have shown that a crude oil having a d13C of -27.4 ppt, when biodegraded in a soil containing SOM with a d13C of -15.7 ppt, resulted in a change of the d13C of the bound soil organic matter reflecting that of petroleum carbon. Comparison of five soil biodegradation tests with this oil and soil, having different amounts and types of fertilizer to stimulate biodegradation, showed that the extent of the d13C change in the bound SOM varied with the extent of oil biodegradation observed. In order to obtain data on the soil organic matter, the residual petroleum was first removed by rigorous extraction with dichloromethane using a Soxhlet apparatus. The extracted soil was then comubusted to release bound carbon as CO2, which was analyzed for 13C. Where the soil organic matter has d13C similar to that of petroleum, 14C measurements of SOM would give similar results. This type of data, referred to as the petroleum 'footprint' in the SOM, could be useful in identifying or confirming intrinsic biodegradation of petroleum in contaminated soil.

Margaret Findlay and Samuel Fogel
Bioremediation Consulting Inc.
55 Halcyon Rd
Newton MA 01259
Tel: 617-969-5913
Fax: 617-969-5968

Sara McMillen
Chevron Research and Technology
100 Chevron Way
Richmond CA, 94802
Tel: 510-242-3485
Fax: 510-242-1954

Jill Kerr
Exxon Production Research
PO Box 2189
Houston TX 77252
Tel: 713-965-7028
Fax: 713-431-7579

ENVIROMENTAL FORENSICS PLATFORM

The Evolving State of Environmental Forensic Investigations. Scott A. Stout, Allen D. Uhler, Kevin J. McCarthy, and Thomas G. Naymik. With increasing frequency, potential PRPs at contaminated sites are faced with the question "Is this contamination really mine, or might it (some, or all) belong to a former property owner or a neighbor? If so, what is an equitable and defensible allocation of these costs?" Unfortunately, because of the magnitude of dollars at stake, many situations in which true PRPs or co-PRPs are identified become litigious and are settled either through arbitration or in court. As a PRP or potential PRP, charting a course to address the questions of ownership, responsibility, and liability can be a technical, legal, and administrative nightmare. Historically, investigators have relied on only one or two facets (e.g., chemical fingerprinting) of a potentially richer base of information in addressing these issues. In many cases, the best way to address the issues of ownership and responsibility is through a thorough Environmental Forensics Investigation. Such an investigation is, by definition, designed to address the specific questions of ownership and responsibility through a detailed study of the nature of the contamination, its movement within the study area and its linkages to a potential source(s) of the contaminants in question. This paper will discuss the necessary integration of tailored site assessment data with a particular siteís operational and regulatory histories, and factor in any unusual conditions or features of the site. How data from such an investigation are interpreted in light of product manufacturing and handling history, sound fate and transport principles, weathering effects, and the potential influence of local geologic and hydrogeologic conditions will be an integral part of the presentation. Several case studies will illustrate the role of records research (to document past practices and history or activities at the site), specialized chemical measurements (to differentiate the nature and source(s) of contamination), chemometrics (numerical and graphical techniques to demonstrate the relationship between the in-place contamination and sources), and geohydrology (to understand and visualize the movement of contamination within the study area). Finally, because many Environmental Forensics investigations are settled through arbitration or in the courtroom, a discussion will be given on how the results of such investigations are presented, complex through it may be, in a manner that is easily understood by predominately lay audiences.

Scott A. Stout, Ph.D.
Allen D. Uhler, Ph.D.
Kevin J. McCarthy
Battelle Environmental Forensics Investigation Group
397 Washington Street
Duxbury, MA 02332
Tel: 781-934-0571
Fax: 781-934-2124

Thomas G. Naymik, Ph.D.
BattelleóHydrogeology and Modeling
505 King Avenue
Columbus, OH
Tel: 614-424-6344
Fax: 614-424-3667

Methane Associated with a Large Gasoline Spill – Forensic Determination of Origin and Source. Paul D. Lundegard and Mark Brearley, Unocal Corporation, Robert Haddad, Entrix, Inc. Hydrocarbon vapors associated with spilled petroleum products arouse regulatory concern and can pose a significant health and safety risk. Identifying the source and origin of these vapors is an important part of evaluating risk and environmental liability. An investigation of the distribution and origin of soil gas methane was conducted at the location of a large gasoline spill in an urban area. A survey of the composition of subsurface vapors showed high CH_4 and CO_2 concentrations both within, and well beyond the limits of the gasoline spill. Site investigations also found that spilled gasoline was not the only subsurface carbon source present. Lake sediments and substantial quantities of wood and sawdust were also encountered. Stable carbon and hydrogen isotope ratios indicated the CH_4 is biogenic in origin and formed by an acetate fermentation pathway. However, these data alone did not allow identification of the source of the methane. Carbon-14 analysis of CH_4 samples provided the strongest indication of the CH_4 source. Methane in soil gas samples from beneath and adjacent to the site had ^{14}C concentrations much higher than 0 percent modern carbon (pMC), the expected value for CH_4 derived from gasoline. Carbon-14 concentration averaged 86 pMC, demonstrating that the spilled gasoline is, at most, a minor contributor to the elevated concentration of CH_4 in the subsurface. It is likely that the underlying lake sediments and/or wood debris are instead the predominant source of the methane. The findings of this investigation lead to a substantial reduction in site liability and costs, and show that CH_4 in association with spilled petroleum products is not necessarily derived from degradation of those products.

Paul D. Lundegard
Unocal Corporation
376 S. Valencia Ave.
Brea, CA 92823
714-577-1625
Fax: 714-577-2367
pdlundeg@unocal.com

Mark Brearley
Unocal Corporation
11720 Unoco Rd.
Edmonds, WA 98020
425-640-7610
Fax: 425-640-7601
mbrearly@unocal.com

Bob Haddad
Entrix, Inc.
590 Ygnacio Valley Rd., Suite 20
Walnut Creek, CA 94596
510-988-1242
Fax: 510-935-5368
rhaddad@entrix.com

Applications of Anthropogenic Lead ArchaeoStratigraphy to Hydrocarbon Remediation. Richard W. Hurst, Hurst & Associates, Inc. and California State University, Los Angeles. Environmental remediation and insurance cost-recovery issues often require an estimate of the year a refined hydrocarbon product was released into the environment. Additionally, it is often necessary to fingerprint the free product in an effort to correlate the release to a potentially responsible party (PRP). Anthropogenic Lead ArchaeoStratigraphy (ALAS) was developed to address both issues: the question of age and that of responsibility. The ALAS Model is based on a calibration curve which plots systematic changes in naturally-occurring lead isotope ratios of gasoline against the known age of a release or year of production of gasoline. Assigning responsibility to PRPís during the era of leaded gasolines (pre-1990) is predicated on the ALAS Model age whose age uncertainty ranges from one to three years for releases which occurred between 1960 and 1990. After 1990, when gasolines are ìunleadedî (ppb levels attributable to inherited lead from crude oils and refining), age estimates can only be stipulated to be post-1990. However, lead isotopic variations among unleaded gasolines/mid-range distillates, now inherited from crude oils and refining, allow us to discriminate different petroleum manufacturerís products. Responsibility is assessed via lead isotopic comparisons between refined products and releases. Examples of ALAS Model applications in California, Florida, and New Jersey will be discussed.

Richard W. Hurst
Hurst & Associates, Inc.
9 Faculty Court
Thousand Oaks, CA 91360-2934
Tel: 805-492-7764
Fax: 805-492-7764

Forensic Hydrocarbon Fingerprinting Saves The Day. Gregory S. Douglas, Ph.D. Arthur D. Little, Inc., and Jeffrey Johnson, Heller, Ehrman, White & McAuliffe. Advanced Chemical Fingerprinting was used to evaluate the chemical composition of spilled products and source samples associated with a release of fuel oil into a marine system. The local regulatory agencies and the United States Coast Guard (USCG) identified the client as the PRP based on a strong correlation of the biomarker signatures between the spilled oil and the oil collected on the shallow water table after a recent UST removal on the clientís property. The potential liabilities include Natural Resource Damage Assessment claims, PRP of a regional groundwater contamination issue, USCG penalties and expense reimbursement, and public relations issues.

After an extensive examination of the historical data from the site, the USCG chemical analyses, and the analyses performed by a previous laboratory hired by the client, the Heller, Ehrman and Arthur D. Little, Inc. team advised the client to proceed with a more extensive investigation. The team developed a sampling and analytical strategy to determine if the floating product collected in the pit sample was due to a UST release and if it was related to the spill sample. The forensic chemistry results of this study conclusively demonstrated that the floating product in the tank pit was part of a larger regional contamination problem. In addition, analysis of additional oil samples from the tank supply line demonstrated that the client fuel was clearly not the source of the contamination. The results of this study were presented to the USCG and the local regulatory agencies and all claims were subsequently dropped, saving the client extensive financial costs and preserving the clientís environmentally friendly reputation.

Gregory S. Douglas, Ph.D.
Vice President
Environmental Forensics Laboratory
Arthur D. Little, Inc
Cambridge, MA 02140-2390
Tel: 617-498-5384
Fax: 617-498-7296
Email: g.douglas@adlittle.com

Jeffery Johnson
Shareholde
Heller, Ehrman, White & McAuliffe
Los Angeles, CA 90017-5758
Tel: 213-689-7655
Fax: 213-614-1868
Email: jjohnson@hewm.com

An Overview of Error Analysis and Its Significance to Environmental Investigations. James E. Bruya, Charlene R. Jensen, and Kurt N. Johnson, Friedman & Bruya, Inc. Error is associated with all chemical measurements. Within the environmental regulatory community, the "error" associated with testing methods has typically been defined by SW-846 and can be considered to be an operational definition. Within many environmental investigations, regulatory definitions of error are of little or no use and one must rely on classical error evaluations. There are at least two ways in which error can be estimated. The most rigorous approach is usually restricted to large projects where the multiple replicate analyses needed are not cost prohibitive. A second approach to error analysis is similar to that used in establishing significant figures. Here, the errors associated with a particular measurement can be estimated and a type of confidence limit applied to any one result. Examples of how this classical approach can be used with forensic and regulatory analyses will be discussed in detail.

James E. Bruya
Charlene R. Jensen
Kurt N. Johnson
Friedman & Bruya, Inc.
3012 16th Avenue West
Seattle, WA 98119
Tel: 206-285-8282
Fax: 206-283-5044
e-mail: fbi@isomedia.com
Fax: 206-283-5044
e-mail: fbi@isomedia.com0

Using MTBE and Other Gasoline Additives in Forensic Environmental Investigations James M. Davidson and Daniel N. Creek Alpine Environmental, Inc.

There are a number of gasoline additives that can sometimes be used to identify the source or timing of gasoline spills. The physio-chemical characteristics of methyl tertiary butyl ether (MTBE), and its historical use pattern since the 1980's, makes it a key compound to study when conducting forensic investigations of gasoline spills. MTBE's low octanol:water distribution coefficient and high solubility cause it to dissolve into ground water more readily than other gasoline components. This allows for identification of new fuel spills, even when substantial subsurface petroleum contamination already exists. MTBE's very low retardation in ground water can be used with transport rate calculations to establish fairly accurate estimates of spill timing.

However, care must be taken regarding the assumption that MTBE is always a conservative compound. Large MTBE plumes can create complex geochemical regimes which in turn may produce different rates of natural attenuation across a single plume. MTBE is considered to biodegrade poorly, but recent research suggests that MTBE biodegradation rates may vary with time and position across a single plume. This, and other subtle MTBE attenuating processes, all affect subsurface transport and mass distribution.

When using MTBE and other oxygenates in forensic investigations, other complicating factors must be addressed including: potential false positives, additives from non-point sources, incidental blending/mixing of additives in gasoline supplies, product swapping by suppliers, and others. Several case studies are reviewed to demonstrate the interaction of these factors when studying MTBE and other additives in forensic investigations.

James M. Davidson
Alpine Environmental, Inc.
203 W. Myrtle Street, Suite C
Fort Collins, CO 80521
970-224-4608 (phone)
970-224-2329 (fax)

Daniel N. Creek
Alpine Environmental, Inc.
203 W. Myrtle Street, Suite C
Fort Collins, CO 80521
970-224-4608 (phone)
970-224-2329 (fax)

Using an Environmental GIS to Implement DQO/DQA Processes for Contaminated Soils at a DOD Facility. William F. Mullen, Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA, and Patrick J. Hooper, Tetra Tech-NUS, Pittsburgh, PA. Department of Defense (DOD) has committed to implementing cost-effective technologies to improve decision making quality in determining clean-up requirements at Installation Restoration Sites. The Data Quality Objectives (DQO) and Data Quality Assessment (DQA) processes outlined in Guidance For The Data Quality Objectives Process (USEPA QA/G-4, 1994) are a preferred method to support that commitment. A frequently debated DQO/DQA topic is the determination of whether a sufficient number of environmental samples have been collected in order to adequately characterize the site. Because environmental data collected under typical DOD environmental investigations historically was biased, spatially clustered and correlated with respect to "source area" contaminant concentrations, classical statistical studies based on the arithmetic mean of results typically overestimated contamination and corrective action costs. Tetra Tech NUS in support of the Atlantic Division, Naval Facilities Engineering Command has implemented an Environmental Geographical Information Systems (EGIS) at Marine Corps Air Station (MCAS) Cherry Point for numerous IR, Base Re-Alignment and Closure (BRAC) and Underground Storage Tank (UST) investigations. MCAS Cherry Point encompasses approximately 11,485 acres of the Atlantic Coastal Plain of North Carolina and provides mission support for Marine Aircraft Wing, Fleet Marine Force Atlantic aviation units as well as a Naval Aviation Depot (NADEP) facility. The EGIS currently consists of over 5000 sample locations and over 400,000 analytical results. The utilization of advanced geostatistical analysis within the EGIS at MCAS Cherry Point allows an effective and defensible method of quantifying spatial uncertainty related to data collection for sites. Cost-benefit analysis performed to weigh the cost of additional data collected against the cost of voluntary removal action. This paper presents specific case studies comparing USEPA guidance with real-world situations in a strategic manner.

William F. Mullen
Atlantic Division,
Naval Facilities Engineering Command.
1510 Gilbert Street
Norfolk, Virginia 23511
Tel: 757-322-4588
Fax: 757-322-4972

Patrick J. Hooper
Tetra Tech NUS
661 Andersen Drive
Pittsburgh, PA 15220
Tel: 412-921-8250
Fax: 412-921-4040

Sonic Cone Penetrometer Technology, Global Positioning System (GPS)/Geographical Information System (GIS) Automatic Mapping System Bruce J. Nielsen, Air Force Research Laboratory, James D. Shinn II, Applied Research Associates, Inc. To improve the speed, cost, and safety of site characterization and monitoring activities, recent DOD and Air Force efforts have focused on developing advanced sensor packages, methods to insure these packages can be delivered to the desired depth; and developing user friendly software mapping and visualization graphics packages which will allow timely decisions to be made. Advancements in these areas are now generating characterization data more rapidly and providing the capability to map site geology and contaminant plumes in near real-time. A recently completed project integrated a Global Positioning System/Geographical Information System (GPS/GIS) with the cone penetrometer. The differential GPS system consists of a roving station and a base station. The roving station is normally located on the CPT truck and used to track and display its position as the truck moves about the site. The roving station can also be mounted in a backpack and used to map the site. Accuracies of up to 2 cm in the x, y, and z directions can be obtained under ideal conditions. Once the truck has been located, its position is automatically logged into the GIS database and CPT data acquisition system. Upon completion of the sounding, the CPT data is saved into the GIS database and can be displayed using the CPT graphical software of the X-Section* software for displaying geologic data in a cross-sectional view. It is applicable for sites where soil data is represented by From-To samples and profile data is recorded at specific depths. An intuitive graphical user interface (GUI) provides an easy to use interface for setup and creating cross-sections, represented by different colored patterns.

Bruce J. Nielsen
U.S. Air Force
AFRL/MLQE
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32404-5323
Tel: 850-283-6227
FAX: 850-283-6227
E-Mail: bruce.nielsen@ccmail.aleq.tyndall.af.mil

James D. Shinn II
Applied Research Associates, Inc
RR1, Box120A
South Royalton, VT 05068
Tel: 802-763-8348
FAX: 802-763-8283
E-Mail: jshinn@ara.com

Preliminary Remediation Goals (PRGs) for Soil Based on Ecological Protection. David Mayhew, Daniel Hinckley, Margaret Bickerton, EA Engineering, Science and Technology, Simeon Hahn and Philip Otis, Naval Facilities Engineering Command, Northern Division. Ecological considerations in soil clean-up decisions are typically based on chemical concentration" criteria" of varying efficacy. Available soil-screening values are often policy-based, with little scientific underpinning. Consequently, clean-up goals are unrealistic. We present a procedure for "calibrating" clean-up targets using food-web exposure modeling, carried out at the Naval Construction Battalion Center in Rhode Island. Initially, food-web exposure modeling assessed risk to terrestrial receptors. Concurrently, soil concentrations at specific sites were screened against available soil benchmark criteria, and were calculated. HQS were also calculated for food-web exposure of robin, hawk, and shrew, which receive virtually their entire exposure via soil. The food-web HQS were then superimposed graphically on the screening HQS to provide "calibration". Typically, the food-web HQS expressed less risk than predicted by screening methods. Proposed PRGs were based on food-web exposure results because they were site-specific and scientifically stronger.

David Mayhew dam@eaest.com
Daniel hinckle dah@eaest.com
Margaret Bickerton mjb@eaest.com
EA Engineering, Science, And Technology
15 Loveton Circle
Sparks, MD 21152
Tel: (410)771-4959
Fax: (410)771-4204

Simeon Hahn sphahn@efdnorth.navfac.navy.mil
Philip Otis psotis@efdnorth.navfac.navy.com
Northern Division
Naval Facilities Engineering Command
10 Industrial Highway
Mail Stop No. 82
Lester, PA 19113
Tel: (610) 595-0567
Fax: (610) 595-0555

Kriging Analysis Of Benthic Bioassay Data In Ecological Risk Assessments of Harbor Sediments. Christopher J. Leadon, Southwest Division, Naval Facilities Engineering Command, San Diego, CA., The application of the spatial statistical technique, Kriging, to the spatial estimation of benthic invertebrate bioassay data, associated with ecological risks from hazardous contamination in harbor sediments, is described in this paper. The types of ecological risk assessments used in stages of the Navy's Installation Restoration program for cleaning up sites contaminated with hazardous substances are described. Benthic bioassay data from contaminated sediments in a large harbor and a smaller channel at California Navy bases are presented as an examples of the bioassay data used in ecological risk assessments of harbor sediments. The Kriging of the benthic biassay data from the example harbors generally show where more samples data may be needed at the larger basinwide scale in the larger harbor, but also how few additional samples are needed to delineate hotspots at a smaller scale. Kriging can be a very effective statistical method for limiting the number of samples needed to spatially characterize smaller harbors or hotspots in larger harbors while still insuring adequate data quality. The laboratory analyses of benthic bioassay samples collected for ecological risk assessments in harbors can be very expensive. Maps of the spatial error variance of sample data of a parameter can be used to place additional sampling points or minimize the number of additional samples needed at a site.

Christopher J. Leadon
Southwest Division
Naval Facilities Engineering Command
1220 Pacific Highway
San Diego, CA. 92101-3327
E-mail: cjleadon@efdswest.navfac.navy.mil
Tel: 619-532-2584
Fax: 619-532-1195

Performance Considerations for Innovative and Emerging In Situ Remediation Technologies. Jesse L. Yow, Jr., Lawrence Livermore National Laboratory, and Norman N. Brown, Integrated Water Technologies, Inc. Applied research and technology development efforts of the past several years are paying off with new in situ alternatives to conventional site remediation methods such as pump and treat. Most of the new in situ remediation (or remediation enhancement) technologies fall into one of three categories: bioremediation, chemical manipulation, or thermal remediation. Field testing and full-scale application can identify and document the advantages and limitations of these new cleanup methods. Performance test results addressing heterogeneous site conditions, subsurface flow and transport processes, or different contaminant chemistries are of particular interest since these factors can affect efficiency and cost in difficult and unexpected ways. Laminar flow and fluid displacement effects, for example, can limit the effectiveness of many kinds of bioremediation and chemical manipulation approaches, while subsurface heterogeneities can seriously hinder in situ air sparging. Similarly, technology performance for cleanup of contaminated groundwater plumes often does not readily carry over to removal or destruction of source areas and free product. Basic principles of environmental geotechnology, coupled with experiences from recent NAPL and VOC cleanup case histories (e.g., thermal remediation technologies at the LLNL gas pad), furnish a foundation for comparing, selecting, and applying in situ methods to treat real-world site cleanup problems more effectively.

Dr. Jesse L. Yow, Jr
University of California
Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550
Tel: 925-422-3521
Fax: 925-422-5514
Email: yow1@llnl.gov

Dr. Norman N. Brown, President
Integrated Water Technologies, Inc.
Post Office Box 2610
Santa Barbara, CA 93120
Tel: 805-565-0996
Fax: 805-565-0886
Email: norm@integratedwater.com

Evaluation of Pneumatic Fracturing on Soil Properties via Innovative Testing and Analysis. Matthew H. O'Brien, Research Triangle Institute. Pneumatic fracturing is a technology designed to increase the efficiency of soil vapor extraction, air sparging and various other in situ bioremediation technologies in low permeability soils. This pretreatment process often facilitates an increase in contaminant removal of 10 times or more, depending on the site geology and the initial level of contamination. Through the use of a lightweight, modular characterization tool that quantifies a soil's permeability to air and propensity to fracture, time and money could be saved during preliminary site characterization. The development of the Backpack Fracture Probe system and a modular Fixed-Flux Soil Permeameter address this issue of fracture potential in clay soils. Recent research activities have focused on clays with high shrink-swell potential (e.g., kaolinite, montmorillinite). Bench-scale and field testing of the new tools and methods completed between October 1997 and August 1998 have shown that detection of small physical changes is quantifiable. These data, can provide the basis for a fracturability rating scale and associated database for use by remediation professionals involved with pneumatic fracturing. Further field testing is being conducted on soil types that predominate in the southeastern and south central U.S.

Matthew H. O'Brien
Research Triangle Institute
3040 Cornwallis Road
Research Triangle Park, NC 27709-2194
Tel: 919-990-8612
Fax: 919-990-8639
E-mail: mho@rti.org

A Field-scale Test of in Situ Chemical Oxidation through Recirculation. Olivia R. West, Steven R. Cline, Oak Ridge National Laboratory, Robert L. Siegrist, Colorado School of Mines, William L . Holden, Frank G. Gardner, Oak Ridge National Laboratory, Thomas C. Houk, Bechtel Jacobs Company LLC. In situ chemical oxidation is a class of remediation technologies where chemical oxidants are delivered to the subsurface to degrade organic contaminants. Laboratory experiments conducted at Oak Ridge National Laboratory and Colorado School of Mines have shown potassium permanganate ($KMnO_4$) can rapidly degrade tlichloroethene (TCE) in both aqueous and soil matrices An oxidant delivery technique was then developed wherein groundwater is extracted from a contaminated aquifer, amended with $KMnO_4$, and re-injected back into the subsurface using a network of injection and extraction wells. This technique, referred to as in situ chemical oxidation through recirculation or ISCOR can be applied to saturated but hydraulically conductive formations. A field-scale test of ISCOR was conducted at a site in Piketon, OH where groundwater was contaminated with TCE at levels indicative of dense non-aqueous phase liquids. The field test was implemented using a pair of 200-ft horizontal wells screened at a depth of 30 fit within a 5-ft thick silty gravel aquifer (hydraulic conductivity = 20 ft/day). For approximately one month, groundwater was extracted from one horizontal well, dosed with $KM110_4$, and re-injected into a parallel horizontal well 90 ft away. MnO_4^-, TCE and pH were monitored in groundwater samples collected from within the treatment zone. Comparison of pre- and post-treatment soil and groundwater levels showed that ISCOR was effective at oxidizing TCE in the saturated region. Lateral and vertical heterogeneities impacted the uniform delivery of the oxidant solution. However, TCE was not detected (at a 5 ppb detection level) in samples from monitoring wells and soil borings in locations where the oxidant had permeated.

Olivia R. West Ph.D.
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831
Tel: 423-576-0505
Fax: 423-576-8543
qm5@~ornl.gov

Robert L. Siegrist,Ph.D.,P.E.
Colorado School of Mines
112 Coolbaugh Hall
Golden, CO 80401-1887
Tel: 303-273-3490
Fax: 303-273-3413
rsiegris@mines.edu

Frank G. Gardner
Oak Ridge National Laboratory
2597 B&3/4 Rd
Grand Junction, CO 81503
Tel: 970-248-6238
Fax: 970-248-6147
fgg@orril .gov

Steven R. Cline,P.E.
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831
Tel: 423-241-3957
Fax: 423-576-8543
qc2@ornl.gov

William L. Holden
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831
Tel: 423-576-2049
Fax: 423-576-8543
n42@1ornl.gov

Thomas C. Houk
Bechtel Jacobs Company LLC
3930 US Route 23S
Piketon, OH 45661
Tel: 740-897-6502
Fax: 740-897-3800
uk9@ornl.gov

MTBE SESSION

MTBE Health Data Review and Estimate of Safe Drinking Water Level. Robert G. Tardiff, The Sapphire Group, Inc., and John Kneiss, Oxygenated Fuels Association. MTBE is widely used in U.S. gasoline to reduce assorted pollutants from mobile emissions. The health benefits include reductions in risk of pulmonary disease and of cancer. At the highest concentrations in fuels, MTBE also decreases the risk of heart attacks among those having pre existing cardiovascular disease. MTBE can contaminate ground water as a result of fuel leaks and surface water as a result of the use of some types of water crafts. Some water in which MTBE was found was used for human consumption. The danger and safety of MTBE in sources of tap water has been investigated extensively worldwide. Toxicity studies at high doses have found no indications of reproductive injury or of developmental abnormalities in the fetus. MTBE, after testing in numerous types of assays, has been shown to not be genotoxic. The primary target organ for the acute or chronic inhalation of MTBE is the central nervous system (depression). Other target organs by either route include kidneys of male rats, liver of female mice, and possibly the testes of rats. MTBE at high inhalation doses has elicited tumors in the same tissues, species, and strains. Numerous mechanistic data have demonstrated that each tumor type results from physiological processes uniquely present in the test organisms and absent in humans. A lifetime gavage study raised the possibility that high doses of MTBE might cause leukemia in rats; these data await replication because of questioned validity.

Taking all information into account and applying the margin of exposure (MoE) approach endorsed by numerous authorities, a safe level in tap water has been estimated at 70 µg/L (ppb). While such a concentration would not likely cause injury to health, it would impart undesirable taste and odors to the water—a situation that would help guide the setting of tolerable limits of exposure.

Robert G. Tardiff
The Sapphire Group, inc.
3 Bethesda Metro Center, Suite 700
Bethesda, MD 20814
Tel: 301-664-8406
Fax: 301-664-8403

John Kneiss
Oxygenated Fuels Association
1300 North 17th Street, Suite 1850
Arlington, VA 22209
Tel: 703-841-7100
Fax: 703-841-7720

Water Treatment Technologies and Remediation of MTBE. Michael C.Kavanaugh, Ph.D., P.E., and Andrew J. Stocking. Malcolm Pirnie, Inc. Fuel Oxygenates are a class of organic compounds currently added to gasoline as an octane enhancer in order to reduce carbon monoxide emissions from non-stationary sources; thus, meeting the requirements of the 1990 Clean air Act Amendments and Oxyfuel program. The most widely used oxygenate is methyl tertiary-butyl ether (MTBE) with an annual consumption of more than four billion gallons in the United States. As a result of its widespread use, MTBE can enter the subsurface by a release involving, typically, a spill or leak of gasoline from a leaking underground storage tank (LUST) or pipeline, or pure product, during transport or production. Once in the subsurface the unique physio-chemical characteristics of MTBE can cause it to be transported further than BTEX compounds. Longer MTBE plumes may result in a greater likelihood of impacted drinking water well-fields, as well as a large more complicated remediation program. However, MTBE can be removed from drinking water very cost-effectively using air stripping and advanced oxidation. In addition, proper management of MTBE-impacted remediation sites and application of the extensive amount of knowledged known about the fate and transport of MTBE in the subsurface can significantly reduce remediation costs. This paper presents treatment options for removing MTBE from drinking water and remediation strategies for cleaning MTBE-impacted sites.

Michael C. Kavanaugh, Ph.D., P.E.
Andrew J. Stocking
Malcolm Pirnie, Inc.
180 Grand Avenue, Suite 725
Oakland, CA 94612
Tel: (510) 451-8900
Fax: (510) 451-8904

Smart Pump & Treat Strategy for Impacting a Public Water Supply Well Field. Joseph E. Haas II , New York State Department of Environmental Conservation,Charles Sosi Environmental Assessment. Recalcitrant organic compounds such as methyl tertiary butyl ether (MTBE) often limit the applicability of many remedial techniques and strategies such as natural attenuation and bio-degradation. The expanded use of MTBE as an oxygenate additive in gasoline often results in it being the main contaminant of concern at gasoline spill sites. Frequently, the only viable remedial technology to address MTBE at these sites is groundwater extraction and treatment (pump and treat). properly designed and implemented pump and treat strategy can lead to cost effective remediation of dissolved MTBE contamination. case study is presented in which three dimensional (3-D) characterization and monitoring of dissolved MTBE contamination was instrumental in the design and operation of an aggressive pump and treat strategy which successfully remediated two (2) two thousand (2000) foot long plumes of MTBE impacting a major public water supply well field in Riverhead , Long Island. Accelerated Site Assessment Procedures (ASAP) were utilized to define the plumes, identify the source areas and configure a 3-D monitoring network of multi-level samplers (nested piezometers). Data from the monitoring network was used in conjunction with a 3-D (MODFLOW) flow model to design a multi-well pump and treat system to remediate the plumes. The plumes which exhibited MTBE concentrations in excess of 2,000 were recovered to an acceptable level (200 ppb) within two (2) years. A Domenico based dispersion-Ñonly model was utilized to identified the acceptable MTBE cleanup level. The cost of the entire project was approximately one third the cost of deepening, replacing or treating the three (3) public water supply wells. The success of the 500,000 dollar project prevented a 1.5 million dollar claim against the New York State Spill Fund.

Joseph E. Haas II
New York State Department of Environmental Conservation
SUNY Building #40
Stony Brook, New York 11790-2356
Tel:516-444-0332
Fax:516-444-0373
Email:jehaas@gw.dec.state.ny.us

Charles Sosik
Environmental Assessment
225 Atlantic Avenue
Patchogue, NY 11772
Tel:516-447-6400
Fax:516-447-6497
Email: sosik@enviro-asmnt.com

Transport Modeling to Expedite UST Site Closure, Rebecca A. Kinal, Raveendra Damera, and Dev Murali, General Physics Corporation, Raymond McDermott, Aberdeen Proving Ground. Soil contamination often poses a threat to groundwater due to leaching of compounds from NAPL and soil gas into infiltrating water. This is particularly true for methyl tertiary butyl ether (MTBE), a volatile and highly soluble oxygenate added to gasoline. Because gasoline contains MTBE and other lighter end hydrocarbons, corrective action for groundwater contamination, in addition to soil treatment, is often required at UST sites. A case study is presented in which active remediation of soil and groundwater is followed by computer modeling of residual dissolved contaminants to achieve site closure for a gasoline UST site located at U.S. Army Garrison Aberdeen Proving Ground, Maryland. SVE/bioventing and air sparging systems were installed at the site to address both soil and groundwater contamination. After two years of system operation, the majority of soil contamination was removed; however, significant dissolved MTBE was still present. Rather than continuing operation of the remediation system and incurring continued operation and maintenance costs, site closure was expedited using a contaminant transport model to ensure residual dissolved contaminants did not pose a risk to potential receptors. The only potential receptor was identified as Dipper Creek, a tributary of the Chesapeake Bay located approximately 2000 feet downgradient of the site. Transport of the dissolved contaminants was simulated using a natural attenuation model. Model results were used to estimate the distance that dissolved contaminants will travel and the amount of time for natural attenuation to reduce concentrations below MCLs/suggested action levels. Using highly conservative transport parameters, the model predicted that significant MTBE concentrations will not reach Dipper Creek. These modeling results were used to justify and seek approval from Maryland Department of the Environment for site closure.

Rebecca A. Kinal
Raveendra Damera
Dev MuraliGeneral Physics Corporation
6700 Alexander Bell Dr.
Columbia, MD 21046
Tel: 410-290-2596
Fax: 410-290-2455

Raymond McDermott
DSHE Environmental Compliance Division
STEAP-SH-EE Building 4603
Aberdeen Proving Ground, MD 21005
Tel: 410-278-5773
Fax: 410-278-4291

BIODEGRADATION OF MTBE: CURRENT STATUS OF RESEARCH James E. Landmeyer, U.S. Geological Survey, 72 Gracern Road 0 Suite 129, Columbia, SC, USA, 29210-7651Some researchers have shown that methyl *tert*-butyl ether (MTBE) is resistant to biodegradation while others have shown that MTBE can biodegrade. This apparent contradiction of results can be explained, however, in terms of the different electron-accepting conditions that these studies were conducted under, or the unique origins of the microorganism (s) examined. The object of this talk is to summarize and clarify the results of current research investigating the microbial fate of MTBE.

Author and Co-Author Information
James E. Landmeyer
Francis H. Chapelle
Paul M. Bradley
U.S. Geological Survey-Water Resources Division
720 Gracern Road-Suite 129
(503) 690-1023
FAX (503) 690-1273

Clinton D. Church
Paul G. Tratnyek
Department of Environmental Science and Engineering
Oregon Graduate Institute of Science & Technology
P.O. Box 91000 Portland, OR 97291-1000
Columbia, SC 29210-7651
(803) 750-6125
FAX (803) 750-6181

MULTI-PHASE EXTRACTION SESSION

Laboratory Examination of Soil Vapor Extraction (SVE) and Multi-Phase Extraction (MPE). Derek J. Yimoyines and Christopher Swan, Tufts University. Soil Vapor Extraction (SVE) is used currently throughout the United States to remediate sites contaminated with volatile organic compounds (VOCs). Multi-Phase Extraction (MPE) is an emerging and potentially more efficient method for remediation of similar contaminated sites. This paper will describe a series of laboratory experiments to compare the ability of MPE and SVE to remove toluene. Experiments were conducted under various conditions including air flowrate (1 and 10 liters per minute), initial toluene concentration (5 and 20 ppm), soil type and method of extraction (SVE or MPE). medium to coarse sand without fines and a uniform Ottowa sand were the two soil types used in experiments. The paper outlines the challenges encountered with equipment and laboratory setup, the final design and procedures implemented, and preliminary data collected during experimentation.

Derek J. Yimoyines
RAM Environmental
140 Samoset Street
P.O. Box 1040
Plymouth, MA 02362
Tel: 508-747-7900
Fax: 508-747-3658

Professor Chris Swan
Tufts University
113 Anderson Hall
Medford Ma. 02155
Tel: 617-627-2212
Fax: 617-627-3994

A Critical Review of Three Multiphase Extraction Pilot Tests for LNAPL Remediation Daniel Groher, Robert Bukowski, Howard Allen, John Bierschenk, Jim Galligan, Ralph Baker, Ph.D. ENSR Multiphase (MPE) or bioslurping is fast becoming a common remedial approach for LNAPL contaminated sites. Good design of MPE systems requires in-depth knowledge of the behavior of LNAPL, water, and airflow in the subsurface, and the site-specific subsurface response to the high vacuums imposed by this approach. Critical site-specific information is best obtained by performing in-situ pilot tests. Case studies of the results from three very different MPE pilot tests performed in Massachusetts will be presented and discussed. The test methods for each were based on the pilot testing protocol developed by AFCEE. One test was performed at an industrial facility with free phase and residual mineral oil present in overburden soil and in shallow bedrock; another was performed at a former chemical manufacturing facility where phthalates exceed cleanup goals due to mobilization in mineral spirits NAPL; and the third was performed for bulk phase jet fuel present in low conductivity hydraulic clays at Logan Airport. The strategies for these pilot tests were dictated by the geologic settings and remediation goals. Comparisons will be made of the test protocols for each study; the pilot test results, including air and fluid flow rates and subsurface vacuum influence; and the factors affecting the success or failure of each test. The implications of the pilot test results on full-scale remediation design for each site will be discussed.

Daniel Groher
Robert Bukowski
Howard Allen
John Bierschenk
James Galligan
Ralph Baker, Ph.D.
ENSR
35 Nagog Park
Acton, MA 01720
Tel : 978-635-9500
FAX : 978-635-9180

Flow analysis and Process Optimization of a Dual-Phase, High Vacuum Extraction System for Subsurface Remediation. The high-vacuum subsurface extraction process has been shown to increase the removal of free-phase hydrocarbon product (free-product) and volatile organic compounds (VOC) from the soil and impacted groundwater present in low permeability soils by about four to five times compared to a conventional soil vapor extraction (SVE) process. The high-vacuum extraction process has been efficiently and cost-effectively used to remediate impacted soil and groundwater present in low permeability soils. Conventional SVE systems are not capable of producing the high vacuum levels required in remediating low permeability soils. Pilot tests are generally performed to evaluate the effectiveness of the system and to design a full-scale system for application to the site. The test data can also be used to optimize the operation of the system to maximize free-product, impacted groundwater, and VOC recovery.

Multi-phase fluid flow through the piping network is varied in the pilot test to study: (1) impact of fluid flow on pressure drops in the pipe and the loss of extraction efficiency; (2) flow regime; and (3) impact of fluid composition of hydrocarbon extraction. Flow analysis results can be used to enhance the operation of the system when applied to the full site.

Several factors contribute to optimizing the dual-phase high-vacuum extraction system, such as, applied vacuum, flow through system piping, flow regime, vapor and water content of the fluid mixture, depth of submergence of drop tube below the water table, soil type, and well placement relative to subsurface contamination. This paper presents a method of optimizing the operation of a high vacuum system based on groundwater extraction, flow analyses and remediation objectives.

Ajit T. Joseph, Ph.D., P.E.
Senior Engineer
ATC Associates Inc.
5150 East 65th street
Indianapolis, Indiana 46220-4871

Use of High Vacuum Extraction for Low-Cost, Maintenance Approach To No. 6 Oil Recovery. Steven Ueland and Kevin Curry, Langan Engineering and Environmental Services, Inc., Brandon Fagan, RETEC. Prompted by operational changes in a facilities boiler system in 1981, an underground storage tank (UST) containing No. 6 heating oil was abandoned in place adjacent to an active New Jersey manufacturing building. Initial assessment activities in 1995 identified subsurface impacts to the soil and groundwater system, including the presence of 10 or more feet of free oil or Light Non-Aqueous Phase Liquid (LNAPL) in site monitoring wells. Manual LNAPL recovery activities and conventional product recoverability testing showed limited success due to the viscous nature of the No. 6 oil. A quantitative evaluation of true LNAPL volume present in the subsurface was completed using a variety of approaches, including bail-down testing, empirical methods, and soil-core sample characterization. Limited soil sampling and LNAPL analytical parameter testing were also employed. Following a remedial option feasibility study, a pilot test for 3-phase recovery of product, groundwater and air using High Vacuum Extraction (HVE) technology was performed as excavation and other engineered remedial strategies proved unfeasible. To provide a basis for HVE application design, a conventional 2-dimensional SVE model solution was used to determine the radius of influence, and migration rates were calculated to evaluate control and containment of the product plume. A cost-benefit analysis was performed on the basis of test results to determine the most favorable application strategy. As a result, an innovative site management approach was developed for LNAPL recovery and migration control through a periodic "maintenance" program of HVE events utilizing conventional, mobile, vacuum equipment. The remedial strategy received approval from the NJDEP as a non-permanent remedy with the benefit of significant cost savings to the client.

Steven Ueland
Kevin Curry
Langan Engineering and Environmental Services, Inc.
Georgetown Crossing, Suite 225
3655 Route 202
Doylestown, PA 18901-1699
Tel: 215-348-7101
Fax: 215-348-7125

Brandon Fagan

RETEC
Damonmill Square
9 Pond Street
Concord, MA 01742-2851, ext. 3060
Tel: 978-371-1422
Fax: 978-369-9279

Enhanced Soil Vapor Extraction for Source Area Remediation Using Dual Phase Extraction with Pneumatic Fracturing. Zahra M. Zahiraleslamzadeh, FMC Corporation. Jeffrey C. Bensch. HSI GeoTrans. William G. Cutler. FMC Corporation. Remediation of volatile organic compounds (VOCs) from clay soils, both saturated and unsaturated, using soil vapor extraction is often difficult due to inadequate air flow through the impacted materials. A dual-phase extraction (DPE) system was designed, installed, and operated to remove VOCs from silty clay soils and shallow groundwater in a former waste storage area at a large industrial manufacturing facility. Air flow through the soils is enhanced by pneumatic fracturing between DPE extraction wells and by supplying continuous low flow/low pressure air to the fractured soils. The increased air flow caused by fracturing, within an otherwise tight clay formation, improves capture of VOCs by the vapor extraction system. The continuous air supply maintains open pathways, desiccates the clay soils, and enhances removal of VOCs by advection and biologic processes. In addition, concurrent groundwater extraction removes highly impacted shallow groundwater. This combination of technologies allows soil vapor extraction to be effective in areas that are typically not well suited for a standard soil vapor extraction system.

Ms. Zahra M. Zahiraleslamzadeh
Environmental Project Manager
FMC Corporation
Environmental Health Safety &
Toxicology Department
1125 Coleman Avenue
P.O. Box 58123
Santa Clara, California 95052-8123
Tel: 408-289-3141
Fax: 408-289-0195

Mr. Jeffrey C. Bensch, P.E.
Senior Engineer
HSI GeoTrans
3035 Prospect Park Drive. Suite 40
Rancho Cordova, California 95670
Tel: 916-853-1800
Fax: 916-853-1860

Mr. William G. Cutler
Remediation Project Manager
FMC Corporation
1735 Market Street
Philadelphia, Pennsylvania 19103
Tel:215-299-6206
Fax:215-299-6067

Innovative and Cost Effective Dual Phase Extraction Using a Vacuum Truck and Standard Monitoring wells. David M. McCabe, Harding Lawson Associates, Robert K. Maggiani, Textron Systems Corporation, Frank W. Lilley and Ellen G. Cool Harding Lawson Associates. Several discrete areas of free product are located within a 6-acre former burning dump. Product has been observed in wells at a thickness ranging from less than one half inch to up to six feet. A conventional groundwater depression and product recovery system had previously been installed at the site. However, due to the heterogeneous nature and low conductivity of the fill the system failed to recover more than a few gallons of product. After a successful pilot test, dual-phase extraction was selected as a remedial option. The technology was adapted for mobile, non-permanent application to address the discrete areas of product and in conjunction with the redevelopment of the site as open green-space. An innovative approach was developed which allowed a conventional vacuum truck to manifold to as many as four monitoring wells for a series of short-term (8-hour) recovery events. The performance of the vacuum truck-based system was comparable to fixed systems in terms of vacuum radial influence, volumetric air flow and product recovery. In some cases, the thickness of the product was reduced from greater than three feet to less than one-half inch after just three or four 8hour events. Pre- and post-event monitoring data have yielded insights regarding the behavior of free product in a heterogeneous landfill environment and the ability of short-term dual phase extraction events to stimulate biodegradation.

David M. McCabe PG
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: (781) 245-6606
Fax: (781) 246-5060

Frank W. Lilley, LSP
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: (781) 245-6606
Fax: (781) 246-5060

Robert K. Maggiani
Textron Systems Corporation
201 Lowell Street
Wilmington, MA 01887-2941
Tel: (978) 657-2477
Fax: (978) 657-2522

Ellen G. Cool Ph.D. LSP
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: (781) 245-6606
Fax: (781) 246-5060

PHYTOREMEDIATION SESSION

Bioavailability of Petroleum Contaminants in Vegetated Soil. M. Katherine Banks and A. Paul Schwab, Purdue University, Karen Miller, Naval Facilities Engineering Service Center, J. Scott Smith, Karrie Rathbone and Peter Kulakow, Kansas State University. Phytoremediation is a promising new soil clean-up technology that uses higher plants to enhance bioremediation. Introduction of higher plants into a bioremediation system can enhance dissipation of target compounds, particularly relatively immobile recalcitrant organic molecules. To further understand phytoremediation processes, the effect of plants on the bioavailability and toxicity of soil contaminants is being assessed by a field project at the U.S. Naval Construction Battalion Center in Port Hueneme, CA. Vegetated and unvegetated control plots have been established in diesel and heavier fuel oil contaminated soil, and contaminant and toxicity of the soil are being assessed over a two-year period. Samples of soil and leachate are taken every three months. Toxicity of soil and water samples is being evaluated using Microtox, shrimp, earthworm, and seed germination assays. Results from this project will provide additional information about acceptable end-points for bioremediated soil.

M. Katherine Banks, P.E., Ph.D
Associate Professor of Civil Engineering
Purdue University
1284 Civil Engineering Building
West Lafayette, IN 47907
Tel: 765-496-3424
Fax: 765-496-1107

A. Paul Schwab, Ph.D.
Associate Professor
Department of Agronomy
Lilly Hall of Life Sciences
Purdue University
West Lafayette, Indiana 47907
Tel: 765-494-4772
Fax: 765-496-2926

Karen Miller
Naval Facilities Engineering Service Center
Code ESC411
1100 23rd Avenue
Port Hueneme, CA 93043
Tel: (805) 982-1010
Fax: (805) 982-4304

J. Scott Smith, Ph.D.
Associate Professor
Department of Animal Science and Industry
Kansas State University
Manhattan, KS 66506
Tel: (785) 532-1219
Fax: (785) 532-5681

Karrie Rathbone
Graduate Research Assistant
Department of Agronomy
Kansas State University
Manhattan, KS 66506
Tel: 913-532-7268
Fax: 913-532-6094

Peter Kulakow, Ph.D.
Research Associate
Department of Agronomy
Kansas State University
Manhattan, KS 66506
Tel: 913-532-7213
Fax: 913-532-6094

The Treatment of Contaminated Soil Using Metal Accumulating Plants. Michael J. Blaylock, Jianwei W. Huang and Burt D. Ensley , Phytotech, Inc. The discovery of metal hyperaccumulating properties in select plants has lead to their application in removing heavy metal and radionuclides from contaminated soil. This process, termed phytoremediation, can be used to selectively remove heavy metals from soil. Since most technologies cannot selectively remove heavy metals, many sites can only be remediated using labor intensive and costly excavation and landfilling technology.

The goal of current phytoremediation efforts is to develop novel approaches for removing contaminants from the environment. By screening and selection methods several metal-accumulating lines of crop plants have been identified. These plants remove heavy metals from soil and concentrate the metals in their stems and leaves. The important features of phytoremediation can include lower costs for treatment, generation of a potentially recyclable metal-rich plant residue, applicability to a range of contaminants, minimal environmental disturbance, reduced secondary air or water-borne wastes and increased public acceptance.

Michael Blaylock SoilRx@aol.com
Jianwei Huang JHPhyto@aol.com
Burt D. Ensley www.phytotech.com
Phytotech, Inc.
1 Deer Park Drive, Suite I
Monmouth Junction, NJ 08852
Tel: 732-438-0900
Fax: 732-438-1209

Biodegradation of TNT in Aerobic Soil Columns. Ari M. Ferro. Jean Kennedy and James Herrick. Phytokinetics. Inc.. North Logan. Utah. phytoremediation project was carried out using TNT contaminated soil from the Volunteer Army Ammunition Plant in Chattanooga. Tennessee from amunitions site.Our objective was to screen several species of grass plants to assess their relative potential to remediate the soil. The only nitroaromatic soil contaminant was TNT (initial concentration 275 mg/Kg). Plants were grown in the greenhouse in well-drained soil columns. and the rates of removal of TNT were compared for the various species. Unplanted soil columns were included in the study as experimental controls. and soil moisture and mineral nutrient status was similar for all columns. Triplicate sets of columns were harvested at 69. 105 and161 days after the planting. Nitroaromatic compounds were extracted from soil and analyzed using HPLC. The rate and extent of TNT removal was generally the same across all treatments, and there was no statistically significant difference between the various grass species or the unplanted soil control. By the 105 day harvest, the TNT concentration had decreased to 50 mg/kg soil. and the concentration remained at that level for soil recovered at the 161 day harvest. For all treatments. three degradative intermediates were observed in soil extracts from the 69 and 105 day harvests. The intermediates included relatively low concentrations of aminodinitrotoluene (6 to 8mg/Kg) as well as two unknown compounds which appeared as large peaks on our chromatograms. By the 161 day harvest. the unknown compounds had disappeared. although the concentration of aminodinitrotoluene had decreased only slightly. Preliminary chromatographic analysis suggested that neither unknown compound was diaminonitrotoluene. mono-or dinitrotoluene. 2- or 4-nitrotoluene. nor acid azoxytoluene. The identity of the unknown compounds is being investigated

Ari M.Ferro. Jean Kennedy. James Herrick
Phytokinetics. Inc
1770 North Research Park Way. Suite 114
North Logan. UT 84341
Tel: 435-755-0891
Fax: 435-750-6296

Assessing the ability of transgenic *Nicotiana tabacum* (tobacco) plants to remediate soils contaminated with mercury. Andrew C.P. Heaton. Institute of Ecology. Clayton L. Rugh. Richard B. Meagher. Department of Genetics. Bruce L. Haines. Department of Botany; University of Georgia. Our study investigates the soil phytoremediation potential of *Nicotiana tabacum* plants that have been transgenically engineered with a modified bacterial mercuric ion reductase gene. ***merA9***. These plants survive on Hg(II)-contaminated substrates which are toxic to non-engineered counterparts. Furthermore. ***merA9***-transformed plants remove Hg(II) from growth substrate. reduce Hg(II) to less toxic Hg(0). and volatilize this Hg(0) from the system. We are currently measuring Hg(0) volatilization and Hg(II) resistance levels for plants grown in a variety of Hg(II)-contaminated soils. We are also modifying ***merA9*** plants to accumulate root-absorbed mercury in aboveground tissues as an alternative to Hg(0) phytovolatilization. Preliminary studies have shown that tobacco plants which express the ***merA9*** gene in roots but not in aerial tissues can mobilize root-absorbed mercury to Hg(0). a substantial portion of which is transported to aboveground tissues. reoxidized to Hg(II). and sequestered.

Andrew C.P. Heaton
Institute of Ecology
University of Georgia
Athens. GA 30602
tel: 706-542-141
fax: 706-542-1387

Clayton L. Rugh
Department of Genetics
University of Georgia
Athens. GA 30602
tel: 706-542-1410
fax: 706-542-1410

Richard B. Meagher
Department of Genetics
University of Georgia
Athens. GA 30602
tel: 706-542-1444
fax: 706-542-1387

Bruce L. Haines
Department of Botany
University of Georgia
Athens. GA 30602
tel: 706-542-1837

An Overview of the U.S. Department of Energy's Soil Remediation R&D Activities under the Environmental Management Program. Stephen C.T. Lien, U.S. Department of Energy. The U.S. Department of Energy (DOE) faces difficult environmental cleanup challenges, many of which involve large volumes of soil and groundwater contaminated by hazardous organic substances, metals, and radionuclides. Approximately 5,700 instances of soil and ground water contamination affect more than 200 million cubic meters of soil and 600 billion gallons of groundœwater across the DOE complex. Subsurface contamination at DOE sites is the result of decades of operations. Sources of contaminants include the release of liquids from seepage basins, cribs, leaking tanks, landfills, waste-disposal areas and injection wells. In this respect, many DOE sites are similar to those within the industrial/chemical manufacturing complex because their environmental contaminants shared many common attributes. The most notable exception is the presence of approximately 3 million cubic meters of mixed or radioactive waste stored or disposed of at some DOE sites. The Office of Science and Technology (OST) manages the DOEs national environmental technology development program for the Office of Environmental Management (EM). In 1995, OST established a Subsurface Contaminants Focus Area (SCFA) to develop, demonstrate, and facilitate implementation of innovative systems for containment, long-term isolation and in situ treatment/remediation of the subsurface contaminants to minimize risks and meet compliance requirements. The technology
portfolio of the SCFA includes six areas: (1) assessment, characterization, and monitoring, (2) containment, (3) stabilization, (4) removal, (5) treatment and (6) disposal. The OST, through its SCFA program, supports field tests and demonstrations of phytoremediation as a potential component of its technology portfolio.In addition, OST also supports a significant basic research effort on phytoremediation through the Environmental Management Science Program
(EMSP). A brief summary of these activities will be presented.

Stephen C.T. Lien, Ph.D.
U.S. Department of Energy, OST/EM-50
1000 Independence Avenue, S.W.Ā
Washington, D.C. 20585
Tel:301-903-7913
Fax:-301-903-7238

An Overview of Phytoremediation of Both Halogenated and Non-halogenated Organic Compounds. Lee A. Newman, Sharon L. Doty, Staurt E. Strand, Paul E. Heilman, Milton P. Gordon, University of Washington.
As overwhelmingly positive results have become available regarding the ability of plants to degrade compounds such as trichloroethylene, phytoremediation studies are expanding. Studies to determine the potential for phytoremediation of fully chlorinated compounds, such as carbon tetrachloride and tetrachloroethylene, and brominated compounds, such as ethylene dibromide and dibromochloropropane, are underway. Methyl-t-butylether, once thought to be an important additive to gasoline to reduce air pollution problems, is now becoming a major water pollutant as it leaks from underground storage tanks and migrates both faster and further than the traditional BTEX pollutants in groundwater. When using phytoremediation, it is important to select not only a plant that is capable of degrading the pollutant in question, but also one that will grow well in that specific environment. In ecologically sensitive areas, such as the Hawaiian Islands, only plants native to the area can be used. One way to supplement the arsenal of plants available for remedial actions is to utilize genetic engineering tools to insert into plants those genes that will enable the plant to metabolize a particular pollutant. Hybrid technologies, such as using plants in pumping and irrigation systems, also enable plants to be used as a remedial method when the source of the pollutant is beyond the reach of plant roots, or when planting space directly over the pollutant. Thus, the potential uses of phytoremediation are expanding as the technology continues to offer new, low cost remediation options.

Using Trees for Closure Caps and Plume Control: Regulatory, Engineering, And Site Design Considerations Trees are often an integral part of natural ecosystems as shelter and food source for animals. Humans have used trees products for shelter and food as well, and for millennia have planted trees for shade, windbreaks, erosion control, and aesthetics. Once a tool of agriculture, wood products industries, and the landscape architecture profession, tree systems are now being applied by remediation engineers and contractors to address a host of environmental clean-up issues. Various species of trees have the ability to uptake and transpire consistently large quantities of water, to aid in detoxifying contaminants is soil and groundwater, and to utilize nutrients that would otherwise be pollutants if released to the environment, and to accomplish these tasks for a relatively low cost over a long period of time. These abilities are being harnessed and applied to environmental remediation, and ecosystem restoration. In this country engineered tree systems are being used to as covers for landfills, soil treatment facilities, mine tailings; to treat landfill leachate; to treat municipal sewage; to capture and contain contaminated groundwater plumes; to protect streams from non-point source pollution; and to, restore soil systems. While trees may be thought of in engineering terms as "self-assembling", solar powered, pump and treat systems that have reliable capacity and predictable output, any phytoremediation system by definition uses living plants, and is liable to a different set of concerns than a mechanical equivalent. As in any innovative technology, these planted systems raise regulatory concerns, some of which are common to all remediation techniques and some of which are unique.

Steven A.Rock
Environmental Engineer
U.S. Environmental Protection Agency
National Risk Management Research Laboratory
26 W. Martin Luther King Dr.
Cincinnati, Ohio 45268
513-569-7149
rock.steven@epamail.epa.gov

RADIONUCLIDES SESSION

A Pathways Analysis Approach to Developing Remediation Standards for Radioactively Contaminated Soils in New Jersey. Thomas Amidon, Robert Stern (Ph.D.), and Jennifer Goodman, New Jersey Department of Environmental Protection. The Brownfield and Contaminated Site Remediation Act (BaCSRA) establishes cleanup criteria for contaminated sites in New Jersey and directed the Department to promulgate remediation standards that could be consistently applied across the State. BaCSRA specifies that remediation shall not be required beyond the regional natural background levels for any particular contaminant. The Department defined the one standard deviation in naturally occurring background radiation doses from both external and internal background doses (excluding radon) as the Total Dose Increment (above background); this was used as the fundamental criteria for soil standard setting. For Ra226, the one standard deviation of background indoor radon concentration was also used as a constraining criteria. To translate the radiation dose criteria into generic soil standards, the department has calculated individual Dose Factors, for both unrestricted and restricted uses, as a function of: 1) the vertical extent (depth) of the contaminated material; and 2) the depth of uncontamianted soil left or placed on the surface. Dose Factors are expressed as the maximum individual dose received (mrem/yr) divided by the residual radionuclide concentration in remediated soil (pCi/g). Dose Factors, as described above, were calculated for each radioactive subchain in the three principal naturally-occurring decay chains. Methodology, scenarios, and assumptions used to calculate Dose Factors are described. Enhancements of existing formulations were developed to calculate external gamma and radon pathways. BaCSRA also allows an applicant or licensee to propose alternatives to the generically derived soil concentrations based on unique site or contamination characteristics, or alternative site uses. The spreadsheet that implements the Department's methodology can accommodate many simple alternative scenarios by changing input parameters (where justified) or "turning off" irrelevant pathways.

Thomas Amidon
New Jersey Department of
Environmental Protection
401 E. State Street
Trenton, NJ 08625-0418
Tel: 609/292-0984
Fax: 609/292-0687
tamidon@dep.state.nj.us

Robert Stern, Ph.D.
New Jersey Department of
Environmental Protection
401 E. State Street
Trenton, NJ 08625-0418
Tel: 609/292-9905
Fax: 609/633-619
bstern@dep.state.nj.us

Jennifer Goodman
New Jersey Department of
Environmental Protection
25 Arctic Parkway
Trenton, NJ 08638
Tel: 609/984-5498
Fax: 609/984-5595
jgoodman@dep.state.nj.us

Human Health Risk Assessment Approach at Sandia National Laboratories / Environmental Restoration (SNL/ER) Project Sally Hoier, SNL/NM, Tommy Tharp, Roy F. Weston, Inc., Craig Brown, Environmental Dimensions Inc.
Risk assessments are currently being performed for Resource Conservation and Recovery Act (RCRA) sites associated with the SNL/Environmental Restoration (ER) Project. Human health risk assessment consists of estimating risk from radiological and nonradiological potential contaminants of concern (COC) with the consideration of site history, physical characteristics, site properties, the applicable land-use, and the associated potential pathways to receptors. Future land-use is expected mostly to be industrial. For the industrial land-use, the pathways typically include soil ingestion, inhalation and direct gamma. Potential intake of the COC by the representative population is calculated by a tiered approach. The tiered approach includes screening steps, followed by potential intake calculations and a discussion of uncertainty. The screening steps are comprised of comparison of COC concentrations with site-specific or site-wide background screening values and then with SNL/NM proposed Subpart S action levels. Toxicological properties of the COC that failed both screening processes are then quantified in terms of potential toxicity effects (Hazard Index) and excess cancer risks. For radiological COC, the incremental total effective dose equivalent (TEDE) and incremental estimated cancer risk are determined. Nonradiological COC risk values are also compared to background risk so that an incremental risk may be calculated. A final conclusion is drawn with uncertainty evaluation and comparison with guidelines established by the EPA and DOE. An example site will be used to demonstrate this human health risk assessment approach. This project is funded by the United States Department of Energy under contract DE-AC04-94AI95000.

Sally N. Hoier, Ph.D.
Sandia National Laboratories
Albuquerque, NM, 87185-1148
Tel: 505-845-9749
Fax: 505-284-2617

Tommy Tharp
Roy F. Weston, Inc.,
6501 Americans Parkway, NE,
Suite 800
Albuquerque, NM 87110
Tel: 505-284-2550
Fax: 505-284-2617

Craig Brown,
Environmental Dimensions Inc.
4206 Louisiana Blovd., NE,
Suite B
Albuquerque, NM 87109
Tel: 505-881-9427
Fax: 505-881-0372

Characterization, Transport, and Stabilization of Cesium-137 in a Canyon at Los Alamos National Laboratory, New Mexico. N. Lu, C. F. V. Mason, G. McMath, H. D. Kitten, P. A. Longmire, CST-7, Los Alamos National Laboratory, D. Katzman, Environmental Restoration Management Golder, Los Alamos Office. At Los Alamos National Laboratory, DP Canyon was subject to radioactive contaminant releases between 1945 and 1978 from the Plutonium Processing Facility. These resulted in the soil/sediment containing multiple radioactive contaminants. Cesium-137 is a major contaminant and is mainly associated with silt and clay fractions. In this study, we performed laboratory and site-pilot experiments to investigate 1) geomorphic characterization for assessing contaminant transport, 2) desorption of ^{137}Cs from soil using natural snow melt water, synthetic groundwater, and synthetic acid rainwater, 3) the effect of colloidal particles in snow melt water on the ^{137}Cs transport, and 4) possible remedial options for controlling ^{137}Cs transport. Geomorphic characterization identified that a plume of radionuclides including ^{137}Cs, ^{241}Am, ^{238}Pu, ^{239}Pu and ^{90}Sr are stored in the sediments of DP Canyon. After 360 days, about 10% to 20% of ^{137}Cs was desorbed from soil using snow melt water and synthetic groundwater, and 30% of ^{137}Cs was removed using synthetic acid rainwater. Sediment transport resulted from water runoff is the primary mechanism of ^{137}Cs mobilization in DP Canyon. The technologies that controls transport of sediments prevent the mobilization of ^{137}Cs.

N. Lu
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 514,
Los Alamos, NM 87545.
Tel: (505) 665-7833.
Fax: (505) 665-4955
E-mail: ningping@lanl.gov

C. F. V. Mason
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 534,
Los Alamos, NM 87545.
Tel: (505) 665-2422,
Fax: (505) 665-4955
E-mail: cmason@lanl.gov

D. Katzman
Environment Restoration Management Golder, Los Alamos Office,
Los Alamos National Laboratory,
Los Alamos, NM 87545
Tel: (505) 662-1318
Fax: (505) 662-1398
E-mail: katzman@fimad.lanl.gov

H. D. Kitten
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 514,
Los Alamos, NM 87545.
Tel: (505) 665-7833
Fax: (505) 665-4955
E-mail: hkitten@lanl.gov

G. McMath
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 514,
Los Alamos, NM 87545.
Tel: (505) 665-7833
Fax: (505) 665-4955
E-mail: gmcmath@lanl.gov

P.A. Longmire
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 534, Los Alamos, NM 87545.
Tel: (505) 665-1264
Fax: (505) 665-4955
E-mail: plongmire@lanl.gov

Adding Another Dimension to Contaminated Soils Cleanup. Anne Woodland, Nicole High, and Michael Haley, Shepherd Miller, Inc. If a picture is worth a thousand words, a three dimensional picture must be worth three thousand. Intergraph's Voxel Analyst, model has the capacity to raise cleanup efficiency to new levels, utilizing three dimensional (3D) modeling. However, several questions must be considered before modeling. For example, has the site been fully characterized? How much data needs to be collected? Is the concentration and mobility of the contaminant related to the lithology? Answers to these questions help determine the cost, complexity, and ultimately, the accuracy of the model. Voxel is diverse enough to handle any type of quantifiable parameter (i.e., chemical or radionuclide constituents). Since manual interpolation of 3D data is a costly, time-consuming process, 2D data interpolation has historically been used to delineate the extent and volume of contaminated soils. The Voxel model, by adding the third dimension, is able to import, statistically interpret, and calculate the total volume of soils to be removed within a fraction of the time required using traditional methods. As a result, decisions can be made concerning the style and magnitude of cleanup. Voxel provides a more accurate estimate of the volume of contaminated soils compared to traditional methods, the net effect of which minimizes unnecessary cleanup. The following case study of contaminated soils cleanup under an evaporation pond at a uranium millsite summarizes the potential of Voxel. The model input consisted of the results of borehole sampling, the lithology of the site, and the configuration of the evaporation pond. The output clearly delineated the lateral and vertical extent of the contaminated soils. Utilizing the output, cleanup supervisors were able to direct excavation activities based on the status of the soil (i.e., contaminated or clean). In this case, Voxel provided a solution that was both time and cost effective.

Anne Woodland
Shepherd Miller, Inc.
3801 Automation Way, Suite 100
Fort Collins, CO 80525
(970) 223-9600
(970) 223-7171 fax
awoodland@shepmill.com

Nicole High
Shepherd Miller, Inc.
3801 Automation Way, Suite 100
Fort Collins, CO 80525
(970) 223-9600
(970) 223-7171 fax
nhigh@shepmill.com

Michael Haley
Shepherd Miller, Inc.
3801 Automation Way, Suite 100
Fort Collins, CO 80525
(970) 223-9600
(970) 223-7171 fax
mhaley@shepmill.com

Innovative Radiation Contamination Controls In Rapid Site Assessments. William Schaal, Kevin J. O'Leary, and Douglas Brown, International Technology Corporation. Recent environmental work conducted in Northern California demonstrates that proper operational planning teamed with radiation contamination controls can provide cost-effective and expedient means for rapid remedial investigations at radiation-contaminated sites. This is evidenced by successful completion of remedial investigations involving soil, groundwater and vegetation in areas known or suspected to have Cesium 137 (Cs-137), Strontium 90 (Sr-90), Radium 226 (Ra-226), and/or Tritium (H-3) contamination.

Rapid remedial investigation techniques include widely used direct push technologies of Cone Penetrometer Testing (CPT), Piezocone Testing (CPTu), Hydropunch™, small diameter temporary wells, and soil coring. Radiation contamination controls involve personal protective equipment (PPE), air and personnel monitoring, radiation contamination level analysis, and engineered safety practices. These controls are designed to minimize personnel exposure and the spread of radiation contamination according to Title 10, Code of Federal Regulations, Section 835 (10 CFR 835) As Low As Reasonably Achievable (ALARA) concepts. Radiation contamination controls can often be cumbersome and time-consuming to implement.

This paper discusses the simplified and innovative radiation contamination controls used to maintain the cost-effectiveness and expedience commonly associated with rapid investigations involving "direct push technologies". Simplified and innovative controls include light-weight PPE; contamination zones established within "direct push" rig interiors; judicious air monitoring; convenient field lab transport and set-up; and contained, sealed steam cleaning systems.

William Schaal, R.G.
International Technology Corporation
4585 Pacheco Boulevard,
Martinez, California, 94553
Phone: 925 372 5224
Fax: 925 372 5220

Kevin J. O'Leary
International Technology Corporation
4585 Pacheco Boulevard,
Martinez, California, 94553
Phone: 925 372 4493
Fax: 925 372 5220

Douglas Brown
International Technology Corporation
Old Davis Road,
One Shields Avenue
Davis, California, 95616
Phone: 530 752 6691
Fax: 530 752 8991

A Complete Remediation Process for a Uranium-Contaminated Site and Application to Other Sites. C. F. V. Mason, N. Lu, H. D. Kitten, and M. Williams. CST-7, W. R. J. R. Turney, ESH-18, Los Alamos National Laboratory. A uranium (U)-contaminated site (200 yd^3) at Los Alamos National Laboratory was chosen as a pilot site for remediation. Proof-of- principle for the process had previously been established on the laboratory scale both for the bicarbonate-leaching process, and also for selection of a suitable anionic exchange resin for recovering U from leach liquors. The pilot-scale remediation process includes three steps: soil sorting, containerized vat-bicarbonate leaching and recovering U from leach liquors using ion-exchange resins. Approximately 200 yd^3 of U-contaminated soil was excavated and sorted into two streams: > 100 pCi/g and <100 pCi/g by ThermoNuclean Services Segmented Gate System. That soil with radioactivity < 100 pCi/g was returned to the site. Containerized vat-bicarbonate leaching process was used to treat 245 ft^3 of the U-contaminated soil with radioactivity >100 pCi/g. Following the leaching, the uranyl solution was passed through a column system of anion-exchange resin for recovering U from leach liquors. Our results showed that soil sorting reduced the volume of the contaminated soil by 96.4%. Analysis showed that the containerized vat-bicarbonate leaching removed 98% of residual U from the soil. Total U remained in the post-leached soil was below the site release criteria (114 pCi/g). Residual U left in the post-leached soil showed a non-uniform spatial distribution in the vat but revealed no signs of preferential flow channels. An anion exchange resin, Ionac™ A641, removed 98.8% of U from leach liquors. Total U in the final liquors after treatment with resin was ≤ 5 pCi/L. This remediation process reduced the potential cost by 77.2%, comparing to the conventional disposal methods (dig and haul). This process is universally applicable to all-uranium contaminated sites when tailored to specific site requirements.

C. F. V. Mason
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 534,
Los Alamos, NM 87545.
Tel: (505) 665-2422,
Fax: (505) 665-4955
E-mail: cmason@lanl.gov

N. Lu
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 514,
Los Alamos, NM 87545,
Tel: (505) 667-1476,
Fax: (505) 665-4955
E-mail: ningping@lanl.gov

H. D. Kitten
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MS J 514,
Los Alamos, NM 87545.

M. Williams
CST-7 Environmental Science and Waste Technology,
Chemical Science & Technology Division,
Los Alamos National Laboratory, MJ 514,
Los Alamos, NM 87545.

W. R. J. R. Turney
ESH-18
Los Alamos National Laboratory, MS K497,
Los Alamos, NM 87545.

RAIL ROADS SESSION

Landfill Cap Remediation Project at a Former Rail Yard. Mark Cambra, P.E. and lames Pietrzak. CHMM. P.E., NES. Inc. The remedial activities at this former 90 acre rail yard site have been completed. Coal ash, grease, and oil from locomotive and rail car repairs were previously disposed of into an area called the "tar pit" When the rail yard was closed and the property sold, the "tar pit" disposal area remained. After a thorough investigation, the best remedy for the situation was to consolidate the washes, contaminated soil, and sediment into a contained on site disposal area. The remedial work strategy: the health and safety program, the contingency plan; the required permits; the design drawings and specifications; and the 30 year operation and maintenance scheme for the project were prepared and approved by the NYSDEC. The project involved the installation of 2,200 feet of three foot wide slurry wall: the capping of 7.7 acres with a dual liner system the excavation of 22,000 cubic yards of contaminated material and 12,000 cubic yards of contaminated sediments; and, the installation of 257,000 square feet of reno mattresses and a gabion basket wingwall . As part of the dual liner system, NES proposed and installed a geosynthetic clay liner in lieu of the standard two foot natural clay layer. This geosynthetic clay liner installation being one of the first approved in Westen New York, reduced the height of the cap by two feet, shortened the schedule by two months, and provided the project with $500,000 savings.

Mark Cambra, P.E.
NES, Inc.
44 Shelter Rock Road
Danbury, CT 06S10
Tel: 203-796-5305
Fax: 203-792-3168 .

James M. Pietrzak, CHMM, P.E.
NES, Inc.
44 Shelter Rock Road
Danbury, CT 06810
Tel- 203-796-5241
Fax: 203-792-316S

TPH Analytical Verification Protocol for Multiple Field Sites. John M. Flaherty, Stephen C. Geiger, David M. Sowko, and Barbara H. Jones, Remediation Technologies, Inc., Roger P. Andes and Christopher P.L. Barkan, Association of American Railroads (AAR). Many railroad companies are faced with the prospect of addressing environmental impacts at sites where groundwater and soil have been impacted by releases of diesel fuel, bunker C, and/or lube oil. Different petroleum fuels (i.e., gasoline and diesel fuel) differ significantly in toxicological and environmental properties. The AAR, as part of the Total Petroleum Hydrocarbon Working Group (TPHCWG) has investigated strategies for developing risk-based soil cleanup levels at petroleum hydrocarbon sites as an alternative to regulatory numerical TPH criteria. This paper presents an evaluation of diesel-impacted soil samples from four geographically-diverse member company railroad sites. The focus of the research effort was the "direct analysis procedure" utilized by the TPHCWG for determining carbon fractions. The important elements of the TPH verification protocol included: comparison of TPH results determined by the direct analysis method to TPH results determined by conventional methods, evaluation of hydrocarbon fraction distribution at a given site and from site to site, evaluation of differences in hydrocarbon distribution between surface and subsurface soil samples, comparison of leaching results using SPLP with predicted values using TPHCWG fate and transport parameters.

John M. Flaherty
Remediation Technologies, Inc.
3040 William Pitt Way
Pittsburgh, PA 15238
Tel: 412-826-3340
Fax: 412-826-3409

Stephen C. Geiger, Ph.D.
Remediation Technologies, Inc.
9302 Lee Highway, Suite 800
Fairfax, VA 22031
Tel: 703-293-7861
Tel: 703-383-5771

David M. Sowko
Remediation Technologies, Inc.
23 Old Town Square, Suite 250
Fort Collins, CO 80524-2473
Tel: 970-493-3700
Fax: 970-493-2328

Barbara H. Jones
Remediation Technologies, Inc.
One Monroeville Center,
Suite 1015
Monroeville, PA 15146
Tel: 412-380-0140
Fax: 412-381-0141

Roger P. Andes
Association of American
Railroads
50 F Street, N.W.
Washington, DC 20001
Tel: 202-639-2210
Fax: 202-639-2295

Christopher P.L. Barkan, Ph.D.
Association of American
Railroads
50 F Street, N.W.
Washington, DC 20001
Tel: 202-639-2276
Fax: 202-639-2295

Phytoremediation of a Nitrogen Impacted Derailment Site. Don Elsenheimer, Braun Intertec Corporation and LeeAnn Thomas, Canadian Pacific Railway. In order to address nitrogen-impacted soil and groundwater resulting from a 1989 derailment, a phytoremediation system was designed and installed at the spill site. During the derailment, approximately 45,000 gallons of anhydrous ammonia was released from three ruptured tank cars; five railroad cars of granular urea were also derailed. The initial response to the release included soil excavation, groundwater extraction and off-site disposal, followed by additional pump and irrigation of the impacted groundwater on nearby agricultural fields. After several growing seasons, these relatively inexpensive and conventional remedial strategies were not approaching state-imposed cleanup goals. An enhanced remediation system was developed that incorporates phytoremediation. The derailment site and adjacent field have been planted with a special cultivar of alfalfa. Alfalfa is a deeply rooted perennial crop with large nitrogen uptake potential. The efficiency of this particular type of alfalfa is enhanced because it cannot fix atmospheric nitrogen, which increases the nitrogen uptake from the soil and groundwater. The crop is watered with impacted groundwater, which acts as liquid fertilizer. Nitrogen removal rates approach 400 pounds per acre with each harvest, and three harvests are typical over a growing season. The system is succeeding because 1) the alfalfa used for phytoremediation is relatively easy to sow, grow and cultivate; 2) the project team of personnel from industry, environmental consulting, USDA's Agricultural Research Service and local agronomists combine the expertise and knowledge of local agricultural conditions with research, site and operational; and 3) we have gained the cooperation of regulators, who have an interest in development of a new, cost-effective remedial strategy that can be used at other nitrogen-impacted sites, such as fertilizer spills and over-fertilized cropland.

Don Elsenheimer
Braun Intertec Corporation
8585 West 78th Street
P.O. Box 39108
Minneapolis, Minnesota
55439-0108
Tel: 612-833-4627
Fax: 612-946-6001

LeeAnn Thomas
Canadian Pacific Railway
105 South Fifth Street
P.O. Box 530
Minneapolis, Minnesota 55440
Tel: 612-347-8255
Fax: 612-347-8170

Using SSL and RBCA procedures to determine appropriate cleanup levels for site remedial action Many states are adopting, in some form, the procedures for determining appropriate soil and ground water cleanup levels using the Soil Screening Levels (SSL) developed by the U.S. EPA and/or the procedures for calculating Risk-Based Corrective Action (RBCA) levels developed by ASTM as a method to determine appropriate cleanup levels at contaminated sites. Both of these approaches involve algorithms that contain numerous variables which describe physical and chemical aspects of a particular site. Both the SSL and RBCA procedures require the analyst either to accept general default values for some or all of the variables, or to determine actual values for variables on a site-specific basis. This presentation will discuss the key concepts and variables that are used in both the SSL and the RBCA procedures, and will highlight the differences between the two approaches. The presentation will illustrate how careful attention to the selection of the values of key variables is needed to determine appropriate cleanup levels. The presentation will discuss the effects of key variables in the context of the cleanup of petroleum-contaminated soils near a rail yard in Illinois

Richard L. Stanford
KEMRON Environmental Services, Inc.
Vienna, Virginia

John Dziak
Indiana Harbor Belt Railroad
Hammond, Indiana

Characterization of Heavy Metal-bearing Cinder-rich soils found in Railroad Yards. Steve Starna and Jeanne Paquette. Dept. of Earth & Planetary Sciences. McGill University.

The heavy metal content and leachability of fine-grained ash (fly ash) produced by coal burning is well documented. Information on coarser cinders is less abundant, yet a basic knowledge of their mineralogy is essential to any assessment of their potential as sources of heavy metals.

Fill material rich in cinders and containing elevated concentrations of Pb, Zn, Cu, and Ni were sampled from 3 railway yards in Quebec and Ontario, at depths ranging from 0.3 to 1.05 m. The material was sieved into three size fractions (fine: <63μm, intermediate: 0.063-2mm, and coarse: >2mm). Two types of cinders were found to make up 70-80% by volume of the coarse fraction.

Type 2 cinders possess an aluminosilicate matrix typical of high temperatures of crystallization (1000-1300°C), and exhibit elevated concentrations of Cu (94-887 mg/kg) and Ni (64-263 mg/kg) and low concentrations of Pb (0-99 mg/kg), Zn (0-49 mg/kg), and S (0.01-0.15 wt.%). Type 1 cinders possess a carbonaceous matrix, and exhibit lower concentrations of Cu (51-148 mg/kg), Ni (14-79 mg/kg), and Zn (24-158 mg/kg), and higher concentrations of Pb (89-1997 mg/kg) and S (0.47-0.92 wt.%). For type 1 cinders, concentrations of volatile elements such as S, Pb, and carbon, and the lack of high-temperature minerals, indicates either a much lower temperature of formation than for type 2 cinders, or a product of incomplete coal combustion.

The cinders show little evidence of chemical alteration, and leaching tests indicate that they do not readily release metals. The leachates from all samples contained metal concentrations lower than the TCLP criteria for hazardous waste. Therefore, while the cinders may contain high bulk concentrations of certain heavy metals, they appear unlikely to release these metals to porewaters in any appreciable amounts.

Steve Starna
Dept. of Earth and Planetary Sciences
McGill University
3450 University Street
Montreal, Quebec, H3A 2A7
Tel: 514-398-6767
Fax: 514-398-4680

Jeanne Paquette
Dept. of Earth and Planetary Sciences
McGill University
3450 University Street
Montreal, Quebec, H3A 2A7
Tel: 514-398-4402
Fax: 514-398-4680

In-situ Bio-Reactors for Treatment of On-going Petroleum Spills at Locomotive Fueling and Servicing Areas. Jay B. Diebold and Richard W. Schowengerdt. Envirogen. Geoffrey Nokes. Wisconsin Central Ltd. Historical and continuing hydrocarbon spills associated with locomotive fueling and servicing are common sources of soil, groundwater and storm water contamination. Fueling, lubrication, DTL and idling stations/locations are all necessary, on-going activities which will continue to contribute petroleum constituents to the environment. Current solutions to this issue largely involve installation of track pans to capture contaminants. The capital and operational costs associated with installation of track pans and waste water treatment would be extensive given the magnitude of WCL's servicing operation (300 locomotives and 2,500 miles of track). WCL is evaluating an in-situ bio-reactor designed to continually consume fugitive hydrocarbons associated with locomotive servicing. Following successful, bench scale pilot testing to obtain performance and system sizing requirements, a surface application, in-situ bio-reactor has been installed and started at a locomotive lubrication station in Wisconsin during the Fall of 1997. The bio-reactor is in essence composed of the track bed itself including tracks, ties and ballast and does not require additional preparation. The bio-reactor ancillary components include a pressurized water service, nutrient mixing tank and injection pump, pop-up type sprinkler heads, analog to digital flow meter, and control panel and telemetry software for remote control and monitoring. The degradation process is accelerated by inoculating the affected area with cultured bacteria capable of degrading the target compounds. On-going elevated degradation rates are sustained by the automated application of appropriate levels of nutrients through the sprinkler system. Nutrient application times can be set around railroad maintenance cycles to prevent conflicts. Periodic (annual or semi-annual) re-inoculation of the affected track area with selected bacteria is anticipated. The system is scheduled to operate for a full growing season in 1998. Contaminant destruction data collected from the bi-oreactor as well as untreated control plots will be presented and evaluated with respect to efficiency and cost/benefit.

Richard W. Schowengerdt
Envirogen
2831 North Grandview Blvd.,
P.O. Box 90
Pewaukee, Wisconsin 53072-0090
Tel: 414-549-6898
Fax: 414-549-6938

Jay B. Diebold, P.E., P.G.
Envirogen
2831 North Grandview Blvd.,
P.O. Box 90
Pewaukee, Wisconsin 53072-0090
Tel: 414-549-6898
Fax: 414-549-6938

Geoffrey C. Nokes, P.G.
Wisconsin Central, Ltd.
One O'Hare Centre
6250 North River Road,
Suite 9000
Rosemont, Illinois 60018
Tel: 847-318-4648
Fax: 847-318-4613

Risk Based Cleanup of Contaminated Soils at a Chemical Manufacturing Plant. A. Basel Al-Yousfi, Peter G. Hannak, James F. Strunk, Jr., Wyn V. Davies, and Sunil I. Shah, Union Carbide Corporation. The current and future land use of this New Jersey chemical facility is intended solely for industrial purposes. The chemicals of concern at the site include polynuclear aromatic hydrocarbon, chlorinated aliphatic and some semi-volatile compounds. Direct human exposure scenarios are the key to the mitigation of risks related to soils since the groundwater migration pathway was interrupted using groundwater recovery. A focused remedial strategy was developed to ensure that the exposure pathways are alleviated and the remedial measures are protective to workers operating/maintaining the site. The risk evaluation process included a preliminary risk assessment (Tier1) based on comparison with pertinent soil cleanup criteria, a prioritization analysis to rank zones, chemicals and pathways of concern, and application of the Risk Based Corrective Action (RBCA) approach (Tier2). The risk assessment identified selected areas which would benefit from remedial actions. Prioritization Analysis classified the site into five high priority (comprising 90% of the total risk), three medium priority (contributing to remaining 10% of the risk), and adequately protected areas. The boundaries and volumes of affected areas were delineated based on soil sampling confirmation and statistical analysis. The remedy selected will achieve appropriate reduction in risk to comply with all State regulations and include (in addition to institutional controls):

- Capping where only immobile semi-volatile contaminants are present,
- Excavation and on-site thermal treatment of the soils impacted by volatile organic compounds, and
- Excavation and off-site disposal of limited volumes of soils.

A. Basel Al-Yousfi
Union Carbide Corporation
HS&ET, Remediation Technology
3200 Kanawha Turnpike
South Charleston, WV 25303
Tel: 304-747-5584

Peter G. Hannak
Union Carbide Corporation
HS&ET, Remediation
3200 Kanawha Turnpike
South Charleston, WV 25303
Tel: 304-747-5334
Fax: 304-747-3680

Sunil I. Shah
Union Carbide Corporation
HS&ET, Remediation Technology
3200 Kanawha Turnpike
South Charleston, WV 25303
Tel: 304-747-5234
Fax: 304-747-3680

Wyn Davies
Union Carbide Corporation
P.O. Box 670
Bound Brook, NJ 08805
Tel: 732-563-5635
Fax: 732-563-5405

James F. Strunk
CH2M Hill
99 Cherry Hill Road, Suite 304
Parsippany, NJ 07054
Tel: 973-316-9300
Fax: 973-334-5847

ASTM'S Risk-Based Corrective Action (RBCA) Initiatives: An Update. Ronald J. Marnicio, Ph.D., P.E. and J. Brad Peebles, Ph.D. An update on the activities of the American Society for Testing and Materials (ASTM) relating to risk-based corrective action for chemical sites will be presented. A brief history of the development of the 1995 ASTM Standard for RBCA at Petroleum Release Sites will be presented as an introduction to the past year's activities on the new Chemical Release Standard. The principal components of the Provisional Standard for Risk-Based Corrective Action (at Chemical Release Sites), designated as PS 104-98, and the attached appendices will be described. Key differences between the Chemical RBCA Standard and the Petroleum RBCA Standard will be identified and discussed. The key issues to be resolved to enable the provisional Chemical RBCA Standard to be come a permanent standard will be highlighted, and the current schedule for events relating to the Chemical Standard will be presented. Other ASTM initiatives relating to the RBCA standards, including the remediation by natural attenuation (RNA) and achievable environmental endpoints standards will be briefly discussed.

Ronald J. Marnicio, Ph.D., P.E.
Foster Wheeler Environmental Corporation
470 Atlantic Avenue, 3rd. Floor
Boston, MA 02210-2208
Tel: (617) 457-8262
FAX: (617) 457-8499

J. Brad Peebles, Ph.D.
Foster Wheeler Environmental Corporation
Royal Palm Financial Plaza, Suite 100
759 South Federal Highway
Stuart, FL 34994-2936
Tel: (561) 781-3415
FAX: (561) 781-3411

Combining Natural Attenuation and Site-Specific Remediation Goals for Site Closure. Peter R. Guest, Douglas C. Downey, Leigh A. Benson and John R. Hicks, Parsons Engineering Science, Inc., Sam A. Taffinder, Air Force Center for Environmental Excellence. Many regulatory agencies are adopting risk-based corrective action (RBCA) policies for petroleum-contaminated sites. Soil remediation based on arbitrary total petroleum hydrocarbon (TPH) concentrations is being reconsidered and often replaced by compound-specific, site-specific remediation criteria. Risk-based evaluation of groundwater contaminants has led to increased acceptance of natural attenuation processes as a viable and economic remediation option. The RBCA approach to remediation ensures that corrective actions are taken only when a potential receptor may be unacceptably exposed. This risk-based process, combined with an engineering evaluation/cost analysis (EE/CA), was applied at a fuel spill site on an Air Force base in South Carolina. The risk-based evaluation concluded that hydrocarbon source reduction was required for soils to achieve the RBCA target cleanup goals and it was demonstrated that these actions would facilitate the remediation of groundwater and reduce long-term monitoring costs. Two horizontal soil venting wells were installed and initially operated in a soil vapor extraction (SVE) mode to reduce vapor-phase hydrocarbons. An internal combustion engine (ICE) was used to perform SVE and to treat extracted vapor-phase hydrocarbons. After the initially elevated concentrations of vapor-phase hydrocarbons were removed by SVE, the vent wells were connected to an air injection bioventing system. Bioventing is providing cost-effective, long-term reduction of the remaining soil hydrocarbons, and it is further reducing the mass loading of contaminants to groundwater. The engineered SVE and bioventing technologies, combined with natural attenuation of hydrocarbons in groundwater, are providing a cost-effective approach to achieve the RBCA cleanup goals.

Peter R. Guest,
Douglas C. Downey,
Leigh A. Benson and
John R. Hicks
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290
Tel: (303) 831-8100
Fax: (303) 831-8208

Sam A. Taffinder
AFCEE
3207 North Road, Bldg 532
Brooks AFB, Texas 78235-5363
Tel: (210) 536-4364
Fax: (210) 536-4330

The Shift from CERCLA to Brownfields: A Case Study from Illinois Stephen W. Kirschner and Thomas M. Legel. Advanced GeoServices Corp. At a site in Illinois undergoing an USEPA-ordered emergency removal action. the owner negotiated the use of Illinois' Tiered Approach to Corrective Action Objectives (TACO) to determine the need for soil or groundwater remedial action(s) based on an industrial/commercial land use. The TACO soil exposure route evaluation determined direct contact was the only route of concern that needed to be addressed in the final remedy. The TACO Tier 3 groundwater fate and transport and surface water mixing modeling indicated VOCs and metals on site above state groundwater quality standards were being naturally reduced to below human health criteria before reaching the point of exposure. During remedial planning, the City approached the owner with a conceptual plan to redevelop this downtown, riverfront site as a recreational area as a boat access area to the river and a trailhead for a regional trail system. A partnering agreement between the owner, City, and State was formed after determining minimal additional remedial work would be necessary to allow the City to implement its redevelopment plans by combining the traditionally separate risk assessment anc risk management processes under the Illinois Site Remediation Program (SRP). The owner and State subsequently negotiated the transfer of technical oversight from the USEPA to the Illinois SRP. The City and State are currently exploring funding and tax-breaks to offset additional site development costs which maybe incurred by the City and owner. while final remedial/restoration plans are completed. Long-term care, and possibly ownership of, the site may be transferred to the City following issuance of a No Further Remediation letter to the owner from the State. This partnering agreement has resulted in a win-win situation for the City and owner.

Stephen W. Kirschner
Advanced GeoServices Corp.
Routes 202 & 1, Brandywine One Suite 202
Chadds Ford, PA, 19317-9676
Tel: 610-558-3300
Fax: 610-558-3300
email: skirschner@agcinfo.com

Thomas M. Level
Advanced GeoServices Corp.
Routes 202 & 1, Brandywine One Suite 202
Chadds Ford, PA, 19317-9676
Tel: 610-558-3300
Fax: 610-558-3300
email: tlegel@agcinfo.com

RBCA Delaware: Risk-Based Corrective Action In A Coastal Plain Setting. Emil Onuschak, Jr.. Delaware Department of Natural Resources and Environmental Control. Underground Storage Tank Branch. ASTMís Standard Guide for Risk-Based Corrective ActionóRBCAó Applied at Petroleum Release Sites (E 1739-95) was developed and promulgated with sustained input from a wide range of knowledgeable stakeholders. But substantial differences between specifying an object and specifying a complex procedure such as RBCA, complicate implementation of the RBCA procedure far beyond what may be indicated by a simple reading of the Standard. Numerous state-specific policy decisions must be identified, quantified and resolved before RBCAís assessment and evaluation procedure can be applied. Delaware determined to make its RBCA program a downwardly compatible enhancement of its 10-year old existing effort to provide programmatic continuity, promote comparability of data where possible, and to maximize public acceptance by the regulated community.

Emil Onuschak, Jr.
DNREC/UST Branch
391 Lukens Drive
New Castle, DE 19720-2774
Tel: 302-395-2500
FAX: 302-395-2601
e-mail: eonuschak@dnrec.state.de.us

14th ANNUAL CONFERENCE ON CONTAMINATED SOILS (OCTOBER, 1998) Application of Data Quality Objectives and Risk-Based Cleanup at a Gasoline Pipeline Release Site. Kiran Srinivasan and Dana Shepherd . Woodward-Clyde International-Americas. A risk-based approach was adopted to address a catastrophic release from a buried unleaded gasoline pipeline. The release site included 80 acres of pipeline right-of-way, swamp, and a river system. Multiple regulatory agencies were partnered in every step of the decision process, ensuring speedy approval of the approach. A Data Quality Objectives approach was adopted to address the sampling. Instead of delineating the extent of contamination by gridding the site and collecting samples at regular intervals, sampling was structured solely around potential exposure. This was done due to the complexity of the site and in order to optimize sampling and analysis costs and effort. Receptors and exposure pathways (including crayfish ingestion) were identified and a Site Conceptual Exposure Model was developed. Soil/sediment/groundwater and surface water samples were collected only in areas which were considered to have a potential for exposure. Thus sampling and analysis costs were significantly reduced. More importantly, the data obtained from the sampling were immediately suitable for RBCA use. The sampling results showed that the majority of the released product had naturally attenuated. The released gasoline was fingerprinted and a profile of constituents was obtained. From the product composition and sampling results, BTEX, naphthalene and TPH-Gasoline Range Organics (TPH-GRO) were identified for the risk assessment. Aliphatic and aromatic surrogate toxicity values were identified for assessing TPH-GRO. Risk-based Corrective Action Levels (CALs) were calculated for potential remediation purposes. Results indicated that potential risks at the site were within acceptable levels. Of the 80 acres involved, only a very localized area of approximately 150 feet by 100 feet showed contamination above site CALs. A Corrective Action Plan is being developed for the site recommending continued monitoring.

Kiran K. Srinivasan
Woodward-Clyde International Americas
One Northwind Plaza, Suite 600
7600 W. Tidwell
Houston, Texas 77040
Tel : (713) 744-9066
Fax : (504) 744-9099
e-Mail : KKSRINI0@WCC.COM
(KKSRINI'ZERO')

Dana C. Shepherd
Woodward-Clyde International Americas
2822 O'Neal Lane
Baton Rouge, Louisiana 70816
Tel : (504) 756-4234
Fax : (504) 753-3616
e-Mail : DCSHEPH0@ WCC.COM
(DCSHEPH'ZERO')

REMEDIATION I SESSION

ROD Amendment for On-Site Treatment of Hazardous Waste Pit Materials. William A. Plaehn, Peter R. Guest, Timothy C. Shangraw, and Kent A. Friesen, Parsons Engineering Science, Inc., Lori T. Tagawa, Waste Management, Dennis D. Bollmann, City and County of Denver. The Former Tire Pile Area (FTPA) waste pits are located at the Lowry Landfill Superfund Site in Arapahoe County, Colorado. From the mid-1960s until 1980, the Site was operated as an industrial liquid waste and municipal solid waste landfill. Waste disposed at the site contained hazardous substances such as volatile organic compounds (VOCs) and heavy metals. The initial Record of Decision (ROD) specified removal of surface and subsurface drums, associated free liquids, and other visible contamination, followed by off-site disposal of the removed materials. In October 1997, an Explanation of Significant Differences (ESD) to the ROD was approved by EPA that specified on-site treatment and disposal of waste pit materials excavated from the FTPA. Treatability testing determined that vapor extraction can be used for treating the waste pit solids/sludges and rendering the waste pit materials non-hazardous. Parsons ES designed an aboveground treatment cell that will be constructed for the waste pit materials for ex situ vapor extraction. The air removed from the treatment cell will be treated in an off-gas treatment system to below allowable emission standards. The total volume of bulked material to be placed in the treatment cell is estimated to be 28,000 cubic yards. A constructability test was performed on approximately 2,000 cubic yards of soil to verify design parameters and treatment cell configuration to be used during full-scale operations.

William A. Plaehn
Peter R. Guest
Timothy C. Shangraw
Kent A. Friesen Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290
Tel: (303) 831-8100
Fax: (303) 831-8208

Lori T. Tagawa
Waste Management, Inc.
3900 S. Wadsworth Blvd., Suite 800
Lakewood, Colorado 80235
Tel: (303) 914-1454
Fax: (303) 914-9927

Dennis D. Bollmann
City and County of Denver
Department of Environmental Health
1391 Speer Blvd., Suite 700
Denver, CO 80204-2558
Tel: (303) 285-4036
Fax: (303) 285-5619

Field Demonstration, and Comparison of Natural Attenuation and Insitu Technologies at a Former Tank Farm. J.R. Rao and Julio O. Torres, Bristol-Myers Squibb Company, John M. Bierschenk ENSR.
Comprehensive predesign pilot studies were conducted within a former tank farm area at a pharmaceutical production facility operated by Bristol-Myers Squibb Company on the island of Puerto Rico. The former tank farm consisted of twenty-six (26) underground storage tanks containing kerosene, methyl isobutyl ketone (MIBK), methlylene chloride, methanol, isopropyl alcohol and xylene. The purpose of the predesign pilot program was to evaluate, select and design the most appropriate insitu technology for remediation of compounds of concern (COC) in soil associated with a former tank farm area. Since both lighter and heavier than water compounds were present at this site, an array of technologies were tested individually to determine their effectiveness and whether a combination of technologies would be necessary to reach risk based standards. Three insitu technologies were chosen for field pilot testing: product skimming for LNAPL recovery; bioslurping for insitu bioremediation and NAPL recovery; and multiphase extraction for saturated zone COC. In addition, geochemical and respirometry measurements were collected for the purpose of evaluating the effectiveness of natural attenuation processes to remediate COC in soil and groundwater.

This case study will present details on the application of each remediation technology at this site, testing objectives, results and final recommendations. The methodology used to demonstrate natural attenuation will be presented. This includes how the results of fate and transport modeling were coupled with geochemical and biological measurements to complete a demonstration of natural attenuation processes, and how these were shown to be occurring in the vicinity of the tank farm area.

The case study documents the successful application of a technology demonstration from start to finish, at a site with varying concentrations of COC. The project concluded with a no further action (NFA) outcome based on the approach presented in the paper.

John M. Bierschenk
ENSR
35 Nagog Park
Acton, MA 01720
Tel: 978-635-9500
Fax: 987-635-9180

J. R. Rao
Bristol-Myers Squibb Company
P.O. Box 4755
Syracuse, NY 13221-4755
Tel: 315-432-9653
Fax: 315-432-2988

Julio Ortiz Torres, P.E.
Squibb Mnfg. Inc.
P.O. Box 609
Humacao PR 00792-0609
Tel: 787-852-1255
Fax: 787-850-6924

Enhancing Hydrocarbon Recovery in a Low Permeability Montmorillonitic Clay Through Pneumatic Fracturing A Case Study. Joseph M. Fuhr. Enviro-Logical Solutions. Inc. Pneumatic fracturing, a technique developed during the early 1990's, utilizes low pressure injections of large volumes of air over discreet intervals to enhance existing fractures and to create new ones, thereby increasing the effective permeability of a formation. This technique was recently applied to a site in the panhandle of Florida. The site is an active gasoline service station with contamination present in the stratigraphic column from the surface to approximately forty feet. A low permeability montmorillonitic clay exists from approximately fifteen to twenty-seven feet. The existing remediation system employs dual-phase extraction and has effectively remediated all but the fifteen to twenty-seven foot zone. To enhance the permeability of this zone, pneumatic fracturing was applied to five specially installed wells strategically placed around the site to maximize the efficiency of the existing system. Injections were made in each of the five wells from approximately seven and one-half feet to thirty-two feet below grade at two and one-half foot intervals. Injection pressures ranged between 125 psi and 175 psi, depending on depth. Pre and post-fracture dual-phase extraction tests were performed to determine the effectiveness of the pneumatic fracturing. Results from the tests indicated a dramatic increase in the radius of influence, hydrocarbon concentrations in soil vapor, and air flow within the zone. The results suggest that pneumatic fracturing effectively increased the permeability of the formation and reduced heterogeneities with depth adjacent to the borehole, which should expedite the cleanup and closure of the site.

Joseph M. Fuhr
Enviro-Logical Solutions, Inc.
Palms of Carrollwood
13135 North Dale Mabry Highway
Tampa, FL 33618
Phone: 813.963.0811
FAX: 813.962.2804
elsjoe@combase.com

John J. Liskowitz
ARS Technologies, Inc.
271 Cleveland Avenue
Highland Park, NJ 08904
Phone: 732.296.6620
FAX: 732.296.6625
jjl@arstechnologies.com

Edward Schaper
Epec Oil Company
1001 Louisiana Street
Houston, TX 77002
Phone: 713.420.2753
FAX: 713.420.6825
schapere@EPEnergy.com

The Fast-Track Assessment and Remediation of a Chlorinated Solvent Plume Using Recirculating Well Technology. Mark J. Salvetti and Willard A. Murray, Harding Lawson Associates, Barbara R. Nwokike, Southern Division, Naval Facilities Engineering Command.
Quick and cost effective site investigations and remediation are possible through partnering, combined with the use of innovative field techniques and remedial technologies. These tools were used to expedite the assessment of a chlorinated solvent release, allay community concerns, meet regulatory requirements, and address the contamination of a nearby lake with an innovative technology - recirculation wells with in-well air stripping. Initial investigations at the site identified groundwater contamination with chlorinated solvents. When VOCs were detected in a downgradient lake, risk characterizations were quickly performed and presented to the public, and a focused field program was designed to refine the site conceptual model and provide data required to evaluate remedial options. Direct push sampling techniques and a field lab were used to provide rapid and economical site characterization. Remedial challenges included the need to minimize disturbance of the local ecology and very little vadose zone. Evaluation of remedial technologies led to the selection of a reverse-flow recirculating well system to intercept the plume. Two recirculating wells were installed and began operation in December 1997. Recirculation well treatment efficiency and capture zone analysis will be presented to demonstrate the effectiveness of the technology to prevent contaminant migration into the lake.

Mark J. Salvetti, P.E.
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: 781-245-6606
Fax: 781-246-5060
msalvett@harding.com

Willard A. Murray, Ph.D., P.E.
Harding Lawson Associates
107 Audubon Road
Wakefield, MA 01880
Tel: 781-245-6606
Fax: 781-246-5060
wmurray@harding.com

Barbara R. Nwokike
Southern Division, Naval Facilities
Engineering Command
2155 Eagle Drive
North Charleston, SC 29406
Tel: 803-820-5566
Fax: 803-820-5563
brnwokike@efdsouth.navfac.navy.mil

The Alhambra Manufactured Gas Plant Site Remediation Thomas D. McMahon, Southern California Gas Company

The Alhambra Manufactured Gas Plant (MGP) was constructed on a 2.4 acre parcel In 1906 by California Coke and Gas Company. Thereafter, the operation of the oil gas plant and the distribution system were transferred to Valley Gas and Fuel Company, a corporation wholly owned by California Coke and Gas Company, both of which are now defunct. Manufactured gas operations continued lentil 1913 when the plant and its distribution system were sold to Los Angeles Gas and Electric Corporation (LAG&E), a company that later merged into Southern California Gas Company (The Gas Company). LAG&E dismantled the plant sometime during its ownership, although the exact date is unknown. The Gas Company appears in the chain of title m 1939 for a period of six months, after which the property was sold to an individual who subdivided the lots for residential development beginning in 1940. Today the former site comprises twenty residential lots, consisting of eighteen single family homes and two duplexes. The Site is bordered by paved streets to the west, north and east and two residential lots to the south. The homes along Edith Avenue were constructed In 1940 and 1941 while the homes along Curtis Lane were built in 1947 and 1948.

The Alhambra Site Investigation and remediation were carried out under the oversight of the California Environmental Protection Agency, Department of Toxic Substances Control (DTSC). The Gas Company performed the activities under an Expedited Remedial Action Enforceable Agreement, signed in April 1996. The Alhambra Site is one of 42 sites in southern and central California In which The Gas Company has some involvement. However, the Alhambra Site is the only one which is entirely residential.

A Draft Remedial Action Plan (RAP) was released for public comment m the first quarter of 1997, for a 30-day period. The RAP proposed the excavation and offsite thermal desorption treatment of PAH contaminated soils down to approximately two to three feet below ground surface from 17 of the 20 lots. The recommended remedial alternative included the removal of all landscaping, driveways, planter areas, patios, garage slabs and two feet of soil from exterior areas, and between 12 to 18 inches of soil from the crawl spaces beneath these 17 houses. The RAP also proposed the temporary relocation of the residents in each of these homes. Only minor comments were received and the RAP was approved by the DTSC.

Remediation began in July 1997 with the temporary relocation of four families and excavation activities at three lots. Thereafter, up to five or six families were relocated at each stage of the cleanup. Demolition activities consisted of removal of walls, planters, steps, walkways, garage slabs and all landscaped areas. Remediation on each lot consisted of excavation of three to five feet of soil around the structures and between two to three feet of soil from each crawl space. Remediation activities were completed by January 1998 on 19 lots and reconstruction was finished in February 1998. Closure reports were submitted on each lot and certification was received from the DTSC in February 1998. The Alhambra Site was the first project completed under the Expedited Remedial Action Program in California. A major element of this program is the opportunity for orphan share cost recovery. The Gas Company applied for cost recovery through this mechanism since it received a 39% allocation of liability at this Site from the DTSC. A total of $2.8 million was received from the State of California as reimbursement of all costs incurred due to the 61% orphan share allocation for the Alhambra Site.

This presentation will also discuss a detailed cost breakdown of the work, beginning with the planning stages and initial public participation activities through the investigation, remediation, relocation of residents, and final reconstruction of all lots.

Thomas D. McMahon, R.G., Project Manager
Southern California Gas Company
555 West Fifth Street, ML26G I
Tel: 213-244-5826
Fax: 213-244-8458

Operation and Results of Air Sparging & Soil Vapor Extraction at a Large, Multi-Source, Mixed Contaminant Site. Alan Moore, John Bierschenk, & Chris Venezia. ENSR Consulting and Engineering. The soil and groundwater at two adjacent chemical manufacturing properties had become contaminated with BTEX, THF and ketones. Based on the volatility of these volatile organic compounds (VOC) and the permeable nature of the soil, air sparing (AS) and soil vapor extraction (SVE) was seen as the most cost-effective method of in-situ remediation. In addition, the injection of sparge air would stimulate aerobic biodegradation of the VOC, further increasing the rate of remediation. The presentation will discuss the following aspects of the various remediation systems installed on the site:

- Successful AS/SVE remediation to drinking water limits (by a previous contractor) of one plume that initially contained free product and the results of rebound tests;

- Establishment of an AS/SVE array along the toe of a landfill perpendicular to groundwater flow. This barrier attenuates any VOCs that would otherwise migrate down gradient. Most groundwater contaminants down gradient are being maintained below detection limits. Increased dissolved oxygen down gradient suggested both good aeration and the likelihood that biodegradation occurring.

- A pilot study was performed in part of a 1.5 acre chemical landfill to evaluate the effectiveness of AS/SVE to remediate the source of ongoing contamination. Monitoring showed that the pilot system removed about 2000 pounds of VOC (mostly toluene) from 5 SVE wells in 1 year. Groundwater sampling showed concurrent concentration decreases. Based on this success, the system will be expanded to treat the entire chemical landfill.

- Another full scale (100 sparge points, 40 SVE wells) remediation system was installed on an adjacent manufacturing site and recently began operation.

Alan Moore
ENSR Consulting and Engineering
35 Nagog Park
Acton, MA 01720
Tel: 978-635-9500
Fax: 978-635-9180
Email: amoore@ensr.com

John Bierschenk
ENSR Consulting and Engineering
35 Nagog Park
Acton, MA 01720
Tel: 978-635-9500
Fax: 978-635-9180
Email: jbierschenk@ensr.com

Chris Venezia
ENSR Consulting and Engineering
281 Centennial Ave.
Piscataway, NY 08854
Tel: 732-457-0500
Fax: 732-457-0550

REMEDIATION II SESSION

Remedial Technology Screening Tools to Aid the Feasibility Study Process. Samuel J. Goldberg, Stone and Webster; and Christopher Swan, Tufts University. This paper compares the results of three screening tools which may be used to aid in the selection of a remedial technology for the cleanup of hazardous waste sites. The tools are: ReOpt™, an electronic database developed by Battelle Memorial Institute; VISITT, an electronic database developed by the U.S. Environmental Protection Agency (USEPA); and the Remediation Technologies Screening Matrix and Reference Guide (Screening Matrix), developed by the USEPA and the U.S. Air Force (USAF). The methodology of technology selection, parameters used as input, and the resulting output from each screening tool is described. Remedial technologies suggested by each screening tool are compared to those developed from a feasibility study performed for a Massachusetts Military Reservation site with respect to 1) what criteria are used to evaluate the technologies, 2) which remedial alternatives are worth further analysis, and 3) which remedial technology is (would be) chosen for the cleanup of the site. It is concluded that the screening tools can not replace the feasibility study process but can help in determining what are appropriate remedial technologies and what are the similarities and differences in their implementations.

Samuel J. Goldberg
Stone and Webster
245 Summer Street
Boston, MA 02210
Phone: (617) 589-5111
Fax: (617) 290-7507

Christopher Swan
Tufts University
113 Anderson Hall
Medford Ma. 02155
Tel: 617-628-5000 x2212
Fax: 617-627-3994

Innovative Remediation of Jet Fuel Contamination Using In-Situ LandFarming. Ronald Britto, Brian Caldwell, William Hill, Byas Glover, and Mike Keethler. UST 18 at Naval Air Station Pensacola Florida was a fire training area for 45 years until operations ceased in 1997. During this time, jet fuels were released and set on fire in bermed, unlined, circular fire "pits". Assessment of the site under the Installation Restoration Program from 1990-1997 indicated residual vadose zone (averaging three feet in depth) contamination of soil in the immediate vicinity of the pits, and resulting shallow water table contamination emanating from each pit. Remedial analysis indicated a soil volume of 6,000 cubic yards and a groundwater volume of 5.6 million gallons were required to be addressed under the Florida Department of Environmental Protection (FDEP) Petroleum Statutes. Complete evaluation of natural attenuation required specialized sampling of a number of parameters in groundwater to provide evidence that biological contaminant reduction was occurring. The resulting soil and groundwater data was then used to simulate contaminant loading, plume configuration, and transport using the BIOSCREEN model, with input parameters varied to calibrate the simulated contamination to observed field conditions. The complete remedial alternative analysis showed in-situ land farming of soil (considered innovative by the FDEP) and natural attenuation with monitoring for groundwater to be the preferred alternatives. These best balanced the criteria of cost, time required to reach remedial goals, and effectiveness. The Remedial Action Plan recommending in-situ landfarming and natural attenuation as the site remedy has been approved by FDEP.

Ronald Britto
ENSAFE Inc.
5724 Summer Trees Drive
Memphis, TN 38134
Tel: (901)372-7962
Fax: (901)372-2454

Brian Caldwell
ENSAFE Inc.
9040 Executive Park Drive,
Suite 370
Knoxville, TN 37923
Tel: (423)693-7324
Fax: (423)693-5061

William Hill
SOUTHNAVFACENGCOM
2155 Eagle Drive
PO Box 10068
Charleston, South Carolina 29411
Tel: (803)820-7324
Fax: (803)820-7465

Byas Glover
SOUTHNAVFACENGCOM
2155 Eagle Drive
PO Box 10068
Charleston, South Carolina 29411
Tel: (803)820-5651
Fax: (803)820-7465

Mike Keethler
Enviro-Pro-tech
3814 West Jackson Street
Pensacola, FL 32505
(850)432-5766

HIGH VACUUM DUAL PHASE EXTRACTION WELLS REMEDIATING JET-FUEL CONTAMINATED SOIL AND GROUNDWATER AT JFK INTERNATIONAL AIRPORT
Soil and groundwater at Terminal 4 (the International Arrivals Building) at JFK International Airport in Jamaica, New York, were remediated to NYSDEC site specific cleanup criteria in 7 months using high vacuum dual phase extraction (HVDPE) extraction wells. Fifty six wells were installed over an area of 5 acres for the remediation. Based on the monthly monitoring data, 29,600 lbs of petroleum hydrocarbons were removed during the remediation with 63% removed as free product, 21% removed by biological oxidation, 13% removed as extracted vapors, and 3% removed in the dissolved phase during 7 months of operations. The free product and dissolved phases were removed during the treatment of 3,348,000 gallons of extracted groundwater by oil-water separation and liquid phase activated carbon, respectively. During the remediation, the level of free product decreased from 22 inches to non-detectable in all of the HVDPE wells and adjacent monitoring wells.

Robert J. Roth, Ph.D., P.E.
Terra Vac
92 N. Main Street
Windsor, NJ 08561

Marvin Kirshner, P.E.,
Hwang Y. Chen, P.E.,
Bruce Frumer
Port Authority of New York and New Jersey
One World Trade Center - 72 E
New York, NY 10048

Test at Fort Wainwright, Alaska: Preliminary Results of a Radio Frequency System for Enhanced Bioremediation, Michael C. Marley, Xpert Design and Diagnostics, LLC. Stephen L. Price and Raymond S. Kasevich, KAI Technologies, Inc. Preliminary data is presented from an ongoing pilot test sponsored by the U.S. Army Corps of Engineers, which uses radio frequency heating to enhance bioremediation of low temperature arctic soils. Heat is supplied to fuel-impacted soil by four remotely operated 2.4-kilowatt generators housed in a mobile trailer. Pilot-scale air sparging and soil vapor extraction systems are also employed. Four antenna applicators are deployed in a square formation within vertical boreholes separated by 6.1 m. The temperature of the target volume is automatically maintained at a set level by cycling the power of each RF generator, based upon the measured temperatures in the soil near the applicators. A target soil temperature range of approximately 15°C to 30°C is used. Enhanced bioremediation at the site is to be conducted for a period of nine months starting in May 1998. Preliminary results indicate target temperature ranges have been met and enhanced bioremediation has been measured.

Michael C. Marley
Edward X. Droste
Xpert Design and Diagnostics, LLC
199 Constitution Ave., Bldg. 1 Floor 2
Portsmouth, NH 03801
Tel: 603-433-0191
Fax: 603-431-7807

Stephen L. Price
Raymond S. Kasevich
KAI Technologies, Inc.
199 Constitution Ave, Bldg. 1 Floor 1
Portsmouth, NH 03801
Tel: 603-431-2266
Fax: 603-431-4920

Lawrence Acomb
Geosphere, Inc.
3055 Seawind Drive
Anchorage, AK 99516
Tel: 907-345-7596
Fax: 907-345-7596

Cristal Fosbrook
US Army Alaska
Fort Richardson, AK 99503
Tel: 907-384-3044

Mark Wallace
US Army Corps of Engineers
Alaska District
Anchorage, AK
Tel: 907-753-5662
Fax: 907-753-5646

Terese LeFrancois
CH2M Hill
Anchorage, AK
Tel: 907-278-2551
Fax: 907-277-9736

Use of in Situ Thermal Conduction Heating to Enhance Air-Based Soil Rermediation. Ralph S. Baker, ENSR, Harold J. Vinegar, Shell E&P Technology Co., and George L. Stegemeier, GLS Engineering. In well-suited settings, widespread application of soil vapor extraction (SVE), air sparging and other air-based in situ remediation technologies has made possible cost-effective cleanup of soil and groundwater contaminated with volatile organic compounds (VOCs). However, in marginally suited sites, the application of these technologies has not proven to be as effective. Site conditions that limit the effectiveness of air-based in situ technologies include low permeabilities, high moisture contents, stratification, heterogeneity, and preferential pathways. Under these conditions, airflow is not well distributed, and transfer of contaminants from regions not experiencing airflow is diffusion limited, resulting in a very protracted cleanup of such regions. Recent developments in the application of in situ thermal conduction heating as an enhancement to SVE indicate that a reliable method of overcoming these site limitations is now available. In situ thermal conduction heating can be applied to uniformly heat the entire soil volume targeted for remediation. The sweep efficiency of the process is robust regardless of soil conditions or degree of heterogeneity. At elevated temperatures, VOCs and even non-volatile organics can be volatilized and reduced to extremely low residual concentrations. This paper will include the results of a successful remediation using thermally assisted SVE at a chlorinated solvent site in Indiana containing tetrachloroethene in tight clay soil.

Ralph S. Baker
ENSR Corporation
35 Nagog Park
Acton, MA 01720
Tel: 978-635-9500
Fax: 978-635-9180
rbake@ensr.com

Harold J. Vinegar
Shell E&P Technology Company
Bellaire Technology Center
P.O. Box 481
Houston, TX 77001-0481
Tel: 713-245-7361
Fax: 713-245-7323
vinegar@shell.com

George L. Stegemeier
GLS Engineering, inc.
5819 Queensloch Drive
Houston, TX 77096
Tel: 713-729-2054
Fax: 713-245-7323
gstegemeier@shell.com

Use of Hydrogen Peroxide as Remedial Additive for Petroleum Contaminated Soils. Brian V. Moran, L.S.P., Andrew T. Donoghue, David G. Billo, Norfolk International Corp. The use of concentrated hydrogen peroxide has been known for many years as an treatment additive for wastewater applications. Unfortunately the application of this powerful oxidation agent has been largely overlooked for application involving treatment of contaminated soils. The addition of small amount of ferric iron compounds makes the peroxide reagent even more powerful for use as a remedial additive by the creation of hydroxyl radical (Fentons reagent). The authors have been utilizing this technique for treatment of inaccessible soils contaminated with high levels of petroleum compounds (TPH) at petroleum spill sites. The paper presents the results of five (5) case studies on projects where this technique has worked both for soil and groundwater decontamination. Program design criteria, application rates, and theoretical chemical reagent requirements are also discussed, including the pitfalls of improper application.

RISK SESSION

The Bioavailability of DDT, DDE and Chlordane, Andy Davis, Charles Tabor, Geomega; Robert Scofield, Environ. Incorporating soil metal bioavailability has become commonplace in modifying the total soil metal concentration used in risk assessments. However, to date there appears to have been no investigation on the bioavailability of organic xenobiotic compounds. This study assessed the bioavailability of chlordane, DDT, and DDE in three soil samples that contained, 1) 20,000 mg/kg, 3,900 mg/kg, and 3,500 mg/kg of technical chlordane, 2) 900 mg/kg, 150 mg/kg, and 210 mg/kg of DDT, and 3) 270 mg/kg, 120 mg/kg, and 210 mg/kg DDE, respectively.

Using an in vitro method, the average chlordane bioavailability was found to be 1.4%, 4%, and 3.8% for the three soil samples. DDT and DDE were not detected in the in vitro gastric analog solutions. However,using the detection limit of 1 µg/L as a maximum concentration, resulted in bioavailabilities of <1.1%, <6.7%, and <4.8% for DDT and <3.7%, <8.3%, and <4.8% for DDE, respectively. When compared to the default assumption of 50% for these compounds currently used in risk assessments it is apparent that using total soil pesticide concentrations in risk assessments can seriously overestimate the health risk associated with these compounds in soils, with concomitant impacts on the remedial costs.

Andy Davis
Charles Tabor
Geomega,
2995 Baseline Road,
Suite 202,
Boulder, Colorado 80303

Rob Scofield
Environ,
5820 Shellmound,
Suite 700,
Emeryville, California 94608

Decreased Dermal Bioavailability of Chemicals Aged in Soil: Arsenic, Nickel, and Phenanthrene as Models. Mohamed S. Abdel-Rahman, Gloria A. Skowronski and Rita M. Turkall. University of Medicine & Dentistry of New Jersey/New Jersey Medical School. Current governmental regulations for assessing health risk or for establishing goals for remediation of contaminated soil are based on exhaustive soil procedures. However, these procedures can overestimate the bioavailability and the risk from exposure to chemicals aged in soil. Chemical aging refers to the diffusion of chemical from the external surface of soil particles to internal and more remote sites within the soil matrix over a period of time. This process may take weeks, months, or even years. Chemical aging and its effects on dermal bioavailability will be discussed using arsenic, nickel, and phenanthrene as examples of major soil contaminants. Studies were performed on dermatomed pig skin utilizing an in vitro approach consisting of radiotracer and flow-through diffusion cell methodology to determine the amount of chemical which penetrated into receptor fluid beneath the skin and which became covalently bound to skin. The bioavailability of arsenic was decreased by 98% when arsenic was aged for 3 mo in either a sandy or a clay soil versus pure arsenic. A similar decrease in bioavailability was observed for nickel. Although the bioavailability of pure phenanthrene was 65%, aging reduced phenanthrene bioavailability to 15% after 3 mo. Decreased chemical bioavailability will result in lower health risks, less soil that requires remediation, and reduced site restrictions. (Supported in part through funding from the Hazardous Substance Management Research Center and the New Jersey Commission on Science and Technology).

Mohamed S. Abdel-Rahman
Pharmacology and Physiology Department
University of Medicine & Dentistry
of New Jersey
New Jersey Medical School, Rm. I-655
185 South Orange Avenue
Newark, New Jersey 07103-2714
(973) 972-6568
(973) 972-4554 FAX

Gloria A. Skowronski
Pharmacology and Physiology Department
University of Medicine & Dentistry
of New Jersey
New Jersey Medical School, Rm. I-664
185 South Orange Avenue
Newark, New Jersey 07103-2714
(973) 972-6691
(973) 972-4554 FAX

Rita M. Turkall
Pharmacology and Physiology Department
New Jersey Medical School, Rm. I-669
Clinical Laboratory Sciences Department
School of Health Related Professions
University of Medicine & Dentistry
of New Jersey
185 South Orange Avenue
Newark, New Jersey 07103-2714
(973) 972-5096

Ecological Risk Assessment of the Pharmacia & Upjohn Kalamazoo Manufacturing Plant on Wetlands and Wildlife in Receiving Waters. James P. Ludwig, Applied Ecological Services, inc., and Cheryl L. Summer, Michigan Department of Environmental Quality.

Under the rules developed by the USEPA for the Hazardous and Solid Waste Act of 1990, Pharmacia and Upjohn Company was requested to assess the ecological risks to the biota of the local ecosystem. This ecological risk assessment was focused on three upper level predatory species that could be damaged if bioconcentrated metals or chlorinated organics were present at or above critical threshold concentrations. Tissue concentrations of heavy metals, chlorinated solvents, PCBs, and pesticides were measured in resident mute swans, tree swallows, and largemouth bass at the site and nearby control areas with no known sources (other than atmospheric) of these contaminants. The H411E rat hepatoma cell bioassay was used to measure enzyme induction from planar contaminants and PAHs. Endocrine disrupters were assessed using bioassays applied to extracts from semi-permeable membrane devices (SPMDs). The industrial site was found to be generally less contaminated than the control areas (a local nature center and state park). Very localized sources of PAHs, dieldrin, PCBs and lead were detected at specific places in the three study areas, with the industrial site having the fewest occurrences of toxic substances. None of the concentrations found were elevated enough to reach low adverse effect concentrations (LOAECs) Occurrences were readily correlated to known past uses of the three sites. Tree swallow reproduction was excellent at one control and the industrial site, but somewhat depressed at a nature center on the banks or a PCB-polluted river (and Superfund site). Predaceous wildlife were very effective and sensitive monitors of common toxic substances. Whole site ecological risk assessment is likely to become a commonly-requested monitoring initiative in the future.

James P. Ludwig,
Wildlife Ecotoxicologist
Applied Ecological Services, inc.
17921 Smith Rd.
Brodhead, WI 53550
Tel 608-897-8641
Fax 608-897-8486

Cheryl L. Summer
Surface Water Quality Division
Michigan Department of
Environmental Quality
Box 30074
Lansing, MI 48909
Tel. 517-373-1319
Fax 517-373-9958

Applying Risk Assessment and AULs in Place of Remedial Actions at a Petroleum Impacted Site. Richard J. Wozmak, P.E., P.H., L.S.P., GeoInsight, Inc. and Susan A. Sundstrom, Ph.D., D.A.B.T. The Massachusetts Department of Environmental Protection (MADEP) requires that contaminated sites in Massachusetts be remediated to acceptable standards as determined by one of three risk assessments methods. Restrictions on the use of the site (Activity and Use Limitations, or AULs) can be applied to limit exposure as a means of insuring that unacceptable risk does not occur in the future. For a former petroleum distribution facility in Worcester that contained soils impacted with fuel oil from historical releases, the application of a site-specific risk assessment combined with AULs was proven to be a more cost-effective alternative to meet site closure requirements in comparison to soil remediation. Based upon site characterization studies, it was estimated that approximately 2,000 cubic yards of shallow soil was contaminated with oil constituents above generic cleanup standards promulgated by the MADEP and that the most feasible remedial alternative was soil excavation and disposal at a cost of approximately $315,000. A site-specific risk assessment was performed indicating that the site did not pose a significant risk for industrial and commercial uses, however, could pose a significant risk under residential use. An AUL was applied to the site limiting its use to industrial and commercial activities only, and the site was closed without soil remediation. The cost to perform the site-specific risk assessment and implement the AUL was approximately $13,000. It was also concluded that there would be little to no impact to property value by leaving contaminated soil at the site. Therefore, a cost savings was realized by the property owner of approximately $300,000.

Richard J. Wozmak, P.E., P.H., L.S.P.
GeoInsight, Inc.
75 Gilcreast Road
Londonderry, NH 03053
Tel: 603-434-3116
Fax: 603-432-2445

Susan A. Sundstrom, Ph.D., D.A.B.T.
47 Peabody Street
Groton, Massachusetts 01450
Tel: 508-448-2767
Fax: 508-448-3281

Beyond Risk Assessment Guidance for Superfund Assessing Soil Risk Outside the Box Brian Mulhearn, EnSafe Inc. and Constantin Tudan, Princeton University.

Risk assessments should be useful, since they are supposed to facilitate risk management decisions. Human health risk is generally assessed in accordance with federal and state guidance. These cookie-cutter assessments do not always answer all of the important questions, and they do not always provide useful tools to risk managers and remediation engineers. Risk assessments that streamline typical assessment methods and incorporate innovative spatial analyses and graphical presentations, such as those produced by Geographical Information Systems (GIS), are more useful. By providing additional information such as point risk figures and summary tables, risk managers literally see where the risk is, what chemicals account for the risk, and what the risk would be if certain areas were remediated. This is referred to as electronic remediation: selected areas are assumed to be remediated and assigned a risk estimate, after which site-wide risk is recalculated until target risk goals are met and remedial areas are defined. With so many federal, regional, and state risk-based regulations, it is difficult to accurately assess some sites without drawing outside the box. Using GIS and other methods to streamline the approach as well as make the end result more useful to more people has proven to be a successful closure method for Superfund and other types of sites where risk-based closure was possible.

Brian Mulhearn
EnSafe Inc .
5724 Summer Trees Drive
Memphis , TN 38134
Phone : 901-372-7962
FAX: 901-371-2454
Email : HYPERLINK mail to:
bmulhearn@ensafe.com

Constantine Tudan
Princeton University
E -430 Engineering Quad
Princeton , NJ 08544-5263
Phone : 609-258-4609
FAX : 609-258-6744
Email: HYPERLINK mail to:
costi@princeton.edu

Site Closure Through Risk Assessment and Natural Attenuation Monitoring. Michael T. Berger, Braun Intertec Corporation. Site investigation conducted at an active industrial site revealed both soil and groundwater petroleum hydrocarbon impacts associated with a former underground storage tank location. Soil samples were collected to define the extent of soil contamination and to provide information on site-specific soil characteristics. Groundwater monitoring wells were installed to define the extent of groundwater contamination and to evaluate groundwater flow characteristics. Based on soil and contaminant characteristics, site-specific human health cleanup goals were calculated to be at least 1,000 times higher than state generic standards. Petroleum impacts were reported in site soils below risk-based goals calculated for unrestricted (residential) land use. These goals were based on direct contact human health and soil to groundwater leaching potential. Therefore, no active remedial action was required to address petroleum impacted soils. Groundwater monitoring was conducted to evaluate natural attenuation as a remedial option for groundwater remediation. Natural attenuation monitoring indicated that groundwater contamination would attenuate on-site without risk of affecting sensitive downgradient receptors including a state protected watershed. Therefore, no active remedial action was required to address impacted groundwater. Use of risk assessment and natural attenuation monitoring provided the client with significant cost savings compared to other remedial alternatives and allowed for uninterrupted facility operations. In addition, the total project proceeded from discovery to closure submittal in under one year.

Author: Michael T. Berger
Braun Intertec Corporation
6875 Washington Avenue South
Minneapolis, Minnesota 55439
Tel: 612-941-5600
Fax: 612-833-4701

POSTER SESSIONS

ANALYSIS

1) **Comparison of Soil Analytical Methods for Explosives.** Jay L. Clausen and Elizabeth Wessling, Ogden Environmental and Energy Services. A multi-media investigation was conducted at the Massachusetts Military Reservation Cape Cod, MA within a site known as the Impact Area. The study was focused on explosive compounds potentially derived from weapon ordinance training. A field screening method for soil developed by the Army Cold Regions Research and Engineering Laboratory (CRREL) was used during the study and compared with the laboratory based EPA 8330 Method. The CRREL method resulted in numerous false positive results which were later unconfirmed with the EPA 8330 Method. Soil explosive concentration levels were typically less than 1 mg/kg. The potential for false negative results with the field screening method was evaluated and found to be nonproblematic. A cost/time analysis indicated little cost or time savings using the CRREL method versus the laboratory based EPA 8330 Method. Results from the project suggest little advantage using field screening analytical methods for Impact Areas or other similar types of sites having low-level non-point distribution of explosive contaminants.

Jay L. Clausen
Ogden Environmental and Energy Services
239 Littleton Road, Suite 1B
Westford, MA 01886
Tel: 978-692-9090
Fax: 978-692-6633

Elizabeth Wessling
Ogden Environmental and Energy Services
550 South Wadsworth Boulevard.Suite 500
Lakewood, CO 80226
Tel: 303-935-6505
Fax: 303-935-6575

2) **Volatile and Extractable Hydrocarbon Characteristics of Petroleum Products.** Peter J. Kane, Normand Laurianno, Jr., Elizabeth Hynes, Amy Jo Laurila, Catherine Gauthier and Helder Costa, Woods Hole Group Environmental Laboratories. Final methods promulgated by the Massachusetts DEP include guidance on matching methods with products. Accurate risk characterizations rely on applying the correct combination of methods. Additionally, the proficiency of fractionation of extractable hydrocarbons into aliphatic and aromatic ranges greatly affects the determination of risk, and constitutes the greatest source of uncertainty in these methods. In this poster, several fresh and weathered products found at MCP sites are characterized for their volatile and extractable components. The effects of improper fractionation on the determination of risk are examined using laboratory measurements and breakthrough models. Also, non-target volatile and extractable hydrocarbons are characterized using advanced petroleum fingerprinting tools (PIANO compounds, alkylated PAHs, and geochemical biomarkers).

Peter J. Kane
Woods Hole Group Environmental Laboratories
375 Paramount Drive, Suite B
Raynham, MA 02767
Tel: 508-822-9300
Fax: 508-822-3288

Elizabeth Hynes
Woods Hole Group Environmental Laboratories
375 Paramount Drive, Suite B
Raynham, MA 02767
Tel: 508-822-9300
Fax: 508-822-3288

Catherine Gauthier
Woods Hole Group Environmental Laboratories
375 Paramount Drive, Suite B
Raynham, MA 02767
Tel: 508-822-9300
Fax: 508-822-3288

Norman Laurianno, Jr.
Woods Hole Group Environmental Laboratories
375 Paramount Drive, Suite B
Raynham, MA 02767
Tel: 508-822-9300
Fax: 508-822-3288

Amy Jo Laurila
Woods Hole Group Environmental Laboratories
375 Paramount Drive, Suite B
Raynham, MA 02767
Tel: 508-822-9300
Fax: 508-822-3288

Helder Costa
Woods Hole Group Environmental Laboratories
375 Paramount Drive, Suite B
Raynham, MA 02767
Tel: 508-822-9300
Fax: 508-822-3288

3) An Evaluation of Modified EPA Method 1668 for the Determination of Mono through Deca PCBs and Congener-Specific PCBs. William Luksemburg, Martha Maier, Alta Analytical Laboratory (ALTA). The draft 1997 EPA Method 1668 is currently being used for the determination of 13 toxic polychlorinated biphenyls (PCBs) in soil and other matrices by high resolution gas chromatography/high resolution mass spectrometry. Because of the recent increase of information on the toxicity of various PCB congeners, as well as renewed focus on PCB contamination by regulatory agencies, Alta Analytical Laboratory has expanded the method to incorporate the analysis of the ten PCB homologues as well as 39 additional congeners. ALTA is currently evaluating this expanded method for the analysis of soil samples.

Method evaluation: Four different soil types, three of which are known to be contaminated with PCBs, are being analyzed to determine the effects of soil type on data reproducibility and to identify possible matrix complications. Additional extract cleanup options will be evaluated and refined to maximize efficiency and internal standard recoveries. A Method Detection Limit Study (MDL) is also being performed on a clean background soil sample to verify that Method Limits stated in EPA Method 1668 are achievable.

William J. Luksemburg
Alta Analytical Laboratory
5070 Robert J. Mathews Parkway
El Dorado Hills, CA 01950
Tel: 916-933-1640
Fax: 916-933-0940
billux@altalab.com

Martha M. Maier
Alta Analytical Laboratory
5070 Robert J. Mathews Parkway
El Dorado Hills, CA 01950
Tel: 916-933-1640
Fax: 916-933-0940
mmaier@altalab.com

4) The Use of Immunoassay Methods for PCB and PAH Analysis at Manufactured Gas Plant Sites, Kevin W. Miller, Ph.D., Robert S. Potterton Jr., LEP,CPG, Andrew R. Zlotnick, LEP, Fuss & O'Neill, Inc. and William Hoynack, Project Manager, Northeast Utilities System. Immunoassay analysis combines the specificity and binding properties of antibodies with a chromogen to allow colorimetric measurement of low concentrations of chemicals. Immunoassay field screening can be an important tool in conducting a comprehensive and cost effective site characterization and remediation. The assays provide real-time analytical results that allow project managers to make critical judgements in the field. We conducted a two phase study at a manufactured gas plant site. In the first phase of the study we selected samples believed to be representive of low, mid-range, and high concentrations for polychlorinated byphenyls (PCBS) and polyaromatic hydrocarbons (PAHs). Samples were analyzed by immunoassay in an on-site mobile laboratory (EPA SW-846 Method 4020 and 4035) and in a fixed-based laboratory by gas chromatography and gas chromatography mass-spectrometry (EPA Method 8081 and 8270). Based on this information, we determined a site-specific response factor for PCBs, PAHs and benzo(a) pyrene. Using this relationship we then compared the results from the immunoassay screening methods and the fixed-based laboratory. Both immunoassay methods correlated well with the fixed-based laboratory. In some cases where gas chromatographic analysis was effected by matrix interferences from coal tar, the immunoassay may actually have produced more accurate and precise analytical results. Results from the study compared well by regression analysis and by true chart analysis.

Kevin W. Miller, Ph.D.
Fuss & O'Neill, Inc.
146 Hartford Road
Manchester, CT 06040
Tel: 646-2469
Fax: 645-0717

Andrew R. Zlotnick, LEP
Fuss & O'Neill, Inc.
146 Hartford Road
Manchester, CT 06040
Tel: 646-2469
Fax: 645-0717

Robert S. Potterton Jr., LEP,CPG
Fuss & O'Neill, Inc.
146 Hartford Road
Manchester, CT 06040
Tel: 646-2469
Fax: 645-0717

William Hoynack
Project Manager
Northeast Utilities System
Berlin, CT
Tel: 860-665-3455
Fax: 860-665-3777

5) **A review of the effectiveness of the PetroflagTM TPH field screening technology**, Philip W. Moreschi, Kevin Miller, Fuss & O'Neill, Inc. and Joseph V. Cassidy, Connecticut DPW. Underground storage tank removal typically requires sampling of tank grave soils and review of analytical results prior to backfilling the excavation. Performance of EPA method 418.1 in the field can provide an indication of the level of petroleum contamination that can be used as the basis for closing excavations if contaminant levels are below the regulatory action level. Performance of method 418.1 in the field can be unwieldy due to equipment needs and time constraints, and this method is expensive due to high Freon costs. The Dexsil Corporations's PetroflagTM test can be performed in the field with relative ease and cost and can provide reasonable representation of method 418.1 results. Soil samples collected from tank graves were analyzed using PetroflagTM in the field and method 418.1 in a fixed base lab at over 25 tank removal projects in Connecticut. Over 200 soil samples were analyzed using both tests. The results were correlated to determine how representative PetroflagTM was of EPA method 418.1. The results showed a strong correlation between the two methods. PetroflagTM typically over predicted the method 418.1 results and there was very low incidence of false negatives. The use of a field screening method such as PetroflagTM allows the closure of these graves on the same day with follow up confirmation utilizing method 418.1.

Philip W. Moreschi, P.E.
Fuss & O'Neill, Inc.
146 Hartford Road
Manchester, CT 06040
Tel. 646-2469
Fax 645-0717

Kevin Miller
Fuss & O'Neill, Inc.
146 Hartford Road
Manchester, CT 06040

Joseph V. Cassidy, P.E.
Connecticut Department of Public Works
State Office Building, Room 462
165 Capitol Avenue
Hartford, CT 06106
Tel: 566-6322
Fax: 566-6327

6) **Well Development, Turbidity and Laboratory Analytical Measurements.** Jay L. Clausen, Samuel P. Farnsworth, and John F. Rice, Ogden Environmental and Energy Services. A groundwater study was conducted by the Army National Guard at Camp Edwards, Massachusetts. Newly installed and existing monitoring wells were sampled over a 14,000 acre area of Western Cape Cod as part of the investigation. Low-flow sampling for explosives, metals, VOCs, SVOCs, pesticides/PCBs, herbicides and inorganics was performed per EPA Region 1 Guidance using a non-dedicated bladder pump. Turbidity levels in some wells remained high despite extending purging. A the time of sample collection turbidity levels varied dramatically between sample locations (0.30 NTU to 450 NTU). A relationship between turbidity levels and total metals was observed in contrast with other analytical parameters. Filtered and unfiltered groundwater samples were collected and analyzed for metals.

John F. Rice
Ogden Environmental
239 Littleton Road
Suite 1B
Westford, MA, 01886
Tel: 978-692-9090
Fax: 978-692-6633

Jay L. Clausen
Ogden Environmental
239 Littleton Road
Suite 1B
MA, 01886
Tel: 978-692-9090
Fax: 978-692-6633

Samuel P. Farnsworth
Ogden Environmental
239 Littleton Road
Suite 1B
Westford, MA, 01886
Tel: 978-692-9090
Fax: 978-692-6633

7) **Biodegradation of Organic Contaminants as Evidenced by Chromatographic Interpretations.** John F. Amadon, CPSS, and Chris Stone, Stone Environmental, Inc., and Harry Locker, Endyne, Inc. Biodegradation is key to the natural attenuation process. As the focus of contaminated site cleanup methodology shifts increasingly toward biodegradation, accurate methods for documenting the success of microbial activity are needed. One approach is to interpret patterns generated during conventional gas chromatography (GC) analyses (as in EPA Methods 8020, 8015, or 8260). These standard analyses can provide useful data beyond the target analyte concentrations typically reported. The presence (or lack) of lower boiling point peaks relative to the target analytes is important. Such nontarget, and generally unidentified, peaks may be indicative of intermediary metabolites of biodegradation. Various fatty acids and aldehydes have been identified by GC mass spectrometry (GC/MS) at petroleum contaminated sites where other indicators of biodegradation have also been shown (low dissolved oxygen, high dissolved CO_2, reduced iron, microbial counts, etc.). Some simple examples of chromatographic comparisons and interpretations will be presented for these types of forensic investigations. Sample matrices include solids (soils) and liquids (surface, pore, and ground waters) although care must be taken in the sampling and storage phases for appropriate preservation to preclude exsitu biodegradation.

John F. Amadon, CPSS
Stone Environmental, Inc.
58 East State Street
Montpelier, Vermont 05602
Tel:802-229-4541
Fax:802-229-5417

Harry Locker, Director
Endyne, Inc.
32 James Brown Drive
Williston, Vermont 05495
Tel:802-879-4333
Fax:802-879-7103

Christopher Stone
Stone Environmental, Inc.
58 East State Street
Montpelier, Vermont 05602
Tel:802-229-4541
Fax:802-229-5417

8) Biosurfactant And Synthetic Surfactant Enhancement Of n-Hexadecane Mineralisation By Two Strains Of Pseudomonas. aeruginosa. Richard. K. Beal and W. Bernard Betts, York University. In this study the effects of two commercially available synthetic surfactants (an anionic and a nonionic) on the mineralisation of n-hexadecane by a biosurfactant-producing strain (PG201) and a biosurfactant deficient strain (U0299) of Pseudomonas. aeruginosa were investigated. Mineralisation of n-hexadecane was measured as the evolution of $^{14}CO_2$ from ^{14}C-n-hexadecane in a mineral salts medium and growth rates were determined by plate count. An increase in '4CO² evolution and growth rates was observed in PG201 compared with U0299. The rate of '4CO_2 evolution was increased in both PG201 and U0299 with the addition of the nonionic surfactant (synperonic 9116), when added at levels above its critical micelle concentration (CMC). An increase in growth rates was also observed for both strains. The addition of the anionic surfactant (Caflon 3-S-27) caused a decrease in '4CO_2 evolution in both strains, however the decrease was much greater for PG201. An increased growth rate was observed in U0299 with Caflon 3-S27 addition above its CMC, indicating that the surfactant is utilised in preference to n-hexadecane as a carbon source.

Richard. K. Beal
Microbiology Research Unit
Department Of Biology
University Of York
York, North Yorkshire, Y010 5DD
UK.
Tel: 01904 432919
Fax: 01904 432923
Email: rkb101@york.ac.uk

W. Bennard Betts
Microbiology Research Unit
Department Of Biology
University Of York
York, North Yorkshire, Y010 5DD
UK.
Tel: 01904 432810
Fax: 01904432923
Email: wbb2@york.ac.uk

9) In-Situ Bioremediation of Petroleum Hydrocarbons Using Facultative Bacteria and Nutrient Injection - Case Studies. Thomas R. Bymes and Vincent Maresco, Groundwater & Environmental Services, Inc., James E. Clark, Agway Energy Products, and David J. Bender, Sun Company, Inc.

Natural attenuation of petroleum hydrocarbons in soil and groundwater occurs to varying degrees at most release sites through stimulation of native populations of aerobic and anaerobic bacteria. The contaminants are metabolized much faster aerobically. However, dissolved oxygen soon becomes a limiting factor. Degradation rates under the resulting anaerobic conditions are most often unacceptably slow. As an alternative to increasing dissolved oxygen, we present two case studies using injection of concentrated populations of facultative bacteria and nutrients for enhanced in-situ bioremediation at two petroleum release sites. These were harvested populations, naturally-occurring purchased from a supplier. Facultative bacteria metabolize under both aerobic and anaerobic conditions. The two case studies examine the performance of this product in two different hydrogeologic settings. In both cases, several years of monitoring data establish baseline concentrations and negligible rates of natural attenuation. Site A consists of coarse-grained sand and gravel deposits of high hydraulic conductivity. Site B in underlain by inter-bedded sand and silt layers in a fining downward sequence. The radius of influence of each injection point on Site B was enhanced through the use of surfactants. The complete geochemistry of these sites was characterized before and after nutrient and bacteria inoculation. Follow up nutrient injection and inoculation was performed as recommended by the supplier. These case studies evaluate in detail the performance and cost effectiveness of this remedial technology.

Thomas R. Bymes
Groundwater & Environmental Services, Inc.
300 Gateway Park Drive
North Syracuse, New York 13212
Tel: 315-452-5700
Fax: 315-452-3237

James E. Clark
Agway Energy Products
P.O. Box 4852
Syracuse, New York 13221-4852
Tel: 315-449-7430
Fax: 315-449-6682

Vincent Maresco
Groundwater & Environmental Services, Inc.
300 Gateway Park Drive
North Syracuse, New York 13212
Tel: 315-452-5700
Fax: 315-452-3237

David J. Bender
Sun Company, Inc.
01 West Hiawatha Blvd
Syracuse, New York 13204
Tel: 315-446-6215
Fax: 315-426-0112

10) The Use of Hydrogen Release Compound (HRC™) in the Bioremediation of CAHs. Stephen S. Koenigsberg, Regenesis Bioremediation Products.

Regenesis has recently introduced Hydrogen Release Compound (HRC™) as a simple, passive, low-cost and long term option for the anaerobic bioremediation of chlorinated aliphatic hydrocarbons (CAHs). HRC is a proprietary, food grade, polylactate ester that, upon being deposited into the subsurface, slowly degrades to lactic acid. Lactic acid is then metabolized to hydrogen which drives reductive dechlorination. HRC is a moderately flowable, injectable material, that facilitates passive barrier designs for enhanced natural attenuation. Evidence suggests there is competition between reductive dehalogenators and methanogens in which the methanogens compete for the use of hydrogen in the conversion of carbon dioxide to methane. It is believed that a low concentration of hydrogen favors the reductive dehalogenators and starves out the methanogens. The objective, therefore, is to keep hydrogen concentrations low. The time release feature of HRC, which is based on the hydrolysis rate of lactic acid from the ester and the subsequent lag time to hydrogen conversion, facilitates this objective. HRC, therefore, becomes a passive form of enhanced natural attenuation in contrast to the more capital and management intensive alternatives now available. Laboratory and field results will be presented that will expand on the first uses of HRC by ABB Environmental and Montgomery Watson.

Stephen S. Koenigsberg
Regenesis Bioremediation Products
27130A Paseo Espada, Suite 1407
San Juan Capistrano, CA, 92675
Tel: (949) 443-3136
Fax: (949) 443-3145

11) IN-SITU BIOREMEDIATION OF HYDROCARBON CONTAMINATED DRILL-CUTTINGS. Surendra K. Mishra and William Evans, TETRA Technologies, Inc. Presently the hydrocarbon contaminated drill-cuttings generated in the oil and gas exploration are being hauled away from the site of the drilling operations for bioremediation. Handling, hauling and management of this regulated waste material is expensive. A method of in-situ treatment was developed and implemented to remediate the existing hydrocarbon contaminated drill-cuttings pits. In this paper, the method of treatment and results generated during the site-monitoring period are discussed. The results have shown that while during the life of these pits, biodegradation of hydrocarbons in the natural environment has been extremely slow. However, the chemicals and treatment method described in this paper were able to accelerate the process of degradation at a very rapid rate. This allowed the closure of these pits within two to three months of the treatment of the contaminated materials. Test results have also indicated a direct relationship between the reduction in the level of total petroleum hydrocarbon (TPH) and the growth of microorganisms boosted by the chemicals used.

Surendra K. Mishra
TETRA Technologies, Inc.
25025 I-45 North
The Woodlands, TX 77380
Tel: (281) 367 1983
Fax: (281) 367 6471

William Evans
TETRA Technologies, Inc.
25025 I-45 North
The Woodlands, TX 77380
Tel: (281) 367 1983
Fax: (281) 364 4307

12) Bioremediation of a Large Subsurface Hydrocarbon Plume in Silty Soil. Douglas Mose and George Mushrush, Chemistry Department, George Mason University. Approximately 200,000 gallons of diesel fuel, gasoline and jet fuel were inadvertently lost into the ground by a northern Virginia tank farm. The fuel entered the soil near the tanker truck loading rack; typically 400 tanker trucks/day each carry 10,000 gallon fuel loads to area fuel stations. Although the soil has low permeability, fractures in the bedrock which persist almost to the surface in the overlying soil facilitated rapid subsurface movement of the fuel. Evidence suggests that the contamination plume moved to its present length of 2000 feet in less than 5 years. The plume was stopped at its "nose" by a recovery trench which, along with mid-plume recovery trenches and recovery wells, have removed more than half of the fuel from the subsurface. The plume now lies under a suburban neighborhood, so disruptive recovery methods (e.g., excavating the soil to the contamination depth of 30-50 feet) cannot be used. Bioremediation is being used, and estimates of when the local homes and streams will no longer be re-contaminated range from 20-200 years.

Douglas Mose
Chemistry Department
George Mason University
Fairfax, VA 22030
Tel: (703) 993-1068
FAX: (703) 273-2282

George Mushrush
Chemistry Department
George Mason University
Fairfax, VA 22030
Tel: (703 993-1080
FAX: (703) 273-2282

13) Bioremediation of Chlorinated Compounds in Soil and Groundwater with Butane-utilizing Bacteria™. Felix A. Perriello, George A. DiCesare, Raymond C. Johnson, Rizzo Associates, Inc., Jalal Ghaemghami, Lapuck Laboratories, Stephen Simkins, University of Massachusetts. Chlorinated compounds such as 1,1,1-trichloroethane(1,1,1-TCA)and trichloroethylene(TCE)are still the most commonly reported contaminants of groundwater. A full-scale in-situ pilot study currently in the fifteenth month of operation is underway at a hazardous waste site in New England. Shallow subsurface materials at the site consist of sandy fill materials from the ground surface to depths of 7 to 14 feet, followed by coarse sand down to a semi-confining layer of silt at a depth of 28 feet. Butane(four times more soluble in groundwater than methane)is injected with a helium pusher and oxygen(as air)is supplied with an air compressor. Data analysis shows that chloride ion and carbon dioxide concentrations, and cell densities(in groundwater)have increased by several orders of magnitude over background in monitoring wells located within the butane biostimulation zone. The total dissolved-phase concentrations of 1,1,1-TCA and TCE in a monitoring well located within the treatment zone was 150,000 ppb in June 1997, 2,500 ppb in December 1997 and 580 ppb in June 1998. The cometabolism of chlorinated compounds using butane-utilizing bacteria (Patent Pending) is a viable treatment technology.

Felix A. Perriello
Rizzo Associates, Inc.
235 West Central Street
Natick, MA 01760
Tel: 508-651-3401
Fax: 508-651-1189

George A. DiCesare
Rizzo Associates, Inc.
235 West Central Street
Natick, MA 01760
Tel: 508-651-3401
Fax: 508-651-1189

Raymond C. Johnson
Rizzo Associates, Inc.
235 West Central Street
Natick, MA 01760
Tel: 508-651-3401
Fax: 508-651-1189

Jalal Ghaemghami
Lapuck Laboratories
50 Hunt Street
Watertown, MA 02172
Tel: 617-923-0300
Fax: 617-923-0301

Stephen Simkins
University of Massachusetts
Plant & Soil Sciences Department
Amherst, Massachusetts 01003
Tel: 413-545-5211
Fax: 413-545-1242

14) Bioremediation of PCB Contaminated Soils - A Bench Scale Evaluation.
Steven Putrich, PE, Michael McKim, and Nancy Sauer, URS Greiner Woodward-Clyde, Wayne Gould, LTV Steel. Although the production of PCBs in the United States was banned in 1977, the recalcitrance of PCBs, their tendency to bioaccumulate, and the expense of traditional PCB remediation techniques poses an ongoing environmental challenge. Over 18,000 tons of PCB contaminated soils and debris were recently removed from a 50 acre parcel located at the former South Chicago Works of LTV Steel, Chicago, IL. The contaminated soils are associated with a PCB spill which occurred after the 1993 demolition of LTV's steel production facility. The source of the spill is unknown, but believed to have been caused by unauthorized discharges of PCB material at the site. Due to a pending property transfer, bioremediation was not selected as the primary remediation strategy. However, LTV has decided to investigate the potential for bioremediation of PCB contaminated soils for other potential sites. Experiments were conducted to determine the effectiveness of bioaugmentation of PCB contaminated soils under anaerobic conditions. In addition, nutrients were applied at the site in comparable doses with those investigated in the laboratory to address residual low-level PCB contamination present at the site. This study was done to evaluate the effectiveness of bioaugmentation for the remediation of PCB contaminated soils and provide recommendations for future pilot testing. Potential in-situ and land farming applications of the bioremediation technology for PCB contaminated soils are also being considered as a follow-up to this study.

Steven Putrich, PE
Michael McKim
Nancy Sauer
URS Greiner Woodward-Clyde
30775 Bainbridge Road
Solon, Ohio 44139
Tel: 440-349-2708
Fax: 440-340-1514

Wayne Gould
LTV Steel
200 Public Square
Cleveland, Ohio 44114
Tel: 216-622-4530
Fax: 216-622-5058

15) Enhanced n-Hexadecane Biodegradation Using Oxygen Supplemented Bioactive Foam. Mark B. Ripley, Adrian B. Harrison, W. Bernard Betts, Ashley J. Wilson, University of York, UK and R. Kinsey Dart, Loughborough University, UK. Bench-scale studies were conducted to evaluate a novel bioremediation technique, in which microorganisms isolated from sewage were incorporated into a biodegradable, protein-based, and aqueous foam carriers. The effediveness of this method to enhance the biodegradation of a model petroleum hydrocarbon (n-hexadecane) was determined using soil column microcosms. Cultures of n-hexadecane degrading bacteria were isolated; seven individual Acinetobacter spp. and a Pseudomonas sp. were characterised. The organisms in this consortium showed no mutual inhibition or deleterious effects on foam stability. Different column treatments were investigated, including the presence or absence of foam, microbial consortium or oxygen, to determine the extent of n-hexadecane biodegradation in autoclaved soil after 7d. A further study showed the time course over a 15 d period of nhexadecane degradation in the presence of bioactive foams generated with either air or oxygen. In both cases the concentration of residual hexadecane was measured by quantitative gas chromatography. The results of these studies showed that both aerated and oxygenated bioactive foams enhanced the biodegradation of n-hexadecane. Maximal degradation was observed in response to oxygenated bioactive foam treatment. Dissolved oxygen levels in the liquid draining from aerated and oxygenated foams were measured and found to be 5.3 and 19.9 mg l^{-1} respectively, suggesting that biodegradation was enhanced by improved oxygen transfer.

Mr Mark B. Ripley Adrian B. Harrison, W. Bernard Betts, Ashley J. Wilson
Dept. of Biology
University of York
PO BOX 373
York, YO10 5YW
England
Tel: 01904 432810
Fax: 01904 432923
Email: wbb2@york.ac.uk

Dr R. Kinsey Dart
Dept. of Chemistry
Loughborough University
Loughborough Le11 3TU
England
Tel: 01509 222573
Fax: 01509 223925
Email: r.k.dartelboro.ac.uk

16) Overview of Internet Bioremediation Science/Engineering Resources. I. Richard Schaffner, Jr., P.G.; Christopher F. Wright, James M. Wieck, and Steven R. Lamb, C.G.W.P., GZA GeoEnvironmental, Inc. The World Wide Web (WWW) is an effective tool for rapidly accessing technical information from a wide variety of electronic resources. Successful execution of bioremediation technologies requires researchers, practitioners, and regulators remain current with technical developments in spite of the fact information on the subject is in a state of dynamic flux. The WWW is an exceptional tool for remaining current with this rapidly evolving field because it integrates a wide variety of electronic information resources and make them available virtually in real time. This overview summarizes the relevance and limitations of the following WWW resources on bioremediation, and lists pertinent examples of each: 1) web sites; 2) newsgroups; 3) Listservers; and 4) electronic communication (e.g., e-mail, file transfer protocol, Gopher).

I. Richard Schaffner, Jr.
GZA GeoEnvironmental, Inc.
380 Harvey Road
Manchester, New Hampshire 03103
Tel: 603-623-3600
Fax: 603-624-9463
E-mail: rschaffner@gza.com

Christopher F. Wright
320 Needham Street
Newton Upper Falls, Massachusetts 02164
Tel: 617-969-0050
Fax: 617-965-7769
E-mail: cwright@gza.com

James M. Wieck
Steven R. Lamb
GZA GeoEnvironmental, Inc.
380 Harvey Road
Manchester, New Hampshire 03103
Tel: 603-623-3600
Fax: 603-624-9463
E-mail: jwieck@gza.com, slamb@gza.com

17) Simple, Affordable Petroleum Contaminated Soils Bioremediation for Large and Small Sites, William J. Taylor. Advanced Research Associates, L.L.C. and Sheri George, Analytical Chemical Testing Laboratory, Inc. Mobile, AL 36606. Petroleum contaminated sites remain a very common environmental problem for large industrial sites and for thousands of smaller commercial properties. Bioremediation methods have gained acceptance as viable and cost effective clean-up alternatives for large sites. Yet, the conventional dig-haul-dispose remediation approach is still the dominant process chosen by environmental consultants for small sites. The authors argue that bioremediation applications can be simple, inexpensive, and very effective for small and large sites. Methods for cost comparisons are used initially to explore various treatment or disposal option viability. Site characterization methods describe how to select either in-situ or ex-situ methods, employ a simplified Risk Based approach. Rules of thumb provide a convenient method to simplify the calculation of treatment parameters such as amount of biosolvent, nitrogen, phosphorous, trace nutrients, and oxygen. The authors present data needed to bioremediate petroleum contaminated soils with several commercially available nutrients, bacteria, and biosolvent products, for surface soils, vadose soils, saturated soils, (and groundwater) contaminated with regulated petroleum chemicals. The authors developed user friendly software to predict bioremediation parameters for many sites, using a minimum amount of site specific input data. The authors' approach was successfully used to bioremediate levels of light, medium, and heavy petroleum hydrocarbons and regulated non-halogenated organic chemical compounds to levels below regulatory action limits in numerous field applications. The simplified methods, allow final disposal and gained a "no further action" status from regulatory authorities, at a fraction of the cost of off-site disposal without treatment.

J. Taylor
Advanced Research Associates, L.L.C.
166 Montclair Loop
Daphne, AL 36526
Tel: 334-626-2893
Fax: 334-478-8181

Sheri George
Analytical Chemical Testing Laboratory, Inc.
2869 Pleasant Valley Road
Mobile, AL 36606
Tel: 334-479-9205
Fax: 334-478-8181

BROWNFIELDS

18) The Diamond Shamrock Painesville Works Site - Part Two: Case Study of a Site Reuse Evaluation. David E. Rabbe, Chemical Land Holdings. The environmental agenda has shifted gradually from long drawn out remedial investigations to one of more expedited cleanups that emphasize reuse of contaminated sites. Recent publications by the Environmental Protection Agency and the Government Accounting office have demonstrated that more recently listed sites have moved through the CERCLA process with shorter remedial clean up duration. The strong economy and the need for States to revitalize former industrial zones has also contributed to the paradigm shift. The challenge for the managers overseeing the process is to look outside the traditional guidelines and determine if a site is a good candidate for the Brownfields program early in the investigation. This leads to focused investigations, risk assessments and feasibility studies catered to the sites' potential reuses. This case study explores the steps taken at the 1,100 acre Diamond Shamrock Painesville Works Site to expedite the process of moving large parts of the site back into productive use. The goal is to streamline the investigation and return the appropriate portions of the property back to safe, productive use as quickly as possible.

After initial sampling took place it was apparent that the most effect way to evaluate each parcel of the property was to first determine the most likely end use. Knowing the end use stream lines the process allowing the risk assessment to focus on that end use. This information now allows the risk assessors to quickly determine candidate parcels for expedited reuse.

In order to determine the most appropriate end use a developer was brought into the project team. The developer can use his knowledge of zoning and market conditions to design the proper property use. Once he completed his development plan he supplied this information to the site managers.

The results of the risk assessment will provide the information needed for the site managers to determine the economical feasibility of the potential end use.

David Rabbe
Chemical Land Holdings
1015 Belleville Turnpike
Kearny, New Jersey 07032
Tel: 201-955-1888
Fax: 201-955-1063
e-mail: Davermxs@aol.com

19) Using a Peat Barrier to Cleanup PCE/TCE Contaminated Groundwater. C.M. Kao, National Sun Yat-Sen University; W.S. Wu, National Sun Yat-Sen University. Groundwater at many existing and former industrial areas and disposal sites is contaminated by halogenated organic compounds [e.g., tetrachloroethylene (PCE), trichloroethylene (TCE)] that were released into the environment. One cost-effective approach for the remediation of the chlorinated-solvent contaminated aquifers is the installation of permeable reactive zones or barriers within aquifers. As contaminated groundwater moves through the emplaced reactive zones, the contaminants are removed, and uncontaminated groundwater emerges from the downgradient side of the reactive zones. The objective of this proposed study was to assess the potential of using a passive two-stage barrier system to clean up aquifers contaminated by PCE/TCE. This passive active barrier system has advantages over conventional systems including less maintenance, cost-effectiveness, no above-ground facilities, no groundwater pumping and reinjection, and groundwater remediation in situ. We conducted microcosm experiments to assess the feasibility of using peat to activate the PCE/TCE degradation processes. Results indicate that PCE/TCE were biodegraded to low levels using peat as the primary substrate through reductive dechlorination of PCE and aerobic cometabolism of TCE. Results of this study will aid in designing a system for field application. The proposed peat barrier treatment scheme would be expected to provide a more cost-effective alternative to remediate chlorinated-solvent contaminated aquifers. This technology can also be applied for other hazardous waste and petroleum hydrocarbon contaminated sites.

C.M. Kao, Ph.D., P.E., P.H.
National Sun Yat-Sen University
Institute of Environmental Engr.
Kaohsiung, Taiwan
Tel: 011-886-7-525-2000 ext. 4413
Fax: 011-886-7-525-4449

W. S. Wu
National Sun Yat-Sen University
Department of Biology
Kaohsiung, Taiwan

20) Biodegradation of Trichloroethylene Using Chlorobenzenes as the Primary Substrates: Field and Laboratory Studies. C.M. Kao, National Sun Yat-Sen University; James Wang, Geophex, Ltd. Under anaerobic conditions, degradation of trichloroethylene (TCE) has been observed in field studies; in continuous-flow fixed-film reactors; in soil, sediment, and aquifer microcosms; and in pure cultures. Results indicate that TCE can be microbiologically transformed by sequential reductive dechlorination reactions to less-chlorinated compounds such as dichloroethylenes (DCEs), vinyl chloride (VC), and ethylene (ETH). This process requires some form of electron donor, with the chlroinated ethene serving as the electron acceptor. A number of organic compounds, including acetate, methanol, glucose, benzoate, phenol, methylamines, and alkylbenzenes, have been used as electron donors and carbon sources for reductive dechlorination under methanogenic conditions. Methanogens have been shown to play a key role in reductive dechlorination reactions. Activities at a former fire training area at Robins Air Force Base in Georgia resulted in contamination of groundwater with a mixture of TCE and chlorobenzene. Results from the field investigation suggest that the natural bioremediation is occurring and causing the decrease in TCE and chlorobenzene concentrations and increase in TCE byproduct (e.g., DCEs, VC) concentrations. In this study, laboratory microcosm studies were conducted to evaluate the potential for intrinsic biodegradation of TCE using chlorobenzenes as the primary substrates under methanogenic conditions. Contaminated groundwater samples collected from the site were used as the inocula to establish microcosms. Microcosm results indicate that chlorobenzenes induced TCE degradation occurred in the tests. Substantial degradation of TCE indicates that chlorobenzenes can serve as the electron donors and cause the dechlorination of TCE.

C.M.Kao
National Sun Yat-Sen University
Institute of Environmental Engr.
Kaohsiung, Taiwan
Tel: 011-886-7-525-2000 ext. 4413
Fax: 011-886-7-525-4449

James Wang, Ph.D.
Geophex, Ltd.
605 Mercury St.
Raleigh, NC 27695
Tel: 919-839-8515
Fax: 919-839-8528

CLEANUP STANDARDS

21) An Alternate Criterion for Deactivating a Remedial System and Site Cleanup Goals. Adam Chen, Burns & McDonnell waste Consultants, Inc. Technical impracticability (TI) means the inability to achieve required cleanup levels based upon generic ARAR's or site-specific RBCA using best available technologies (sATs). In such cases, an alternative cleanup strategy that is fully protective of human health and environment must be identified. Such an alternative strategy may still include engineered remediation components, such as contaminant source removal and control, in addition to approaches intended to restore to beneficial uses the portion of the plume within dissolved contaminants. To define the site closure criteria under a TI circumstance, an alternate standard for deactivating a remedial system and site closure standard is proposed in this paper based upon the limitations of the BATs and natural contaminant degradation rate. Based upon the proposed alternate standard, when BAT(s) is applied, the following two criteria will be applied and the system will be deactivated when either of two criteria is met: (1) contaminant removal rate of the BAT approaches an asymptotic level and (2) contaminant removal rate is comparable to natural contaminant degradation rate. After a remedial system reaches an asymptotic condition or natural degradation rate of contaminants across the site surpasses the contaminant removal rate achieved by a BAT, the cost for continuously operation of the remedial system is not proportional to benefits, the system operation should be terminated and the site should be closured. In this paper, the rationales for the alternate criterion, appropriate site conditions for applying the criterion, and its successful implementation at several industrial sites in the State of California are elucidated.

Adam Chen, P.E.
Burns & McDonnell Waste Consultants, Inc.
999 Oakmont Plaza Drive
Westmont, IL 60559
Telephone: 630-654-0220
Fax: 630-654-0248
email:achen@megsinet.net

22) Development of a Protocol for Measuring Site-Specific Soil Sorption Constants. Warren Lyman, Camp Dresser & McKee; John R. Smith, Margaret Tabe, Robyn Lampman and James Gruen, Aluminum Company of America (Alcoa), A. Scott Weber, James Jensen, Chih Huang, Maria Mitraka, amd Chungliang Wei, State University of New York (SUNY) at Buffalo. To protect groundwater at hazardous waste sites requiring remediation, many states have derived soil cleanup goals that are based on the concept of equilibrium partitioning of a chemical between soil and water. Typically, a default partition coefficient -- e.g., a KCC sorption constant (often estimated) -- is used in calculations that represent a generic site. However, such an approach does not take into account site-specific variables affecting soil sorption, nor does it allow proper representation of the inherrent heterogeneity. Alcoa, m a collaborative effort with SUNY Buffalo, has developed a laboratory protocol that can be used to obtain site-specific soil/water partition coefficients (K_{oc}s) for organic chemicals as alternatives to the non-sitespecific, default values in state g lidance documents. Experiments focused on the development and evaluation of a soil desorption protocol using PCB-contaminated soils from Alcoa's Massena, NY facility as the test material. Clean site groumdwater was used as the leaching agent. The basic protocol involves batch desorption (for 5 or more days) followed by flocculant-assisted centrifugation for solids/liquids separation. SUNY Buffalo conducted studies of both desorption and subsequent adsorption onto clean soil, as well as comparison column experiments. Laboratory sorption studies were conducted for soils from eight locations at the study site, with test samples being collected as a function of depth (down to 1 m). The tests allowed an evaluation of several variables which may influence the rate and extent of PCB desorption: soil type, PCB concentration, desorption time and temperature, solids/liquids ratio, and use of biological inhibitors.

John R. Smith and Margaret Tabe
Alcoa
EHS Technology Center
100 Technical Drive
Alcoa Center, PA 15069
Tel: 412-337-5432
Fax: 412-337-5315

Robyn Lampman
Alcoa Lebanon Works
3000 State Drive
Lebanon, PA 17042
Tel: 717-270-4882
Fax: 717-270-4804

James Gruen
Alcoa
Park Avenue East
Massena, NY 13662
Tel: 315-764-4135
Fax: 315-764-4444

Warren J. Lyman
Camp Dresser & McKee inc.
Ten Cambridge Center
Cambridge, MA 02142
Tel: 617-252-8829
Fax: 617-621-2565

A. Scott Weber, James Jensen, Chih Huang,
Maria Mitrakal and Chungliang Wei
207 Jarvis Hall
SUNY Buffalo
Buffalo, NY 14260
Tel: 716-645-3446
Fax: 716-645-3667

ENVIRONMENTAL FATE

23) Uncertainty in Predicting the Rate of Mass Removal Created by Soil Vapor Extraction Systems. David L. Barnes. Amarillo National Resource Center for Plutonium. David B. McWhorter. Colorado State University. Since the 1970's the discovery of widespread soil and ground water contamination has resulted in the use of engineered systems designed to mitigate issues posed by these problems. Soil vapor extraction (SVE) is one common method that is used to remove volatile organic compounds from unsaturated soils. Recently, several soil gas flow and vapor transport numerical models have been developed for use in designing SVE systems. This paper examines how uncertainties in soil properties, specifically permeability, corresponds to uncertainties in the prediction of mass removal rates by numerical models.

This study uses, Monte Carlo analyses of volatile organic compound removal from a hypothetically contaminated soil by SVE to examine the effect of system operation time and permeability mean and variance on the uncertainty in mass removal rates as predicted by a numerical model. Relevant geometric and non-geometric parameters are scaled to provide a certain degree of generality.

Results indicate that uncertainty in the predicted mass removal rate increases as both mass removal increases and as the assumed permeability variance increases. The effect of uncertainty in permeability on the prediction of air-pressure drawdown at extraction wells was also examined. Results show that uncertainties in the predication of air-pressure drawdown at extraction wells increases with increasing permeability variance.

David L. Barnes
Amarillo National Resource Center for Plutonium
600 S. Tyler suite 800
Amarillo, Texas, 79101
Tel: 806-376-5533
Fax: 806-376-5561
Email: barnes@pu.org

David B. McWhorter
Colorado State University
Engineering Research Center
Fort Collins, Colorado, 80523
Tel: 970-491-8666
Fax: 970-491-8224

ENVIRONMENTAL FORENSICS

24) Source Identification And Forensic Chemistry Using VPH and EPH Methodologies. Stephen D. Emsbo-Mattingly and David M. Mauro, META Environmental, Inc. The Massachusetts Department of Environmental Protection (MADEP) formally released the Volatile Petroleum Hydrocarbon (VPH) and Extractable Petroleum Hydrocarbon (EPH) methods in January, 1998. These methods offer toxicologically meaningful replacements for traditional measurements of Total Petroleum Hydrocarbons (TPH) which employ infrared (IR) or gas chromatography (GC) techniques. These methods are also two of the first widely employed "performance based" methods. Unlike established EPA protocols, analytical modifications are allowed, provided specific performance criteria are satisfied. While engineers are typically reluctant to use modified methods, this presentation offers compelling reasons for exploring the hidden value of modified VPH/EPH methods in the context of source identification. A modified method is presented which combines the VPH and EPH procedures into one cost-effective analysis. Comparisons are made between traditional TPH-GC and modified VPH/EPH methods from sites with complicated chemical signatures including weathered fuels oils and mixed petroleum-tar releases. The value of a modified VPH/EPH analysis is further demonstrated by the use of forensic chemistry techniques, such as, PAH profiling, biomarker fingerprinting, and principal components analysis.

Stephen D. Emsbo-Mattingly
META Environmental, Inc.
49 Clarendon Street
Watertown, MA 02472
Tel: 617-923-4662
Fax: 617-923-4610

David M. Mauro
META Environmental, Inc.
49 Clarendon Street
Watertown, MA 02472
Tel: 617-923-4662
Fax: 617-923-4610

25) Advances in Measurement and Differentiation of Light Distillate Petroleum Products using Chemical Forensics Techniques. Richard M. Uhler, Allen D. Uhler, Scott A. Stout, and Kevin J. McCarthy, BattelleñEnvironmental Forensic Investigation Group, 397 Washington Street, Duxbury MA 02332. The need to identify the types of petroleum-derived products present at contaminated sites, to determine the relative proportions of inputs from different sources, and to differentiate sources of like products are often critical components of site investigations. Historically, identification and differentiation among similar light distillates by standard EPA methods have been hampered by analytical and interpretative limitations. Forensic investigations of light distillate products should begin with a chromatographic profile, or fingerprint, obtained using a modified EPA 8015 GC/FID analysis. Second level analysis can then determine the detailed chemical composition of the light distillate product(s) via a modified version of EPA Method 8260. The optimization of this purge-and-trap GC/MS method is accomplished primarily through the selection of a targeted list of diagnostic compounds in the C5 to C12 range, representing five important categories of hydrocarbons: Paraffins, Isoparaffins, Aromatics, Naphthenes, and OlefinsñëPIAí compounds. Detailed analysis of the individual hydrocarbons within each class provide much of the information necessary to identify and distinguish between light distillate products. In more complex cases involving the transport and fate of fugitive petroleum products, more advanced chemometric data analysis techniques are necessary. One such technique is multivariate principal component analysis (PCA). In such an analysis, a two dimensional matrix composed of samples and their corresponding PIANO composition is constructed. A multivariate analysis of the normalized data set is performed and resulting in a numerical means for sample differentiation. Forensic techniques developed by Battelleís Environmental Forensic Investigation Group give chemists the ability to deduce the composition and identification of light distillates and differentiate them from other similar products.

Richard M. Uhler[1]
Allen Uhler, Ph.D.[1]
Scott Stout, Ph.D.[1]
Kevin J. McCarthy[1]
[1]Battelle Environmental Forensic Investigation Group
Battelle Duxbury Operations
397 Washington Street
Duxbury MA 02332.
Tel: 781-934-0571
Fax: 781-934-2124

FEDERAL

26) Forward Engineering — Recycling a Military Landfill. Lawrence K. Bowers, P.E., EnSafe Inc., Hampton, Virginia. SWMU (solid waste management unit) 9 is an approximately 80 acre closed landfill at the former Charleston Naval Base and Shipyard. An RFI (RCRA Facility Investigation) determined the landfill could pose a risk to human health and the environment; therefore, it was selected for a corrective measures study (CMS). A typical CMS includes remedial alternative identification, screening, and evaluation. In order to expedite cleanup, enhancements to the USEPA presumptive remedy for military landfills has been advocated for SWMU 9. Remedial objectives include mass containment, exposure control, and assurance of no further degradation of adjacent ecological areas. Potential remedial alternatives include partial or full capping, hot-spot surface soil excavation, groundwater monitoring, boundary and institutional controls. SWMU 9's cleanup poses unique challenges because: 1) Its size and hydrogeologic setting prohibit waste material excavation or treatment, 2) Ecologically sensitive areas are adjacent the landfill, 3) An off-site source is potentially impacting the same ecological community, and 4) Three RFI sites are located within the perimeter of the former landfill. Envisioned reuses of the landfill include: 1) A nature conservancy, 2) Recreational use, and/or 3) Limited industrial or commercial use. The following have been learned during the CMS for SWMU 9: 1) Risk assessments are important; however, the means by which the results are communicated to stakeholders is even more important, 2) Proposal of remedial objectives should be based on facility/property reuse considerations and applicable risk, and 3) Early and frequent public involvement is instrumental in the success of any remedial project.

Lawrence K. Bowers, P.E.
EnSafe Inc.
303 Butler Farm Road, Suite 113
Hampton, Virginia 23666
Tel: 757-766-9556
Fax: 757-766-9558
lbowers@ensafe.com

27) Use of Rotosonic and Dual Rotary Drilling Techniques in an Impact Area. Samuel P. Farnsworth and John F. Rice. Ogden Environmental and Energy Services. A groundwater study was conducted by the National Guard Bureau at Camp Edwards, Massachusetts. A large portion of this study included the installation of the monitoring wells in an Impact Area. The Impact Area, four square miles in size, has been used by the military for weapons training for more than 50 years. Unexploded ordnance (UXO) consisting of live rounds that did not function properly after firing are located in the Impact Area during this period. Drilling pads and roads to the pads were cleared of UXO prior to drilling. Initially only dual rotary drilling (simultaneously advancing casing and drill rods) was used in the Impact Area to minimize subsurface disturbance and potential detonation of UXO. Through the course of the investigation, sonic drilling was incorporated into the Impact Area drilling program. This paper discusses UXO issues, the advantages and disadvantages of each drilling method, and the type of soil and groundwater sampling each drilling method allows.

Samuel P. Farnsworth
Ogden Environmental & Energy Services
239 Littleton Road, Suite 1B
Westford, MA 01886
Tel: 978-692-9090
Fax: 978-692-6633

John Rice
Ogden Environmental & Energy Services
239 Littleton Road, Suite 1B
Westford, MA 01886
Tel: 978-692-9090
Fax: 978-692-6633

28) Case Study of Environmental Impacts due to Military Training Activities. Marc Grant, Jay Clausen. Ogden Environmental and Energy Services. CPT James Boggess, Massachusetts Army National Guard. The National Guard Bureau initiated studies of the Impact Area at the Massachusetts Military Reservation in July 1997. The Impact Area is an area of four square miles that has been used for weapons training by military personnel for over 50 years. The military's activities primarily involved combustion of propellants from firing munitions, and combustion of explosives from detonation of munitions. The recent studies included analysis of soil, groundwater, surface water, and sediment samples for explosive compounds and other target analytes. The Impact Area overlies zones of contribution for current or projected future water supply wells in the towns of Bourne, Falmouth, Mashpee, and Sandwich. This project included: 1) sample collection and drilling in areas containing unexploded ordnance; 2) modification of analytical methods for explosives to include additional target analytes; 3) field screening in the saturated zone to locate well screen depths; and 4) use of groundwater modeling and preliminary risk evaluation to prioritize field activities.

The results of these investigations suggest that long term military training activities have had certain impacts on the environment. The highest concentrations of explosives in groundwater appear to be associated with Demo Area 1, where explosives were burned and detonated for training or disposal, and at several other potential disposal areas scattered in and around the Impact Area. Explosive compounds were present in low concentrations in surface soil at a few locations, but not at the primary targets of artillery and mortar fire. The pattern and magnitude of explosive detections in soil were not consistent with a source of contamination to groundwater. Explosive compounds detected in groundwater appear to be related to one or more point sources, which remain to be identified.

Marc Grant, PE
Ogden Environmental & Energy Services
239 Littleton Road, Suite 1B
Westford, MA 01886
Tel: 978-692-9090
Fax: 978-692-6633

Jay L. Clausen, CPG
Ogden Environmental & Energy Services
239 Littleton Road, Suite 1B
Westford, MA 01886
Tel: 978-692-9090
Fax: 978-692-6633

CPT James Boggess
Impact Area Groundwater Study Office
Building 2816, Room 228
Camp Edwards, MA 02542-5003
Tel: 508-968-5821
Fax: 508-968-5286

29) Sonic CPT and Direct Push Monitoring Point Assessment. James D. Shinn II, Applied Research Associates, Inc., Capt. Deborah Davis, US Air Force. The U.S. Department of Defense (DOD) and Department of Energy (DOE) have been instrumental in developing advanced sensors to be delivered by the cone penetrometer to speed up the environmental site characterization process. As probe sizes have increased (from 1.44-in OD to 1.75-in OD and larger), the ability of CPT to reach a desired depth for a given rig weight (reaction force) has been reduced. Over the past three years, the DOD and DOE have funded efforts to integrate vibratory techniques with CPT to advance cone penetrometer sensor packages past the current depths of refusal. A prototpye Sonic-CPT unit has been built and tested at three DOD sites and one DOE site. The Sonic-CPT unit has demonstrated an increased depth of penetration over conventional CPT truck systems.

In addition to these efforts, the DOD has been evaluating CPT installed monitoring wells as a supplement to conventional drill. As CPT wells can be installed at a much lower cost than drilled wells, gaining acceptance for CPT installed wells by regulatory agencies could yield large cost savings. A program was conducted by the U.S. Air Force at Hanscom AFB to assess the CPT installed groundwater quality monitoring wells.

The program included the development of a detailed sampling, analysis, and quality assurance plan. Samples were collected from both existing and CPT installed monitoring points using the EPA Low Flow Sampling procedure. Analytical results from the conventional and CPT wells were compared according to a statistically based experimental plan and demonstrate good correlation between the two well types. An important finding is that development of CPT wells is critical to obtaining high quality samples equivalent to those obtained from conventionally drilled wells.

James D. Shinn II
Applied Research Associates, Inc.
RR1, Box120A
South Royalton, VT 05068
Tel: 802-763-8348
FAX: 802-763-8283
E-Mail: jshinn@ara.com

Capt Deborah E. Davis
US Air Force
AFRL/MLQE
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403-5323
Tel: 850-283-6254
Fax: 850-283-6064
E-Mail:
debbie.davis@ccmail.aleq.tyndall.af.mil

30) Enzyme Enhanced Bioremediation of Fuel Contaminated Soil at Thule Air Base, Greenland. Robert Vinson, Versar, Inc., and Kenneth Garrett, Enzyme Technologies, Inc.
Thule Air Base (TAB) experienced a 23,000 J-8 fuel spill in March 1997. The release occurred adjacent to the North Star River and 1-mile from the mouth of North Star Bay. Versar mobilized an emergency response team to prevent the fuel from reaching the water where it could impact the fragile arctic marine wildlife the indigenous population depends upon for sustenance level hunting and fishing. During the excavation, additional contamination from previously undocumented releases was identified. Computer modeling estimated total contamination was equivalent to a release of 100,000 gallons.

Operating in temperatures as low as -50°F, Versar excavated approximately 16,000 CY of fuel contaminated soil, then placed approximately 9,000 CY of backfill and reconstructed the portions of the riverbank and channel impacted by the release. Human health and ecological risk assessments were performed to establish a risk based cleanup criteria.

Soil remediation technologies were screened for cost, logistical constraints and ability to support the technology in a remote arctic location. Enzyme enhanced bioremediation was selected and a pilot scale treatability study conducted during summer of 1998. A 1000 cubic yard landfarm was constructed and three applications of enzymes & nutrients were applied approximately one month apart.

The study assessed the effectiveness of 1) applying a multi-enzyme compound break down the fuel into simple fatty acids 2) adding nutrients to promote bacteria growth and 3) watering and mixing the soil maintain suitable moisture and oxygen content to enhance the bioremediation process.

Robert Vinson
Versar, Inc.
45 N.E. Loop 410, Suite 890
San Antonio, TX 78216
Tel: 210-344-5700

Ken Garrett
Enzyme Technologies,
2233 N.E. 244th Ave., Bldg. C1
Troutdale, OR 97060

31) Generic Screening Level Fate and Transport Analysis for Mercury at Natural Gas Metering Sites. Mark Gerath and Lisa J. N. Bradley Ph.D., DABT, ENSR.
A generic fate and transport analysis was conducted to aid in the identification of clean-up levels for elemental mercury present in soils due to accidental releases from manometers at natural gas metering sites. A conservative, general conceptual model was developed to analyze the migration of mercury at a typical metering site. Since a pipeline can have hundreds of such metering sites, the model was developed to address the sites generically. A three-fold analysis was conducted: evaluating the fate of mercury between source soils and the water table, evaluating mercury concentration in infiltrating soil water at the water table to predict groundwater concentration, and predicting movement and dilution effects on the concentration of mercury in the groundwater.

Unlike many other metals, mercury is a volatile liquid at ambient conditions. As such, elemental mercury behaves, in some respects, like an organic compound in the unsaturated zone. EMSOFT, a model that accounts for volatilization, leaching, and the impact of a soil-air boundary on the flux of substances was used to predict leaching of mercury from the unsaturated zone to the aquifer.

This unsaturated zone model demonstrated that, at a typical site, a mercury source of 20 mg/kg in soil would not migrate to the water table at concentrations that could leach into the groundwater at unacceptable levels. However, as a means of further evaluating the potential behavior of mercury, a saturated zone transport model was performed for the case that assumes that elemental mercury does reach the water table.

The analysis was used to develop a standard clean-up policy for typical metering sites. In the few cases where conditions at a particular site are less conservative than those assumed in the conceptual approach to this analysis, further investigation may be warranted. The modeling approach helped to define the critical conditions and identify the sites that need more focussed analysis.

Mark Gerath
ENSR
35 Nagog Park
Acton MA 01720
Tel: 978-635-9500
Fax: 978-635-9180

Lisa J. N. Bradley Ph.D., DABT
ENSR
35 Nagog Park
Acton MA 01720
Tel: 978-635-9500
Fax: 978-635-9180

32) In Situ Remediation of Hexavalent Chromium in Subsurface Soils and Groundwater. Nora L. Keel, Ricky A. Ryan, P.E., Jaret C. Johnson, P.E., and C. Len Smith, P.E., Harding Lawson Associates. Hexavalent chromium [Cr(VI)] presents a problem in our environment due to its high toxicity and carcinogenic effects. In addition, the generally high solubility and mobility of Cr(VI) species tend to increase risk of Cr(VI)transport in groundwater. At a Superfund site in the Southeast, a conventional pump-and-treat groundwater remediation system is currently serving as an interim action for the hydraulic control and treatment of Cr(VI) contaminated groundwater. However, an innovative in situ remedy for the full-scale remediation of groundwater at the site has been successfully field-tested at the site. The in situ remedy, which utilizes an acidic solution of ferrous sulfate, is a subsurface chemical reduction and precipition technology, whereby sorbed Cr (VI) is displaced from aquifer solids and soluble Cr (VI) is reduced to the trivalent state [Cr (III)]. The residual Cr (III) in groundwater is then remediated via the formation of an insoluble iron-chromium hydroxide solid solution. Thus, both Cr (VI) and total chromium are effectively treated to below applicable regulatory levels, without the presence of residual chromium sorbed to aquifer solids. The acidic ferrous sulfate reagent is injected into the aquifer using chemical metering pumps and vertical injection wells. Data indicate that groundwater concentrations between 0.1 and 4.4 milligrams per liter (mg/l) of total chromium have been effectively treated to below the SDWA MCL of 0.1 mg/l.

Nora L. Keel
Harding Lawson Associates
1400 Centerpoint Boulevard, Suite 158
Knoxville, TN 37932
Tel: 423-531-1922
Fax: 423-531-8226

Jaret C. Johnson, P.E.
Harding Lawson Associates
107 Audubon Road, Suite 25
Wakefield, MA 01880
Tel: 781-245-6606
Fax: 781-246-5060

Ricky A. Ryan, P.E.
Harding Lawson Associates
1400 Centerpoint Boulevard, Suite 158
Knoxville, TN 37932
Tel: 423-531-1922
Fax: 423-531-8226

C. Len Smith, P.E.
Harding Lawson Associates
1400 Centerpoint Boulevard, Suite 158
Knoxville, TN 37932
Tel: 423-531-1922
Fax: 423-531-8226

33) **Residual Pesticide Contamination in Soils - A Case Study of an Orchard.** Randy S. Kertes, C.P.G. and Raymond A. Ferrara, Ph.D., Omni Environmental Corporation. Pesticides, specifically lead arsenate and chlorinated organic compounds, were applied to fruit trees in an orchard in Monmouth County, New Jersey from circa 1960 to 1970. The application rates of these pesticides, typically three to fifteen pounds per 500 gallons of water, are well documented for the orchard. Pesticides were applied to fruit trees on a weekly basis from April through October of the growing season. Soil sampling data collected in 1996 showed residual concentrations of lead, arsenic and a variety of chlorinated organic pesticides present in the surface soils on the orchard property. Arsenic and lead concentrations ranged from 8 milligrams/kilogram (mg/kg) to 150 mg/kg and undetected to 470 mg/kg, respectively. Chlorinated organic pesticides (e.g., dieldrin, DDD, DDE, and DDT) were detected in concentrations up to 2,100 micrograms/kilogram. Elevated concentrations of arsenic in the soils are complicated due to the presence of arsenic as a naturally occurring metal in several Cretaceous-aged clay geologic formations which outcrop in the Coastal Plain Region of New Jersey. At this site, the presence of arsenic is both related to the application of lead arsenate (as a pesticide) and the occurrence of natural background concentrations. By plotting the relationship between arsenic and lead, an estimated background concentration of arsenic was calculated. Remediation alternatives for these soils containing residual levels of pesticides were evaluated based upon the existing levels of residual pesticides, cost and existing New Jersey Department of Environmental Protection Direct Contact Soil Cleanup Criteria.

Randy S. Kertes, C.P.G.
Omni Environmental Corporation
211 College Road East
Princeton, NJ 08540
Tel: 609-243-9393, ext. 21
Fax: 609-243-9297
E-Mail: rskomni@aol.com

Raymond A. Ferrara, Ph.D.
Omni Environmental Corporation
211 College Road East
Princeton, NJ 08540
Tel: 609-243-9393, ext. 14
Fax: 609-243-9297
E-Mail: rafomni@aol.com

34) **Advances in the Science of Heavy Metal Treatment; Chemical Treatment/Crystallization - The MAECTITE Process; Description and Case Study.** Sevenson Environmental Services, Inc., Steven A. Chisick, C.P.G., Charles B. McPheeters. During the last several years advances have occurred in the practice of remediating toxic heavy metals in soils and other media. Pozzolanic and silicic systems which attempt to entrap contaminants and chemical buffering systems which seek to minimize metals solubility by maintaining pH at artificially high levels are being phased out. Growing in use are chemical treatment/crystallization systems that incorporate heavy metals into durable, insoluble mineral crystal forms. The MAECTITE® process targets the formation of phosphate minerals, especially apatites. The hardness, chemical stability, thermal stability, and isomorphic properties of apatites make them ideal for reducing the leachability of metals. Since 1990, more than 700,000 tons of heavy metal contaminated soil, sludge, sediment and debris have been successfully treated at over 50 sites using the MAECTITE® process. Advantages over other methods include cost savings, simple and flexible application (ex-situ, in-situ, or in-line), regulatory acceptance, ability to handle both ionic and metal species (e.g. Pb, As, Cr, Cd, U, Sr), consistency of analytical results, treatment longevity, improved leachability control, and in most cases, reduction in waste volume. The poster presents the evolution of the MAECTITE® chemical treatment process, and offers a full-scale case study. The case study illustrates the treatment of lead contaminated soils from small arms target ranges at the Massachusetts Military Reservation. The authors believe that the advantages of chemical treatment/crystallization will establish it as the remediation method of choice for toxic heavy metals and radionuclides.

Steven A. Chisick, C.P.G.
Sevenson Environmental Services, Inc.
9245 Calumet Avenue, Suite 101
Munster, IN 46321
Tel: 219-836-0116
Fax: 219-836-2838
EMail: SevensonMW@aol.com

Charles B. McPheeters
Sevenson Environmental Services, Inc.
9245 Calumet Avenue, Suite 101
Munster, IN 46321
Tel: 219-836-0116
Fax: 219-836-2838
EMail: SevensonMW@aol.com

35) Application Of in vitro Bioaccessibility Test Data To A Public Health Risk Assessment Of ArsenicContaminated Soils. John Peters, Thomas Eschner, Harding Lawson Associates, and Thomas Strunk, Sudbury Annex BRAC Environmental Coordinator. Even progressive public health risk assessment techniques which incorporate relative absorption factors (RAFs) to compensate for differences in bioavailability between environmental and laboratory media, fail to consider site-specific factors that can substantially affect bioavailability. This is in particular the case for arsenic, which is typically found in a highly bioavailable form in water (the exposure medium associated with the majority of epidemiological data). Using standard risk assessment methods, arsenic is typically assumed to have the same bioavailability in all media, but may in fact be substantially less bioavailable in substrates such as soil. An in vitro study was used to develop estimates of the gastrointestinal bioaccessibility of arsenic in soils contaminated with up to 540 mg/kg arsenic. The bioaccessibility data were then used to derive an RAF for the soils of interest. The RAF was applied in the calculation of cancer and non-cancer risk estimates for human exposures at a facility with over 26 miles of arsenic-contaminated transportation corridors. Results of the in vitro study indicate that the bioaccessibility of arsenic in the soils of interest are 30% to 50% of the bioaccessibility of arsenic in water. Application of these data in human health risk assessment yields cancer and non-cancer risk estimates that are up to three times lower than estimates based on standard bioavailability assumptions for arsenic.

John Peters
Harding Lawson Associates
107Audubon Road
Wakefield, MA 01880
Tel: 781 -245-6606
Fax: 781-246-5060

Thomas Eschner
Harding Lawson Associates
511 Congress Street
Portland, ME 04101
Tel: 207-775-5401
Fax: 207-772-4762

Thomas Strunk
Sudbury Annex BRAC Environmental
Coordinator
30 Quebec Street, Building 666
P.O. Box 100
Devens, MA 01432-4429
Tel: 508-796-3839
Fax: 508-796-3133

36) A Literature Review of Anthropogenic and Natural Sources of Beryllium. David A Wright, ENSOL, Inc. and Thomas P. Army, ENSOL, Inc. Beryllium is a naturally occurring element found as a constituent in a number of minerals, and as a trace constituent in coal, alumina oxide clays, igneous rocks, and in soil. Beryllium first came into commercial use in the 1920s when beryllium alloys and refractories were produced. Beryllium may have been used as a rocket propellant in the late 1940s, and as a phosphor in lamps until the late 1940s. In recent years, the principal use of beryllium is in the production of copper-beryllium alloy, which is used in the semi-conductor, computer, and defense industries. The relatively specialized historic and present day industrial uses do not appear to account for the ubiquitous nature of beryllium in urban soils. The combustion of coal has been identified by a number of researchers as the principal anthropogenic input of Be into the environment, and the relative abundance of Be in urban soils appears likely to have originated from coal ash. The geochemistry of Be is described as being similar to the geochemistry of aluminum. Like aluminum, Be will form hydroxide complexes in solution, and its solubility is anticipated to be pH dependent, high at either pH extreme with a minimum near neutral pH values. This analysis suggests that the principal source of Be in urban soils is coal ash, and that the Be is likely to be relatively immobile in typical urban soils, which may support the presumption that Be observed in urban soils is derived from historical patterns of land use and not from an industrial release of Be. Such an argument suggest that a distinct background concentration for Be in urban settings may be appropriate.

David A. Wright
ENSOL, Inc.
100 Treble Cove Road
Billerica, MA 01862
Telephone: 978-670-0755
Fax: 978-670-0767

Thomas P. Army
ENSOL, Inc.
100 Treble Cove Road
Billerica, MA 01862
Telephone: 978-670-0755
Fax: 978-670-0767

37) Input/Output Tests for Chlorinated Dioxins and Furans during Catalytic Oxidation of VOC-laden Air. F.A.M. Buck and E. Anthony Lipka. King. Buck Technology. Ambient air samples taken close to an HD CatOxTM operating at Edwards Air Force Base, California, showed detectable levels of PCDD and PCDF (polychlorinated dibenzo-dioxins and -furans, respectively). The CatOx treats VOC-laden air from a remediation project using soil vapor extraction and air stripping of recovered groundwater. The subsurface contaminants are mixed petroleum VOC and chlorinated VOC; the Cl-VOC present at highest concentration is TCE (trichloroethene). The CatOx system includes a product-to-feed gas heat exchanger and an acid gas (HCl) quench and caustic scrubber. To see whether the catalytic oxidation process produces dioxins/furans as by-products, the U.S. EPA Region IX arranged a test sequence by a contractor using EPA and CARB (California Air Resources Board) test protocols. Three sets of samples were taken over three days and analyzed for 2,3,7,8-TCDD and numerous other PCDD and PCDF congeners. Samples were taken of the ambient air, from the inlet vapor stream to the CatOx, from two intermediate points within the CatOx, and from the effluent vapor discharge to ambient air after the HCl neutralizer. Test results are summarized as follows: (1) The concentrations of all dioxin/furan congeners upwind of the CatOx were higher than downwind. (2) The concentrations of dioxins/furans in the effluent vapor were lower than in the inlet vapor stream. Expressed as pg/dsm3 (picograms per dry standard cubic meter), the sum of all PCDD and PCDF congeners were inlet vapor = 896 and effluent vapor = 128. Thus, VOC reduction was accompanied by an 86% reduction in the dioxins/furans that were also being recovered from the subsoil and subsurface groundwater in the inlet vapor stream to the CatOx.

F.A.M. Buck
King, Buck Technology
2356 Moore Street, Ste 102
San Diego, CA 92110
Tel: 619-299-8431
Fax: 619-299-8437
e-mail: kingbuck@worldnet.att.net

E. Anthony Lipka
King, Buck Technology
2356 Moore Street, Ste 102
San Diego, CA 92110
Tel: 619-299-8431
Fax: 619-299-8437
e-mail: kingbuck@worldnet.att.net

38) Evaluation of the Well Stripper: An Innovative In-Well Ground-Water Treatment Technology. J.Patrick Byrnes, L.J. Buddy Bealer, EnviroTrac Ltd. and David A. McNeil, Shell Oil Products Co. The 1990ís have seen a dramatic increase of new and innovative remedial technologies for both soil and ground-water. This surge in technology development is the direct result of efforts to offer more effective cleanup alternatives, both technically and economically. One such technology, the Well Stripper, is presented and evaluated under field conditions. As with other in-situ technologies, the patent pending Well Stripper is based on the methods of in-situ well stripping and groundwater recirculation. Historically and often to this date, remediation of groundwater contaminated by volatile organic compounds (VOCs) is frequently accomplished by pumping followed by air stripping, commonly referred to as Pump and Treat. The Well Stripper employs the same principles as traditional air-stripper systems; however treatment occurs below the ground surface. The Well Stripper can be used to treat common VOCs such as chlorinated solvents and petroleum hydrocarbons. Results of field testing in New York and New Jersey demonstrate that the Well Stripper can be used as an effective remedial alternative to traditional Pump and Treat.

J. Patrick Byrnes
EnviroTrac Ltd.
561 P. Acorn Street
Deer Park, NY 11729
Tel: 516-586-1800
Fax: 516-586-1879

L.J. Buddy Bealer
EnviroTrac Ltd.
400 Corporate Court, Suite E
South Plainfield, NJ 07080
Tel: 908-757-1900
Fax: 908-757-0017

David A. McNeil
Shell Oil Products Co.
30 Jericho Executive Plaza
Suite 500 West
Jericho, NY 11753
Tel: 516-365-7240
Fax: 516-338-4369

39) A.I.R.2000 Process: Advanced Photocatalytic VOC Destruction Bill de Waal and Robert Brunet, Trojan Technologies, Inc; J.R. Kittrell, KSE, Inc.; Gregory Mackin, Collins and Aikman, Inc.: and Craig Wise, Ensafe, Inc.
At many Superfund sites, contaminated soils may be economically cleansed by soil vapor extraction (SVE). However, this can lead to air emissions of toxic air pollutants, often chlorinated hydrocarbons. An innovative air purification technology has been developed which destroys such contaminants, and is superior to conventional technology for managing toxic air emissions.

The Adsorption-Integrated-Reaction (A.I.R.) Process enjoys a proprietary photocatalyst to trap toxic contaminants from the air, while being illuminated and activated by ultraviolet (UV) light. This photocatalyst destroys the contaminants, producing environmentally safe products such as water and carbon dioxide. The process operates at ambient temperature, and only oxygen in the air is needed as a reactant. The technology has been recognized by the 1997 SBIR Technology of the Year Award for Environment, Energy & Resource Management, the 1998 R&D 100 Award, and the 1998 EPA Environmental Innovator Technology Award.

A case study is presented for the first installation of this innovative technology to destroy air emissions of chlorinated hydrocarbons from a SVE installation at the Stamina Mills Superfund Site, Rhode Island. **The A.I.R.2000** Process has achieved 99.99% destruction efficiency, avoiding the production of secondary wastes as in activated carbon treatment and at one-fiftieth the operating cost of carbon. The use of UV light bulbs to photocatalytically destroy pollutants provides simple controls. The unit can be turned on or off by a light switch. The ambient operating temperatures result in low energy consumption and low cost. The ambient temperature unit can be constructed of low-cost engineering plastics, rather than the expensive, exotic alloys used in high temperature oxidation. **The A.I.R.2000** Process has clear advantages over alternative air emissions control options.

Dr. William de Waal
Dr. J.R. Kittrell
Mr. Robert A.H. Brunet KSE, Inc.
Trojan Technologies, Inc.
P.O. Box 368
3020 Gore Road
London, Ontario N5V 4T7
Ph: (519) 457-3400
Fax: (519) 457-3030

Mr. Gregory N. Mackin
Collins & Aikman Products Co.
P.O.Box 32665
Charlotte, NC 28232
Ph: (704) 548-2091
Fax: (704) 548-2098

Dr. J.R. Kittrell
KSE, Inc
P.O.Box 368
Amherst, MA 01004
Ph: (413) 549-5506
Fax: (413) 549-5788

Mr. Craig A. Wise
Ensafe, Inc.
P.O.Box 34315
Memphis, TN 38184
Ph: (901) 372-7962
Fax: (901) 372-2454

MISCELLANEOUS

40) The Evolving Role of Treatability Studies in Remedy Screening, Selection and Design. Christopher C. Lutes and David S. Liles, ARCADIS Geraghty & Miller.
This paper and poster presentation will summarize the author's experience in conducting more then a hundred treatability studies for a wide variety of chemical, biological, and physical treatment technologies as well as in reviewing numerous studies conducted by other groups. Observations will be made on the following questions:
1) When and for what technologies is treatability testing necessary?
2) When is field pilot testing more appropriate then laboratory treatability testing?
3) Who is best able to conduct various types of treatability studies: the technology vendor, the engineering design firm or an independent testing organization?
4) What are the most common experimental design failings in treatability testing?
5) How has the role of treatability studies changed as remediation technologies mature?
6) How has the role of treatability studies evolved as the regulatory philosophy driving remediation has changed to emphasize voluntary cleanup programs, brownfields remediation, risk based corrective action?
A major theme of the paper will be how the practice of treatability testing has evolved since the publication of the EPA document series Guide for Conducting Treatability Studies under CERCLA in the early 90's. A second major theme will be that the appropriate role and nature of treatability testing changes for many technologies as they mature. Several case studies will be used to illustrate the issues discussed.

Christopher C. Lutes
ARCADIS Geraghty & Miller
4915 Prospectus Dr., Suite F
Durham N.C. 27713
Phone 919-544-4535
Fax 919-544-5690

David S. Liles
ARCADIS Geraghty & Miller
4915 Prospectus Dr., Suite F
Durham N.C. 27713
Phone 919-544-4535
Fax 919-544-5690

41) Mechanical Effects on Landfill and Mine Waste Liner Performance in Tropical Savanna Laterites The savanna region of Southern Brazil has limited amounts of the fine-grained soils that are usually required for construction of containments to isolate municipal, mining and industrial wastes. Thousands of years of wet - dry cycling and warm temperatures have severely altered the local residual soils. Weathering processes include leaching of silica, formation of kaolinites, and deposition of ferrous and aluminum oxides. The latter coats aggregations of finer grained particles to form saprolites and laterites with a sand-like texture, high porosity and high permeability (hydraulic conductivity). However, these soils can be disaggregated with added moisture and heavy compactive efforts, beyond that usually required to remold temperate fine-grained soils. This disaggregation exposes more surface area to interaction with permeants yet allows production of low permeability liners, dikes, and caps. Despite a low cation exchange capacity, these soils have the capacity for sorption of metals by the amorphous oxides over a range of pH levels.

Hydraulic control and contaminant sorption are not enough to create a sustained "artificial geology" of a waste disposal site. The containment components must display sufficient shear strength and stiffness to maintain overall dimensional integrity and design alignments. The focus of this work is a comparative study of geotechnical properties of two materials of similar particle mineralogy, but differing texture and geochemical behavior: a residual kaolinitic clayey silt from the Southeastern Pennsylvania Piedmont, and a similarly described soil from the Brazilian Savanna. The basic goal was to determine values of geotechnical properties such as shear strength and stiffness and the sensitivity of both parameters to the stress state. However, soil structure affects all properties. In the course of the study, other features such as the rate of saturation and the partially saturated permeability were determined. In the context of sites with limited useful (depositing) life, and seasonal moisture changes, such information is useful to determine if saturated analysis of in-situ behavior is appropriate at all.

Samples of both the temperate zone soil and the Brazilian savanna soil were compacted at optimum moisture content using the Nogami method. This was used in place of the customary Proctor method to better quantify volumetric sensitivity to compactive efforts, i.e. compare density to the level of applied energy. By either method, Nogami or Proctor, the tropical soils were about 10% less dense than the temperate soils, indicating that the original microstructure was preserved. Triaxial shear and flexwall permeameter tests were then run on prepared samples to establish relationships bewteen shear strength or permeability to the initial compaction energy and changing stress state. The flexwall tests showed significant decrease in permeability with increasing confining stress, indicating a greater assurance of liner sealing with increasing waste overburden. However, the method of saturation was varied to illustrate the magnitude of soil suction and its effects on initial liquid penetration. Permeation with non-reacting solutions was also done at intervals to determine changes in effective porosity. This data, in concert with the geochemical properties, will improve prediction of contaminant breakthrough times as well as steady-state seepage rate. However, an equally important result is generation of trends that influence physical stability.

Dr. Joseph P. Martin, Assoc Professor, Civil & Architectural Engineering Dept, Drexel Univ. Philadelphia, PA

Mr. Adam Hockenberry, Graduate Student, Civil & Architectural Engineering Dept, Drexel Univ. Philadelphia, PA

Dr. David H. Pohl, Project Manager, Roy F. Weston, Inc, West Chester, PA

MTBE

42) The Toxicology of MtBE - A Review of Current Literature. Richard A. Adams, Jr., Lincoln Environmental, Inc. The use of methyl tert-buytl ether (MtBE) in gasoline has been increasing dramatically since the late 1970s. MtBE is used as an octane enhancer in gasoline to promote cleaner combustion and thus reduce harmful emissions such as carbon monoxide to the atmosphere. MtBE's chemical properties allows it to be highly mobile in both soil and groundwater. Concerns regarding exposure to MtBE via inhalation, dermal contact, and to a lesser extent contaminated drinking water has prompted several toxicological studies. States such as California, Maine, and Alaska as well as the Environmental Protection Agency (EPA) have been evaluating the overall impact of the use of oxygenated fuels. Specifically, the majority of the studies-to-date have been conducted on laboratory animals in hope of extrapolating for possible human effects. The short term effects of exposure to MtBE is fairly well documented, however, the long term effects are a source of great contention. No toxicological data exists on the long term effects of human exposure to MtBE. Certain portions of the population appear to be sensitive to the new gasoline mixture and have reported dizziness, nausea, and increased asthma episodes. Several studies have shown an increased cancer risk associated with exposures to high concentrations of MtBE. Additionally, studies have also indicated that formaldehyde (a byproduct of MtBE) concentrations in the atmosphere are on the rise. Several studies have shown carcinogenic effects in rats associated with exposure to formaldehyde. However, the overall toxicological data suggests that MtBE can be toxic and even carcinogenic to humans at high concentrations but not at the lower concentrations that the general population are exposed.

Richard A. Adams, Jr.
Lincoln Environmental, Inc.
15 Park Drive
Westford, Massachusetts 01886
Tel: 978-392-7971
Fax: 978-392-7926

PAH

43) Polycyclic Aromatic Hydrocarbon Concentrations in Surface Soils of the Seneca-Babcock Neighborhood, Buffalo, New York. Donald W.R. Miles, Lloyd R. Wilson, G. Anders Carlson and Nancy K. Kim, New York State Department of Health. Polycyclic aromatic hydrocarbons (PAHs) are multi-ringed organic compounds of both man-made and natural origin. They are a health concern for possible cancer and non-cancer health effects. There are a limited number of studies evaluating PAHs in urban soils. This study provides data on urban soils in two residential neighborhoods with different histories of land use. We collected 24 soil samples in the Seneca-Babcock neighborhood of Buffalo, New York and 9 samples in a nearby neighborhood for comparison. We selected locations without bias, using a 160 meters grid superimposed over a map of each neighborhood. Each sample was collected from the surface to one inch deep. The concentration of 17 individual PAHs and the total PAHs and total carcinogenic PAHs in the two neighborhoods were statistically significantly different, with the concentrations in the Seneca-Babcock neighborhood averaging about twice the concentration of the other neighborhood. Concentrations of total PAHs averaged 30 milligrams per kilogram (mg/kg) and carcinogenic PAHs averaged 15 mg/kg in the Seneca-Babcock neighborhood. These concentrations are higher than the data reported in the literature for other residential neighborhoods and are attributed to a long history of commercial and industrial uses, including energy production, vehicular traffic and industrial emissions.

Donald W.R. Miles, Research Scientist
Bureau of Environmental Exposure Investigation
New York State Department of Health
2 University Place
Albany, NY 12203
Tel: 518-458-6316
FAX: 518-458-6372
E-Mail: dwmO3@health.state.ny.us

Lloyd R. Wilson, Ph.D., Research Scientist
Bureau of Environmental Exposure Investigation

G. Anders Carlson, Ph.D., Director
Bureau of Environmental Exposure Investigation

Nancy K. Kim, Ph.D., Director
Division of Environmental Health Assessment

PHYTOREMEDIATION

44) Phytoremediation of Lead Contaminated Soils with Perennial Plants. Ruby S. Beil, A. Martin Petrovic and Thomas H. Whitlow, Cornell University, Leon V. Kochian and Wendell A. Norvell, USDA-ARS Plant, Soil & Nutrition Laboratory. Lead (Pb) contamination of surface soils is considered one of the most frequently encountered problems of environmental concern, and Pb toxicity in humans is known to be an immediate environmental risk associated with Pb-contaminated soils. Phytoextraction, using plants to remove chelated metal ions from soil, is a popular subject of recent phytoremediation research. Major limitations of lead phytoextraction are low Pb availability in soil and poor Pb translocation from roots to shoots. These limitations indicate that the accumulation of lead in shoots can only be feasible through the application of synthetic chelation agents, such as EDTA, which facilitate metal solubility, uptake, and translocation. The induced phytoextraction of Pb from contaminated soil has already been demonstrated by Brassica juncea (indian mustard), but B. juncea may not be ideal for phytoextraction because of its low biomass and annual nature. Tree and turf species have yet to be discovered as possible candidates for Pb-phytoextraction. The objective of this study is to induce lead uptake from contaminated soil in low-imput perennial plants, Festuca arundinacea (tall fescue) and Acer rubrum (red maple), through the proper timing and application of the chelation agent, EDTA. This study evaluates the ability of F. arundinacea, A. rubrum, and the control species, B. juncea, to remove Pb from soil according to the following criteria: transpiration rates; leaf areas; dry weights of harvested and separated roots, shoots, and leaves; concentrations of Pb in harvested and separated plant tissues; concentrations of applied EDTA ranging from 0.0 to 12.0 g EDTA per kg soil; decreases in total soil Pb concentrations; and amounts of soluble Pb leaching through greenhouse lysimeters.

Ms. Ruby S. Beil
Cornell University
48-C Plant Science Building
Ithaca, NY, 14850
Tel: 607-255-9405
Fax: 607-255-9998
e-mail: rsb12@cornell.edu

Dr. A. Martin Petrovic
Cornell University
29-A Plant Science Building
Ithaca, NY, 14850
Tel: 607-255-1796
Fax: 607-255-9998
e-mail: amp4@cornell.edu

Dr. Thomas H. Whitlow
Cornell University
14 Plant Science Building
Ithaca, NY, 14850
Tel: 607-255-1793
Fax: 607-255-9998
e-mail: thw2@cornell.edu

Dr. Leon V. Kochian
USDA-ARS Plant, Soil and Nutrition Laboratory
Cornell University
Ithaca, NY, 14850
Tel: 607-255-2454
Fax: 607-255-2459
e-mail: lvk1@cornell.edu

Dr. Wendell A. Norvell
USDA-ARS Plant, Soil and Nutrition Laboratory
Cornell University
Ithaca, NY 14850
Tel: 607-255-8808
Fax: 607-255-2459
e-mail: wan1@cornell.edu

45) Genetic Engineering of Plants for the Phytoremediation of Methylmercury Contamination. Scott P. Bizily and Richard B. Meagher, University of Georgia. Methylmercury (CH_3Hg^+) is an environmental toxin that biomagnifies through the aquatic food chain. Despite being present at very low levels in contaminated waters, it may be concentrated 6 to 8 orders of magnitude in fish and their predators. In order to remediate polluted wetlands, we are proposing to use aquatic plants to filter out CH_3Hg^+ and detoxify (demethylate) it. The inorganic product, Hg(II), could then be sequestered in plant tissues or reduced to the volatile, less reactive form, Hg(0), which evaporates from plant tissue and is vastly diluted in the atmosphere. Because plants do not naturally catalyze mercury conversions, we have taken a transgenic approach and engineered them to express two bacterial enzymes, organomercurial lyase (*merB*) and mercuric reductase (*merA*). By transforming the model species Arabidopsis thaliana and Tabacum nicotiana with merB, we have enabled them to degrade methylmercury absorbed from growth substrates and survive on concentrations that are at least 50X those that kill untransformed plants. Furthermore, by coupling merB with merA, we have constructed plants that will remove (volatilize) Hg(0) from a solution containing 25µM organic mercury. ***MerA/merB*** plants also survive on higher concentrations of CH3Hg+ than merB plants, suggesting that they do not significantly accumulate Hg(II). We are currently preparing aquatic monocots with the *merA and merB* genes and designing experiments to assess whether mer-containing plants remove mercury from natural soils.

Scott P. Bizily
Genetics Department
Life Sciences Bldg.
University of Georgia
Athens, GA 30605
Tel: 706-542-1410
email: sbizily@arches.uga.edu

Richard B. Meagher
Genetics Department
Life Sciences Bldg.
University of Georgia
Athens, GA 30605
Tel: 706-542-1444
email: meagher@arches.uga.edu

46) Using Phytoremediation To Address Contaminated Soil At An Active Facility In Wisconsin - An Update. Eric P. Carman and Tom L. Crossman, ARCADIS Geraghty & Miller. Edward G. Gatliff Applied Natural Sciences. A fuel oil release occurred in the 1970s at an industrial facility in Wisconsin. Petroleum hydrocarbons in groundwater are below Wisconsin's groundwater standards, although soil contamination in the vadose zone (measured as diesel range organics [DRO]) in hotspots at the facility remain above standards. Bench-scale testing was performed to determine the feasibility of soil bioremediation and the best method to enhance bioremediation of soil at the facility. DRO in soil samples decreased 40% to 90% during a 24 week bench-scale bioventing study. After evaluating several options for bioremediation, phytoremediation was selected to enhance the subsurface conditions for microbial growth and promote bioremediation of the soil within the rhizosphere of trees. An agronomic assessment indicted that conditions were favorable for tree growth and phytoremediation was implemented as a low-cost in-situ bioremediation alternative. Willow trees were planted in the hotspots in May 1996 and trees have exhibited fair to excellent growth in the first three growing seasons. Tissue samples collected from trees have assisted in developing an onging fertilizing program and insecticides have been applied annually. Water levels in nearby wells have been measured beginning in Spring 1997 to determine the effect of the trees on subsurface conditions. Direct observations of roots show that the rhizosphere is expanding across the soil hotspots as the trees grow. Soil samples will be analyzed in late 1998 to determine if DRO concentrations are decreasing as a result of the phytoremediation program.

Eric P.Carman
ARCADIS Geraghty & Miller, Inc.
126 North Jefferson St., Suite 400
Milwaukee, WI 53202
Tel: 414-276-7742
Fax: 414-276-7603

Tom L. Crossman
ARCADIS Geraghty & Miller, Inc.
14497 N. Dale Mabry Hwy., Suite 115
Tampa, FL 33618
Tel: 813-264-3404
Fax: 813-264-1850

Edward G. Gatliff
Applied Natural Sciences
7225 Dixie Hwy.
Fairfield, OH 45014
Tel: 513-942-6061
Fax: 513-942-6071

47) Transpiration in Black Willow Phytoremediation Plots a Determined by Heat Balance Methods. Robert Mark Conge BASF Corporation, and Dr. Ralph J. Portier, Louisiana Stat University, Institute for Environmental Studies. TV process of transpiration is a critical factor to derive th net water flux in phytoremediation plots. This flux is E important variable to model the groundwater flow and solut transport and ultimately determine the time expected t achieve remedial goals. Determining growth rate is anothe important factor in order to accurately predict futul transpiration for such modeling efforts. TV phytoremediation plots of black willow (*Salix niger*) were planted during October 1996 over separate shallot groundwater plumes at a site in South Louisiana Concentrations of less than 10 mg/l of the herbicide bentazon were present in shallow groundwater less than one half meter below ground. Two-meter plant spacing was used is both plots which are slightly more than 0.1 and 0.3 hectare in size and contain 438 and 1000 trees respectively. In June 1998, experiments to measure sap flow using the heat balance method for small diameter trees and the thermal dissipation method for large diameter trees were begun. These sap flow measurements provided an indication of transpiration in the black willow phytoremediation plots. Strain gauge dendrometers were used to determine the growth rates on each plot. Sap flow was indexed to the stem area and the maximum effective water flux was estimated for each experiment.

Robert Mark Conger
BASF Corporation
P.O. Box 457
Geismar, LA 70734
Tel: 504-339-7941
Fax: 504-339-2369

Dr. Ralph J. Portier
LSU Institute for Environmental Studies
18 Atkinson Hall
Baton Rouge, LA 70803
Tel: 504-388-8521
Fax: 504-388-4286

48) First Phytoremediation Project in New Hampshire. E.W. Peter Jalajas, ARCADIS Geraghty & Miller, Inc. The site is a residential property in rural southern New Hampshire. Beginning in the 1940s, approximately 400 ill-managed drums of hazardous waste (chlorinated solvents, aromatics, ketones) came to be located on the site. After conducting the RI/FS, USEPA issued the Record of Decision for the site in 1992. The selected remedy involved conventional pumping and treating the groundwater and soil vapor extraction. This remedy was estimated to cost the client PRP $30,000,000. ARCADIS Geraghty & Miller designed an innovative remediation system in place of a conventional groundwater extraction and treatment system. Our strategy at this site (estimated cost: $5,000,000) is multi-faceted, including vacuum-enhanced recovery (VER), capping, phytoremediation, and natural bioattenuation. VER was used from 1995 through 1997 to quickly remove the regulated compounds from the vadose zone. Active (expensive) on-site remediation work at this site has been reduced from an estimated 20 years to a maximum of 3 years with this change to remediation design. The VER design system will be replaced with a passive (inexpensive) phytoremediation system to be installed in spring 1998. The phytoremediation system will increase oxygen levels in the subsurface, perform plume control, and complete the mass removal from the vadose zone and shallow groundwater. Additionally, subsequent to the active mass removal of the VER and phytoremediation phases, natural attenuation will bring the groundwater concentrations to cleanup levels in 10 to 20 years. The phytoremediation controls plume migration by growing densely-planted, deep-rooted hybrid poplar trees, one of the fastest growmg metabolisms in the plant kingdom. A description of planned installation, monitoring, and maintenance activities will be presented.

E.W. Peter Jalajas
ARCADIS Geraghty & Miller, inc.
175 Cabot Street, Suite 503
Lowell, MA 01854
Tel: 978-937-9999 x315
Fax: 978-937-7555

49) Phytoremediation Potential of Yucca Plants. . Victor F. Medina. Kerry Prindeville, Steven L. Larson and Steven C. McCutcheon. Washington State University, Tri-cities. The Crane Naval Weapons Station is located in south-central Indiana. It is the site of a weapon's testing and firing range and of weaponís packing and loading facility. Both of these activities have led to contamination by munitions: 2,4,6-trinitrotoluene (TNT), RDX and their amino-derivatives. Yucca plants were found growing in areas heavily contaminated with munitions. Other plants found in uncontaminated parts of the area do not grow in these contaminated areas, presumably because of toxic affects from the munitions. Analytical results on the yucca plants indicate that they accumulate munitions at high levels. Research has indicated that certain plant enzymes can degrade many explosives, including TNT and RDX. The possibility of phyto-transformations of the munitions by yucca plants is being investigated. Amino-derivatives of TNT were found in the plant tissue, suggesting phyto-degradation may also be occurring. Phytoaccumulation of munitions by yucca plants, with or without phytodegradation, could lead to a cost-effective treatment for soils contaminated with munitions.

Victor F. Medina
Washington State University, Tri-cities
2710 University Dr.
Richland, WA 99352
Tel: 509 372 7306
Fax: 509 372 7471

Steven L. Larson
USACE-WES
3909 Halls Ferry Rd.
Vicksburg, MS 39180
Tel: 601 634 3431
Fax: 601 634 2742

Kerry Prindeville
Washington State University, Tri-cities
2710 University Dr.
Richland, WA 99352
Tel: 509 372 7306
Fax: 509 372 7471

Steven C. McCutcheon
USEPA/NERLA
960 College Station Road
Athens, GA 30605
Tel: 706 355 8235
Fax: 706 355 8440

50) Vegetative Growth and Trace Metal Accumulation on Metalliferous Wastes J. Pichtel, Ball State University, and Carol A. Salt, University of Stirling, Scotland.

Many sites in the UK, including abandoned metal workings, closed mines, and chemical facilities are contaminated with suites of metals. The degree of contamination poses at worst a public health threat, and is at a minimum detrimental to plant growth, with the potential for soil erosion, runoff of metallic effluents, groundwater contamination, and the development of aesthetically unsightly situations. A greenhouse study was conducted to investigate the growth of the grass cover crops *Agrostis capillaris, Festuca ovina, F. rubra, Lolium perenne*, and *Phleum pratense* and their accumulation of Cu, Pb, Zn, Ni and Cr in three metal-contaminated wastes arising from a steelworks, a lead mine, and a chemical works. Soil metals were extracted by five reagents (Mehlich 1, 0.1 M HCl, 0.005 M DTPA, 0.005 M EDTA, 0.005 M NTA) and values were correlated with plant tissue accumulation of metals. *Agrostis capillaris* accumulated the greatest concentration of metals from each waste material. Dry matter production for all grasses decreased on contaminated substrates compared to the control; however, overall ground cover was satisfactory except for *A. capillaris* on the chemical works waste. *Lolium perenne and P. pratense* consistently produced the highest dry matter yields. All grasses accumulated significant amounts of Cr on the chemical waste and Pb on the mine waste, presumably from reservoirs in the readily-extractable and soluble forms. The extractability of most metals was generally 0.1 M HCl > Mehlich 1 > DTPA=EDTA=NTA. No extractant was able to represent metal uptake by a particular grass in a linear fashion.

John Pichtel
Ball State University
Natural Resources and Environmental Management
Muncie, IN 47306-0495
Tel: 765-285-2182
Fax: 765-285-2606

Carol A. Salt
University of Stirling
Department of Environmental Science
Stirling FK9 4LA
United Kingdom
Tel: 1786 467840
Fax: 1786 467843

51) Rhizosphere-Enhanced Benefits for Remediating Recalcitrant Petroleum Compounds. Charles M. Reynolds, Chad S. Pidgeon, Lawrence B. Perry, U.S. Army Cold Regions Research and Engineering Laboratory, Terry J. Gentry, Duane C. Wolf, University of Arkansas. We evaluated the ability of winter rye (Secale cereale L.) to enhance bioremediation of jars of petroleum contaminated soil contaminated withf both aged and recent petroleum compounds. We monitored s oil concentrations of total petroleum hydrocarbons and selected petroleum constituents.. as well as four organic constituents of petroleum in soil vegetated with winter rye or left bare. Vegetation did not significantly increase the total amount of alkanes removed during the incubation period but did enhance their initial removal rates. Rapid disappearance of alkanes in the vegetated soil was followed by a significant increase in the rate and extent of removal of recalcitrant compounds. At the end of 26 weeks 8% of the original pristane remained in the vegetated soil compared to 36% remaining in the unvegetated soil. Reduction of pyrene was 46% in the vegetated soil compared to 1% in unvegetated soil. These data demonstratedsuggest that rhizosphere-enhanced remediation increased treatment rates ofmay help speed removal of thereadily metabolized and fractions as well as the more recalcitrant petroleum fractions. Enhanced remediation rates would be beneficial in cold regions where field operations are limited by cost, location, or climate.

Charles M. ReynoldsU.S. Army Cold Regions Research and Engineering Laboratory (USA-CRREL)
72 Lyme Road
Hanover, NH 03755
Tel. 603 646 4394
Fax 603 646 4561

Chad S. Pidgeon
USA-CRREL
72 Lyme Road
Hanover, NH 03755
Tel. 603 646 4343
Fax 603 646 4561

Lawence B. Perry
USA-CRREL
72 Lyme Road
Hanover, NH 03755
Tel. 603 646 4624
Fax 603 646 4561

Terry J. Gentry
Department of Agronomy
University of Arkansas
Fayetteville, AR 72701
Tel. 501 575 5735
Fax 501 575 7465

Duane C. Wolf
Department of Agronomy
University of Arkansas
Fayetteville, AR 72701
Tel. 501 575 5739
Fax 501 575 7465

RADIONUCLIDE

52) An Overview of the Installation of Horizontal Wells For Groundwater Extraction At Brookhaven National Laboratory. Joseph Carelli, Brookhaven National Laboratory, Alex Lowe, A&L Underground, Inc., Nicholas C. Pressly, Pressly Associates, Inc. This paper reports on the success of a horizontal well drilling project performed under radiological controls for both a Radiation Area and Contamination Area. Two horizontal wells were installed to access groundwater containing radioactive tritium beneath the High Flux Beam Reactor (HFBR). The objective was to identify potential source areas which included the spent fuel canal and a potential up-gradient source known as S3. This was to be achieved by assessing groundwater quality over time, taking into account seasonal fluctuations in the water table elevation. In addition, the wells were designed to provide a means of future groundwater extraction, if required. The wells were placed up-gradient and down-gradient of the spent fuel canal, which is suspected to be the primary source of the tritium leak. Future sampling from the horizontal wells will be used in conjunction with other data from nearby vertical wells to verify or eliminate potential source(s) of the tritium contamination. The success of the drilling project was based on an appropriate well design, a comprehensive drill fluid management plan, and accurate placement of the well screen and casing. The drilling systems and equipment used in combination with a carefully planned well design were the key to meeting target parameters for a successful horizontal well completion.

Joseph Carelli
Brookhaven National Laboratory
75 Cornell Ave. Bldg 750
Upton, NY 11973
516-344-5979
Fax: 516-344-5822

Alex Lowe
A & L Underground, Inc.
201 E. Loula
Olathe, KS 66051
913-829-0167
Fax: 913-829-3264
alex@alunderground.com

Nicholas C. Pressly
Pressly Associates, Inc.
15 Ocean Place
Brookhaven, NY 11719
516-286-5890
Fax: 516-776-0245

53) **Environmental Assessment and Cleanup at MBTA's Commuter Rail Maintenance Facility (CRMF).** Peter H. Baril, Albert Ricciardelli, GZA GeoEnvironmental, Inc. and David Agnello, Gannett Fleming. The Massachusetts Bay Transportation Authority (MBTA) operates the CRMF, a 36-acre railroad engine yard in Somerville, Massachusetts. Over the past 10 years, comprehensive environmental site assessment activities have occurred at the CRMF leading to the successful implementation (in 1997) of a groundwater treatment facility. The historic use of the site, large quantity storage of fuel oil, extensive network of underground utilities, and on-going facility-wide reconstruction activities provided special challenges in the assessment, design and implementation of remedial response actions at this 100-year- old site. The project scope included assessing the nature and extent of soil and groundwater contamination, designing and constructing a remedial system, along with Massachusetts Contingency Plan (MCP) and NPDES surface discharge permitting compliance. Subsurface explorations and chemical testing confirmed the presence of petroleum hydrocarbon contamination (primarily diesel) in soil, groundwa-ter, and as separate phase product. Laboratory and on-site pilot-scale tests identified appropriate technologies for treating recovered groundwater consisting of a highly emulsified mixture of oil and water. The treatment system consists of eleven groundwater/product recovery wells, gravity oil/water separator, dissolved air flotation, granular activated carbon contactors, plus belt filter press for mechanical dewatering of sludge. Future work will include implementation of an additional subsurface exploration program to provide confirmatory soil and groundwater data and an updated Risk Characterization leading to closure under the MCP.

Peter Baril, LSP
GZA GeoEnvironmental, Inc.
320 Needham Street
Newton, MA 02164
Tel: (617) 630-6396
Fax: (617) 965-7769

Albert Ricciardelli, LSP
GZA GeoEnvironmental, Inc.
320 Needham Street
Newton, MA 02164
Tel: (617) 630-6277
Fax: (617) 965-7769

David Agnello, P.E.
Gannett Fleming
150 Wood Road
Braintree, MA 02184-2509
Tel: (781) 380-7750
Fax: (781) 380-7754

54) **Investigation of Lead Impacted Soil using Portable XRF Field Screening Instrument.** Thomas A. Dahl, Kurt M. Geiser, and Steve C. Geiger, RETEC. A remedial investigation (RI) and corrective action was conducted at a former railroad facility where lead is a primary chemical of concern. The site covers approximately 40 acres. Due to the size of the site and planned development as a business park, a rapid, real-time field method for measuring soil lead concentrations was needed. A portable x-ray fluorescence (XRF) instrument was used to field analyze the soil samples collected for lead. During corrective actions, the XRF was used to direct excavation of lead impacted soils. Depending on the work being conducted, 10 to 25 percent of soil samples were submitted to a laboratory for total lead analysis to confirm the accuracy of XRF results. This data was used to determine a statistical correlation between the XRF field analysis results and laboratory results. Based on the statistical correlation, the XRF was determined to be an effective field method for delineating the extent and magnitude of lead impacts to soil. It was also determined that increased sample preparation provided a stronger correlation of XRF results when compared to laboratory results. Approximately 2,400 XRF field measurements were collected for this project. Using only laboratory analytical methods to define lead impacts at this site would have been unrealistic and more costly than XRF field methods given the scope and time constraints for completing this project. The XRF has proven to be a cost effective, time efficient, and reliable method for identifying lead concentrations in soil.

Thomas A. Dahl
RETEC
413 Wacouta Street, Suite 400
St. Paul, MN 55101
Tel: (651) 222-0841
Fax: (651) 222-8914

Kurt M. Geiser
RETEC
413 Wacouta Street, Suite 400
St. Paul, MN 55101
Tel: (651) 222-0841
Fax: (651) 222-8914

Steve C. Geiger
RETEC
1005 W. Ninth Ave.
Suite A.
King of Prussia, PA
15238-1359
Tel: (610) 992-9950

55) **Remedial Design Contingency Plan Guidelines For A Former Railyard Site.** James M. Pietrzak, P.E., Mark Cambra, P.E., NES, Inc. The former railyard Superfund site located in southeastern Pennsylvania consists of a 28-acre railyard and the surrounding 400-acre watershed. The watershed area includes residential properties and was the primary area of concern. Oils containing PCB's were used, handled, stored, treated, transported and disposed at the site. During the Remedial Investigation, soils were sampled from the nearby residential area yards and along roadway drainage features. These samples had PCB concentrations in excess of 10 ppm. PCB's were also detected in stream area sediments and at elevated concentrations in fish from local creeks. The primary intent of the Remedial Design Contingency Plan (Plan) was to complete the preparation of design work for the approved remediation goals. The Plan was intended to insure compatibility between the EPA, the Client, the Remedial Design Professional, State and local authorities. This compatibility formulated a basis to resolve any potential failures and/or problems of the design components. These failures included unforeseen situations that may occur during the design and subsequent construction. The Plan stipulated responses to a variety of situations that may occur during field work, sample collection, pilot testing, analyses, and throughout the design process. The Plan supplemented the Health and Safety Plan (HASP) that controls emergency response, site monitoring, and environmental issues. The anticipated insufficiency and problem areas that may be experienced were considered during the design contingency planning phase of the project. These areas were investigated in project planning and were included in the Plan.

James M. Pietrzak, P.E.
NES, Inc.
44 Shelter Rock Road
Danbury, CT 06810
Telephone: (203)796-5241
Fax #: (203)792-3168

Mark Cambra, P.E.
NES, Inc.
44 Shelter Rock Road
Danbury, CT 06810
Telephone: (203)796-5305
Fax #: (203)792-3168

RBCA

56) The Past and Present of Risk-Based Corrective Action. Shawn L. Sager and Eric M. Rainey, ARCADIS Geraghty & Miller, Inc. Risk-based corrective action (RBCA) represents a significant change in how regulatory agencies look at site closure. The initial push for RBCA came from the petroleum industry which found itself upgrading tanks, addressing releases, and not having access to reimbursement funds to cover some of all of their costs. Regulatory agencies realized if reimbursement funds were failing, a new approach needed to be identified to allow reimbursement funds to meet costs and remain solvent. A task group affiliated with the American Society for Testing and Materials (ASTM) developed the RBCA standard for petroleum release sites (E 1739) which was finalized in 1995. Concurrently, the U.S. Environmental Protection Agency (USEPA) , in a cooperative agreement with ASTM, developed a training program for state regulators. To date, 46 states and territories have expressed interest in RBCA training and several have implemented RBCA for petroleum release sites. Although ASTM Standard E 1739 is focused on petroleum sites, it is a good starting point for other sites wither similar constituents. To that end, some states are applying RBCA to hazardous waste sites. This paper focuses on the RBCA standard and a description of the risk-based decision making process. A case study utilizing the RBCA process to obtain closure for an underground petroleum release site in Oklahoma is presented.

Shawn L. Sager, Ph.D.
ARCADIS Geraghty & Miller, Inc.
2840 Plaza Place, Suite 350
Raleigh, NC 27612
Tel: 919-571-1662
Fax: 919-571-7994

Eric M. Rainey, P.G.
ARCADIS Geraghty & Miller, Inc.
5100 E. Skelly Drive, Suite 1000
Tulsa, OK 74135
Tel: 918-664-9900
Fax: 918-664-9925

57) Streamlining the Multi-Agency Project with End-Based Objectives: A Case Study. Brian A. Finnell, R.G., C.E.G., ENSR. An electric utility company in the Northeast is currently under permit requirements to complete RCRA Corrective Action activities at one of their facilities. In addition, the utility is under an Order on Consent (the Order) to investigate and remediate, as necessary, historical oil spills from past operations at the facility. The New York State Department of Environmental Conservation's (NYSDEC) Division of Hazardous Substances Regulation has authority over RCRA Corrective Action activities while NYSDEC's Spills Management Division has authority over spillrelated activities.

Both the RCRA Corrective Action program and the spills program require the same types of activities, such as soil and groundwater sampling and delineation of impacted areas, and both programs have the same end-point: evaluating and mitigating identified risks posed by environmental impacts at the facility. However, since these programs are being overseen by two separate agency departments, there is a potential that drastically different requirements could be developed for what are essentially, the same activities. From the facility's point of view, the objective is to formulate one program which addresses the concerns of both agency departments while minimizing repetitive activities, streamlining the agency oversight process, and reducing the ultimate costs of both programs.

This paper discusses how a multi-agency program was developed for this facility. The objectives of both the RCRA Corrective Action program and the spills program and how these objectives are incorporated into a site-wide program which focuses on end-based objectives are discussed. Various strategies used to streamline agency oversight are presented. In addition, we introduce how the investigative activities for both programs were incorporated into a site-wide plan.

Brian A. Finnel l, R.G., C.E.G.
ENSR
35 Nagog Park
Acton, MA 01720
Email: Bfinnell@ensr.com
Tel: 978-635-9500
Fax: 978-635-9180

58) EPH/VPH. **E.W.** Peter Jalajas, ARCADIS Geraghty & Miller, Inc., Lowell, Massachusetts, Shawn Sager, ARCADIS Geraghty & Miller, inc., Raleigh, North Carolina. If you didn't know any better, during a MADEP MCP risk assessment, you might go to the unnecessary expense of collecting new EPH/VPH data at areas of your site where you have only old TPH data. This presentation is intended to increase the awareness that MADEP guidelines permit the estimation of the EPH/VPH parameters results in areas of sites where only TPH results have been obtained in the past. This estimation of EPH/VPH results for historic data is permissible when the old TPH data and the new EPH/VPH data have been confirmed to have been collected from the same OHM. The presentation will describe a case study risk assessment where following this new guidance saved several thousand dollars of sampling and analytical costs.

Author One:E.W. Peter Jalajas
ARCADIS Geraghty & Miller, inc.
175 Cabot Street, Suite 503
Lowell, MA 01854
Tel: 978-937-9999 x315
Fax: 978-937-7555

Shawn Sager
ARCADIS Geraghty & Miller, inc.
Cross Pointe II
2840 Plaza Point
Suite 350
Raleigh, NC 27612
Tel: 919 571-1662
Fax: 919 571-7994

59) RESOLVING PROBLEMS WITH ON SITE STABILIZATION OF LEAD-CONTAMINATED SOIL: CASE STUDY Dean Tagliaferro, Mary Ellen Stanton. U.S. Environmental Protection Agency Cleanup of highly contaminated soils at a former scrap yard presented interesting technical challenges. Over 15,000 tons of soil with lead levels of up to11 percent were treated with a stabilization agent, Portland cement, and disposed of as non-hazardous material. Complications were encountered with achieving "passing" Toxicity Characteristic Leaching Procedure (TCLP) test results during the full scale soil stabilization project. A treatability study performed prior to mobilizing to the site indicated that a cement to soil ratio of 10 to 30 percent cement would result in successful treatment of the waste. However, once on-site operations began, approximately 35 percent of the TCLP tests performed indicated failure. EPA site managers (OSCs) reviewed all operational parameters and performed additional treatability studies. However, they did not resolve the problem until they thoroughly reviewed all the "raw data" for the TCLP tests performed on the stabilized samples. The presentation will discuss the critical factors affecting the TCLP test results, including the test requirement that one of two different extraction fluids may be selected during analysis. The apparent randomness with which the extract fluid could be selected caused EPA great difficulty in resolving the problems with chemical stabilization. Prior to understanding the intricacies of the test, EPA took corrective action based solely upon TCLP data. This resulted in unexpected and unsuccessful consequences. Only by acquiring a thorough knowledge of the TCLP procedure and by reviewing the TCLP raw data, was EPA able to determine that, for this waste material at this site, a low cement to waste soil ratio was necessary to achieve successful stabilization.

Dean Tagliaferro
US EPA OSC
90 Canal Street
Boston, MA 02114
TEL: (617) 223-5596
FAX: (617) 573-9662

Mary Ellen Stanton
US EPA OSC
90 Canal Street
Boston, MA 02114
TEL: (617) 573-9670
FAX: (617) 573-9662

REMEDIATION

60) CROW™ Remediation Demonstrations. Lyle A. Johnson Jr and L. John Fahy, Western Research Institute and Alfred P. Leuschner, Remediation Technologies, Inc. Western Research Institute began adapting secondary and heavy oil recovery technologies to remediate industrial sites contaminated with dense, nonaqueous-phase liquids (NAPLs) in the mid-1980's. One such process, the Contained Recovery of Oily Wastes (CROW™) process uses hot-water or steam displacement to reduce organic contaminants in subsurface soils and underlying rock. The organic contaminants are mobilized by controlled insitu heating and are displaced to extraction wells for recovery. The remediation area is hydraulically isolated so that contamination is not spread into uncontaminated areas and the downward penetration of dense organic liquids is reversed. The recovery of the mobilized material leaves an immobile residual organic saturation and greatly enhances conditions for microbial degradation. The CROW technology was successfully tested in the laboratory as part of the U.S. Environmental Protection Agency SITE Emerging Technology Program and was then advanced to the SITE Demonstration Program. The site selected for the demonstration project was a former manufactured gas plant site which was contaminated with a dense coal tar. Another CROW remediation project is also being operated at an active wood treatment facility in New Brighton, Minnesota. As of May 1998, 2267 cubic meters or 25% of the estimated oil in the pattern area had been recovered. A third CROW remediation demonstration to clean up a large underground coal tar holder was completed in early 1998. Hot-water or steam was injected at the outer edge of the tar holder while water and coal tar were removed from a center well. Over 180 cubic meters of coal tar were removed. Produced water was treated with activated carbon and disposed.

Lyle A. Johnson Jr.
Western Research Institute
365 North Ninth Street
Laramie, WY 82072
Tel: 307-721-2281
Fax: 307-721-2233

L. John Fahy
Western Research Institute
365 North Ninth Street
Laramie, WY 82072
Tel: 307-721-2348
Fax: 307-721-2233

Alfred P. Leuschner
Remediation Technologies, Inc.
Damonmill Square, 9 Pond Lane
Concord, MA 01742
Tel: 978-371-1422
Fax: 978-369-9279

61) **Kinetic Analysis of Pilot Test Results of Simultaneous Co-Treatment of a Chlorinated Solvent Plume Overlain by a BTEX Plume by the C-Sparge™ Process.** William B. Kerfoot, Ph.D.K-V Associates, Inc., Ing.C.J.J.M. Schouten MSc. MateboerMilieutechniek B.V., Mw. Drs. V.C.M van Engen-Beukeboom,Bureau Bodemsanering. Plume regions often contain mixtures of dissolved chlorinated solvents and petroleum products,presenting a need for co-treatment. The following reportdescribes a pilot test and kinetic analysis of the C-Spargeprocess for remediation of a deep plume of dissolved chlorinated solvents in groundwater. A 900 ft long, 60 ftwide plume of dissolved trichloroethene was overlain by a separate plume originating from an underground storage tank leak of dissolved petroleum volatile organic compounds (VOC's; BTEX). Both sets of compounds were treated during a test conducted by Mateboer Milieutechniek B.V. for the Provincial Government of Utrecht in the vicinity of Rembrandt Street in Bilthoven, The Netherlands, from March 27th through April 4, 1997. The C-Sparge system was designed to inject and distribute microbubbles into the fine sandy aquifer. The presence of microbubbles, gas release, dissolved oxygen changes and halogenated volatile organic compounds (HVOC) change defined the enlarging treatment zone over the ten day period. Based upon time sequence, a long axis extending outwards over 100 ft (30 m) in a westerly and easterly direction was reached with a minor axis (at right angles) of about 56 ft (18 m) from a single treatment spargewell. A gyre generated beside the spargewell had a three day rotation characterized by circular groundwater movement and chemical tracer changes.

A kinetic analysis of the reaction rates was performed. HVOC concentrations of up to 14,500 ug/l(ppb) were reduced to below 1000 mg/l(ppb) during the 10 day test. Both HVOC and BTEX concentrations exhibited a logarithmic decay rate between .09 and .14t (HVOC) and between .07 and .20t (BTEX). The time to bring the treated 3-dimensional region to 1 ppb was computed. With HVOCs the time ranged from 50 to 100 days. For BTEX compounds, the time ranged between 20 and 60 days.

William B. Kerfoot, Ph.D
K-V Associates, Inc.
766 Falmouth Road, #B-12
Mashpee, Massachusetts 02649
Phone: (508) 539-3002
Fax: (508) 5393566

Ing.C.J.J.M. Schouten MSc.
Mateboer Milieutechniek B.V.
Steurstraat 7
1317 NZ Almere The Netherlands
Phone: 011 31 36 5302410
Fax: 011 31 36 5301128

Mw. Drs. V.C.M van Engen-Beukeboom
Provincie Utrecht
Bureau Bodemsanering
Dienst Water en Milieu
Postbus 80300, 3508 TH Utrecht
The Netherlands

62) **Multiphase Extraction Pilot Test to Remediate Jet A Fuel, a Case Study.** Michael J. Pierdinock, LSP, Joseph B. O'Brien, John C. Mesheau, and Derek J. Yimoyines, RAM Environmental, LLC and Stephen B. Wood, Cambridge Electric Light Company. A historic release of Jet A Fuel at a Cambridge Electric Light Company facility resulted in the presence of Jet A Fuel in soil and groundwater and non-aqueous phase liquid ("NAPL") on groundwater at the Site. RAM Environmental, LLC conducted a two-day multiphase extraction pilot test to assess the feasibility of utilizing this technology to remediate NAPL and Jet A Fuel impacted soil and groundwater at the Site. This paper provides an overview of the nature and extent of contamination, an overview of MPE technology, Pilot Test results, empirical data generated during the Pilot Test, and the interpretation of the data for the final MPE design. The Pilot Test results are graphically presented and include the following: MPE vacuum radii of influence versus vapor phase contaminant extraction rates; MPE well spatial requirements; optimum extraction air flow rates; groundwater withdrawal rates versus groundwater extraction rates; optimum groundwater and/or NAPL recovery rates; the characterization and quantification of extracted groundwater and vapor contaminant concentrations to estimate mass loading and conceptual MPE design. The Pilot Test results established the feasibility of utilizing MPE at the Site and provided the empirical data necessary for full scale MPE design.

Michael J. Pierdinock, LSP, Principal
Joseph B. O'Brien, Senior Project Engineer
John C. Mesheau, Project Engineer
Derek J. Yimoyines, Engineer
RAM Environmental, LLC
One Roberts Road
Plymouth, Massachusetts 02360
Tel: (508) 747-7900
Fax: (508) 747-3658
Pdinockm@ramenvironmental.com

Stephen B. Wood,
Director of Environmental Programs
Cambridge Electric Light Company
2421 Cranberry Highway
Wareham, Massachusetts 02571
Tel: (508) 291-0950
Fax: (508) 291-6275

63) Case Study of Accelerated Superfund Site Remediation Project. Rick P. Milhoan and Samuel C. Reed, R&R International, Inc. In 1984, the DeRewal Chemical Company site located near Frenchtown, New Jersey, was designated as a Superfund Site due to soil and groundwater contamination resulting from past industrial operations at the site. Various chemicals were handled at the site including copper aluminum sulfate, ammonia, acrylic acid, ferric chloride, and etching solutions. Subsequent to a 1985 remedial investigation/feasibility study and the 1989 Record of Decision (ROD), cleanup of the site was undertaken through Federal actions by the U.S. Environmental Protection Agency (EPA). The EPA worked with the U.S. Army Corps of Engineers (USACE) to secure a remediation contractor (R&R International, Inc.) through an existing Preplaced Remedial Action Contract (PRAC). The USACE Philadelphia District is managing remedial work at the site. Remedial efforts include the excavation and disposal of approximately 45,000 cubic yards of contaminated soil and debris, asbestos and lead-based paint removal activities, demolition of the manufacturing facility, and site restoration including reconstruction of impacted wetlands areas. Several features complicate work at the eight-acre site. These include the Delaware River which forms the western site boundary; wetlands which cover approximately 50 percent of the site; an occupied residence on the site which is to be protected during construction; and a public bike path which bisects the site. The bike path was to remain open to the public during the remedial efforts. The work initially was anticipated to be completed by Fall 1998. However, R&R worked closely with the USACE and EPA to implement time saving methodologies such as the use of Geoprobes for in-situ waste characterization to accelerate the remediation schedule. Currently, work at the site is expected to be complete by August 1998, roughly six months ahead of the original schedule. The current contract value for this project is approximately $11.4 million.

Samuel C. Reed
R&R International, Inc.
6760 Tussing Road, Suite 105
Reynoldsburg, OH 43068
Phone: (614) 751-5344
Fax: (614) 751-5345
e-mail: rrsreed@aol.com

Rick P. Milhoan
R&R International, Inc.
1234 South Cleveland-Massillon Road
Akron, OH 44321
Phone: (330) 665-1520, ext. 215
Fax: (330) 668-1148
e-mail: rmilhoan@rrint.com

64) Sparge and Vent Remediation of a No. 2 Home Heating Oil Release Under a Private Residence.
Art Taddeo, Daniel Groher, Robert Bukowski, and Joseph Salvetti, ENSR Consulting and Engineering
The release of No. 2 heating oil from an UST has led to contamination of soil and groundwater around and beneath a Central Massachusetts residence; the contamination includesd floating product. The site is listed with the MADEP. The homeowner's insurance company has been involved with identifying a cost-effective investigation and remediation approach to the site. Initial remediation efforts included UST removal and active free product recovery. As a second phase of remediation, ENSR has designed and implemented a novel in-situ system which incorporates air sparging, venting, and monitoring points underneath the house, as well as adjacent to it. The site is characterized by challenges of heterogeneous soils, a perched and transient groundwater table, and logistical issues related to remediation of an active residence. The system is currently pulsing air into the groundwater to provide oxygen andto stimulate bioventing. Vapor extraction wells are operating to recover volatile organic compounds stripped by the sparging operations, to prevent intrusion of contaminated air into the residence or an adjacent residence, and to promote biodegradation in vadose zone soils. The design and one year of operational data of this integrated system will be presented and discussed.

Art Taddeo
ENSR
35 Nagog Park
Acton, MA 01720
Tel: 978-635-9500
Fax: 978-635-9180
Email: ataddeo@ensr.com

Robert Bukowski
ENSR
35 Nagog Park
Acton, MA 01720
Tel: 978-635-9500
Fax: 978-635-9180
Email: rbukowski@ensr.com

Daniel Groher
ENSR
35 Nagog Park
Acton, MA 01720
Tel: 978-635-9500
Fax: 978-635-9180
Email: dgroher@ensr.com

Joseph Salvetti
ENSR
35 Nagog Park
Acton, MA 01720
Tel: 508-888-3905
Fax: 508-888-6689
Email: jsalvetti@ensr.com

65) Conducting Ecological Risk Assessment in New Jersey. Patricia A. Conti. Excel Environmental Resources. Inc. New Jersey's "Technical Requirements for Site Remediation" (New Jersey Administrative Code 7:26E) require that a baseline ecological risk evaluation (BEE) be conducted for every contaminated site or identified area of concern as part of the site investigation process. This procedure allows for a rapid and cost effective screening of sites to determine if concerns over ecological risk are warranted and appropriate. The BEE should be based on both site investigation results and a site inspection conducted by someone experienced in the use of techniques and methodologies for conducting ecological risk assessments in accordance with United States Environmental Protection Agency guidance. The BEE is to be qualitative in nature with the main objective of the baseline evaluation being to determine the co-occurrence of (1) contaminants of potential ecological concern: (2) environmentally sensitive areas; and (3) a chemical migration pathway to existing sensitive areas. The BEE is meant to be a cost-effective screening process which assures that all contaminated sites are addressed for potential ecological effects early in the remedial process. If the co-occurrence of the three conditions is lacking, then potential ecological risks are precluded and no further action is required. If there is co-occurrence of the three conditions at a site or area of concern, then further ecological evaluation and/or investigation is required. Based on the results of the additional ecological assessment, it is determined whether no further action is warranted or an ecological risk assessment is necessary. An ecological risk assessment must include determination of actual or potential risks to sensitive areas, development of site-specific ecologically-based remediation standards for contaminants of concern and recommendations for mitigation of actual or potential ecological risks. However, only limited guidance is provided for completion of ecological risk assessment investigations and reports.

Patricia A. Conti
Excel Environmental Resources, Inc.
825 Georges Road
North Brunswick, NJ. 08902
Tel: 732-545-9525
Fax: 732-545-9425

66) Ecological Risk Assessment Approach at Sandia Laboratories (SNL)/Enviromental Restoration Project Sally N. Hoier, SNL; N. Timothy Fischer, Douglas G. Bowen, and Linda Meyers-Schöne, IT Corporation.
Risk assessments are currently being performed for Resource Conservation and Recovery Act (RCRA) sites associated with the SNL/Environmental Restoration (ER) Project. Predictive ecological risk assessments are being performed as part of the risk assessment process for the program. The assessment follows the ìFramework for Ecological Risk Assessmentî as recommended by the Environmental Protection Agency and is consistent with the general concept of a screening level assessment. Constituents of potential ecological concern (COPEC) are site-specific and include a variety of inorganic and organic chemical including high explosives, and radionuclides. The sites are semiarid and terrestrial in nature. COPEC are confined to soil and the sediment of ephemeral drainages and are not known to affect surface water. A perennial grass, a deer mouse, and a burrowing owl (species of management concern) have been selected as ecological receptors. The potential fate and transport of COPEC from soils to other media is considered and evaluated in relation to exposure. Hazards are predicted using the quotient method supported by literature-obtained toxicity data and exposure estimates made using models (radiological and nonradiological) developed for the ER Project. Site-specific conditions are incorporated into the final weight-of-evidence approach in the assessment of risk. A hypothetical ER site will be used to demonstrate our ecological risk assessment methodology. This project is funded by the United States Department of Energy under contract DE-AC04-94AI95000.

Authors: Sally N. Hoier, Ph.D.
Sandia National Laboratories
Albuquerque, NM. 87185-1148
Tel: 505-845-9749
Fax: 505-284-2617

N. Timothy Fischer,
Douglas G. Bowen,
Linda Meyers-Schone, Ph.D.
IT Corporation
5301 Central Ave., NE: Suite 700
Albuquerque, NM. 87108
Tel: 505-262-8800
Fax: 505-262-8855

68) Human Health Risk Assessment for Construction of a Proposed Park at a Former Fire Site. M. Todd Hutchison* Shawn L. Sager, and Charles Castelluccio, ARCADIS Geraghty & Miller, Inc. Removal of contaminated soil from a site can prove to be a time consuming and costly part of remediation. When possible, keeping contaminated soil on site can provide a reduction in remediation costs while providing beneficial uses at the site. A fire recently destroyed several buildings at an industrial facility. Debris from the fire and soil were placed in the footprint of one of the destroyed buildings. As part of the reconstruction at the site, it was proposed that a park area be constructed atop the footprint for the enjoyment of the site workers. To assure that there are no risks to human health from the constituents in the soil, soil samples were collected before construction of the park. Based on anticipated potentially exposed receptors at the proposed park, a human health risk assessment was completed. Exposure receptors included a park visitor, a gardener, a lawn maintenance worker, and a utility worker. Exposure scenarios were based on both state guidances and professional judgment incorporating the site location and climate. Risks were calculated and evaluated for both carcinogenic and non-carcinogenic effects for the four exposure scenarios. This poster summarizes the strategy used to develop the risk assessment and remedial strategy.

M. Todd Hutchison
ARCADIS Geraghty & Miller, Inc.
2840 Plaza Place, Suite 350
Raleigh, NC 27612
Tel: 919/571-1662
Fax: 919/571-7994

Dr. Shawn L. Sager
ARCADIS Geraghty & Miller, Inc.
2840 Plaza Place, Suite 350
Raleigh, NC 27612
Tel: 919/571-1662
Fax: 919/571-7994

Charles Castelluccio
ARCADIS Geraghty & Miller, Inc.
Wannalancit Office Center
175 Cabot Street, Fifth Floor
Lowell, MA 01853
Tel: 978/937-9999
Fax: 978/937-7555

* Current address: The Marasco Newton Group, Ltd., 2801 Clarendon Boulevard, Suite 100, Arlington, VA 22201. Telephone 703/516-9100. Fax 703/516-9108

69) Risk Assessment for Expo 98, Lisbon, Portugal. Ruud H. B. Kersten, Shawn L. Sager, and Ben Viveen, ARCADIS Heidemij Advies and ARCADIS Geraghty & Miller, Inc. Petroleum companies formerly occupied a 50 hectare river front site in east Lisbon. Activities at the site included petroleum refining. The result was several distinct areas of soil and groundwater contamination. The properties of the petroleum companies were turned over to Parque Expo 98, a state-owned enterprise responsible for the construction of the 1998 International World Exposition (Expo 98). The land for Expo 98 is being redeveloped for multiple uses. The former petroleum companies' facilities are part of the Expo site. Other land adjacent to this will be developed for residential and recreational purposes. The risk assessment was used to develop site-specific remediation goals based on the intended future use of the properties. This paper will outline the risk assessment performed for the site and the methodologies used to ensure that future users of the properties will be protected.

Ruud H. B. Kersten, Ph.D.
ARCADIS Heidemij Advies
Utrechtseweg 68
6800 AH Arnhem, The Netherlands
Tel: 31-2637778620
Fax: 31-264457549

Shawn L. Sager, Ph.D.
ARCADIS Geraghty & Miller, Inc.
2840 Plaza Place, Suite 350Raleigh, NC 27612
Tel: 919-571-1662
Fax: 919-571-7994

Ben Viveen
ARCADIS Heidemij Advies
Utrechtseweg 68
6800 AH Arnhem, The Netherlands
Tel: 31-2637778609
Fax: 31-264457549

70) Bioavailability of Freshly Added- and Aged-naphthalene in Soils under Simulated-Gastric Conditions. Baoshan Xing, Zhaowei Jin, and Stephen Simkins, University of Massachusetts. Aged contaminated soils often show reduced bioavailability of organic compounds due to sequestration. However, assessments of the risk of exposure to contaminated soils are usually based on either chemical concentrations using vigorous extraction means (aiming for a complete recovery) or models assuming equilibrium without considering the actual conditions. The objective of this paper is to determine availability and desorption kinetics of freshly added- and aged-naphthalene from a peat and mineral soil under simulated-gastric conditions. Soil samples were spiked with naphthalene at two concentrations (2 mg/g and 20 mg/g) and aged from 0 to 135 days. Desorption kinetics were determined using a simulated gastric solution (0.1 M NaCl, 0.1 M HCl, 0.01 M NH4Ac, pH = 1) and a neutral solution (0.2 M NaCl, pH = 7) representing the pH of intestinal conditions and most soils. Though both acidic and neutral extracting solutions could desorb naphthalene, little apparent aging effect was observed in peat while desorption from the mineral soil declined markedly with aging. In addition, the percentage of naphthalene that desorbed from the mineral soil was greater for the higher incubation concentration. The desorption of naphthalene from the peat and mineral soil was higher into the neutral solution than into the gastric solution. These results suggest that aging, exposure conditions, concentration effect, and soil organic matter content should be taken into account in predictive models and risk assessments.

Baoshan Xing, Ph.D.
Department of Plant and Soil Sciences
University of Massachusetts
Amherst, MA 01003
Tel: 413-545-5212
Fax: 413-545-3958

Zhaowei Jin, M.Sc.
Department of Plant and Soil Sciences
University of Massachusetts
Amherst, MA 01003
Tel: 413-545-5212
Fax: 413-545-3958

Stephen Simkins, Ph.D.
Department of Plant and Soil Sciences
University of Massachusetts
Amherst, MA 01003
Tel: 413-545-5211
Fax: 413-545-3958

SEDIMENTS

71) Strategy for Remediating a Massachusetts River Near a Former MGP Site to "Local Conditions". Robert K. Cleary, Bay State Gas Company; Paul D. Anderson, Samuel P. Farnsworth, Kathleen Sellers, Ogden Environmental and Energy Services. Gas manufactured from coal helped to power the Industrial Revolution. In the late 1800's and early 1900's, some 40,000 facilities manufactured gas, typically in industrial areas and often near rivers. Many of these sites now require remediation to remove manufacturing byproducts. At one former gas works in Massachusetts, tar was discharged into an adjacent river. As a result, sediments near the site contain tar residuals, particularly polynuclear aromatic hydrocarbons (PAHs). An ecological risk assessment could provide ambiguous results, as the river is tidal, flows through an old industrial area and has received discharges from a variety of sources for over a century. The Massachusetts Contingency Plan recognizes that in such cases it may be more appropriate to restore a site to "local conditions" than to create a so-called "clean hole in a dirty river". Samples were collected from upstream and downstream locations in the river and analyzed for PAHs, grain size, and total organic carbon in order to characterize "local conditions". Analysis of the data indicated that concentrations of PAHs upstream of the site, where the river flows through an industrial area, were elevated relative to downstream conditions. As a result, the Phase III study of remedial alternatives for the site should focus on feasible means to restore the river sediments near the site to "local conditions".

Robert K. Cleary, LSP
c/o Bay State Gas Company
300 Friberg Parkway
Westborough, MA 01581
Tel: 508/836-7275
Fax: 508/836-7072

Paul D. Anderson, Ph.D.
Samuel P. Farnsworth
Kathleen Sellers, PE
Ogden Environmental and Energy Services
239 Littleton Road, Suite 1B
Westford, MA 01886
Tel: 978/692-9090
Fax: 978/692-6633

SITE ASSESSMENT

72) Short-Term, Cost-Effective Environmental Investigation Results for Gasoline Service Station Sites. E. Eric Cordis, PE, LEP, Joseph D. Devine IV, Lenard Engineering, Inc. The combined use of direct push technologies, real-time soil and groundwater field screening, and traditional environmental drilling provides increased data quality, shortened site investigation time frames, and reduced long-term subsurface investigation and remedial costs for gasoline service station sites. In the recent past, traditional drilling techniques only allowed for the installation of a limited number of data collection points at a site in a given time period. Direct push technologies allow for the installation of up to 5 times as many soil borings within a similar time frame and using smaller, less obtrusive drilling equipment. Combining this technology with available real-time on-site petroleum hydrocarbon soil & groundwater screening techniques allows for the development of more accurate three-dimensional subsurface contaminant models. The increased number of soil borings is also useful in identifying contaminant release sources, which may otherwise be missed or difficult to identify with a limited number of monitoring wells. This approach increases the efficiency of site investigations, thus reducing return site visits to collect additional subsurface investigation data. Soil and groundwater data collected during this phase provide valuable information for locating permanent on-site monitoring points and identifying long-term site remediation goals. However, direct push technology is not suitable for all sites since subsurface geologic conditions vary widely throughout the northeast. In many instances, traditional overburden and bedrock monitoring wells, drilled independently or in combination with direct push techniques, may be a more cost-effective solution. The use of a "packaged" investigation approach, combining the right mix of innovative site assessment methodologies and proven investigation techniques, can significantly reduce investigation time frames and, therefore, long-term site investigation costs. This approach provides for the quick identification of the full extent of a siteís contaminant distribution, a necessary condition for expediting the site remediation process.

Edward Eric Cordis, L.E.P., P.E.
Lenard Engineering, Inc.
1066 Storrs Road
Storrs, CT 06268-0580
Tel: (860) 429-5400
Fax: (860) 429-1367

Joseph D. Devine IV
Lenard Engineering, Inc.
1066 Storrs Road
Storrs, CT 06268-0580
Tel: (860) 429-5400
Fax: (860) 429-1367

73) Organic and Inorganic Constituent Relationships at a By-Products Coke Plant. Scott E. George, P.G., CHMM, QST Environmental Inc. An extensive environmental investigation of a by-product coke plant resulted in the analysis of numerous soil, groundwater, surface water, and sediment samples. These samples were analyzed for a suite of organic and inorganic parameters. The analytical data was placed into a dbase II database and run through a series of statistical programs: scatter plots, frequency distributions, analysis of variation, regression analysis, etc. In part, normalized and transformed data was used to develop constituent relationships. Linear and nonlinear relationships were established between various constituents. As an example, ammonia and cyanide were shown to have a linear correlation, likely due to the formation of ammonium thiocyanate in the coking process. Relationships were also shown to exist between risk drivers (i.e., benzene, benzo-a-pyrene, arsenic, etc) and chemical family totals (total volatile aromatic compounds (TVACs) and total polynuclear aromatic hydrocarbons (TPAH). These relationships demonstrate the utility of using chemical family totals in the characterization process.

Scott E. George, P.G., CHMM
QST Environmental
11665 Lilburn Park Road
St. Louis, Missouri 63146
Telephone # 314/567-4600
Fax # 314/567-5030
E-Mail: segeorge@qstmail.com

74) Borehole geophysics in the Potomac Group: an environmental case study, Steve Maloney, KEMRON Environmental Services, Jerry Kashatus, Woodward-Clyde A borehole geophysics and seismic program was implemented as part of a Remedial Investigation at Aberdeen Proving Ground, Maryland. The purpose of the Remedial Investigation was to characterize and delineate the extent of TCE contaminated groundwater on the installation. A geophysics program was designed and implemented in order to economize the investigation in two ways. First, gamma and electric logging were performed in boreholes in order to define the lithologic characteristics of each boring. This information was used to determine proper well screen intervals, so as to delineate contamination in the different layers of the variant, unconsolidated aquifer. Second, borehole geophysical and seismic logging were used to identify geophysical and seismic characteristics of major lithologic units. This information was used to support a surface geophysics program that would map the post's geology non-intrusively. The vast amount of geophysical and seismic data collected during the investigation is currently being used to develop a hydrologic model of the site.

Steve Maloney
KEMRON Enviromnental Services
8150 Leesburg Pike
Suite 1200
Vienna, VA 22193
Tel: 703-893-4106
FAX: 703-893-5636
Email: spade-archergworldnet.att.net

Jerry Kashatus
Woodward-Clyde
200 Orchard Ridge Dr
Suite 101
Gaithersburg, MD 20878
Tel: 301-670-3375
FAX: 301 -869-8728
Email: gpkashaO@wcc.com

75) Statistically Based Focussed Remediation of Soils at a RCRA Facility - A Case Study. Aamer Raza and Scott Cormier O'Brien and Gere Engineers. Delineating the extent of impacted materials is important in achieving cost effective soil remediation at RCRA Solid Waste Management Units - judicious examination of site data is crucial in achieving these objectives. This paper describes a statistically based focussed remediation of a soil consolidation area at a large automotive parts manufacturing facility. The area received soil/ sludge containing elevated nickel. chrome and zinc (indicator analytes) from site source areas (settling lagoons. drying beds. retention basins. sludge lakes). Based on historical information, it was hypothesised that soils within the area would be represented by at least three discrete populations : "background" (native materials). "intermediate" (mixed native soil/sludge). and "high end" (impacted materials). Statistical techniques - normal quantile plots and cluster analyses - were applied to examine the statistical distributions and groupings of indicator analyte concentrations in on-site soil data - three distinct goups were discerned. Log normal parameters were fit to each group and the upper and lower 99 % tolerance limits on each population derived. The limits for the "background" group compared well with published concentrations for area native soils. Weighted average loading calculations (WALC) from source areas were also performed as an independant estimate of potential concentrations in impacted materials. The upper limit for the "intermediate" soils was lower than the lower limit for impacted soils based on WALC. This suggested that the "intermediate soils" represented mixed clean soil/sludge samples whereas the 'high end" samples were consistent with impacted materials. Consistent with the site specific closure plan. the "high end" soils were excavated and disposed (3.000 cubic yards) whereas the background and intermediate soils (25.000 cubic yards) were closed in place. The focussed soil remediation resulted in a cost savings of approximately $ 2.2 M. as compared with removal and disposal of all soils within the defined landfarm area.

Aamer Raza
Senior Scientist
O'Brien and Gere Engineers
5000 Brittonfield Parkway
Syracuse. New York. 13221
Tel: (315)-437-6100
Fax: (315)-463-7554
e-mail : razaa@obg.com

Scott Cormier
Managing Engineer
O'Brien and Gere Engineers
39830 Grand River Avenue
Suite B-2
Novi. MI 48375
Tel: (810)-426-8970
Fax: (810)-426-8997

76) Expedited Site Characterization – A Case Study. Thomas M. Rose, Michael R. Hill, Dev M. Murali, General Physics Corporation. The assessment of site geology is a key element in completion of a thorough site characterization. A combination of geologic sample analysis and geophysical techniques provide quality data to assess site conditions. A case study is presented demonstrating the use of such methodologies in aiding the rapid and thorough characterization of an underground storage tank (UST) site. The site characterization was completed in a compressed timeline to meet the client's schedule. These activities were completed at an active vehicle maintenance facility located in Baltimore, Maryland that operated four UST fields. The four tank fields were screened using a hydraulic push (geoprobeTM) sampling technique to characterize the horizontal and vertical extent of local geology and contamination. During a previous investigation. four groundwater monitoring wells were installed in a shallow (<40 feet) bedrock aquifer. Water levels in these previously installed wells were compared with the hydraulic push data and indicated that the bedrock aquifer was under semi-confined conditions. Therefore. the previously installed bedrock wells were screened in the contaminated weathered bedrock(saprolite) allowing the groundwater to contact this material. Thus, these wells were abandoned and replaced with wells containing protective surface casing. During well installation, samples were analyzed for lithological. geotechnical. and chemical properties. Multiple geophysical (natural gamma. sonic. electro-magnetic induction. etc.) and borehole video logging techniques were performed to corroborate geologist's field logs and determine location and orientation of bedrock fractures. In-situ aquifer testing was performed to obtain necessary hydrogeological data to support a Risk-Based Corrective Action (RBCA) analysis. Currently the site is under a quarterly monitoring program in preparation for closure under RBCA. The understanding of the relationship between geology and contamination present has been increased due to the use of proper investigative methodologies and therefore expedited the site characterization process.

Thomas M. Rose
General Physics Corporation
6700 Alexander Bell Drive. Suite 400
Columbia. MD 21046
Tel: 410-290-2300
Fax: 410-290-2455

Michael R. Hill
General Physics Corporation
6700 Alexander Bell Drive. Suite 400
Columbia. MD 21046
Tel: 410-290-2300
Fax: 410-290-2455

Dev M. Murali
General Physics Corporation
6700 Alexander Bell Drive. Suite 400
Columbia. MD 21046
Tel: 410-290-2300
Fax: 410-290-2455

77) Remedial Pilot Testing with the Data Acquisition and Processing Laboratory (DAPL). Kenneth J. K. Smith and Michael Sarcinello, Groundwater & Environmental Services, Inc. Groundwater and Environmental Services, Inc. (GES) has designed and built a mobile testing system used to perform remedial feasibility and pilot tests at contaminated sites. The Data Acquisition and Processing Laboratory (DAPL) is a completely self contained vehicle that is equipped with a full complement of equipment necessary to conduct total-phase extraction, soil vapor extraction, air sparging, groundwater pumping, and enhanced NAPL recovery tests individually or in any combination. Test equipment is configured to allow ready switching among components, thus providing maximum flexibility. All of the hardware is fully integrated with an automated computerized data acquisition and analysis system that provides the capability for continuous logging and real-time monitoring of up to 32 channels of process and field data. The data management system permits full correlation of process and field response data, as well as real-time monitoring of test conditions, performance evaluation, and test validity. Using the DAPL testing platform, test conditions are evaluated continuously prior to demobilizing from the site. Feasibility tests can be readily modified while underwayóor stopped and completely reconfigured, thus ensuring that the objectives of the testing program are met in the most efficient and cost effective manner. In addition, preliminary remedial concepts and designs can be developed and tested while on site.

GES has used this unique testing system successfully at numerous locations and has several case studies ready for review and presentation.

Kenneth J. K. Smith
Groundwater & Environmental Services, Inc.
410 Eagleview Boulevard, Suite 110
Exton, PA 19341
Tel: (610) 458-1077
Fax: (610) 458-2300
Email: ksmith@gesonline.com

Michael Sarcinello
Groundwater & Environmental Services, Inc.
410 Eagleview Boulevard, Suite 110
Exton, PA 19341
Tel: (610) 458-1077
Fax: (610) 458-2300
Email: msarcinello@gesonline.com

Primary focus of the Environmental Research Center:

To conduct applied and fundamental research addressing environmental technology development. Researchers in the ERC strive toward rapid technology transfer from the laboratory to the field by working closely with industry, municipalities, engineering consulting firms and regulators.

Some of the recent and on-going research projects are described below.

Craig Adams' Current Research

Coupled UV/Hydrogen Peroxide-Biological Treatment of Fuel Oxygenates

(Investigators: C. Adams and Joel Burken; Sponsor: University of Missouri Research Board)

The Clean Air Act of 1990 mandated that fuel oxygenates be used in blended fuels to reduce carbon monoxide emissions. Methyl-tert-butyl ether (MTBE) and ethyl-tert-butyl ether (ETBE) are gasoline oxygenates that have been used widely to meet the oxygenated fuel requirements of the 1990 Clean Air Act, comprising as much as 15% of the fuel mix. Unfortunately, MTBE is a suspected carcinogen and is persistent in both aerobic and anaerobic conditions as it is resistant to microbial, chemical, and physical degradation. The goal of this recently initiated work is to investigate the use of the UV/H_2O_2/Fe(II) AOT to treat MTBE- and ETBE-contaminated groundwater or process water. The goal of this project is to develop and optimize a continuous chemical-biological recycle reactor for the efficient treatment of wastewater or groundwater containing the fuel oxygenates, MTBE and ETBE, as well as other pollutants (e.g., 1,4-dioxane).

Development of an Innovative Technology for Heavy Metals Recovery

(Investigators: C. Adams and H. Huang)

Research has recently been initiated on the modeling and development of an innovative reactor designed to remove and recover heavy metals from metal plating and manufacturing wastestreams. This process is designed to replace conventional coagulation, flocculation, and sedimentation processes with a single unit operation.

Recovery of Complexed Metals from Industrial Wastewater and Hazardous Wastes

(Investigator: C. Adams; Sponsor: National Science Foundation)

A series of projects have been conducted on development of integrated process for the recovery of complexed heavy metals from wastewater utilizing preoxidation with ozone or advanced oxidation combined with ion exchange, electrowinning or hydroxide precipitation. One study examined the effect of UV/H2O2 pretreatment on the recovery of Cu, Fe, Ni, and Zn from a synthetic boiler cleaning wastewater containing ethylenediaminetetraacetic acid (EDTA) and ammonia. Advanced oxidative pretreatment was found to have a positive effect on the rate, yield, and current efficiency associated with electroplating of selected metals from a preoxidized solution. Oxidative pretreatment had only a slight effect on precipitative recovery of metals, however, from preoxidized solutions. Other projects have examined the recovery of copper, chromium and cadmium from synthetic textile wastes and hazardous waste using preoxidation and ion exchange.

Treatability of Organic Contaminants Using Activated Carbon Adsorption

(Investigator: C. Adams; Sponsor: Missouri River Public Water Supply Association, and the Missouri Department of Natural Resources)

Cyanazine and atrazine, two of the most commonly used herbicides in the United States, are frequently found in surface and groundwaters in the Midwest. Cyanazine and atrazine degrade to a variety of byproducts through biological and chemical reactions in the environment (as well as in water treatment plants). The purpose of this study is to assess the technical and economic viability of using powdered activated carbon (PAC) and/or granular activated carbon (GAC) for the treatment of cyanazine and selected s-triazine metabolites. Adsorption isotherms for these s-triazines on PAC and GAC are being determined under a variety of process conditions in both synthetic and natural (Missouri River) waters. The results of this study will be helpful to water utilities to assist in developing plans and strategies to address potential future requirements by regulatory agencies. The results will also help engineers and regulators assess whether GAC (with its higher effective capacities) will be required to reach low effluent levels for cyanazine and selected s-triazine metabolites, or whether PAC (with its ease of use) will be sufficient.

Innovative Treatment of Swine Farm Effluents using Integrated Systems

(Investigators: R. Reed, C. Adams, others)

Research has recently been initiated on the development of an innovative, closed-loop process for the effective treatment of swine farm effluents. The process involves the coupling swine production and residuals treatment with aquaculture using conventional and innovative process operations. The research will be conducted at both bench- and full-scale in rural Missouri. The results of this work are expected to have wide application in the swine industry across the Midwest.

Kinetic Studies of Heavy Metal Complexes

(Investigator: C. Adams; Sponsor: National Science Foundation)

Many hazardous wastes from manufacturing and treatment processes result in solutions containing heavy metals and radionuclides complexed with synthetic chelating agents. The most common of these chelating agents is ethylenediaminetetraacetic acid (EDTA). EDTA destruction prior to metal recovery by conventional means, has been shown to be effective. In this recently completed study, second-order ozonation rate constants were developed for the reaction of ozone with metal:EDTA complexes. The effect of metal species (Na, Ca, Cd, Cu, Mg, and Zn), metal:EDTA ratio and pH were examined. Empirical correlations were developed to allow estimation of second-order rate constant as a function of these parameters. These results facilitate both the estimation of expected removal rates of EDTA in reactors with low concentrations, as well as expected scavenging and process efficiency in wastewaters operating in the mass transfer limiting regime due to higher chemical concentrations.

Biodegradability Enhancement Biorecalcitrant Compounds using Advanced Oxidation

(Investigator: C. Adams; Sponsor: National Science Foundation)

Many surfactants, including many ethoxylates and quaternary amines, are often not readily degradable in many conventional aerobic biological treatment processes. A series of studies have been conducted examining the integration of ozone, ozone/hydrogen peroxide, and Fenton's reagent with conventional biological treatment of biorefractory organics. The results have shown that the effectiveness of preoxidation for biodegradability enhancement of surfactants and related compounds is dependent of the nature of the parent compound and oxidant process selected. For most (but not all) compounds studied, preozonation or advanced oxidation markedly increased the rate and extent of biodegradation.

Mark Fitch's Current Research

Note: The following is provided for your interest, and not as a scientific report for citation. Please contact Dr. Fitch for literature references of this research.

Constructed Wetlands for Metal Removal

(Investigator: M. Fitch, G. Burken; Sponsor: Doe Run Company)

Problem: Water containing low concentrations of toxic metals such as lead and zinc.

Proposed solution: To flow the water through constructed wetlands. The wetlands develop anaerobic conditions, creating sulfides from the sulfates present in the water. These sulfides react with metal ions, producing metal sulfides. Metal sulfides have very low solubilities, and therefore the metals precipitate from solution and are trapped within the wetland.

Current Results: More than 90% removal of lead (100 ppb influent) and 70-80% removal of zinc (200 ppb influent) in lab-scale wetlands during more than 200 days operation. This successful operation was observed in wetlands at both room temperature and at 15 °C. A variety of wetland substrates were studied, with little variance in results observed to date.

Future Work: The systems work too well, and higher hydraulic loadings will be studied to determine when breakthrough occurs; loading may only be limited by the hydraulic conductivity of the substrate ('soil'). One important issue is the capacity for the wetlands to treat these waters for years as would be expected of an engineered system to remove metals from a water or wastewater. To address this, several lab-scale wetlands will be operated for a long duration. Also, the impact of plants in these wetlands will be studied at a future date under Dr. Burken's advisement.

Membrane Biofiltration

(Investigator: M. Fitch; Sponsor: Oak Ridge Associated Universities)

Problem: Air containing low concentrations of hazardous air pollutants (HAP) which are below regulatory limits but still might be treated if an inexpensive method was available. The limiting cost is generally the operating cost of a blower to push air through a treatment system.

Proposed solution: To pass the air through a membrane bioreactor. The membrane allows for a reactor design with a minimal pressure drop. Air flows on the inside of a membrane in the shape of a tube or straw. The HAP, which for these studies is benzene, diffuses through the membrane to the outside of the tube, where a biofilm eats the HAP. The biofilm is contained in a nutrient solution.

Current Results: Two reactors have been operated, and a model was successfully built to analyze the operation of the systems. One reactor used a membrane module developed for the oxygenation of blood consisting of a large number of fine tubes about the size of human hair. The other reactor was a silicon rubber tube. The head loss through the membrane module was high and increased with time, while the silicon rubber tube shows almost no head loss. Removal in both reactors was similar, with 70-80% removal of benzene (120 ppm inlet). Biofilm growth was visible and wispy. A numerical integration model of the membrane module was developed and fitted to data generated in a similar module at the University of Massachusetts (Amherst) in Dr. Sarina Ergas's lab. The model was then applied to the reactor operated in this work with success, showing that biofilm density and kinetics and the biomass density in the liquid phase dominate the rate of removal of benzene and toluene, but HAPs with a lower diffusivity will be mass-transfer limited.

Future Work: Due to the high head loss in the membrane module, other configurations are being characterized for head loss, abiotic mass transfer, and ultimately bioreactor use. These new modules have significantly larger tubes and thus should give a lower head loss while providing higher surface area than single silicon rubber tubes. Simultaneously, the silicon rubber bioreactor is being operated for an extended duration to examine long-term operation.

Leaching of Radionuclides from Soils at the St. Louis Airport Site

(Investigator: M. Fitch, N. Tsoulfanidis; Sponsor: United States Geological Survey)

Problem: A soil contaminated with radium, thorium, and uranium. The site will be remediated, but the minimum concentrations of radionuclides requiring remediation are not clear. To assist the regulatory agencies involved in the process, the potential for leaching of the radionuclides into groundwater needs to be elucidated.

Proposed solution: Take several soil samples with contamination in the range of concentrations currently proposed as an end point for remediation. Determine the short- and moderate-term leaching of the radionuclides from the soils under a variety of conditions, ranging from anaerobic groundwater to EPA's TCLP procedure (an extraction with weak acid).

Current Results: The project has just begun.

Future Work: The research will generate a very small data set for a large site. However, it is anticipated that the results will act as a signpost for the regulators in finding the appropriate end point for remediation.

Intrinsic and Stimulated Cometabolism by In Situ Methanotrophs

(Investigator: M. Fitch; Sponsor: University of Missouri Research Board)

Problem: Groundwaters and soils contaminated with trichloroethylene (TCE), the most frequently found groundwater contaminant. One proposed solution is to inject methane into soils. Methanotrophs, which eat methane, can sometimes degrade TCE in a process which gives the methanotroph no benefit, termed cometabolism. However, field trials of this process have had mixed results.

Proposed solution: Study, in the lab, injection of methane into synthetic groundwaters of varying composition. After significant biomass has formed, determine the capacity for that biomass to degrade TCE, as well as the rate of methane uptake, the amount of biomass formed, and the microbial characteristics in terms of phospholipid fatty acid carbon chain length.

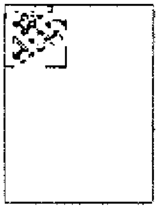
Current Results: A large number of groundwaters were studied, with a focus on the effect of metal concentrations. All experiments were performed in triplicate at both room temperature and also at 12 °C. Phosphate and cobalt were determined to be significantly correlated to the amount of biomass formed and the activity of that biomass. At low temperatures, minimal growth was observed over two months in almost every case. Chain length of lipids was found to be highly variable, but generally C18 was dominant, corresponding to the type of methanotrophs known to degrade TCE. Although TCE degradation rates are still being analyzed, it would appear that the rate of degradation is quite low in all cases despite the lipids found in the samples.

Future Work: Based on the poor results in most cases, the reasons for success of methane injection at some sites should be explored.

Joel Burken's Current Research

Being a new professor at UMR (arriving in 1997), my research program is still developing and expanding. I have a number of different research areas under development, however there are common threads in my research. These common areas are natural and biological systems. I feel that there is a push in the environmental engineering field toward simple systems that are robust and can serve a variety of objectives. The specific research areas that I am active in are phytoremediation of organic compounds, constructed wetlands for metals removal and domestic wastewater treatment, and combined biological/advanced oxidation treatment of recalcitrant organics.

Phytoremediation



Phytoremediation is the use of plants in the in-situ treatment of contaminated soils or waters. Phytoremediation is an emerging technology that may be applied to sites that cover vast areas or are contaminated to levels. Traditional technologies may not be cost effective or applicable to these sites. Phytoremediation may also be effectively as a polishing step in conjunction with other technologies, concurrently serving to revegetate the site and treat residual contaminants.

There are five basic applications for phytoremediation: Phytotransformation, rhizosphere biodegradation, phytostabilization, phytoextraction, and rhizofiltration. Phytostabilization and phytoextraction are applied for remediation of soils contaminated with metals and radionuclides. Phytostabilization is applied in effort to stabilized contaminants, limiting transport via leaching or erosion. Phytoextraction treatments are designed to accumulate the contaminants in the above ground portions of the vegetation. Plant biomass can then be ashed and contaminants recovered. Rhizofiltration is applied to aqueous contamination and serves to sorb and accumulated the aqueous metals or radionuclides. My research has targeted the other two applications of phytoremediation and organic contaminants. Phytotransformation involves the uptake of organic contaminants followed by transformation or storage as non-toxic metabolites. Rhizosphere bioremediation relies on the degradation of organic contaminants by the rich microbial populations associated with the rhizosphere, or root zone.

In earlier work initiated at the University of Iowa, uptake and fate of atrazine was examined in laboratory experiments. It was quickly discovered that atrazine is taken up by hybrid poplar trees. The form of the atrazine stored in the hybrid poplars was then investigated. It was discovered that the atrazine was metabolized in the plant tissues, and only 8% of the total mass remained as atrazine after 80 days. Most of the atrazine appeared as deethylatrazine (DEA) and dethylhydroxyatreazine (DEHA). Lower metabolites such as hydroxydealkylated products were detected along with unavailable bound residues that were incorporated into the plant biomass.

Work has also been done and is continuing on volatile organic compounds (VOCs). A series of VOCs were investigated and many were found to volatilize to the atmosphere from the leaf tissues. The compounds tested included the BTEX compounds (benzene, toluene, m-xylene, ethylbenzene), TCE and chlorobenzene. All were found to volatilize at different rates. Work in this area continues today. We are currently looking into volatilization from unsaturated soils to ascertain the impact of the phytoremediation on contaminants in the vadose and saturated zones.

We are also looking at the rhizosphere bioremediation of recalcitrant and hydrophillic compounds. This work is in initial stages and has yet to be published. This is also an area of upcoming research.

"Phytoremediation is a striking example of a new, innovative technology that can dramatically change the way that we remediate soils. As many of you probably know the cost of soil removal and remediation is one of the most expensive components of a site cleanup. Phytoremediation using natural or bioengineered plants offers opportunity for a far more effective, environmentally attractive solution."

Don Ritter, Chairman of the National Environmental Policy Institute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Combined biological/advanced oxidation treatment
Sorry, this site is still under construction

DESIGN OF PHYTOREMEDIATION AT CONTAMINATED SITES

Jerry Schnoor
CGRER, 202 IATL
The University of Iowa
Iowa City, IA 52242
jschnoor@cgrer.uiowa.edu

For use of EPA Conference
Brownfields '97
Kansas City, MO
September 4,1997

APPLICATIONS

Phytotransformation

Rhizosphere bioremediation

Phytostabilization

Phytoextraction

Rhizofiltration

Application	Media	Contaminant/s
Phytotransformation	S, GW, WW	ORGS
Rhizosphere Bioremediation	s, ww	ORGS
Phytostabilization	S	Metals, ORGS
Phytoextraction	s, ww	Metals
Rhizofiltration	WW, GW	Metals, ORGS

S = soil; GW = groundwater; WW = wastewater

DESIGN CONSIDERATIONS

- Plant Selection
- Treatability
- Planting Design and Pattern
- Irrigation, Inputs, Maintenance
- Groundwater Capture Zone/Transpiration Rate
- Contaminant Uptake Rate/Clean-up Time
- Analysis of Failure Modes

CONTAMINANTS FOR PHYTOREMEDIATION

- Organics (BTEX, PAHs, PCBs, TNT, RDX, chlorinated aliphatics, pesticides)
- Metals (Pb, Cd, Zn, Ni, Cu, As, Cr, Se, radionuclides)
- Nutrients (nitrate, ammonium, phosphate)

Metals Hyperaccumulators

Defn: Conc in plant 20-200 times higher than other plants growing in the same soil (Reeves, Baker, Brooks; 1995)

Zn	>	10,000 mg/kg in plant tissue
Cd	>	100
Pb	>	1,000
Se	>	100

Plants*

Sunflowers	*Helianthus annus*
Indian mustard	*Brassica juncea*
Crucifers	*;aerulescens* *Thlaspi elegans*
Violet	*Viola calaminaria*
Serpentine plants	*Alyssum bertolonii*

Other: corn, nettles, dandelions

*Reeves, Baker, Brooks (1995) Mining Environ. Mnqmnt.

Is Accumulating

Thlaspi c

Metal

Phytoextraction Design Criteria Metals

1) Yield $\geq$ 3 tons dry matter/acre-yr in harvestable portion
2) Acc. Factor $\approx$ 100
3) 30 year design life

$$\boxed{Acc.\ Factor = \frac{mg/kg\ plant}{mg/kg\ soil}}$$

Plants Used in Phytoremediation

Salix Family (poplars, cottonwood, willow)

Phenolics Releasers (mulberry, apple, osage orange)

Grasses (fescue, rye, sorghum, reed canary grass, switchgrass)

Legumes (alfalfa, alsike clover, cowpeas)

Wetland Plants

Emergents - Bullrush, cattail, coontail, arrowroot, pondweed, duckweed

Submerged - algae, stonewort, *Pofamogeton* spp., parrot feather, eurasion water milfoil, *Hydrilla* spp.

Organics Treatability

log	Mechanisms
< 1.0	Possible Uptake & Transformation
1 .0-3.5	Uptake, Transformation,
> 3.5	

K_{ow}

olatilization

Rhizosphere bioremediation or
Phytostabilization

Uptake

ate _ Organics

$$U = (TSCF)\ (T)\ (C)$$

where U = uptake rate of contaminant, mg/day

TSCF = transpiration strea

concentration

factor

T = transpiration rate, L/day

C = aqueous phase conc, mg/L

WASTECH, INC.

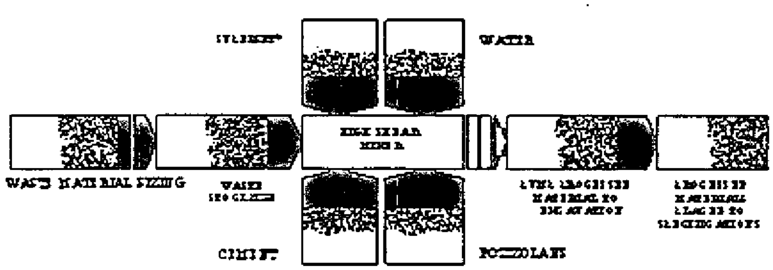
(Solidification and Stabilization)

TECHNOLOGY DESCRIPTION:

This technology solidifies and stabilizes organic and inorganic contaminants in soils, sludge, and liquid wastes. First, a proprietary reagent chemically bonds with contaminants in wastes. The waste and reagent mixture is then mixed with pozzolanic, cementitious materials, which combine to form a stabilized matrix. Reagents are selected based on target waste characteristics. Treated material is a nonleaching, high-strength, stabilized end-product.

The WASTECH, Inc. (WASTECH), technology uses standard engineering and construction equipment. Because the type and dose of reagents depend on waste characteristics, treatability studies and site investigations must be conducted to determine the proper treatment formula.

Treatment usually begins with waste excavation. Large pieces of debris in the waste must be screened and removed. The waste is then placed into a high shear mixer, along with premeasured quantities of water and SuperSet®, WASTECH's proprietary reagent (see figure below).



WASTECH Solidification and Stabilization Process

Next, pozzolanic, cementitious materials are added to the waste-reagent mixture, stabilizing the waste and completing the treatment process. The WASTECH technology does not generate by-products. The process may also be applied in situ.

WASTE APPLICABILITY:

The WASTECH technology can treat a wide variety of waste streams consisting of soils, sludges, and raw organic streams, including lubricating oil, evaporator bottoms, chelating agents, and ion-exchange resins, with contaminant concentrations ranging from parts per million levels to 40 percent by volume. The technology can also treat wastes generated by the petroleum, chemical, pesticide, and wood-preserving industries, as well as wastes generated by many other chemical manufacturing and industrial processes. The WASTECH technology can also be applied to mixed wastes containing organic, inorganic, and radioactive contaminants.

STATUS:

The technology was accepted into the SITE Demonstration Program in spring 1989. A field demonstration at Robins Air Force Base in Warner Robins, Georgia was completed in August 1991. WASTECH subsequently conducted a bench-scale study in 1992 under glovebox conditions to develop a detailed mass balance of volatile organic compounds. The Innovative Technology Evaluation Report will be available in 1997. The technology is being commercially applied to treat hazardous wastes contaminated with various organics, inorganics, and mixed wastes.

This technology is no longer available from the vendor. For further information about the process, contact the EPA Project Manager.

FOR FURTHER INFORMATION:

EPA PROJECT MANAGER:
Terrence Lyons
U.S. EPA
National Risk Management Research Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
513-569-7589
Fax: 513-569-7676

513-569-7589 Terry Lyons
2/10/99, ~12:30pm – I left message for Terry asking him to please c/b.
2/11/99 – 3:15pm – left message asking for report, and to please c/b. I left my phone # + address.

The question has been answered.