U.S. EPA TECHNICAL SUPPORT PROJECT
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U.S. EPA TECHNICAL SUPPORT PROJECT CO-CHAIRS

Engineering Forum:
JoAnn Cola, Region 9 • Steve Kinser, Region 7 • Frank Vavra, Region 3

Ground-Water Forum:
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Federal Facilities Forum:
Meghan Cassidy, Region 1 • Steve Hirsh, Region 3
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TUESDAY, NOVEMBER 17

Welcome Address and Introductory Remarks

The plenary session of the Technical Support Project (TSP) meeting opened with welcome addresses by Herb Levine, Ground-Water Forum Co-chair; William Honker, Chief of the Arkansas, Oklahoma and Texas Branch Superfund Division, EPA Region 6; Colonel C. Rick Coneway, Executive Director, Air Force Center for Environmental Excellence (AFCEE); and Marty Faile, Technical Assistant, Technology Transfer Division, AFCEE.

William Honker, Chief, Arkansas, Oklahoma, and Texas Branch Superfund Division, EPA Region 6

Region 6, comprising of Texas, Arkansas, Louisiana, Arizona, and New Mexico, is diverse geographically, geologically, culturally, climatologically, and demographically. It encompasses a contrast of people and industry, with the majority of the population residing along the coast of the Gulf of Mexico. Region 6 has a variety of remediation sites, but is unique in that most federal facilities (all but seven) and all base closures are governed under RCRA rather than Superfund. Organizationally, Region 6 has a self-contained Superfund program, encompassing the remedial and removal programs and legal (enforcement) within a single division. Even though the legal staff will be reassigned shortly to the General Counsel's office, they will remain co-located with the Superfund Division. This fosters a close-knit, team approach among the Community Involvement staff, Remedial Project Managers, On-Scene Coordinators, and the lawyers.

Region 6 is adding sites to the National Priority List (NPL). Four new sites were added recently and four more are proposed. The site assessment program is expanding, and the region has an excellent relationship with the states; implementation of cleanup is occurring faster than before. Along with the rest of the Agency, Region 6 is focusing on Superfund Administrative Reforms. Public concerns and a recognition that original remedies were not working lead to reviews and revised remedial decisions at 12 sites, which decreased the cost of remedies by about $100 million.

The types of sites coming into the Superfund Program are changing—the really bad sites of the 1980s and 1990s are a thing of the past. Honker said that Region 6 is seeing borderline-insolvent RCRA generators and treatment, storage and disposal (TSD) facilities—rendered bankrupt by RCRA Corrective Action requirements—being added to the NPL. He added that if the economy worsens, more RCRA and TSD sites may be added. Superfund is also seeing a reduction in unlicensed landfills and sites that contain mixtures of contaminants. Cleanup is being done increasingly in more populated areas, such as in private homes and yards, for contaminants such as lead and arsenic.

The nature of enforcement is changing, and sites are being cleaned up through Brownfields initiatives and voluntary State programs instead of through Superfund. Large expenditures and greater containment remedies will be needed to operate and maintain sites that have a variety of contaminants. Superfund is therefore getting adept at dealing with individual homeowners as well as large organizations. The enforcement nature of the program is also changing. Complementary programs such as Brownfields and the State Voluntary Cleanup Programs are creating other opportunities for dealing with responsible parties outside the NPL. Sites now have fewer willing and cooperative PRPs, and there will be more fund-lead cleanups on the new NPL sites compared to the past.

Containment is increasing, as are administrative reforms, which lead to future challenges for long-term management of containment and institutional controls. Honker cited several sites where spending on containment is very high.

Honker concluded by emphasizing that there many challenges for the future. The Superfund Remedy Review Board has found that most large (>$30 million) new sites contain radioactive materials or contaminated sediments. There are major sediment issues in every region. Ecological issues are increasingly important at sites. Biotreatment is not working well at many wood treatment sites, and remedial actions have had to be revised. There are long-term operating and maintenance issues that will need to be addressed—failure to do so will see the sites reopened. He said sites will have to be revisited to develop long-term operating and maintenance solutions and there is much to think about.

C. Rick Coneway, Executive Director, AFCEE

Coneway described AFCEE as a "one-stop-shop for environmental issues." AFCEE provides the Air Force with a full range of services in planning, environmental, design and construction management. He cited natural attenuation and associated ground-water modeling, passive treatment walls, landfills, recirculating wells, and training on BIOPLUME III as some of the issues of current mutual interest with EPA. Coneway gave a brief overview of AFCEE's structure and mission.

Coneway said that the Environmental Restoration Program (ER) mission is to clean up sites and protect human health and the environment, while serving as good stewards of the taxpayer's money. The services available through ER are study and design contracts; full-service remedial action contracts; regional soil remediation and tank contracts (particularly with small businesses); and technology transfer contracts that provide demonstrations, evaluations, and educational services. With respect to Environmental Restoration Management Services, AFCEE provides a cradle-to-grave approach and is actively involved with the customer, hires contractors, handles quality assurance, and manages the project cost and schedules.

AFCEE's Environmental Conservation and Planning Services provide environmental analysis, environmental planning, natural resources planning, cultural resources planning and overall comprehensive planning.

Through Environmental Quality, AFCEE provides customers with quality products and services and enhances performance of facilities, resources, and weapon systems through pollution prevention, smart environmental investments, and better management practices. This is done by incorporating compliance and pollution prevention and providing technical support, education and training, partnering, contract support, communications and feedback, and program initiatives.

AFCEE provides services in Design and Construction in three areas: (1) the Design Group Division, which advances the aesthetic and functional quality of the built and natural environment through architecture, interior design and landscape architecture; (2) the Medical Division, which provides the design and construction manager for the Air Force Medical Military Construction Program; and (3) the Family Housing Division, which manages family housing, architect and engineering contracts.

AFCEE's environmental offices are divided into the Eastern, Central, and Western regions. Their mission is to assist the Air Force in sustaining DoD leadership in environmental stewardship through innovative management and facilitating consistent application of environmental regulations Air Force wide. Their role is to support compliance, cleanup and pollution prevention.

The compliance offices build relationships with regulators, oversee execution of media compliance programs, assess impacts of new or changes to the laws/regulations and resolve conflicts and develop compliance strategies. The cleanup offices advocate cleanup standards, assist in resolving cleanup problems and elevate cleanup issues that require policy decisions.

The pollution prevention offices identify leadership opportunities for Air Force participation, recommend strategies for pollution prevention and facilitate exchange of pollution prevention information through partnerships.

Coneway concluded by saying that AFCEE is part of a team involving the customer, contractor and the regulator. This team effort requires mutual trust, growth and meeting any challenges that come their way.

Marty Faile, Technical Assistant, Technology Transfer Division, AFCEE

AFCEE's Technology Transfer Division has four mission objectives: (1) Formulate strategies based on Air Force requirements; (2) Demonstrate the "Broad Agency Announcement"procurement program and field test technologies; (3) Validate major initiatives and develop and distribute of tools (thousands of protocols, design manuals, and models); and (4) educate through published findings, public presentations, technological symposiums, and tool kits.

Fuels and solvents in ground water represent 90% of AFCEE's problems. Other major issues include landfills and firing ranges. AFCEE is not restricted to any particular laboratory, institution, or source, and has the flexibility to select the best match.

The Technology Transfer Division uses various methods of source reduction and control. Faile cited bioventing project (123 pilots, 15 full-scale, 21 O&M); vacuum enhanced free-product removal of fuels at 45 sites using bioslurping; dual-phase extraction of chlorinated solvents and petroleum; surfactant-enhanced remediation of chlorinated solvents at Hill AFB; and the MAECTITE system for lead remediation.

Natural attenuation represents AFCEE's major effort and major area of collaboration with EPA. There are 45 intrinsic remediation demonstrations; 12 that use a risk-based approach to cleaning up fuel contamination; upgrading of the BIOPLUME III model for simulating natural attenuation (in collaboration with EPA's Robert S. Kerr Environmental Research Laboratory); 10 demonstrations of natural attenuation at small sites (like gas stations) in response to criticism that NA was too complicated and expensive for small sites; a risk based approach to cleaning up chlorinated solvent contamination at 3 sites (in early stages); and support for the BIOSCREEN natural attenuation screening tool, the BIOCHLOR natural attenuation screening tool, and a model for natural attenuation of chlorinated solvents. The latter three also involve EPA's Kerr Laboratory.

For plume management and control, the Technology Transfer Division uses in-well aeration and recirculation wells, passive treatment walls for chlorinated solvents, phytoremediation of chlorinated solvents with hydraulic control, hydrogen addition for chlorinated solvents, and substrate amendments such as molasses and multiple carbon sources. Faile acknowledged that he was not completely convinced that phytoremediation and evapotranspiration covers are a suitable option for hydraulic control.

Off-gas treatment technologies include six demonstrations of internal combustion engines, four flameless oxidizers for organics, three biofilters, and ozone-enriched volatile organic carbon destruction.

Remedial process optimization and long-term operations and maintenance (LTO/LTM) include remote operations of remediation systems; a remedial process optimization guide; an integrated methodology for designing long-term monitoring plans; a soil vapor extraction (SVE) optimization design tool; TCE sensor development; and an aggressive program on diffusion sensors.

In summary, the Technology Transfer Division has emphasized the demonstration and application of cost effective remediation technologies, but the emphasis is shifting to reducing operation and maintenance costs through modeling and LTO/LTM process improvements and addressing solution failures through a remedial systems optimization process.

Natural Attenuation Case Study: Comparative Analysis of Monitored Natural Attenuation at a Military Landfill

Patrick Haas, Air Force Center for Environmental Excellence, Brooks AFB, Texas

The case study presented a site with comprehensive data at which the EPA/AFCEE protocol on monitored natural attenuation (MNA) was implemented. The process complied with the current EPA/OSWER directive on MNA (9200.4-17) . The case study was intended to demonstrate, through multiple lines of evidence, that MNA occurred. The landfill was in use from 1941 to 1989; it was capped in 1995. The site conceptual model hypothesizes that the cap was effective in reducing contaminant flux, but the lower level contaminants would likely persist for decades. There is a strong trend towards decreasing concentrations, and the dissolved contaminant mass is assumed to be decreasing over time.

The current plume is most likely the result of multiple releases at different locations over time. The plume is 16-18,000 feet long and 6-7,000 feet wide. It contained carbon tetrachloride, tetrachloroethene (PCE), and trichloroethene (TCE) at less than ten times the maximum contaminant levels for drinking water in the lower aquifer. Ground-water seepage was 1 ft/day at the head increasing to 3 ft/day at the tail. The water table was from 40-80 feet below ground surface (bgs), and the contaminants of concern were located from 90-160 feet bgs. The site poses little risk to human health and no risk to the environment. The community and the regulators were willing to apply MNA and “see the science.” A companion objective was to evaluate any injury to the natural resources at the site.

The natural attenuation (NA) screening process requires constituent-specific and geochemical data representing different zones inside the plume and in the background; locations of sources and receptor exposure points; and an estimate of ground-water flow direction and seepage velocity. The protocol’s NA screening process awards points for various characteristics; the higher the score, the more likely that MNA is occurring. Positive indicators include presence of an organic substrate, presence of daughter products, and reducing conditions. The site scored a “24” on the protocol’s screening assessment; anything above “20” is “strong evidence” for biodegradation of chlorinated organics.

Technologies screened for applicability included the no-action alternative; focused ground-water extraction, treatment, and reinjection (ETR) systems; enhanced bioremediation; permeable or impermeable containment walls; ground-water recirculation wells; additional capping of landfill areas; natural attenuation alone and natural attenuation together with plume-capture ETR. The focused feasibility study considered eight unique alternatives or technologies and over 16 unique configurations. The ETR systems considered captures from 0.5 million gallons per day (mgd) at “warm spots” to 8.7 mgd across the entire width of the plume. Between 1989 and 1998, 656 ground-water samples were collected and 85 duplicates analyzed to verify data quality. Plume data were compiled to provide trends. Haas judged the current data set adequate to determine whether the plume was expanding, stable, or shrinking; to determine if the contaminant mass is increasing or decreasing; and whether the plume concentrations are increasing or decreasing. In 1998, 63 monitoring wells were sampled, and 25 exceeded at least one MCL. The data collection efforts were focused on multiple lines of evidence (following the Protocol). Primary lines of evidence included concentrations over time, total contaminant mass over time, and plume configuration over time. Secondary lines of evidence included known contaminant breakdown products and biodegradation indicator compounds.

Site characterization considered the nature and extent of contamination and both nondestructive fate and transport processes (dilution, sorption, volatilization) and destructive processes (abiotic and biotic degradation). Statistical and visual analyses were used to determine contaminant concentrations in individual wells over time, plume stability, center of mass over time, and ground-water flow rate. This combination of techniques reduce subjectivity and uncertainty. Eighty percent of the wells analyzed with the Mann-Kendall test showed stable trends.

Biodegradation rates were calculated along five transects according to the method of Buscheck and Alcantar (1995), which is applicable to steady-state plumes and incorporates advection, dispersion, sorption, and biodegradation. Apparent biodegradation was much greater than advection, diffusion, dispersion, or absorption. Biodegradation rates ranged from 9.6 x 10^{-4}/day to 1.5 x 10^{-4}/day, with biodegradation half-lives ranging from 2.0 to 12.8 years. Different zones in the plume have differing biodegradation, and different contaminants have different biodegradation rates. These rates tracked extremely well with modeled predictions.

The case study offered a number of technical conclusions:

- Peak plume concentrations over time are not significantly different between MNA and ETR alternatives, based on models calibrated with field data.
- Contaminant mass removal using ETR is inconsequential.
- MNA will remove 5,700 lbs over 50 years at a projected cost of $2.7 million. ETR will remove an additional 76 lbs at a projected cost of $71 million.
- DoD, regulators, and the public will still be dealing with a plume deep under residences in 20 years even if ETR is implemented.
- ETR operational costs will be high; there is no short-term exit strategy.

In conclusion, Haas noted that it has taken over 30 years for the plume to develop as large as it is. Given its size and extent, ETR has little prospect of accelerated cleanup compared to MNA. ETR systems extract from the lower contaminated interval and reinject in the upper drinking water zone, which poses a real public health risk; since there is no public or environmental exposure to MNA, there is no unacceptable risk. MNA safety is assured by a package of actions that include performance monitoring with triggers for process contingencies and risk management by providing alternative public water supply. ETRs should be implemented only if MCL triggers are exceeded. The biodegradation data demonstrate that contaminants are being destroyed, and seep sampling has confirmed that no detectable concentrations of contaminants are present at these locations. Haas stressed that remedial objectives must be defined in detail and achievable.

<u>Questions and Answers</u>

Q: Was there a non-aqueous phase liquid (NAPL) present?
A: There is no indication of the existence of a NAPL in the sample concentrations. Coring was done throughout the saturated zone without evidence of NAPLs.

Q: Did you sample in the landfill mass?
A: Not too much because it was too difficult. Most samples were taken along the fence lines.

Q: Could the site history help identify the contaminant source?
A: The recordkeeping at the site was not very good. Test pits did not yield much. Most of the waste came from the motor pool and aircraft maintenance facilities, and there was little inventory data.

Q: Did your hypothesis include no free phase?
A: Correct. Field data will be used to test that hypothesis.

Q: Did you have cluster wells downgradient with different screens?
A: Yes. High-density vertical profiles were conducted with at least two, and often with four, screens.

Q: How many background samples were taken?
A: There were two or three background wells. They also found sites within the plume with background characteristics. A total of 6-10 wells supported the background indications.

Q: Was the biodegradation model calibrated?
A: Yes, through sensitivity analyses on biodegradation rates, and the model was able to match the field data.

Permeable Reactive Treatment Walls

Edward Marchand, Technology Transfer Division, AFCEE

Permeable reactive treatment walls are used to treat ground water contamination. They contain the source area but do not treat it. The most commonly used reactive medium used in reactive walls is iron, which can treat organics, including chlorinated ethenes, some chlorinated ethanes, and ethylene dibromide (EDB), trace metals, including chromium and uranium, and other contaminants, such as sulfate, nitrate, phosphate, and arsenic. Iron does not work, however, on dichloromethane, 1,2-dichloroethane, chloroethane, chloromethane, chlorobenzenes, chlorophenols, or ammonium perchlorate and should not be considered a “panacea.” Other potential reactive media include sawdust/leaf waste nitrate for nitrate removal; municipal compost and lime for copper, lead, zinc, nickel and cadmium removal; a proprietary metal oxide for phosphorus removal; phosphate for uranium removal; and amorphous ferric oxyhydroxide for uranium removal.

There are patent issues associated with installing a reactive wall. Environmental Technologies, Inc. (ETI), a spin-off of the University of Waterloo to market reactive walls, has a patent on the technology. The royalty fee is stated as 15% of the capital costs of the wall; however ETI has indicated that 10-15% is acceptable for larger sites. Some types of implacement techniques and wall designs may not be covered by ETI’s patent (#5,266,213).

Reactive walls can be constructed in a continuous or “funnel and gate” design. The funnel and gate design directs ground-water flow toward the wall with wing walls. Emplacement techniques for walls include typical funnel and gate, continuous trenching, mandrel, jet-assisted grouting, soil mixing/augering, slurry wall-type emplacements, vertical fracturing, and jet emplacement. The reactivity of iron can be reduced when using the latter five techniques because they use a slurry containing guar gum and an enzyme breaker to inject the iron. NASA has used a variation of the soil mixing/augering technique in order to construct deeper walls. They create a line of iron columns and then stir the columns up mixing the iron with soil. Vertical fracturing was used to install a 3-in thick wall to depths of 80-120 ft at the Massachusetts Military Reservation.

The thickness of a reactive wall will depend on the seepage velocity, contaminant concentration, and reaction rate. Higher seepage velocities and higher concentrations require thicker walls. Reactive walls are the best alternative to other containment technologies in areas where the aquifer is permeable, but has a low hydraulic gradient. Seepage velocity is the most critical reactive wall design factor because sufficient residence time in the wall is required, but depth of contamination, dissolved oxygen levels, nitrate and sulfate levels, high alkalinity, microbes, and proximity to surface water must also be considered. Since the dechlorination reaction is anaerobic, the presence of dissolved oxygen will rust the iron, reducing its permeability. High alkalinity may cause problems with precipitation of metals.

As of May 1998, at least 15 reactive walls had been installed. The oldest was installed in 1991 at the Canadian Forces Base (CFB) Borden site in Ontario. The first commercial full-scale system was constructed in Sunnyvale, California, to replace a pump-and-treat system. The wall paid for itself in 3 years. Demonstrations of reactive walls have been conducted or are ongoing at several DoD sites, including Lowry AFB in Colorado, Moffett Field Naval Air Station in California, Cape Canaveral Air Station in Florida, and Otis AFB in Massachusetts. A full-scale treatment system was installed at the Elizabeth City Coast Guard Station in North Carolina

The demonstration at Cape Canaveral involved the installation of a 50-ft long continuous iron wall—half of which was installed using the mandrel technique and half by jet-assisted grouting—with two 10-ft walls in series. The walls were installed to 60 ft bgs into a semi-confining layer. The depth to ground water was 5 ft bgs, and the ground-water flow rate ranged from 0.1-1 ft/day. The contaminant concentrations in the ground water were 90 mg/L TCE, 7 mg/L vinyl chloride, and 170 mg/L total DCE. The demonstration began in 1997, and no performance results are available yet.

Installation of the mandrel wall at Cape Canaveral took 19 days versus the 24 days for the jet-assisted grout wall. In addition, no spoils were created using the mandrel technique, but 4,000 gallons of liquid and 24 tons of solid were generated by jet-assisted grouting. However, installation costs (mobilization, demobilization, construction, and iron) were greater for the mandrel method: $290K versus $244.5K. The greatest difference was due to construction costs, which were twice as much for the mandrel method.

The demonstration at CFB Borden involved the installation of a funnel and gate reactive wall in 1991 to treat ground water with 250 mg/L TCE and 43 mg/L PCE. The wall was installed in an unconfined sand aquifer with a water table depth of 8 ft bgs. The wall contained 700 ft^3 of a mixture of 22% iron and 78% sand. The ground-water flow rate at the site is 0.3 ft/day. Performance results indicated a 90% reduction in TCE and 86% reduction in PCE. As of June 1996, no noticeable plugging was observed in the permeable reactive zone.

A 10-ft long funnel and gate iron wall was installed in 1995 at Lowry AFB to treat ground water contaminated with 850 μg/L TCE and 14 μg/L PCE. The wall is 17 ft deep and keyed into a confining layer. The depth to ground water is 8 ft. The ground-water flow rate is 1 ft/day in the aquifer and an estimated 2.6 ft/day in the reactive zone. The performance results indicate a greater than 99% reduction in both TCE and PCE concentrations. The pH of the ground water increased from 7 to 10 and the redox level decreased from 100 mV to -500 mV through the wall.

<u>Questions and Answers</u>

Q: How deep are the flow meters at Cape Canaveral? Are they nested?
A: The flow meters were installed to one depth—40 meters. The deepest interval of flow meters will depend on the seepage velocity and direction of ground-water flow.

Q: What measures are taken to provide construction quality assurance, especially with 3- and 4-inch walls?
A: We measure the inclination of the tools and each section of the wall when they are at depth. If they are within the prescribed tolerances, they are withdrawn and reset. I do not recommend constructing

a wall deeper than 40 ft, because if it is slightly off-vertical, it will not be of uniform thickness. Each wall section has a 4-in overlap to prevent gaps.

C: Installation using a two-mandrel "leap frog" technique would also be useful in maintaining quality assurance.

Q: Is one installation technique better than another with respect to underground utilities?

A: The jetting technique is better suited to go around utilities, but reactive walls should be constructed parallel to utilities.

Q: How important is the effect of soil compaction next to the wall when a mandrel is used for installation?

A: The mandrel vibrates as it is withdrawn from the hole so it loosens the compacted soil a bit. However, the effect has not been determined specifically.

Landfill Covers, National Perspective

Steve Rock, U.S. EPA National Risk Management Research Laboratory, Cincinnati, Ohio

Landfill wastes can present a risk through physical contact, contamination of ground water by landfill leachate and the production of explosive methane gas. Physical contact can occur through direct dermal contact, vectors such as rodents and birds, or litter. Risk management options for landfills can range in expense and complexity from natural attenuation to multi-layer composite covers. Evapotranspiration (ET) covers fall in the less expensive and complex portion of this continuum.

To be effective, ET covers must achieve a mass balance between the water that enters the cover by precipitation and run-on and the amount exiting via evaporation and transpiration and runoff, to prevent percolation through the cover into the buried wastes. Use of ET covers is appropriate where the water balance is protective of ground water, gas capture is not an issue, conventional covers may not be feasible, or where a conventional cover is a contingency. ET covers work best in arid and semi-arid climates that receive less than 20 inches of annual precipitation. A mix of local plants such as prairie grasses works best. A cover designed for a wet climate (20 in/yr) may include hybrid poplar or willow trees. The roots of these trees can reach to depths of 8-10 ft and may reach the landfill waste.

Approximately 1,000 trees per acre of landfill would use 5-25 gallons of water per tree per day. The trees essentially act as a pump-and-treat system, but with smaller operating and installation costs. Monitoring systems for ET covers include rain gauges to measure precipitation, weirs and tip buckets for run-off, a meteorological station for evaporation, sap flow meters for transpiration, and lysimeters or a soil moisture probe system for infiltration.

The advantages of using ET covers include their lower installation and maintenance costs, creation of wildlife habitats, and potential beneficial uses such as parks or the production of pulp for paper. Their disadvantages include their short history of application and evaluation, the potential for infiltration to occur during warm wet winters, and their unpredictability as living systems. Unpredictable occurrences may include destruction of the trees by beavers or the consumption of leaves by bugs which reduces the trees' pumping capacity.

ET covers, like RCRA covers, must result in compliance with ARARs. They must prevent physical contact with the waste, ground-water contamination, and harmful gas production. There is a concern that if roots penetrate the waste, transpiration of volatile wastes may occur or conduits for percolation may be created. Contingencies must be considered such as what will be done if trees are knocked down or diseased.

The Remediation Technologies Development Forum's (RTDF) Phytoremediation of Organics Action Team is participating in the Alternative Cover Assessment Program (ACAP) with the Desert Research Institute in Nevada. ACAP is led by Steve Rock, and made up of members from EPA regional offices and state regulators. The group will assess the performance of a cover installed by SAIC. The landfill owner and operator will provide the test site and maintenance. The Desert Research Institute will collect and analyze the data.

Questions and Answers

Q: What is the water usage rate for poplar trees decrease in the winter time?
A: The usage rate decreases to zero in the non-growing season. However, willows and other phreatophytic trees keep their leaves 6-8 weeks longer than others in the West.

Evapotranspiration (ET) Landfill Covers

Victor L. Hauser, Mitretek Systems, San Antonio, Texas

The remediation of landfills usually requires a cover. Conventional covers are expensive because they use costly barriers. It has been estimated that it would cost $2.4-4.3 billion to cover all Air Force landfills. Therefore, innovative, alternative covers that are effective and less costly are being researched.

A clear statement of cover performance requirements is very important to apply innovative technologies at landfills. All covers are required to protect human health and the environment from hazardous waste by minimizing the flow of water through the cover and waste, separating receptors from contaminants, and controlling landfill gas, if necessary. Seventy-nine percent of the Air Force's 229 landfills have been inactive for more than 20 years. Landfills with bottom liners constitute less than 1% of the total because they were constructed prior to cover regulations.

The fundamental component of a typical RCRA landfill cover is a clay barrier with a hydraulic conductivity less than or equal to 1×10^{-7}cm/s. The barrier prevents the escape of landfill gases and the infiltration of precipitation. No clay barrier is involved in an ET cover. An ET cover is constructed with a foundation of soil over the landfill and a soil cover planted with as many native grasses as possible. The soil used must have adequate thickness, water-holding capacity, and plant nutrient capacity. Furthermore, proper bulk density, soil salinity, temperature, and soil water content must be established for good root growth. The ET cover uses two natural processes to control infiltration: (1) the soil provides a water reservoir; and (2) natural evaporation from the soil plus plant transpiration empties the soil water reservoir.

The Air Force is verifying the ET cover concept at several locations west of the Mississippi River: at 5 experimental ET cover sites (receiving a range of precipitation); from USDA water balance records for 5 locations (each studied for over 20 years prior to 1936); and from 3 long-term studies of the effects of soil grass cover. The 5 USDA locations had been planted with continuous wheat and natural grasses, and monitoring records indicated that water at the sites never infiltrated below the root zone—even at a site with sandy loam soil. The long-term effects studies were conducted in Texas, Colorado, and the Northern Plains. The study at the Texas site indicated that water flow had been minimized for centuries—soil water content, chloride content, and total salt measurements indicated that water was not drawn below the root zone. The study of a large area in the Northern Plains suggested that water flow was minimized for 12,000 years. Saline seeps developed in this area only after the native grasses were plowed. These seeps now make the land unproductive.

The Air Force has successfully modeled ET covers with EPIC (Environmental Policy Integrated Climate). The model is widely used and has been tested at 200 sites around the world. The model has yielded accurate estimates of monthly deep percolation, during both wet and dry periods, at many of these sites. Input includes plant, soil, and climate data. It is also important to consider critical events—those resulting in the greatest soil water content during the period of analysis—when implementing EPIC.

ET covers are generally effective west of the Mississippi River; their success to the east is site specific. Misapplication of ET covers generally results from climate, inadequate soil depth, soil compaction during construction (which reduces the water-holding capacity and root growth), or failure to consider critical events. A useful reference to use when selecting landfill covers is "Choosing the Most Effective Hazardous Waste Landfill Cover" by R.W. Warren, T.E. Hakonson, and K.V. Bostick (1996) in Remediation published by John Wiley & Sons, Inc.

ET covers should be used where applicable because they fulfill the requirements of a landfill cover by minimizing the flow of water through the cover, separating receptors from contaminants, and controlling gas, if needed. Construction and maintenance costs are minimized, plus, ET covers provide natural, self-renewing covers. The Air Force has 7,900 acres of landfills in the continental United States, and it is estimated that 3,400 are suitable for ET covers. Since ET covers offer a conservative savings of $150,000 per acre, the Air Force can potentially save over $500 million by using them.

Questions and Answers

Q: At the USDA sites with wheat, did water percolate below the root zone?
A: No, but it is not recommended that wheat be used.

Q: In the Northern Plains study it was suggested that water flow was minimized in the 12,000 years it was planted with natural grasses. Did water percolate the root zone during short-term events with heavy rain?
A: No, there is no evidence that the water percolated below the root zone, because saline seeps would have developed.

Q: What is the cost savings per acre if good soil has to be hauled in to construct the cover?
A: Good soil should be within 3-4 miles of the landfill for the $150,000 per acre savings. However, conventional covers have the expense of hauling soil as well.

Superfund Innovative Technology Evaluation (SITE) Program Update

Annette Gatchett, NRMRL–Cincinnati

The SITE demonstration program began in 1987. The program now stresses the need to locate suitable host sites either before or concurrently with selecting an applicable technology. Ninety-eight field demonstrations have been completed and 13 are on-going. Fifty-one SITE vendors have reported 1,895 contracts resulting from the program between 1990 and 1996.

SITE offers third-party evaluation, high-quality data collection, resources leveraged by funding data collection, analysis, and reporting, technical expertise to assist vendors with the demonstration, and an option to evaluate more than one technology at the same time and place.

SITE issued on October 30 the third solicitation for host sites. The application/selection board consists of representatives of the Interstate Technology & Regulatory Cooperation (ITRC)—27 states are now participating—DoD's Office of Science and Technology, DoD/ESTCP (which is similar to SITE), and EPA regulatory program offices, regions, and researchers.

During 1998-2002, SITE will emphasize the following topics:

Ground Water	**Soils**	**Sediments**	**Containment**	***In Situ***
Organics/inorganics DNAPLs in fractured bedrock and karst Oxygenate compounds Chlorinated compounds Aromatics Creosote Phenols	Metals Pesticides Chlorinated compounds Aromatics Phenols	Pesticides Chlorinated aromatics Metals	Alternative caps Walls/bottoms New Materials and delivery systems	New Materials/ Processes Evapotranspiration covers

SITE will consider and accept several possible scenarios: the host site has a particular vendor and technology chosen to address their particular waste need; the site has chosen a family or category of technologies with no particular vendor in mind; and the site chooses to solicit for one or more technologies in a variety of technology areas.

Proposals are due January 6, 1999, and peer-reviews will be completed February 19. Reviewer comments will be compiled by March 1 and the successful applicants will be notified by March 17. Typically, applications are accepted with conditions, which require some negotiation or response on the part of the applicants.

Current and planned SITE projects include:

Ground Water

- Chromium at Aladdin Plating/Electrokinetics shallow ground water (Spring 1999)–selected from Host Site Application
- Organics/inorganics using PRBs at Rock Flats (August 98-August 99)
- Organics/inorganics/pesticides/explosives at Rocky Mountain Arsenal (Spring 1999)–joint program with START
- Nitrates/carbon tetrachloride at Bendena, Kansas using biological denitrification with ozone cartridge filter (January 1999-June 1999)

NAPLs in Ground Water

- ITT Night Vision–bioremediation of TCE enhanced with pulsed methane (March 1998-December 1998)
- O.K. Tool–surfactant flood (PITT) in glacial overburden (Spring 1999)
- Naval Shipyard Pearl Harbor–vacuum enhanced recovery, surfactant flush, standard recovery, and heat enhanced (August 1998-February 1999)
- NASA– possible technologies at Cape Canaveral include surfactant, cosolvent thermal steam, and electrical resistance (Spring 1999). Vendor not yet selected.
- Loring AFB–fractured bedrock (Summer 1999)
- Shrader Automotive–fractured bedrock (Summer 1999)
- Carswell AFB–phytoremediation final sampling (October 1998)

Soils

- Lead at Ohio Pottery–stabilization (September 1998)
- Lead at Naval Shipyard Pearl Harbor in high levels within the top 15 ft of soil–electrokinetics (March 1999-March 2000)
- Chlorinated organics at Rocky Mountain Arsenal–*in situ* thermal desorption (Spring 1999)—joint program with START. ROD at site calls for innovative treatment for hexachloropentadiene.

Ground Water and Soils
- PCBs at Pearl Harbor–*in situ* thermal blanket, chemical extraction, and biological (March 1999)—joint program with START
- PCBs at Beede Waste Oil and Cash Energy–biological (Spring 1999)–selected from Host Site Application

***In Situ* Technology Evaluation**
- New materials/processes at DOE Oak Ridge using a frozen soil barrier (November 1997-September 1998)

Other
- KSE soil vapor extraction at Stamina Mills, Rhode Island (September 1998-November 1998)

Gatchett encouraged anyone interested in observing a demonstration to contact her. She also solicited assistance from forum members who could participate in the 1999 solicitation review meetings during the next few weeks. Travel to Cincinnati would be paid by SITE. She also solicited advice on updates of the emphasis areas and any general comments to improve the program. Further information on any of these projects is available from the SITE home page (http://www.epa.gov/ord/site).

Questions and Answers

Q: Is the frozen soil barrier at Oak Ridge temporary?
A: The demonstration is a test of the barrier technology itself. It would be emplaced temporarily (perhaps up to 10 years), allowing natural attenuation to resolve the problem.

Q: Are there any projects that emphasize DNAPLs in fractured rock—are the Loring or Shrader sites on fractured rock?
A: Not yet. Some *in situ* heating projects have been proposed, and they have received inquiries about Loring. Pearl Harbor does not have fractured rock. The ITT Night Vision site overlies shale with mud seams.

Wednesday, November 18

Updating Remedy Decisions at Select Superfund Sites, Summary Report FY1996 and FY1997

Matt Charsky, Office of Emergency Response and Remediation, Washington, DC

Updating remedy decisions is one of 45 recent EPA reforms and will be available on EPA's web site soon. EPA has always been able to perform remedy updates, so the reform really just provides a new ability to track updates. During FY96 and FY97, EPA updated remedies at over 200 sites, reducing estimated future clean-up costs by more than $1 billion. There were 101 Explanations of Significant Differences (ESDs) and 40 Record of Decision (ROD) amendments representing both cost savings and increases. Cost decreases represented $65 million, which is a fraction of the total saved. Parties outside EPA initiated 90 updates, EPA initiated 34 updates, and more than one party initiated 24 updates. Ground water and soil were the most commonly addressed media in the updates. Updates with cost savings have occurred in all Regions (most occurring in Regions 3, 4, and 5), saving over $745 million.

The total savings from 77 ground-water updates in FY96 and FY97 were $416 million. Ground-water remedy updates accounted for 56% of the total cost savings while only representing 36% of all remedy updates. Eighteen of the 77 ground-water updates were ROD amendments; six took less than 1 year to review, seven took 1-2 years, and five took more than 2 years. Fifty-eight of the 77 were ESDs; 36 took less than 1 year, 13 took 1-2 years, and nine took more than 2 years. Four of the updates were memos or letters-to-file; three took less than 1 year and one took 1-2 years.

The types of changes made for ground-water remedy updates were as follows:

<u>Treatment updates (37)</u>
22 Treatment to treatment
15 Treatment to reduced treatment

<u>Monitoring updates (1)</u>
6 Treatment to natural attenuation with monitoring
4 Treatment to monitoring
1 Monitoring to no monitoring

<u>Non-technical updates (24)</u>
17 Old clean-up level to new clean-up level
7 Change in discharge location

<u>Non-technical updates (8)</u>
6 Treatment to containment
2 Containment to containment

Updating ground-water remedy decisions during FY96 and FY97 has brought over 50 old remedies up-to-date with current science and technology and over 20 other old remedies current with non-technical changes. There are still a number of ground-water remedies older than 5 years that could be updated, either because the selected remedy was built and did not perform as expected, or because additional technical information was gathered as part of the remedial design and this information could lead to a remedy update. Of the ground-water remedies updated based on science and technology, over 66% of the updated remedies went from one treatment remedy to another treatment remedy. Therefore, EPA has not abandoned its preference for treatment while updating remedies.

<u>Questions and Answers</u>

Q: The updates seem to represent a diminishment of activity. Do any updates result in a more aggressive action?

A: Yes. The treatment-to-treatment updates represent aggressive remedies being changed to aggressive remedies.

Natural Attenuation Roundtable

Moderator: Chuck Newell, Groundwater Services, Inc., Houston, Texas
Panelists: Ned Black, U.S. EPA, Region 10
Ron Buchanan, DuPont Engineering, Wilmington, Delaware
Patrick Haas, AFCEE, Brooks AFB, Texas
Guy Sewell, U.S. EPA NRMRL-Subsurface Protection Research Division, Ada, Oklahoma
Ron Sims, DuPont Engineering, Wilmington, Delaware
Bob Starr, LMITCO, Idaho Falls, Idaho

Dick Willey (Region 1) introduced the moderator and panelists. Each of the panelists, representing various government agencies and private industry, has extensive and varied experience in monitored natural attenuation (MNA) evaluations. Willey pointed out that technical consensus on issues was not expected from the panel, and that the panelists were invited to express their opinions on the complex issues involved in natural attenuation. Newell posed questions prepared by the Ground-Water Forum to the panelists. The following is a summary of the responses, not a verbatim transcript.

Question 1: What are the major technical uncertainties that hinder technical consensus in MNA evaluations? What information (data collection activities) would help minimize these uncertainties?

Haas: There is no easy path to reducing uncertainties. Adopting a strategy of “weight of evidence” is very important; the complexity of a site drives the amount of supporting evidence that is needed. Sometimes, however, there is a lot of supporting evidence for natural attenuation at a site, yet someone will point to one monitoring well with a high dissolved oxygen level to rule it out. To reduce uncertainty, you should take the first line of evidence (contaminant concentration and loss) and pair it with the strength of the geochemical data. This can then be coupled with the risk level and other components in the OSWER directive.

Buchanan: These are good points. The first step in evaluating MNA is to understand the type of contamination involved, and then to deduce the type of evidence to look for. There are three lines of evidence to consider: (1) decrease in contaminant concentrations downgradient; (2) contaminant mass loss downgradient; and (3) laboratory microcosm tests. Microcosm tests should only be used when necessary; perhaps at large sites contaminated with chlorinated solvents. There needs to be a consistent approach based on the type of contaminants. Using scoring systems is not recommended to evaluate natural attenuation applications.

Sewell: A big factor that affects our ability to evaluate MNA is the variability of the site. Modeling alone is insufficient for effective MNA evaluation. A holistic understanding of the site is needed to properly interpret the type of data needed and the analytical results.

Starr: When evaluating a data set for MNA, you may find that it is insufficient. If you are considering MNA in the future, look at the data gaps you have now and install those extra monitoring wells to fill them. General types of information needed include whether anaerobic or aerobic conditions exist, the types of contaminants and degradation products present, and the presence of conservative tracers.

Black: I agree with Starr in that microcosm studies are a problem. I do not want to rely on them to fill the third line of evidence, but they can be useful in determining whether biological activity is occurring. It is important to look at forensic DNA evidence as well.

Newell: *Are there any examples of sites with too much uncertainty? What data were missing?*

Sewell: The most common problem is using a 2-dimensional approach to site characterization. Natural attenuation processes have as much variability as the subsurface geology.

Buchanan: I agree. This goes back to the site conceptual model. If we had not tracked the third dimension at Dover AFB, we would not have observed that part of the plume was plunging.

Black: There are a large number of sites with minimal characterization data—they are the biggest source of proposals for MNA that I reject. Information over 2-3 more years than originally anticipated may be needed. It is difficult for EPA to go to the PRP and tell them that their data are inadequate because the PRP may have to collect several years of data to adequately demonstrate MNA. Sometimes, there is no way around it though.

Starr: At the Idaho National Engineering and Environmental Laboratory, there is a TCE plume a couple of miles long. The data show that the TCE is probably being remediated by natural attenuation, but most of the monitoring points are in the upper **a** of the plume, and there are no data in the middle portion of the plume. So we'll have to sink some wells at $100K each and monitor for years to prove natural attenuation is occurring. Hopefully, this will pay off.

Haas: I've seen MNA proposals with inadequate data for sites that were approached mechanically—first line of evidence data were presented without being integrated with the other lines of evidence. The problem can be reduced by measuring ground-water velocities. Most sites have velocities less than 100 ft/yr and have a low potential plume migration; thus, data insufficiency problems often arise. Sites with faster velocities can establish plume trends more quickly. There needs to be a better plume presentation in site characterizations to show where a point within the plume will migrate. I prefer more "impersonal" means to depict plume trends. We need to plot data at individual wells and use simple statistics to indicate whether a decreasing trend exists. Statistical methods that may be used to assess trends in plumes include the Mann-Kendall and Tyson polygon methods. These methods are not covered in the EPA MNA protocol.

Newell: In contrast, a recently developed ASTM standard concerning the MNA of petroleum hydrocarbons have shown that the level of uncertainty is lower at fuel sites. The standard says that demonstration of a stable or declining trend in the plume is sufficient to demonstrate MNA.

Haas: The trend is already established for fuel plumes. Because of this, the State of Texas will not pay for alkalinity and carbon dioxide analyses at state-lead sites. Although Texas recognizes the weight of evidence, regulators prefer contaminant data and oxygen, nitrate, and sulfate concentrations over time. However, for chlorinated solvent sites, we must bolster confidence in alkalinity and carbon dioxide measurements.

Buchanan: At DuPont, a suite of analyses are typically recommended, including: chlorinated VOCs and their degradation products, including speciation of the DCE isomers; metabolic gases (methane, ethane, ethylene, and propane); total organic carbon in water and the matrix; dissolved oxygen and redox conditions; pH, conductivity, and temperature; and inorganic ions (iron, manganese, chlorine, nitrate, sulfate, and hydrogen sulfide) and alkalinity. We've measured hydrogen at Dover AFB, and the concentrations were extremely sensitive to the sampling method. We have not found consistent results in the field.

Starr: How useful are measurements of dissolved hydrogen, assuming you have consistent sampling protocol?

Black: The point of measuring hydrogen is to determine what microbial processes are occurring. I agree that it is not worth measuring hydrogen based on difficulty and expense—other approaches are better for obtaining this information.

Sewell: It is important to understand what the dissolved hydrogen measurement means. It is a dynamic variable and represents local conditions at a certain time. How the data are interpreted is what causes problems. An average value of hydrogen concentrations does not mean anything.

Newell: Do you need to measure dissolved hydrogen at most sites?

Sewell: There is not a simple answer, but no.

Buchanan. I agree.

Starr: There are also difficulties in the sampling and analysis of dissolved hydrogen, so I'd say no as well.

Haas: As a practice, no. The measurement should not be done in new wells or wells with mechanical pumps. People are working on a field analysis method, however, and it is encouraging that headspace samples are not degrading when shipped across the country for analysis. Although AFCEE does not analyze dissolved hydrogen as a practice, these measurement may be useful for confirmation purposes at certain sites.

Question 2: Should MNA determinations require a higher standard of proof than that which is needed for an engineered remedy?

Haas: The answer should be no. Each remediation technology has a specific set of parameters to measure, but MNA does require a higher weight of evidence. If the MNA protocol is implemented properly, sufficient proof of MNA can be obtained, although monitoring may have to continue for several years. I recommend the approach of the National Research Council's study that classified sites based on the complexity, which helps determine whether a higher standard is needed. The study showed that 19 of 77 Superfund sites using pump-and-treat did not achieve containment. Therefore, a higher standard may be needed for pump-and-treat, air sparging, etc.

Black: MNA should not be held to a higher standard of proof, and all types of remedies should be technically valid. Public perception is also an important factor in selecting MNA. The public is less accepting of natural attenuation than other remedies and as a result, MNA *will* be held to a higher standard to satisfy the public.

Starr: MNA as a remedy requires the collection and analysis of more data than required for engineered remedies partly because it is a new technology.

Newell: *Critics of MNA say that it will fail and at some point the plume will reach receptors. Is the standard of proof high enough to prevent this?*

Sewell. MNA should be held to a higher standard of proof, particularly with more complex sites, because it is a more complex process. We thought we understood pump-and-treat, but some systems still cannot contain plumes. We still do not have a handle on the MNA of more challenging contaminants.

Haas: The public is skeptical of MNA. A possible failure mode includes remarks made by regulators that are critical of MNA. A few critical comments can kill a proposal for MNA.

Question 3: Comment on the need for, and recommend approaches to identify principal flow path(s), or core, of a plume for an MNA determination in primary, secondary, and dual porosity terrains.

Newell: A compilation of plumathon studies in Texas, Florida, and California has shown that BTEX plumes from gas stations are relatively short. It has been suggested, however, that they are longer because they dip down, and as a result, monitoring systems cannot monitor the plumes effectively.

Sewell: At complex sites with preferential flow paths, we should expect plumes to be irregular and should try to find them. Characterization of the flow paths is required to fully understand a plume. The potential for natural attenuation to terminate, however, must be considered.

Buchanan: Good characterization of flow paths is needed for any remedy. At Dover AFB, we conducted a transect study with 103 strata probes across the plume and found one of John Cherry's "pencils." The site is underlain by sands and silts and has complex hydrogeology, but good definition of the plume was obtained. However, it did not change our conclusion about the site. The need to characterize a plume in detail depends on the hydrogeology of the site.

Haas: In terms of techniques, I recommend looking for the core of the plume and preferential flow paths. If a site is complex, then approach it technically; install geoprobes or multiple implants. Also, use borehole flowmeters, plume residence tracers, and diffusion samplers.

Question 4: What considerations/criteria should be used initially to set or alter the frequency of long-term monitoring? What impact should seasonal changes have on sampling frequency?

Buchanan: Sampling frequency should depend on how fast the water is moving and the proximity of receptors. If the ground-water flow rate is slow, then you may be resampling some of the same water. Any type of plume should be considered similarly.

Black: At an ideal site, we would consider the ground-water flow rate, the time to implement a contingency, and the distance to receptors, to come up with a monitoring frequency.

Buchanan: Agreed with Black. Our goals in determining a frequency should be based on the protection of human health and the environment. The frequency should be determined holistically and on a site-by-site basis.

Starr: If the reason for doing long-term monitoring is to determine whether natural attenuation is working, sampling frequency should depend on how fast you expect the definition process to take. If a process has a long half-life, then annual sampling may be adequate. Changes in contaminant concentrations along the flow path or over time is complicated by variability in sample handling and analysis. To separate noise from trends, I'd conduct replicate sampling rather than more frequent sampling.

Sewell: Quarterly sampling is a good starting point because natural attenuation has the potential to stop. The geochemical data should be monitored for changes.

Haas: We should look at the basis for quarterly sampling. It may be warranted at a site that receives 120 inches of precipitation annually, and there may be instances were more frequent sampling is needed. Primary drivers in determining the necessary frequency of sampling include: (1) the effect of seasonal changes and related changes in hydrogeologic conditions; (2) the existence of any preferred flow paths; and (3) travel time of ground water. To avoid laying out $71 million for a pump-and-treat system, more frequent sampling or the addition of monitoring wells to show the effectiveness of natural attenuation may be warranted.

Question 5: What technical factors should be used to judge the reasonableness of MNA time frames relative to other alternatives?

The panelists cited anywhere from 5-10 years to 100 years when asked how long MNA should continue. Newell pointed out that there is a good deal of uncertainty in suggesting appropriate time frames. He asked how long is too long when evaluating MNA?

Starr: The answer may be more political than technical. The objectives of remediation must be clearly articulated for any remedy. The upper time limit for MNA will depend on the site. You do not want the plume to affect receptors.

Sewell: Time should not be a consideration. There are sites that will never be cleaned up. We should be thinking in terms of risks.

Buchanan: There are pump-and-treat systems that may never clean up a site. The time frame for MNA should be compared to the time frames for other remedies. However, at larger sites, the potential for a impacts to receptors should be a primary factor in judging the reasonableness of MNA time frames.

Black: From a resource trustees perspective, ground water *is* a natural resource, so we have impacted a receptor by virtue of contaminating the ground water.

Haas: The OSWER Directive says that MNA will be acceptable if the clean-up time frame is comparable to more active remedies. The issue is how well have the time frames for more active remedies been established? An understanding of mass transfer limitations is needed—especially for fuel plumes. Some sites are going to take hundreds of years to clean up, even with active pumping, so MNA should be considered if the time frames are comparable.

Newell: *Should the life-time expectancy of MNA be established in documentation supporting all sites at which MNA is employed? If so, how do you do this?*

Buchanan: We have a site in Missouri with a vinyl chloride plume. We estimated that it would take 11 years to clean up the plume to MCLs using MODFLOW MT3D. We have tracked the plume over several years, and the model is on target. Site-specific data is need to make this call though—it is not a generic answer.

Black: I do not require documentation of the estimated lifetime of MNA treatment systems. The answer is site-specific and depends on a comparison to other remedies.

Starr: But the public wants to know the answer. Simulations should be done to estimate time frames. In support of public meetings at INEEL, time frames were simulated for comparison of remedial alternatives.

Sewell. An estimated time frame is needed to make a decision on applying MNA.

Black: To clarify my previous answer, I do not think a number should be chosen in advance. It should be driven by site-specific information.

Haas: Lifetime estimates generally are not needed at fuel sites. Within CERCLA, there are criteria for discussing short- and long-term effectiveness. I would like a directive that says we do not need a time frame for MNA unless equally developed time frames are required for other remedies.

Question 6: Efforts to decrease uncertainty with respect to plume history matching and/or contaminant transport rates are likely to dramatically improve estimates of MNA or engineered remedy time frames. What are some of the better methods to accomplish this? Should environmental tracer use be encouraged more?

Newell: If a report cites a transport rate of 0.2%/day, why is this a line of evidence?

Buchanan: I would convert the rate to a half-life first and then translate it back to the type of degradation in the plume. However, this is not a simple question to answer because there are mass transfer limitations. There are simple spreadsheet models to determine how the plume is changing with time and what the rates are.

Haas: There are several methods available to determine biodegradation rates. Trends in degradation rates, rather than absolute numbers are important, and can be determined using statistical methods such as Bushek and Alcantar (1995), which accounts for dispersion and advection. I advocate the use of plume residence tracers. For example, trimethyl benzene or dimethyl pentane can be used as tracers for fuel compounds because they have the same fate and transport characteristics as BTEX compounds, but are less biodegradable. Chloride can be used as a tracer at chlorinated solvent sites. Methods to back out degradation rates from tracer data are being developed by John Wilson at NRMRL-Ada. I am familiar with a site at which tracer tests were suggested 5-6 years ago, but due to expense and the potential loss of tracer, they were not conducted. Today, the plume is still not understood, so although tracers are expensive and there are potential risks, they are very useful and may save money in the long-term.

Starr: I agree with Haas. Conservative tracers allow you to separate the destruction processes from dispersion. One method of calculating degradation rate is to plot contaminant concentrations over time or distance; the slope of the line is the overall degradation rate. Another is to correct concentrations for dilution to obtain degradation rates by looking at the conservative tracer data. The Bushek and Alcantar method assumes a 1-dimensional, steady-state plume, and reaction rate constants can be backed out from the data. There is consensus, however, that while plumes are not 1-dimensional, the Bushek and Alcantar method is not conservative enough—the estimated flows are too fast. The Weidermeier method is effective for correcting contaminant concentrations using conservative tracer data.

Buchanan: Chloride is a good tracer for chlorinated solvent sites because it is already there and does not have to be added. At Dover AFB, the concentration of chlorides in the plume is 4-5 times greater than background levels. We backed out biodegradation rates from the chloride data and found that the biodegradation is responsible for the majority of the degradation of the plume.

Black: For large BTEX plumes, degradation by-products such as benzyl succinates may be used as partial conservative tracers. Benzyl succinates are products of microbial degradation of the BTEX, but are further degraded at slower rates.

Newell: Comparing the results of different rate calculations can be like comparing apples to oranges. A concentration versus time calculation indicates source removal, a concentration versus distance calculation ro the Bushek and Alcantar method indicates how quickly the dissolved constituent disappears after it leaves the source. The result indicates how far the contaminant will travel.

Questions and Answers

Question: Could an expert panel such as this be assembled to help in applying the data quality objective (DQO) process to MNA? In general, decision-makers need assistance in identifying the limiting factors involved in MNA, and would benefit from the development of guidance or a handbook.

Buchanan: There are several guidance documents already available that would be a good start. The RTDF has developed a handbook for use at fuel sites. In addition, AFCEE and EPA have jointly issued a natural attenuation protocol for chlorinated solvents in ground water.

Haas: When the fuels protocol were first developed, we observed that many sites had gone through the DQO process and prepared QAPPs. However, the DQOs for collecting nitrate, sulfate, and other data to support MNA were not included. The rationale for collecting the data must be explained. The authors of the AFCEE protocol considered what level of data quality was sufficient and provided a table showing the DQOs for several methods.

Comment: We have questions regarding data sufficiency and the frequency and length of monitoring. These issues can be addressed using the DQO process as well.

Haas: I agree that there is work to be done.

Comment: The recent OSWER directive on natural attenuation includes recommendations that the time frame estimated for MNA, as well as for alternative remedies, be determined in the remedy selection process. In addition, the directive recommends that a dense monitoring array be established to evaluate contaminant source changes with respect to time and space.

Comment: I evaluate MNA at landfills that are large and have variable contaminant sources over time and space. Therefore, a dense monitoring network is needed, but landfill monitoring networks are usually designed for extent.

Black: I agree that a dense monitoring network is needed for large and variable sources. However, from a microbial perspective, landfills offer a lot of microbial activity.

Question: How can the sustainability of anaerobic microbial activity, and thus continued biodegradation of contaminants be assessed?

Black: Analyzing biological oxygen demand (BOD) study may be useful. BOD was on the list of parameters at a site in California's Santa Clara Valley, but I advised the consultant to drop the analysis because I did not think it was warranted. I now regret the decision and wonder what the other panelists recommend regarding BOD.

Newell: BOD has a high detection limit, but it will tell you how much food is available for microbes. A lot of fermentables are needed to drive the dechlorination of chlorinated hydrocarbons.

Buchanan: If the site has BTEX contamination, then you need to consider the electron acceptor pool because the electron donor (BTEX) is present. For chlorinated organics, reductive conditions close to the source area are needed. Organic carbon is also needed to feed the microbial reactions. Site-specific conditions need to be fully evaluated, however, in order to adequately understand the point(s) at which aerobic conditions occur for further dechlorination of the compounds. To do this, TOC or BOD should me measured. I prefer TOC because measuring low levels of BOD is difficult.

Sewell: You need to look at the geochemistry. If the system is currently carrying out the appropriate processes, then you can be comfortable that process is continuing. Nitrogen and sulfur are potential indicators of changing conditions.

Haas: I agree. You need to look at the actual utilization of and the nature of carbon sources. Landfills have a long-lasting source of carbon, but if they are recently capped, the same carbon load will not come out. I was asked at one site whether the carbon source would be available in the future. Dissolved organic carbon was detected about 20 years downgradient of the landfill, which may indicate that it has been persistent. On the other hand, it may indicate that the carbon is not properly utilized. The carbon coming out of the landfill is apparently utilized early, but not fully so it still supports methanogenesis downgradient. BOD and COD measurements are "hit or miss." It is best to compare the two together and see which the microbes prefer.

Newell: To determine whether the carbon source is going to disappear, you can plot concentrations over time for a number of years. If the slope of dissolved organic carbon or TOC is steeper than the contaminant slopes, than it may run out faster.

Question: To what extent is the increase of daughter products, such as vinyl chloride, a concern? Can the rate of increase be modeled? Are there models that incorporate the increase in daughter products when calculating degradation rates?

Buchanan: For chlorinated solvents, if the system is driven anaerobically, then there will be an increase in daughter products, followed by a decrease downgradient. However, if the right microbes are not present, daughter products will accumulate. The applicability of models to project the rate of increase for daughter products is site-specific. At Dover AFB, the vinyl chloride is actually degrading faster than the other contaminants. The accumulation of daughter products can be modeled using chemical engineering sequential reaction techniques.

Newell: The BIOCHLOR model will combine advection, dispersion, sorption, and sequential decay and the generation of daughter products. The model is currently under review by EPA and will be released soon.

Haas: At chlorinated solvent sites, you need to determine whether the plume is at steady state. If vinyl chloride is being produced, it will be produced in the future. Vinyl chloride concentrations must be monitored to see that it does not accumulate. The accumulation of daughter products is a concern where subsurface conditions undergo a dynamic change, such as capping of a landfill—a landfill becomes highly anaerobic when it is capped. Treatment systems such as chemical oxidation and air sparging introduce oxygen to the subsurface and may convert an anaerobic area that is degrading PCE and TCE to one where PCE and TCE are recalcitrant.

Question: How can the use of MNA be juxtaposed effectively with engineered remedies?

Buchanan: Both remedies need to be complementary. For instance, air sparging systems should not be installed in areas where reductive dechlorination is occurring.

Newell: As a rule-of-thumb, I believe that a pumping remedy upgradient of a reductive dechlorination area cannot be too antagonistic if it serves to contain the source zone. It would be worse to pump in the source zone.

Haas: Frank Chapelle (USGS) and Todd Weidemeier (Parsons Engineering) are trying to address this issue and will publish a paper soon that will consider how each remedy will affect natural attenuation at fuel and chlorinated solvent sites. The use of both MNA and engineered remedies is a complex issue.

Sewell: We need to consider the process that needs to be protected and ask why is it occurring? If the process does not provide a benefit for the microbial population, it is not going to occur. Does creating a different set of geochemical conditions, favor the process?

Partitioning Interwell Tracer Test: Case Study at Hill Air Force Base Operable Unit 2

Hans Meinardus, Duke Engineering and Services

Operable Unit 2 (OU2), located on the northeastern boundary of Hill AFB in Utah, was used from 1967 to 1975 to dispose of unknown quantities of chlorinated organic solvents from degreasing operations. These dense non-aqueous phase liquids (DNAPLs), primarily trichloroethene (TCE), were placed into at least two unlined disposal trenches underlain by an alluvial sand aquifer. This shallow unconfined aquifer consists of a heterogeneous mixture of sand and gravel and is contained in a buried paleochannel eroded into thick clay deposits. A large volume of DNAPL remains in the subsurface as a mobile phase pooled in the topographic lows of the clay aquiclude, and as an immobile or “residual” phase retained as ganglia by capillary forces in the aquifer’s pore spaces.

Earlier in the century, hydrogeologists recognized the inadequacy of parameters for measuring field-scale hydraulic conductivities and developed pumping tests. It is now possible to use partitioning interwell tracer tests (PITTs) to estimate NAPL volumes over field-scale distances rather than relying on cores alone to locate and estimate NAPL volumes in the subsurface. These PITTs represent a DNAPL characterization tool able to accurately determine: the total aquifer volume swept during the tests; the total amount of DNAPL present in the aquifer volume swept by the tracers; and the average residual saturation present in the swept volume, and its spatial distribution. This proven technology provides data essential for designing effective remedial actions and is also used as a performance assessment tool used to quantify NAPL source remediation effectiveness.

PITT consists of the injection of a suite of conservative and partitioning tracers into one or more wells and the subsequent production of the tracer solution from one or more nearby extraction wells. While the conservative tracers will be unaffected by the presence of DNAPL in the pore spaces (it will bypass the DNAPL without attenuation), the partitioning tracers undergo retardation due to their partitioning (dissolution) into and from the DNAPL. The observed chromatographic separation of the tracers from analysis of samples taken from the extraction well is due to this partitioning and is used to estimate the volume of DNAPL (or LNAPL) in the swept interwell zone between the injection and extraction wells.

The 0retardation of the partitioning tracers relative to conservative tracers is caused by the rapid, reversible dissolution and exsolution of the partitioning tracers into and from the stationary DNAPL. The equilibrium partition coefficient (K_i) of a partitioning tracer "I" is defined as:

$$K_i = \frac{C_{iD}}{C_{iM}}$$

where C_{iD} is the concentration of the "i^{th}" tracer in the DNAPL, and C_{iM} is the concentration of the "i^{th}" tracer in the mobile phase—the air or ground water transporting the tracer. Conservative tracers have a partition coefficient of zero relative to the DNAPL. For larger values of the partition coefficient, the affinity of a partitioning tracer for the DNAPL relative to the aqueous phase increases. Higher affinities result in longer average time periods spent by the tracer within the stationary DNAPL. Thus, when DNAPL is present, the recovery of partitioning tracers at the extraction well is retarded relative to the recovery of the conservative tracer. The average DNAPL saturation (S_D), defined as the fraction of pore space occupied by stationary DNAPL in the tracer-swept volume (the pore volume "swept" by the tracer solution) is calculated using the following equation:

$$S_D = \frac{(R_f - 1)}{R_f + K - 1}$$

where R_f is the retardation factor defined as:

$$R_f = \frac{\bar{t}_p}{\bar{t}_n}$$

where $\bar{t}_p$ and $\bar{t}_n$ are the first temporal moments of the partitioning tracer and non-partitioning (conservative) tracers, respectively. The terms $\bar{t}_p$ and $\bar{t}_n$ can be thought of more simply as the mean residence times or average travel times for the partitioning and non-partitioning tracer to travel from the injection well to the extraction well during a partitioning tracer test, and are calculated as follows:

$$\bar{t}_n = \frac{\int_o^{t_f} tC_n(t)dt}{\int_o^{t_f} tC_n(t)dt} - \frac{t_s}{2}$$

and

$$\bar{t}_p = \frac{\int_o^{t_f} tC_p(t)dt}{\int_o^{t_f} tC_p(t)dt} - \frac{t_s}{2}$$

where t_s is the "slug size" or tracer-injection duration, t_f is the duration of the PITT, and $C_p(t)$ and $C_n(t)$ represent the partitioning and non-partitioning tracer concentrations, respectively, at the extraction well as a function of time, t. Because the retardation factor for each partitioning tracer, R_f, is a function of both the partition coefficient (K_i) for the tracer and the average DNAPL saturation, S_D, of the DNAPL-contaminated aquifer. Therefore, S_D can be determined by measuring R_f for tracer pairs with known partition coefficients, K_i.

Knowing both S_D and t_n, the tracer-swept pore volume (V_p) can be estimated for a particular extraction well by:

$$V_P = \frac{m}{M} \frac{Q\bar{t}_n}{1 - S_D}$$

where M is the total mass of the tracer injected, m is the tracer mass produced from the extraction well under consideration, and Q is the total fluid injection rate at the injection well. The DNAPL volume in the tracer-swept pore volume is then calculated by $V_D = S_D * V_P$.

In theory, only one partitioning and one non-partitioning tracer are required to determine the volume of DNAPL in a swept volume. In practice, however, PITTs are designed conservatively, using a suite of partitioning tracers to account for potential variation in the amount of DNAPL present in the swept volume. The suite of partitioning tracers, with known partition coefficients for the water/DNAPL system, are employed to ensure that at least one tracer response curve will be generated with sufficient separation from the conservative tracer ($K_i = 0$) response curve to calculate the volume of DNAPL in the tracer-swept pore volume. If additional tracer response curves are produced with sufficient separation during the test duration, then additional DNAPL volume calculations can be performed to increase confidence levels for the PITT results.

Two variations of surfactant-enhanced aquifer remediation (SEAR) were recently demonstrated at OU2. As part of these surfactant flood demonstrations, five separate PITTs were conducted. The PITTs were conducted before and after each SEAR demonstration to provide remediation performance assessments. They were hydraulically controlled, without the use of sheetpile walls, and the volume sampled by each PITT was on the order of 6,500 ft^3 (14,000 gallon pore volume). The injected tracers recoveries ranged from 79% to 92%, implying that, within experimental error, all injected tracers were recovered. The method of temporal moments was used to analyze each PITT, and the resulting DNAPL volume estimates were in close agreement with other measurements (DNAPL recovered during each SEAR, and estimates based on core data). Thus, in sandy alluvium, PITTs are very accurate estimators of DNAPL volumes and provide an excellent characterization and performance assessment tool for DNAPL remediation efforts. Based on the success of these PITTs, the Air Force recently completed a series of four large-scale PITTs (each approximately 110 ft in length) to characterize the DNAPL source zone at OU2. These PITTs represent the first large-scale application of the technology.

The successful implementation of field-scale PITTs requires an engineering design strategy using careful and systematic modeling. First, conventional site characterization activities such as drilling, sampling, and hydraulic testing programs were conducted, including conservative tracer tests. The resulting data, along with laboratory studies conducted at the University of Texas at Austin, were incorporated into a geosystem model that integrated site-specific stratigraphic, hydraulic, and contaminant data. UTCHEM, a 3-D multiphase multi-component compositional simulator was then employed to design the PITTs for each SEAR demonstration.

The logistics of conducting a PITT in the field have evolved considerably through the experiences gained at OU2 since 1995. Significant process and systems performance and hence cost savings have been achieved through this experience, mainly in the area of reducing labor requirements through instrumentation and automation. For example, prior to the development of PITTs, there were no protocols for analyzing alcohol concentrations at the low concentration levels needed for a tracer test, so DE&S chemists developed new analytical procedures for this purpose. DE&S utilizes automatic injection into in-line gas chromatographs to provide real time tracer data at the test site. In addition, selected samples are sent to a subcontracted lab for confirmation and low tracer concentration analyses.

Tracer slugs, once injected in a time-consuming batch mode that required a large and unwieldy amount of tankage, are now mixed automatically and extremely accurately on the fly directly into the injection line. Extraction and injection flow control is maintained automatically with a system of flow meters and actuated valves, and 40 ml VOA samples are collected automatically using refrigerated ISCO VOC sampling systems. Samples can also be taken manually at dedicated sample ports. The tracer injection, flow control, and sampling systems are electronically monitored and controlled by the SCADA, which also monitors pressure transducers in each well. The SCADA can be controlled remotely via modem and has built-in alarms that page the operator if a system fails or if a monitored parameter falls out of a set range. Remote access to the system via modem allows control of the processes from off site. The whole system is mounted in a self-contained insulated trailer that is towed onsite and connected to the well field. This automation has reduced the manpower requirements for PITT operations from three 8-hour shifts per day to one 8-hour shift per day.

Questions and Answers

Q: Is the tracer test conducted under a forced gradient, and does the amount of the force affect the results?
A: Yes, it is done under a forced gradient. The force and gradient is a design issue. The tracer is in equilibrium with the NAPL, so it needs a certain residence time. There is a hydraulic gradient in the velocity field, so the velocity of the tracer should be optimized. They conduct a water flood first to remove any mobile or free NAPL; the PITT design is geared to the residual NAPL. If there is any free product, the PITT will underestimate its quantity.

Q: Is there any worry about precipitation in the system?
A: Yes, there is a need for operations and maintenance as the test progresses. There are bypass valves that allow the technicians to maintain samplers without stopping the PITT flow. However, it has not been a problem.

Q: What kind of water is used in the test, and could that affect microbial activity?
A: Potable water. They need to be careful not to change the geochemistry in the aquifer. Sometimes the water is doped with calcium carbonate to avoid flocculation. Temperature is another critical factor. The injected water has oxygen, but the level is not high enough to be concerned about biological activity or stimulating biofouling.

Q: Is there any fouling of the injection wells?
A: The NAPL is saturated with petroleum grease, and there is some coating on the injection tubes with grease. No biofouling was seen.

Q: Do permeability differences within the aquifer cause any problems?
A: Yes, but not insurmountable problems. The foam flood process was designed to avoid these problems.

Q: When do you know when the test is complete?
A: Continuous monitoring is conducted, and the stopping criterion is when the tails drop to 1% of the tracer peaks.

Q: At Pease AFB, in New Hampshire, site characterization showed DNAPLs within heterogeneous fine-grained deposits and clays. How can you ensure that the tracer does not bypass the DNAPL in low-permeability zones?
A: It is possible to design the PITT to control mobility and make the fluid go through the low-permeability areas using polymers or foam to increase the viscosity of the fluid. This decreases the shear forces in the fluid and mitigates the effects of heterogeneity. They can cause other problems, however.

Direct Push Technology Sampling

Richard Steimle, U.S. EPA, Technology Innovation Office

EPA headquarters is interested in learning if any federal or state regulatory office has used direct push technologies (DPT) instead of traditional drilled wells to collect ground-water samples used for regulatory decisions. DPT has been used extensively in the field for screening purposes and for well siting, but there may be regulatory barriers to its use for such purposes as Hazard Ranking System scoring. EPA is interested in learning if there is any evidence that DPT can be relied upon to produce definitive and legally defensible data, and whether there are any restrictions on the quality of data it can produce compared to drilled wells.

EPA's National Risk Management Research Laboratory (NRMRL) Subsurface Processes and Remediation Division in Ada, Oklahoma, is conducting research to gather and review existing datasets that consist of ground-water samples of environmental contaminants collected by both DPT and traditional wells at the same site. They want to create a working group involving states and regions to help frame the right questions and define the information needed.

The NRMRL will be preparing an issue paper, which could lead to discussions on changing the Hazard Ranking System. Nominations for membership on the working group should be submitted to Steimle at 703-603-7195. Steimle encouraged anyone with DPT experiences or data to contact Deanna Crumbling of the Technology Innovation Office (703-603-0643), Randall Ross at the NRMRL-Ada (580-436-8611), or Robert Hitzig in the Office of Emergency and Remedial Response (703-603-7158).

Questions and Answers

Q: Is headquarters interested only in cone penetrometer data or small-diameter wells and coring, and only water samples or innovative *in situ* instrumentation?
A: Water samples taken from the subsurface using any type of non-traditional technologies (other than drilled and screened wells).

Q: DPT is used frequently for screening. Is the purpose of this project to see if the data can be used for decision-making?
A: Yes. To replace drilled wells for site characterization and monitoring.

Q: Marty Faile (AFCEE) commented that DPT and drilled wells were compared at Hanscom AFB, but he has not seen the results.

AATDF Surfactant/Foam Demonstration at Hill Air Force Base Operable Unit 2

Hans Meinardus, Duke Engineering & Services

Rice University has contracted with INTERA to demonstrate a surfactant/foam aquifer remediation process at Operable Unit (OU2), Hill AFB, Utah. The surfactant/foam project focuses on the use of foam as a mobility control for the surfactant remediation process, and seeks to evaluate the effectiveness and efficiency of using the surfactant/foam process to remediate DNAPL zones. Removal of DNAPL contamination by surfactant-enhanced aquifer remediation (SEAR) is very effective in homogenous formations it the surfactant formulation has adequate solubilization or mobilization capability. Typically, however, natural sediments are heterogeneous, and the surfactant solution has a tendency to flow through the higher permeability layers and bypass the lower permeability layers. This tendency is compounded by the fact that the relative permeability (reduction in permeability due to the presence of other phases) is increased as DNAPL is removed. The result is that heterogeneous systems require much more surfactant to sweep the entire area of interest with the injected fluid than homogeneous formations.

The sweep efficiency of a surfactant flood in heterogeneous systems can be improved by controlling the mobility of the fluids in the formation. The traditional approach used in surfactant flooding enhanced oil recovery has been to add a polymer to the surfactant solution and the following water drive. The use of foam as an alternative method of mobility control for the oil recovery process has been evaluated in the laboratory and has been utilized in the petroleum industry. In its application at OU2, the benefit of foam is to improve the sweep efficiency of the surfactant injected to solubilize the DNAPL contamination in the test zone. Foam is generated by injecting slugs of a gas (in this case air) into the surfactant as it is being injected. The foam preferentially enters the higher permeability layers and maintains a large trapped gas saturation that reduces the relative permeability of the injected liquid. This reduced mobility of the liquid in the high permeability layers results in a more uniform mobility profile for the subsequent liquid injection.

The Surfactant/Foam Process project was divided into two main phases. Phase I was the remediation process development and scale-up in the laboratory, and Phase II was the field demonstration. Phase IIa, the reconnaissance and initial field work was completed in the winter of 1996.This work included characterizing the test area, installing the well array, and conducting hydraulic tests (including a conservative interwell tracer test, or CITT) to obtain the design parameters needed to design the surfactant/foam flood. The design of the demonstration was effected using a version of UTCHEM enhanced to stimulate the foam process. The field work for the demonstration (Phase IIb) was divided into the following components:

- a pre-remediation partitioning interwell tracer test (PITT);
- the surfactant/foam flood;
- a post-remediation PITT; and
- post-remediation confirmation soil borings.

The primary objectives of demonstration were to:

- solubilize and recover the DNAPL in the test region of the OU2 alluvial aquifer;
- demonstrate the use of foam as a mobility control for surfactant remediation;
- reduce the amount of surfactant required to remove the DNAPL; and
- assess the performance of the surfactant/foam precess through the use of PITTs and soil core analysis.

Following the initial PITT, which included a DNAPL volume of 21 ± 7 gallons in the test area, one pore volume of brine was injected to bring the test volume to optimal salinity. Then, 3.2 pore volumes of 3.5 wt% surfactant solution was injected at a constant rate. After approximately eight hours of surfactant injection, air injection began with each of the three extraction wells in turn receiving air for approximately two hours. Air pressure was controlled to allow air to enter the upper screen interval of the aquifer while surfactant solution continued to flow into the lower part. The surfactant/foam injection was followed by a more dilute brine injection and then a water flood to break the foam and recover the surfactant.

The final PITT indicated that a DNAPL volume of 2.6 ± 2 gallons (a residual saturation of 0.03 ± 20.02%) remained in the test area upon completion of the flood. These values correspond to a DNAPL displacement of about 88%. Moreover, DNAPL production curves obtained from the extraction wells indicate that a total of 45 gallons of DNAPL were produced, indicating the during the test, DNAPL was migrating into the test zone from a pool just outside of the well array. Numerical simulations substantiate this interpretation. In spite of the influx of additional DNAPL, the final PITT and the confirmation borings showed that very little DNAPL remained after the test. In fact, the final residual saturation achieved was commensurate with that achieved during the AFCEE SEAR demonstration previously conducted at OU2. While both tests were conservatively designed, it is worth noting that the surfactant/foam test used only about 60% as much surfactant per unit of swept volume.

Questions and Answers

Q: Were sandbox experiments conducted prior to the field work?
A: Yes, two experiments were conducted in a 5 x 8 ft sandbox.

In Situ **Bioremediation by Co-Oxidation**

Gregory Sayles, U.S. EPA, National Risk Management Research Laboratory, Cincinnati, Ohio

Co-oxidation is a treatment process in which a contaminant is oxidized fortuitively when fed another chemical or "cosubstrate." It differs from oxidation in that the contaminant is not used directly as the food source. Some contaminants, such as TCE and 1,1,1-TCA, cannot be directly oxidized; however, microbes can be tricked into using them by adding another food source. For example, if a cosubstrate is introduced to TCE contamination, the cosubstrate is oxidized by microbes to produce CO_2 and water. The enzymes produced in the reaction help drive the conversion of TCE, oxygen, and water to CO_2 and HCl. Known substrates include toluene, phenol, propane, butane, methane, fuels, and ammonia. Fuels and TCE are commonly found in fire training areas at military installations. Therefore, only oxygen need be added to the site to enhance co-oxidation processes.

The co-oxidation mechanism can use mono-oxygenases, which add one oxygen at a time to the contaminant, or di-oxygenases, which add two. In designing a co-oxidation remediation system, it is important to consider competition for the enzyme. Systems that deliver high concentrations of substrates saturate the system and prevent the TCE from accessing the enzymes. This problem can be minimized by injecting the cosubstrate in pulses.

The co-oxidation mechanism can be used in several types of remediation techniques. To treat ground-water contamination in the ground water, the cosubstrate must have adequate water solubility. For example, toluene and air can be injected into TCE-contaminated ground water to co-oxidize the TCE to CO_2 and HCl. Less soluble cosubstrates can be used to biosparge the plume—strip the TCE into the vadose zone where it can be broken down by soil microbes in the presence of cosubstrate and oxygen. Co-oxidation can also be used to treat just soil contamination by injecting air and a cosubstrate such as propane into the vadose zone to co-oxidize TCE to CO_2 and HCl.

There are four pilot or full-scale field projects in process to co-oxidize TCE in ground water and six pilot or full-scale field projects to co-oxidize TCE and/or TCA by biosparging or bioventing. Two case studies— one on cometabolic bioventing and one on ground water co-oxidation—were summarized.

Cometabolic Bioventing: A cometabolic bioventing pilot field test is currently being conducted at Dover AFB by the Remediation Technologies Development Forum's (RTDF) Bioremediation Consortium. The Consortium is made up of representatives from EPA, Zeneca Corporation, Dupont, and the Air Force. The 20 x 30 ft test plot is adjacent to a jet engine maintenance facility. The vadose zone is 10-ft thick and contains concentrations of TCE up to 7 mg/kg and TCA up to 150 mg/kg.

Prior to the field demonstration, laboratory microcosm tests were conducted on samples of site soil. The tests evaluated cosubstrates, nutrient requirements, stoichiometries, and rates. Propane, toluene, methane, and a mixture of toluene and propane were tested as cosubstrates, and propane was selected. Prior to commencing bioventing, a total of 82 soil samples were collected and analyzed for TCE and TCA to establish baseline concentrations.

This demonstration involved the injection of air and propane into three wells screened 4-10 ft below ground surface (bgs) at a total flow of 1 cfm. The concentration of propane in the feed gas was 300 ppmv (parts per million volume). Soil gas concentrations and soil temperature were measured at soil gas monitoring points, which were screened at varying depths within the 4-10 ft interval. The propane uptake was periodically measured during shutdown tests. The bioventing system was shut down for a day and the decrease in propane and oxygen concentrations in the soil gas was measured.

A cometabolic bioventing treatability protocol is under development by EPA. The protocol advocates testing various cosubstrates, measuring rates and stoichiometries. The technology is being tested on various soils, and the results of demonstrations at Dover AFB and Hill AFB will be compared.

Ground Water Co-oxidation: A field demonstration of ground water co-oxidation was conducted by researchers at Stanford University to treat a TCE plume at Edwards AFB Site 19. The site is underlain by an upper and lower aquifer separated by an aquitard. Concentrations of TCE in the plume range from 500-1,200 μg/L. Two dual-screened treatment wells—each screened within the upper and lower aquifers—were installed a distance of 10 meters apart.

A mixture of toluene, peroxide, and oxygen was injected into the upgradient well and mixed with water from the upper aquifer, which was then pumped into the lower aquifer via the lower screen. This formed a bioreactive zone around the lower screen. The treated water in the lower aquifer took about 5 days to migrate to the downgradient well where water was pumped from the lower screen and discharged via the upper screen into the upper aquifer. The ground water reinjected into the upper aquifer contained toluene and oxygen from the upgradient injection, and additional toluene, oxygen, and peroxide were added to the downgradient well forming a bioreactive zone in the upper aquifer.

Toluene was pulsed into the wells once a day at an average feed concentration of 11-13 mg/L. The concentrations of pure oxygen and hydrogen peroxide in the feed gas were 29-44 mg/L and 35-71 mg/L, respectively. The treatment period was 410 days. The concentrations of TCE measured in post-treatment samples were significantly reduced throughout the upper aquifer, although a hot spot of 1,149 μg/L was present in the north of the upgradient treatment well.

The Air Force recently published a guidance document entitled *IRP Cometabolic In Situ Bioremediation Technology Guidance Manual and Screening Software Users Guide* in June 1998. The guide and the screening software are available at http://en.afit.af.mil/env/insitubio.htm.

Advanced Applied Technology Demonstration Facility: Single Phase Microemulsions

Mike Annable, University of Florida

A Winsor Type I surfactant/alcohol mixture was used as an *in situ* flushing agent to solubilize a multi-component NAPL as a single-phase microemulsion (SPME) in a hydraulically-isolated test cell at Hill AFB, Utah. The surfactant (polyoxyethylene (10) oleyl ether) and alcohol (n-pentanol) together comprised 5.5 wt% of the flushing solution. The NAPL was extremely complex, containing over 200 constituents and a 'pitch' fraction which was associated with the soil and was not solvent-extractable. The

NAPL removal effectiveness of the SPME flood was calculated using information from soil cores, partitioning tracer tests, and NAPL constituent breakthrough curves (BTCs) measured at extraction wells. Soil core data for the most prevalent NAPL constituents indicated that approximately 90-95% of the target constituents were removed from the cell by the SPME flood. Integration of NAPL constituent BTCs indicated 60-80% removal of the target NAPL constituents, when partitioning tracer data was used to estimate the initial amount of NAPL present; and > 90% removal of two target constituents when soil core data was used to estimate the amount initially present. A comparison of pre- and post-flushing partitioning tracer data indicated that approximately 72% of the measured NAPL volume was removed by the SPME flood. However, this may be an artifact of partitioning of the tracers into the post-flushing residual pitch.

Questions and Answers

Q: Is there a disconnect between the saturation evaluation and the free phase observed?
A: I think the cores agreed fairly well with the tracer tests. There was a fair amount of NAPL removed, but the numbers from the tracer tests are uncertain. Running the test long runs the risk of degrading the tracers.

Q: Where have these studies been published?
A: Ann Arbor Press will be publishing a monograph soon. A third study on reuse and recycling will be included.

Contaminated Sediments Risk Management

Dennis Timberlake, U.S. EPA, National Risk Management Research Laboratory, Cincinnati, Ohio

EPA estimates that 10% of U.S. rivers and harbors have contaminated sediments that are impacting the ecosystem—100% of the Great Lakes have fish advisories. Sediments used to be considered contaminant sinks. Contamination in the sediments was considered a better alternative to a contaminated water column. However, it is now known that contaminated sediments can impact the food chain, moving from benthic organisms to fish to humans.

Sediments differ from soil in their typically greater moisture content, finer particle size, and higher organic content. Because of these differences, a lot of remediation technologies designed for soil are not effective for sediment. Additional factors that distinguish sediments is that they have higher salt content in marine areas, they are more difficult to handle, and their contaminant concentrations do not be as high to affect the food chain.

Sediments can be managed through maintenance dredging or remediation. Maintenance dredging is conducted to keep the river or harbor open to traffic. Remediation does not necessarily require dredging but may affect the ecosystem. The regulatory framework for sediments is confusing—there are six acts of Congress regarding sediments, and seven federal agencies, including EPA, USGS, and NOAA, are involved in implementing them.

There are three major short-term research issues associated with sediment risk management: dredging, natural recovery, and capping. *Environmental dredging* involves removing contaminated sediments in such a way that the spread of contaminants to the surrounding environment is minimized. The cost of environmental dredging is typically $15/yd^3 versus $1-5/yd^3 for navigational dredging. Critics of dredging say that it does not remove 100% of the contaminants, it resuspends contaminants, and it uncovers old contamination. During dredging, an estimated average of 2-5% of the *in situ* volume of contaminated sediment is resuspended. This is not a very large volume, but can have a significant effect on the ecosystem if the contaminant is PCBs or pesticides. There are controls that can minimize resuspension, such as screens, curtains, and diver-assisted dredging. River currents must be considered when selecting a control. NRMRL is conducting projects to determine the effectiveness of dredging in reducing risk. Some studies have shown that PCBs can be volatilized during dredging. Pre- and post-dredging samples, such as fish tissue samples, are being studied for the effects of dredging. Environmental dredging can cost $15-20/yd3 and the cost of disposal ranges from \$15-50/yd^3 for CDF and \$20-24/yd^3 for a landfill. This compares to \$23-54/yd^3 for physical separation and \$50-300+/yd^3 for treatment.

Natural recovery is a more passive approach to managing contaminated sediments. Natural recovery involves the physical, chemical, or biological processes that act without human intervention to reduce mass, toxicity, mobility, volume, or concentration of contaminants. These processes include biodegradation, dilution, volatilization, burial, and diffusion. Selecting natural recovery is a question of rate: what rate of cleanup is acceptable, because the ecosystem may be impacted during an extended period of time. Limitations of natural recovery are that it can only be used in depositional areas, it is poorly understood, and a monitoring strategy must be developed to see if it is working.

NRMRL is conducting several projects to investigate natural recovery including modeling of adsorption and desorption, isotopic analysis, evaluation of natural recovery remedies, and restoration of salt marshes. NRMRL is also planning a natural recovery field project and is seeking suggestions for sites with PCB and PAH contamination.

In-place capping is the controlled, accurate placement of a clean, isolating material cover or cap over contaminated sediments without relocating or causing a major disruption to the original bed. Capping has several limitations. A capped sediment should not be subjected to disruption, scouring, or navigational dredging. The sediment bed must be capable of supporting the cap, and long-term monitoring is required. Placement precision is also a concern because mixing occurs when a slug of clean material is dropped on to the sediment must be considered.

Risk management decision making involves a consideration of the costs and benefits of contaminated sediment risk management. There are *in situ* and *ex situ* sediment treatment options are available. *In situ* options include biorestoration and the immobilization of lead. *Ex situ* technologies include containment, such as the addition of chemical amendments to reduce metal mobility, CDF treatment (*e.g.*, hydrogen to dechlorinate organics, zero-valent iron to dechlorinate organics, land biotreatment, and composting), and non-CDF treatment.

There are several research efforts related to those at NRMRL including those of the Contaminated Aquatic Sediment Remedial Guidance Work Group (CASRGW), Industry's Sediment Management Work Group, the National Academy of Sciences (NAS), and the Remediation Technologies Development Forum (RTDF) Sediment Action Team. The Industry's Sediment Management Work Group is made up of members of the regulated community. Its mission is to advance risk-based scientifically sound approaches for the evaluation of sediment management decisions, and it advocates more passive approaches to sediment management. The NAS began a 16-month effort on October 1 for the assessment of risks from remediation of PCBs in contaminated sediments. The NAS is concerned with the dredging ban that started with an FY98 House Report. The language of a ban is still in the FY99 appropriations.

For information on the CASRGW, contact Ernie Watkins (EPA, Headquarters) at (703)603-9011 or consult http://www.epa.gov/oerrpage/test/sediment. The Sediments Action Team is an industry/government partnership with both assessment and treatment subgroups. Further information can be obtained at http://www.rtdf.org or by contacting Co-chair Dennis Timberlake at (513)569-7547 or timberlake.dennis@epa.gov.

Questions and Answers

Q: Are there many active research projects regarding active capping?
A: No.

Q: Is this due to the lack of guidance on how to install them?
A: Dave Petrovski will address the capping guidance being developed during the next presentation.

The Hydrogeologic Characterization, Performance Prediction, and Monitoring at Capping and Natural Recovery Sites

David Petrovski, U.S. EPA, Region 5 and CASRGW

The Contaminated Aquatic Sediment Remedial Guidance Work Group (CASRGW) is working to develop guidance to help make informed decisions for managing sediments. Participants in the guidance development include representatives from USGS, the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station, and the U.S. EPA Region 5 in Chicago. The guidance will be produced as a USGS report, although it may contain the EPA and USACE logos. The anticipated completion date for the report is September 1999.

The USGS project will focus on chemical containment achieved by capping. It assumes physical containment (*e.g.*, the cap stays in place and is stable with time and will not erode to expose and erode sediment). Contaminant transport will emphasize the advection and dispersion of dissolved contaminants, although colloidal-facilitated transport may be addressed.

The performance of a cover is controlled by the cover's characteristics and site hydrogeology. The cover should be a continuous homogeneous porous medium. The thickness, hydraulic conductivity, effective porosity, and sorptive capability of the cover material must be considered in the design. The sorptive capability of the medium is especially important, because the caps are thin. Understanding the site's hydrogeology is also important because the cover should not alter the local hydrogeology. The hydraulic conductivity of the cover should be equal to or greater than the hydraulic conductivity of the sediments. Recharge and discharge areas should be delineated, and the advective ground-water velocity determined. To be acceptable, covers must meet containment goals while contending with site characteristics.

The mechanisms of contaminant transport include diffusion, which is slow but ubiquitous; advection which is relatively rapid and commonly drives transport; and hydrodynamic dispersion, which is due to mechanical mixing and diffusion. If the ratio of advection to diffusion (the PECLET number) is greater than 1, then advection predominates.

The USGS report will address four issues: (1) site characterization; (2) cover performance predictions; (3) uncertainty analysis; and (4) performance monitoring. The *site characterization* section will include information on how to predict cover performance.—the types and amounts of hydrogeologic information to collect and the methods of collection. The report will explain how to use the site characterization information for *performance predictions*. The cover performance is predicted by transport equations. The advection-dispersion equation is a 1-dimensional model that considers the vertical component of flow only. The solutions are calculus based. The input required in the equation include:

- constant ground-water velocity estimation (vertical direction);
- dissolved C_0 constant in the pore water and at the sediment/cover interface; and
- dispersion and sorption characteristics of the cover.

The input parameters must be average values to reflect the integrated performance of the cover. The output of the equation is the amount of contaminant migration through the cap with time. The cover/surface water interface is the position of interest because the length of time if takes for the contaminant to reach this position is the breakthrough time of the cover.

The report will also include a discussion of *uncertainty analyses*, which determine how good the performance predictions are. The laboratory-derived, 1-dimensional equations assume the hydrogeology and cover to be homogeneous (measured average value equals the true value). The uncertainty analyses assume that behavior of the contaminant is the same at all points within the cover. However, the magnitudes and direction of hydraulic gradients are time dependent, and measurements have uncertainty. Furthermore, the *in situ* geology, natural cover, and engineered cap are heterogeneous materials. Therefore, the data are invariable limited, because the input is based on mean statistics. Performance predictions may not reflect performance because the performance will vary over the cover leading to different breakthrough times and contaminant fluxes. The USGS report will attempt to estimate uncertainty in performance using error propagation and the Monte Carlo method

The report will also discuss *performance monitoring*. Methods to monitor contaminant migration, breakthrough, and contaminant flux will be included, although not many methods are available. Since performance varies across the cover, the need for multiple sampling locations versus statistical sampling must be considered.

<u>Questions and Answers</u>

Q: Are you limited to using conservative containment goals?
A: No. The document does not set goals—they are site-specific to be determined by risk assessors. If the contaminant flux out of the sediments can be predicted, I may be able to do no better than to say that the goals must be the Aquatic Water Quality Criteria.

Q: Does advective ground-water velocity mean vertical hydraulic conductivity?
A: Yes. We are interested in the vertical component of ground-water flow.

Perchlorate I (Basics)

David Vanlandingham, U.S. EPA, Region 6

As the regional point of contact for perchlorate issues, Vanlandingham provided an overview of the significant problems with perchlorate contamination currently recognized in Region 6 and earlier receiving much attention in Region 9, particularly in California. The Interagency Perchlorate Steering Committee (IPSC) was formed in January 1998 to bring together federal, state, tribal, and local government representatives to facilitate and coordinate accurate accounts of related technological issues (occurrence, health effects, treatability and waste stream handling, analytical detection, and ecological impacts) and to create related information transfer links for interagency and intergovernmental activities.[1]

Ninety percent of perchlorate salts, such as ammonium and potassium perchlorate, are manufactured as propellants for solid rocket fuel by DoD and NASA facilities and their contractors. The remaining 10% of perchlorate salts are used in the manufacture of fireworks and some types of fertilizers. Records

[1] Federal Steering Committee member agencies include EPA, the Air Force, and the Agency for Toxic Substances and Disease Registry.

indicate that perchlorate is manufactured only in the United States. In water, perchlorate salts readily dissociate into the perchlorate ion, which is highly stable, mobile, and persistent in the environment. The salts do not sink or float in water and sorb poorly to soils.

Perchlorate was recognized as a problem first at the Aerojet General Superfund Site, near Sacramento, where a cleanup and abatement order was issued. It was found that little information currently is available on the specific dose-related toxicological effects of perchlorate on human health and ecology As a result, a need exists for evaluation of toxicological data, refinement of analytical data, treatment technologies, and occurrence data.

Perchlorate has been shown to have an anti-thyroid effect by inhibiting iodine uptake, resulting in a reduced thyroid condition known as Grave's disease. The current EPA provisional oral reference dose ranges from 4 to 18 ppb, and California has adopted 18 ppb as a provisional action level and drinking water standard. In order to identify this range of concentrations in the environment, the analytical method for perchlorate was refined and the detection limit reduced to 4 ppb. A peer-reviewed study conducted by TERA, an independent organization, found in March 1997 that insufficient data are available to assess risk. On March 2, 1998, perchlorate was added to the SDWA Contaminant Candidate List in an effort to obtain adequate information for detection levels by 2001. Currently, perchlorate is not listed as a hazardous waste under RCRA and does not have a reference dose specified in IRIS.

In California, perchlorate was detected in 110 wells; 30 wells were subsequently were shut down. At Lake Mead, which is the primary drinking water source for Los Angeles and Las Vegas, levels greater than 16 ppb were identified, and no biodegradation was observed. Perchlorate has been in the Colorado River, which may pose an additional impact to tribal communities who use the Colorado River for irrigation purposes. Perchlorate has also been found in groundwater in Texas and Arkansas. In Region 6, perchlorate contamination involving large numbers of receptors has been identified at three sites:

- McGregor Naval Weapons Industrial Research Plant near Waco, Texas, where a concentration of 96 ppb (of 35-37 samples) was identified in surface water;

- Longhorn Army Ammunition Plant in Texas; and

- Schumaker Naval Ammunition Depot, Arkansas, where RCRA facilities now lease property that formerly contained open burning/open detonation (OBOD) areas. Region 6 has issued a §3007 request to DoD and the Navy in an attempt to collection additional site characterization information.

Studies have shown that typical water and wastewater treatment methods do not work at perchlorate sites. Bioreactors, however, show promise for perchlorate removal in high-concentration influents.

EPA anticipates revising the RfD by the end of November 1998 to include reproductive, developmental, and immunotoxicity factors, and conducting additional ecological toxicity studies. EPA, DoD, and the ATSDR play significant roles in IPSC efforts to assist in protocol development, communicate information to the public, and establish stakeholder partnerships that will facilitate communications and secure funding. Additional information may be obtained from Vanlandingham at 214-665-2254 or vanlandingham.david-s@epa.gov, or the Web site www.epa.gov/ogwdw/ccl/perchlo.html.

Perchlorate II (Case Study): The Air Force Perspective

Daniel Rogers, Wright Patterson AFB, Dayton, Ohio

The information base on perchlorate is constantly changing. Normally, soil is not a good binder for perchlorate, but perchlorate will bond to sand, but the reasons are unknown. Human health effects of perchlorate are primarily associated with thyroid disease. Perchlorate action levels, based on internal EPA documentation, has been 4 to 18 ppb. The current research effort coordinated by EPA's National Center for Environmental Assessment is the first complete work-up for perchlorate. Prior to 1997, analytical detection limits for perchlorate were on the order of 400 ppb, based on methods developed by Aerojet General. This was not considered a problem, since Aerojet's interests were not related to drinking water. Aerojet made some analytical breakthroughs in January 1997 that dropped the detection limits to about 100 ppb. In April 1997, the California Department of Health was able to reduce the limits to 4 ppb; therefore, the search for perchlorate in water became practical.

The Interagency Perchlorate Steering Committee (IPSC) was established by EPA, Air Force, the Agency for Toxic Substances and Disease Registry (ATSDR), and the states, with the Executive Committee consisting of representatives of EPA's Office of Solid Waste and Emergency Response (OSWER), Region 9, the National Center for Environmental Assessment (NCEA), Office of Water, and the Air Force. Subcommittees were formed for health effects, peer review, treatment technologies, ecological impacts, and analytical methods.

The goal for IPSC is to provide the best scientific information to ensure protection of the nation's drinking water supply; to get the scientific information on toxicity and occurrence to decision makers and the public; to develop methods and technologies as required; and to maintain the integrated approach of federal, state, and DoD agencies as a model for future cooperation.

The preliminary study on ecological risk is completed, and will be sent from NCEA to OSWER in December. Health effects and toxicity research consists of eight studies, six of which will be completed and delivered to OSWER in the next couple of months. Of the studies identified as needed, EPA felt that developmental neurological and the 90-day "all other organs" (other than thyroid) were most critical for determining the reference dose for inclusion in EPA's Integrated Risk Information System (IRIS).

EPA's research budget contained a Congressional appropriation for $2 million to support a conference on potential treatment technologies for perchlorate in California and a grant to the American Water Works Association Research Foundation and the California Metropolitan Water District to support seven research projects.

Solid-fuel rocket boosters must be re-fueled every 20 years or so, which entails a high-pressure washout of the rocket motor assembly. Rogers said that the Air Force has developed and implemented practices that can recover and reuse perchlorate at high concentrations (1-20% by weight), and has developed and is implementing a multi-stage ammonium perchlorate bioreactor that can clean waste waters at the 10 to 10^{-4} ppm level. The reactor can operate at high volumes and successively converts perchlorate (ClO_4) to perchlorite (ClO_3) to chloride (ClO_2) to chlorine and oxygen, and will discharge to surface waters below regulatory levels. Under development is an immobilized enzyme reactor that will treat very low concentrations of perchlorate.

How does perchlorate get into the water in the first place? The assumption is that if perchlorate exists in the water, DoD is responsible. But, while commonly associated with military solid rocket fuels, perchorate, is not just a DoD issue. Suffolk County, New York, found perchlorate in 30 ppb concentrations, and after searching land-use data, associated it with a former Bomarc site, an old Army tactical missile. However, when they contacted the Air Force, they were convinced that since the Bomarc site did no maintenance or assembly, it was highly unlikely that solid rocket fuel could have leaked. After further searching, they also discovered that the county police also used the area to destroy confiscated fireworks (which also may contain perchlorate), and coincidentally discovered that perchlorate can be a significant ingredient in fertilizers manufactured from saltpeter (sodium nitrate) imported from Chile. While Rogers discovered that the Chileans did acknowledge adding perchlorate to the saltpeter, he could get no explanation for why they do so. After some consultation, the Air Force and the State of New York discovered concentrations of perchlorate in fertilizers.

Questions and Answers

Q: Does DoD have a list of facilities that used perchlorate?
A: Yes. The list of all sites where perchlorate was used, distributed, or stored for any purpose was delivered to OSWER two months ago. This included laboratories, training, or maintenance.

Q: Will DoD begin screening and characterizing these facilities on its own or wait until EPA requires it?
A: Where the Air Force believes that there is potential for contamination, they are asking the field programs to begin studies. As yet, this is just a request rather than a requirement. Vanlandingham added that the responsibility is shared by EPA; EPA has the list of sites and should begin to contact the states where perchlorate may be a problem. Regional people could contact him for the list if they do not have it from OSWER.

Q: Were feedstocks sampled at fertilizer plants to determine where the contaminated saltpeter was used? Where was the suspect fertilizer used? Is it wet or dry fertilizer?
A: The fertilizer was used primarily in the West and Midwest on grains and citrus. The only tests to confirm its presence were conducted on dry fertilizer. The fertilizer manufacturers were contacted, but are not very cooperative. Rogers pointed out that the knowledge that perchorate was put into Chilean saltpeter was only confirmed a couple of months ago, and the Chileans have thus far refused to cooperate. The U.S. Department of State is pursuing the issue.

Q: Saltpeter is a constituent of gunpowder; are Navy facilities affected?
A: Do not know.

Q: With respect to the affinity of perchlorate for sand, has anyone tried zeolite in treatments?
A: EPA's National Exposure Research Laboratory in Athens, Georgia, is looking into the sand/perchlorate affinity; Rogers did not know if they are considering zeolite.

Kelly Air Force Base Success Story

Tim Underwood, KPMG Peat Marwick

Underwood (formerly with EPA Region 6) provided a summary of events, activities, and challenges involved in the successful redevelopment of Kelly Air Force Base (AFB), San Antonio, TX, a facility closed in accordance with the July 1995 round of closures recommended under the Defense Base Closure and Realignment Commission (BRAC) Program. Prior to closure, the Army and Air Force used the facility for personnel training and air testing. The facility was active for 80 years, 40-50 of which it was used for heavy industrial purposes. As a result, equipment such as solvent cleaning lines and underground storage tanks are located on at the facility, and contaminated areas are being cleaned under DoD's

Installation Restoration Program. The site is regulated under RCRA, but is not listed under CERCLA as a Superfund site.

As the largest employer in southern Texas, Kelly AFB supported 15,000 jobs and the largest concentration of industrial activity in San Antonio. The facility consists of 10.7 million square feet of building space and 4,000 acres, 1,878 of which are slated for reuse. Operations conducted on the base comprise industrial operations related to airframe repair and engine maintenance; warehouse and distribution; and administration, housing, utilities, and support facilities.

Following announcement of the base closure, the city of San Antonio immediately embarked on efforts for redevelopment of the property, and the Greater Kelly Development Corporation (GKDC) was formed to plan and implement a redevelopment strategy. Primary elements of the plan include development of a transportation center and conversion of the industrial areas to the private sector, while a portion of the base property is being realigned to the nearby Lackland Air Force Base. Approximately 50% of the base property was turned over to the GKDC.

Redevelopment opportunities include airframe maintenance by Boeing Corporation; aircraft engine maintenance through an open competition issued by the Air Force; inter-modal transport by corporations such as Ryder Trucking and UPS; and build-to-suit industrial space to be used by industries such as Railcar America. In order to minimize time gaps between shut-down of Air Force activities and start-up of new operations, and thus maintain employment opportunities, new tenants such as Boeing Corporation have moved in while shut-down activities (such as solid waste management unit closure) are completed.

This simultaneous use of the property is made possible through provisions of the Base Closure Community Assistance Act, which states that DoD must consult with EPA before entering into any lease. A memorandum of understanding between EPA and DoD was completed in May 1994 pursuant to this requirement. In addition, indemnification of property transferees from any legal actions arising from DoD activities at any closing installation is provided by the National Defense Authorization Act of 1993. Methods used to limit risk during redevelopment include the use of existing information, enhanced site characterization, facility modification, indemnification, insurance from a consortium of providers, and expanded use of alternative dispute resolution. The GKDC has experienced few problems obtaining credit from financial lenders because leasing is of a long-term nature.

Primary partners in the redevelopment team are the GKDC, which is responsible for raising funds for base property purchases and upgrading the infrastructures; Air Force Base Conversion Agency; BRAC Implementation Directorate; San Antonio Air Logistics Center; federal agencies (including EPA, Department of Housing and Urban Development, Health and Human Services, Department of Interior, and Department of Defense); and state agencies. Currently, 44% of the surplus property acreage is under lease. Of the non-realigned property, 30% is under lease and 32% is under leaseback arrangements.

Dioxin: Formation Mechanisms, Full-Scale Emission, and Control

James Cudahy, Focus Environmental, Inc., Knoxville, Tennessee

Dioxins are created in all fires— coal, forest fires, combustion— not just those involving hazardous waste. There are 210 dioxins: 75 congeners of dibenzo-para-dioxin (for example 2,3,7,7-tetrachloro-dibenzo-para-dioxin) and 135 congeners of dibenzofuran. There is a strong world-wide emphasis on dioxin emissions. The Clean Air Act (§112[c][6]) requires identification and control of sources, and probably addresses 90% of overall emissions in the United States. There is a proposed hazardous waste combustion MACT (Maximum Achievable Control Technology) standard for dioxin of 0.2 nanograms per deci-standard cubic meter (ng/dscm) International Toxic Equivalents (I-TEC), corrected to 7% oxygen. Key researchers on dioxin formation include Brian Gullett (EPA), Kevin Bruce (Accurex), Elmer Altwicker (RPI), Otto Hutzinger (Germany), Hanspaul Hagenemaier (Germany), and Christopher Rapp (Sweden).

There are several critical requirements or mechanisms for dioxin formation: gaseous condensation of chlorinated precursors (chlorinated organics, chlorobenzenes, chlorophenols), condensation on particulates, catalytic formation on particulates, formation during a relatively narrow temperature window and critical residence times. Information on gas-phase condensation comes from full-scale experience, and shows that good combustion is very important. Dioxin formation is a function of the specific combustion system (wet or dry scrubbers). Boilers increase dioxin formation because they create more particulates and typically have greater residence times. Condensation on particulates is catalyzed primarily by the presence of copper or iron. Typical incinerator particulates contain 500-4,000 ppm copper and iron in the percent range. Full-scale experience comes from tests on cement kilns with no copper and spiked with copper. There does not appear to be any effect on polychlorinated dibenzo-dioxin or polychlorinated dibenzo-furan (PCDD/PCDF). The combustion chamber operates typically at 1800-2500°F (1,000-1,400°C). Since dioxin's window of formation is 400-800°F (200-400°C), the cooler gases favor formation in the boiler (during energy recovery) and the air pollution control equipment. Using dry scrubbers, the gas residence time at the critical formation temperatures is on the order of seconds, with very high dioxin formation. Where wet scrubbers are used (rapid quenching), the residence time is a fraction of a second and there is minimal dioxin formation (typically <0.2 ng TEQ/dscmc, and <0.01 ng TEQ/dscmc are not uncommon).

It is a false but common precept that indirectly fired combustors are inherently better at minimizing dioxin formation; the afterburner technology is very forgiving of process failures and transients. However, the associated recovery of carbon is a new technology and must be factored in to the overall emission control. EPA has recommended carbon injection as the MACT for dioxin and products of incomplete combustion (PIC) control based on limited experience in the laboratory. Full-scale experience by Rollins in Kansas with carbon-injection showed that carbon and fly ash from the baghouse had very high concentrations of adsorbed dioxins. It is believed that the dioxins were being formed on the carbon in the baghouse. The dioxin can be destroyed thermally in a rotary kiln incinerator. Carbon injection for dioxin and PIC control should consider adsorption of organics and operational issues such as temperature, location of injection, type of carbon, and contact time. This whole question requires further research.

Estimated annual dioxin emissions (grams per year) from various sources are:

- Hazardous waste incinerators 15
- Cement kilns 62
- Municipal waste combustors 215
- Medical waste incinerators:323

for a total of 615 grams per year total emissions of dioxins in the United States.

Questions and Answers

Q: Polyvinyl chloride (PVC) is a very strong precursor. Is this due to the chlorine or the polymer?
A: Unknown. It may be related to the situation in the late 1970s when burning PVCs produced lots of polychlorinated biphenyls (PCBs). PCBs are similar in structure to dioxins and furans.

Institutional Controls

Open Discussion

Paul Leonard informed the audience that there are institutional controls (ICs) training materials developed by Region 9 (Mark Filipini is the coordinator) encompassing deed restrictions, legal authorities, and responsibilities of various parties. The course can help participants to address the practical considerations needed to ensure ICs or land use control measures remain effective over the long-term.

Steve Hirsh stated that assistance is needed to better understand the: (1) IC provisions appropriate for incorporation in a ROD; (2) legal assistance necessary to determine the type of mechanism that will ensure ICs are implemented properly; and (3) actions required to ensure ICs continue to be implemented in accordance with a ROD. Leonard agreed that remedial project managers need a thorough understanding of the actions needed to implement ICs, and in particular, a clarification of IC terms. For example, a fence may be considered an “engineered control,” while land use controls are considered ICs. Craig said that DoD often tries to install fences or “no trespassing” signs as ICs.

Jim Barksdale commented that adequate site characterization and risk analysis are necessary before implementation of an IC. Craig agreed, noting that DoD often attempts to implement ICs instead of completing site characterization activities. At Adak Naval Air Station (where property is being transferred to a tribal community) for instance, the Navy spent $5 million on fencing and signs that are expected to last two years. EPA responded that this approach is inadequate for protecting human health and the environment. In another case, a fence was installed within the perimeter of the contaminated area, leaving a portion of the contaminated area accessible to the public. Harry Craig suggested that other mechanisms be used, such as dig permits, zoning restrictions, well installation permits, and annual monitoring.

Participants commented that enforceability of ICs is a major concern. The distinctions are unclear between what activities may be allowed on private property versus property owned by a PRP. Often, private property owners do not allow site characterization and remedial activities because of potential political or resale problems. At Adak, for example, the Aleut Tribe did not want the responsibility for IC management. Consideration of a property’s end use should be taken into account early in the process to determine if residential use is anticipated; if so, ICs will not work. Zoning has proven to be relatively ineffective, and cannot be considered the only IC tool available. The possibility of building residences on concrete slabs could be considered, but this approach (as with most land restrictions) likely would lower property values. Discussions with private property owners should be held prior to releasing plans for institutional controls.

Participants agreed that the use of ICs rather than actual cleanup appears to be increasing, and that federal facilities avoid strict IC plans that involve enforceability within a short amount of time. Any remedy that does not reduce the contamination will require ICs. Methods are needed to ensure that deed restrictions remain effective during all future property transfers. Although restrictions should be found during title searches, they may be lost in the process. A complete understanding of local law is needed to determine if an approach other than deed restrictions, such as permits, are needed. The use of permits may not solve the problem, however, because they may not be obtained. The biggest related concern may be the use of ICs at sites with unexploded ordnance, for which potential dangers become increasingly overlooked over time. Helge Gabert suggested that a retrospective study could look at ICs installed five or 10 years ago to see if they worked. Steve Kinser related an example from Times Beach, Missouri, where dioxin-contaminated fill dirt was buried and left with an IC that requires a state permit to drill; Kinser was skeptical that all wells would be permitted. Leonard pointed out the importance of continual monitoring of such sites.

The discussion ended with a note that other federal agency laws must be considered when ICs are considered or implemented, and reiteration that ultimate land use is a key factor in determining whether, and which, ICs are appropriate.

Thursday, November 19

Toxic Substances Hydrology Program

David Morganwalp, U.S. Geological Survey, Reston, Virginia

The goal of the Toxic Substances Hydrology Program is to provide scientific information on toxic substances in the Nation's surface and ground waters to avoid human exposure, develop effective remedial strategies, and prevent further contamination. The program's research approach is to establish long-term representative research sites (field laboratories); develop interdisciplinary research teams; follow a holistic (system-concept) approach; generalize results to other similar sites; and develop and transfer methods and models.

The major research areas of the program are point-source ground-water contamination, nonpoint-source contamination, and hard rock mining related contamination. There are intensive field investigations ongoing across the United States including a fractured rock site at Mirror Lake, New Hampshire, three hydrocarbon sites in New Jersey and Minnesota, and chlorinated hydrocarbon sites at Picattinny Arsenal, New Jersey, and Pensacola, Florida. A study near Yucca Mountain, Nevada, is looking at how ground water moves in an arid environment. There are also nonpoint source sites in the Midwest, Mid-Atlantic Coastal Plain, the Mississippi Delta, and the San Francisco Bay.

The Mirror Lake site was selected for study because of the difficulties in investigating ground-water flow in fractured bedrock. The ground water at the site is uncontaminated, and the fractures in the granite and schist bedrock have extremely variable hydraulic properties. The approach to studying the site was to "think heterogeneity." There are abrupt spatial changes in the hydraulic properties of fractures, and geologic structures control the ground-water flow. Pumping tests were conducted to measure drawdown in observation wells screened in various fractures. The fracture zones were also packered off and sampled to assess water quality parameters. The results of hydraulic testing were combined with seismic tomography results to better understand the 3-dimensional character of the rock and to construct a conceptual model of heterogeneity. The end result was a MODFLOW model that showed zones of different hydraulic conductivity. Another technique used at the site was radar tomography coupled with tracer testing. This technique allowed comparison of before and after tomograms to determine where the plume was moving.

The Toxic Substances Hydrology Program is now seeking a contaminated fractured bedrock site to investigate and would like to know the research needs of the TSP. The program is open to the location of the site and types of contaminants. Contact David Morganwalp, Assistant Coordinator, at dwmorgan@usgs.gov or Herb Buxton, Program Coordinator, at hbuxton@usgs.gov with suggestions of sites or research needs.

The USGS is developing a Characterization Tool Box for fractured rock aquifers which covers geologic and fracture characterization, subsurface fracture detection, ground-water flow and hydraulic characteristics of fractures, chemical transport in fractures and rock, as well as synthesis, hypothesis testing, prediction, risk assessment, ground-water flow, and chemical transport modeling.

Further information on the Toxic Substances Hydrology Program can be obtained at http://toxics.usgs.gov/toxics/. The USGS's web site is http://www.usgs.gov/, and the Water Resources group is at http://h2o.usgs.gov.

Question and Answers

Q: How would this MODFLOW model developed at Mirror Lake hold up in the Rocky Mountains or the Sierras?
A: The model would hold up pretty well, but there may be variations in the overall paradigm.

DNAPL Remediation

Richard Steimle, U.S. EPA, Technology Innovation Office

Remediation of dense non-aqueous phase liquids (DNAPLs) involves three technologies: 1) *in situ* oxidation, which actually destroys DNAPLs; 2) surfactant and cosolvent flushing, which remove but do not destroy DNAPLs; and 3) thermal enhancements to soil vapor extraction (SVE) or pump-and-treat systems, such as dynamic underground stripping with hydropyrolysis oxidation, which does both.

Remediating DNAPLs first requires locating the source through ground-water monitoring or by examining the history of the site. Partitioning interwell tracer testing (PITT) is a promising technique to estimate NAPL volumes over field-scale distances. PITT tests have been conducted at Hill AFB, Dover AFB, and Camp Lejune, and it seems to be the only test that can delineate fragments, pools, or fingers of the DNAPL. The accuracy of the PITT test is based on the assumption that water goes where the PITT is located. A good geological characterization of the site is critical in all cases; they cost about $20,000-$30,000.

EPA will publish a report in December 1998 that will describe *in situ* oxidation at 15 sites. Major research and guidance documents have been written on surfactants and co-solvents based on 44 demonstrations of surfactant and co-solvent (including one full-scale cleanup) and 16 thermal enhancement sites (one full-scale cleanup done in Chicago). Any new publications regarding the technologies will be posted on TIO's "CLU-IN" web site (http://clu-in.org).

In situ oxidation is a permanent low-energy solution that destroys NAPLs and enables rapid cleanup and closure. However, it can volatilize contaminants and does require the use of hazardous chemicals. Furthermore, subsurface biomass is destroyed. *In situ* oxidation is best used for compounds with unsaturated carbon-carbon bonds. A strong oxidant such as hydrogen peroxide, ozone, potassium permanganate, or dissolved oxygen oxidizes organics is needed. *In situ* oxidation requires the use of large quantities of the oxidizing agent at high contamination sites and possible incomplete oxidation and formation of intermediate contaminants.

Surfactant and cosolvent flushing treat a wide range of contaminants and can remove NAPLs. It enhances existing pump-and-treat systems with little modification. On the other hand, there are problems associated with the technology:

- Increased plume size and concentrations due to surfactant combining with the NAPLs
- Surfactants may be difficult to recover and may increase the cost of cleanup
- Surfactants can cause well fouling
- Regulatory hurdles associated with the reinjection of treated ground water

Thermal enhancement to SVE or pump-and-treat is a simple technology that requires heating the subsurface by steam, electrical conductivity, or radio frequency. This technique causes the DNAPLs to be mobilized, solubilized, or vaporized. It is currently being used at the Savannah River and the Lawrence Livermore sites. Thermal enhancement does not require additional permits and can be used for most subsurface media. However, it is expensive, it needs plume control, and it destroys the subsurface biota. Studies are currently being done on the reintroduction of biological activity.

Quantitative testing and analysis of DNAPL technologies are being performed at the ground-water remediation field laboratory at Dover AFB, which has a permit to allow the actual injection of contaminants into the ground water. The quantity of injectant is controlled so that mass balances can be calculated. Other DNAPL test sites include: 1) Launch Pad 34 in Cape Canaveral, where the DNAPL Consortium is conducting a side-by-side comparison of three *in situ* technologies in a sand aquifer; 2) The Bedrock Remediation Project in Smithville, Canada, which contains PCBs in fractured rock; and 3) Plant Y-12 in Oak Ridge, Tennessee, which contains TCE in fractured rock. Contamination extends to 500 ft, and the technology is not available that will allow cleanup of a plume at that depth.

Ten states (mainly on the East Coast, Mid-West, and Oregon) have legislation, money, and interest to address the remediation of solvents at dry cleaners. The State Dry Cleaners Project brings together 10 experiences with a common focus on DNAPLs, site size, and contaminants. Lessons learned from the first site, in Jacksonville, Florida, will be used at the other nine sites. Steimle expects to hold a workshop in the spring of 1999. The State Dry Cleaners Project will have periodic conference calls to discuss issues and programs. More information is on CLU-IN at http://clu-in.org/dryclean.

The Ground-Water Research and Technical Assistance Center's (GWRTAC) report, *Technologies for Remediation of Sites Contaminated with Dense Non-Aqueous Phase Liquids*, will be available soon at http://www.certrac.ctc.org. EPA's 1991 report, *Dense Non-Aqueous Phase Liquids*, is available at http://www.epa/ada/issue.html.

Questions and Answers

Q: Some people feel that there is an overselling of the PITT test. Do we know what our success rate is at these sites?
A: These sites are new and determining success will require much monitoring.

Q: Has there been an economic and regulatory bottleneck?
A: We interviewed the states and they want us to show them a plan.

Extreme Short-Range Variability in VOC-Contaminated Soils

Brian A. Schumacher, U.S. EPA, National Exposure Research Laboratory, Las Vegas, Nevada

EPA's National Exposure Research Laboratory's Environmental Sciences Division (NERL-ESD) is conducting a research program aimed at improving the sampling of VOC-contaminated soils. NERL-ESD is examining the physical sample collection, sample handling, and sample preservation as well as the processes influencing VOC concentrations and distributions in the soils environment. In order to accurately characterize the distribution of VOCs at a site, the long-range and short-range variability of VOCs and other soil parameters must be known. The objective of this program is to assess extreme short-range variability of VOC concentrations within the soil profile within a vertical distance of 15 cm.

Two sites were selected: the Western Processing Site in Kent, Washington, and the Oregon Fir Supply Company in Portland, Oregon. The Western Processing Site had been used as an anti-aircraft battery and a waste material handling facility. The site has shallow ground water overlain by fill and alluvium. Over 80 priority pollutants are present including TCE, *cis*-1,2-DCE, PCE, 1,1,1-TCA, and vinyl chloride. The Oregon Fir Supply Company Site (the former Holman Redevelopment Area) is currently a jet delivery service. Ground water is 6.5-9 ft below ground surface (bgs) and is overlain by silty alluvium with fine sands from the Columbia River. The site is contaminated with TCE, PCE, 1,1,1-TCA, *cis*-1,2-DCE, and 1,1-DCE.

An initial pilot hole was drilled at each site to a depth of 91 cm bgs by hollow stem augering. A 91-cm long, 8-cm inner diameter split-spoon sampler was pushed to a depth of approximately 152 cm bgs. The spoon was lined with five brass rings (15, 7.5 7.5 7.5 7.5 and 7.5 cm in length), but the upper ring (15 cm) was not sampled because it was exposed to the atmosphere. Five-gram, 20-g, and 120-g samples were collected from the upper and lower pairs of 7.5-cm rings. Each sample was collected immediately from freshly exposed core faces, alternating upper versus lower pairs and top versus bottom pairs.

The VOC samples were collected first and placed directly into methanol (MeOH) at a 1:1 soil:MeOH ratio. The remaining soil was bagged and used for determinations of moisture content, total organic carbon (TOC), and particle size distribution. Field duplicates of the 5-g and 20-g samples were randomly collected. The soil:MeOH mixtures were shaken by hand and thoroughly mixed and the soil dispersed. After about 20 hours at ambient temperatures, the clear supernatant was removed via pipette, transferred to 2-mL minivials that were crimp-sealed with Teflon™-lined rubber septa and stored at 4°C until analyzed.

The VOCs were extracted following SW-846 Method 5035 high-level purge-and-trap procedures, and were quantified following SW-846 Method 8021. The soil moisture was determined gravimetrically in the field after drying overnight in an oven at 105°C. The TOC was determined by high-temperature combustion using LECO® CNS-2000, and the particle size analysis was conducted using a hydrometer.

The results showed that approximately 75% of the soils were in the sand, loamy sand, or sandy loam textural classes; the remaining soils were loams, silt loams, or silty clay loams. The Western Processing Site samples ranged from 25.2-92.2% sand, and 1.5-22% clay. At Oregon Fir Site, the ranges were 2.6-74.7% and 8.9-38%, respectively. The TCE concentrations measured in the samples at the Western Processing Site ranged from 84-5,036 ηg/g; the range at the Oregon Fir Site was 16-2,978 ηg/g. Similarly large ranges were measured for the other chlorinated VOCs. At each site, a hotter area was easily distinguished by VOC concentrations 10- to 100-fold greater than surrounding areas. At the Western Processing Site, the "hot" concentrations were 2,200-5,000 ηg/g, and the cleaner soils were 80-800 ηg/g. The hot concentrations measured at the Oregon Fir Site were 600-3,000 ηg/g, and the cleaner soils were 0-60 ηg/g.

The relative percent differences (RPDs) measured for the TOC and particle size distribution samples were both less than 10%. The RPDs measured for the VOC results were less than 30%, with a few exceptions. There was a much greater variation between the upper and lower 15-cm brass ring pairs than there was between field duplicate samples. The RPD ranges for TOC, particle size, and VOCs were 0.7-161.3%, 0-95.9% (sand), 0-116.5% (clay), and 0-191%, respectively. The absolute values for TOC differed by up to 4-fold; the absolute values for particle size differed up to 3-fold for sand and 4-fold for clay; and the absolute values differed up to 43-fold for TCE, 25-fold for PCE, and 3-fold for TCA.

To explain the large variability in the VOC results, the Anderson-Darling normality test was applied to the particle size and TOC data. The results showed that they were non-normally distributed, so the non-parametric Wilcoxon signed rank test was used. No differences were found. In general, when radical differences (RPDs >40%) in clay contents existed, the greatest differences were identified in TCE and PCE concentrations. No similar trend was observed for TOC.

At the Western Processing Site, TCA was found to be significantly higher in the lower 15-cm section than the upper 15-cm section. This trend was the same for TCE and PCE, but it was not statistically significant. Possible explanations for the TCA trend was the presence of clay and/or sand lenses at depth, sampling across pedogenic horizons, anthropogenic site disturbance, irregular flow and subsequent accumulation of spilled VOCs, non-typical sites, and a small data set size.

It was concluded that natural resultant variability is the primary cause of VOC concentration variability. This natural variability can create large differences in the values of the parameters studied. One must aware when planning a soil investigation of where in the soil profile the sample is being collected. Sampling at a fixed depth without knowledge of soil features may lead to orders of magnitude differences in VOC concentrations.

<u>Questions and Answers</u>

Q: Why were not the samples preserved on ice immediately following mixing with MeOH?
A: There is no benefit to storing samples on ice if they are preserved with MeOH.

Q: Is there still an objection to using MeOH in the field?
A: There was an early objection because the addition of MeOH to the sample automatically creates a hazardous waste. DOT regulations must be followed to transport the material.

Q: Is there ASTM guidance for this procedure?
A: The guidance has been passed by main ballot and is approved. The guidance is basically done, but is not yet available from ASTM.

Modeling Tools

Chuck Newell, Ground Water Services, Inc., Houston, Texas

Modeling tools are used to glean information and make decisions from data. They are typically used in remedial design, evaluation of natural attenuation, and risk assessments. The key modeling questions to answer in these applications are where will the plume migrate and how long will it be there? Models can be systems to organize site data, to help understand site processes, or to obtain additional lines of evidence—particularly in natural attenuation evaluations. Models should not be used, however, as a method for predicting something precisely.

Models play different roles in various protocols and standards. In the ASTM Risk-Based Corrective Action Standards and the AFCEE Natural Attenuation Protocol, the use of models is emphasized. However, in the ASTM RNA standard, models are used to provide optional lines of evidence, and in the OSWER Directive on Monitored Natural Attenuation, models are simply mentioned.

Ground-water models address four key processes: advection, dispersion, sorption, and biodegradation. *Advection* refers to the movement of solutes through the bulk motion of a fluid and can be represented by the Darcy velocity (V_d) or the seepage velocity (V_s). Darcy velocity is distinguished from seepage velocity in that it is used to determine flow information, rather than information about the velocity of solutes. *Dispersion* refers to the *in situ* micro-scale mixing that results as a fluid flows through a porous medium. It can be estimated using rules of thumb or based on scale using the method by Galhar, et al. (1992). *Sorption* to naturally occurring carbon on the aquifer matrix serves to slow the movement of certain contaminants such as dissolved hydrocarbons. The distribution coefficient (k_d) for organic chemicals can be estimated by multiplying the fraction of organic carbon in the soil by the organic carbon partition coefficient, which can be estimated using regression equations or obtained from the literature, reference books, or chemical databases. *Biodegradation* is typically considered to be a first-order decay process or as electron acceptor limited.

The goal of fate and transport modeling options is to simulate all transport processes on the computer. There are numerous options for fate and transport models, which can be analytical or numerical, 1-, 2-, or 3-dimensional, transient or steady state, deterministic or statistical. Numerical models are appropriate for large (e.g., Superfund) sites with complex flow and sources and for sites undergoing pump and treat. Analytical models, on the other hand, can be used for series of smaller sites (e.g., gas stations) with uniform flow and simple sources. Analytical models have lesser data needs and, therefore, can save resources.

The selection of a model will depend on the whether a Tier 2 (analytical) or Tier 3 (numerical) model is required. Tier 2 models are simple fate and transport models, where Tier 3 models are complex. Tier 2 models are appropriate if your process goals are conservative estimates, methods that are easy to use and review, and in minimal data. Examples of Tier 2 models include BIOSCREEN, BIOCHLOR, and GSIRBCA; Tier 3 models should be selected if your process goals are less conservative, more complex use and review, and more data. Tier 3 models include the APIDSS (American Petroleum Institute Decision Support System), BIOPLUME III, MODFLOW/MT3D, and MODFLOW/RT3D.

The AFCEE Protocol suggest the use of BIOSCREEN and BIOPLUME III to model natural attenuation of fuels. These models can be compared as follows:

Feature	BIOSCREEN	BIOPLUME III
Method:	Equation-based	FD solution
Site Conditions:	Isotropic, homogeneous	Non-isotropic, heterogeneous
Source Term:	Vertical plane source with 1st order dissolution	Injection source that can vary over time
Biological Reactions:	First order decay or instantaneous reaction	Separate sequential reactions for each electron acceptor: first order, instantaneous, and monod

BIOSCREEN considers biodegradation reactions as first order decay or as instantaneous reactions. The first order decay model has been described as a "lumped" model, and does not utilize electron acceptor data. The published half lives for benzene for use in the first order decay equation range from 7 to 730 days. Instantaneous reaction models assumes that microbial kinetics are fast in comparison to the residence time in the plume. Furthermore, transport is limited by the availability of electron acceptors.

BIOPLUME III has several features: it simulates fuel organics, oxygen, nitrate, iron, sulfate, and carbon dioxide; accounts for aerobic and anaerobic reactions; models sequential utilization of electron acceptors; accounts for a decaying source; and handles complex sources, complex flow, and pumping. In addition to first order decay and instantaneous reactions, BIOPLUME III also considers biodegradation as monod reactions. The model is limited in that it simulates single constituents or BTEX compounds together. In addition, it does not account for microbial growth, and it requires data or assumptions about microbial kinetics.

BIOCHLOR is a planning level natural attenuation model and database for solvents that is being developed by representatives from Groundwater Services, Inc., AFCEE, and Battelle Pacific Northwest National Laboratory. The model addresses advection, dispersion, sorption, a spatially-varying source, sequential biodegradation reactions (Y. Sun and T.P. Clement), and different biodegradation zones. It is similar to BIOSCREEN in that it uses a Domenico analytical model on a Microsoft Excel platform. It is user friendly and based on a site database. The BIOCHLOR database is based on plumes at 25 sites from the Air Force, Beak Consultants, U.S. EPA, and Radian Corporation.

The BIOSCREEN, BIOPLUME III, and BIOCHLOR models can be obtained free of charge at http://www.epa.gov/ada/kerrlab.html or by calling the Robert S. Kerr Research Laboratory at 405-436-8718.

Contaminant Adsorption and Oxidation Via Fenton-Generated Hydroxyl Radicals

Scott G. Huling, U.S. EPA, National Risk Management Research Laboratory, Ada, Oklahoma

A ground-water treatment process is proposed involving advection, adsorption, and oxidation. Adsorption of an organic compound onto granulated activated carbon (GAC) containing iron results in the immobilization and concentration of contaminants from the ground water onto the reactive media. Subsequently, hydrogen peroxide (H_2O_2) is applied which reacts with iron fixed to the GAC resulting in the formation of hydroxyl radicals which then oxidize sorbed contaminants. Laboratory results are presented which illustrate 2-chlorophenol (2CP) adsorption and oxidation via the H_2O_2-driven Fenton mechanism. Transformation of 2CP was indicated by the formation of carboxylic acids and release of $C1^-$. Seventy-six percent and 82% GAC (1 g) regeneration were measured using 110 mL H_2O_2 at 0.59 M and 2.9 M, respectively. The treatment efficiency increased with increased GAC, Fe, and 2CP concentrations. The rate and extent of oxidation increased with increased concentrations of H_2O_2. Lower treatment efficiency was measured at high concentrations of H_2O_2 (2.1 M) and was attributed to increased hydroxyl scavenging by H_2O_2.

Competition kinetics can significantly reduce treatment efficiency and minimize effectiveness when scavengers react with hydroxyl more rapidly than does the target compound. Limited reaction kinetics is the condition where low concentrations of the target compound limits the second-order reaction, but it often significantly greater than the clean-up goal for the target compound in the ground water. Techniques are discussed which can minimize these and other limiting factors to Fenton oxidation.

Although the laboratory study was based on the oxidation of 2CP, the proposed treatment system could be used to treat ground water contaminated with mixed wastes such as halogenated compounds, polycyclic aromatic hydrocarbons, and fuel compounds (BTEX). This and related systems offer promise as remediation technologies based on conversion efficiency, reliability, flexibility, and cost effectiveness. On this basis, an *in situ* ground-water treatment system was proposed, and preliminary engineering carried out. Flexibility in process control exists in the treatment process which aids in optimizing treatment efficiency. This is important since it allows for site-specific modifications to optimize *in situ* contaminant destruction and to minimize potential limitations.

Huling asked the TSP for suggestions of sites where aqueous phase concentrations are at an unacceptable risks, but natural attenuation is not an option.

Questions and Answers

Q: Why doesn't the hydroxyl ion attack the GAC?
A: It could. The GAC could be weathered. I will have to do experiments to see if this occurred.

Limitations of Radius of Influence Testing for Soil Vapor Extraction Design

Dominic C. DiGiulio, U.S. EPA, National Risk Management Research Laboratory, Ada, Oklahoma

The following write-up is the introductory section to a draft paper entitled "Limitations of Radius of Influence Testing for Soil Vapor Design" by Dominic DiGiulio and Varadhan Ravi (Dynamac Corporation). A copy of this paper can be obtained from the authors at NRMRL-Ada.

Soil vacuum extraction (SVE) is widely used in the United States to remove VOCs and SVOCs from subsurface unconsolidated and consolidated media. The technology is conceptually simple. A vacuum is applied to subsurface media creating a pressure differential inducing air flow to a well. The extracted air is often treated above ground prior to discharge to the atmosphere. Removal of VOCs in subsurface media is achieved by NAPL evaporation, NAPL dissolution, desorption, air-water partitioning, biodegradation, and abiotic degradation. Removal of SVOCs is achieved partly through abiotic processes but primarily through biodegradation due to the effective delivery of oxygen.

The most common method of SVE design is through the use of radius of influence (ROI) testing. The method was introduced by Johnson, *et al.* (1990). When using ROI testing for SVE design, well spacing is based on an extrapolated or measured radial extent of vacuum propagation (R_I) determined during SVE testing, typically between 0.01 to 0.1 inches of water pressure differential. Overlapping circles of R_I are then drawn on a site map to ensure capture of VOCs. Extrapolation to low pressure differential is often accomplished by transforming radial distance to a logarithmic scale.

In the ROI approach to SVE design, there is an implicit assumption that vacuum propagation to 0.1 or 0.01 inches of water ensures adequate air circulation in contaminated soils. As Johnson and Ettinger (1994) point out, however, measurement of a ROI at best only ensures containment of contaminant vapors. This may even be in question at applied pressure differentials low enough to be affected by variation in barometric pressure and fluctuation in ground-water level. For instance, 0.1 inches water pressure differential is equivalent to 0.25 mbar (Massmann and Farrier, 1992).

The fundamental problem with the ROI-based approach to SVE design is that a radial flow equation is used to simulate what is largely 3-dimensional flow. Mathematically, the psuedo steady-state radial flow equation used for ROI testing demands strict radial flow and a constant pressure boundary chosen at some arbitrary radial distance. However, strict radial flow rarely occurs in the field due to partial penetration of screened intervals, leakage from the surface, and physical heterogeneity. In this paper, we utilize data from an actual site to demonstrate that ROI testing results in overestimation of radial pneumatic permeability, and provides little insight on the effects of flow rate, screened intervals, anisotropy, and boundary conditions on subsurface flow. We demonstrate how vacuum propagation to 0.01 to 0.1 inches and in some cases well above 0.1 inches of water pressure differential does not ensure adequate radial distance from an extraction well, effectively rendering the ROI concept meaningless. We argue that at least in soils contaminated with NAPLs, ROI testing leads to well spacing that results in limited or prolonged soils remediation and recommend that SVE design be based instead on specific discharge calculations.

<u>Questions and Answers</u>

Q: This method needs to be communicated to the regulators. Is there an issue paper that can be distributed?

A: This paper has been submitted for publication and is still receiving comments. However, it can be the basis for a future issue paper. It is not the first paper to criticize the ROI method,.

Q: Do anisotropic conditions increase or decrease the ROI of a well?
A: Anisotropic conditions increase the magnitude of the vacuum away from the well. More vacuum is needed to maintain the same specific discharge.

SVE Optimization

Edward Marchand, AFCEE, Brooks AFB, Texas, and Jim Cummings, U.S. EPA, Technology Innovation Office

Site characterization leading to the use of soil vapor extraction (SVE) at a contaminated site uses a downhole tool and applied vacuum on a triangular pattern of fully-screened wells (new or existing) to determine the vertical distribution of contamination and air permeability in the vadose zone. “PneuLog™” is used in “characterization mode” to measure cumulative flow and contaminant concentration along the length of the well and yields air and contaminant production profiles. Future wells should be screened in these hot zones. Optimum flow rates can be determined by manipulating the vacuum and performing an air-phase step test. This procedure has been demonstrated at Beale AFB, California, Griffis AFB, New York, and Nellis Air Force Base, Nevada.

The “optimization mode” of operation involves modifying the well head to accept the “PneuLog™” tool and measuring the existing conditions to determine productive and clean zones. By changing the vacuum and performing the step test you can determine optimum extraction rates. Non-productive zones are packed off (as applicable) and operation may continue at optimum flow. A joint EPA and Air Force demonstration is planned at McClellan AFB to look at existing SVE systems and perhaps alter the configuration.

The benefits to the characterization process is a savings in time (since only one mobilization is required to locate the lateral and vertical extent of the contamination) in developing design data, optimizing flow for extraction, and the starting the well fields. There are also monetary savings such as the reduced paperwork costs, obtaining appropriate design data, and accelerating remediation.

The drawbacks include higher initial costs, greater coordination of field activities, and restriction to 4-inch-diameter walls (a tool is in testing for a 2-inch-diameter well).

The soil vapor extraction (SVE) optimization program has recently seen major changes and improvements. It is developing a “Troubleshooting and Optimization Guide,” deploying the “Pneulog™” tool, and developing a baseline on the performance of existing systems. The impetus for the program came from concerns over site characterization and SVE system design and performance monitoring at sites requesting closure and concerns that the practice may be lagging behind the state-of-the-science. Needless inconsistency from site to site may be wasting resources. There are various ways to define performance, and “norms” may need to be defined.

The “Troubleshooting and Optimization Guide” could be a technical supplement to the *Presumptive Remedies Guide for Volatile Organic Carbons*. The guide will contain two pages of “precepts,” 50-60 pages of technical attachments, and 50-60 pages of case studies. The guide is expected out in Spring 1999.

“Pneulog™” deployment will follow up the initial characterization work at Beale, Griffis, and Nellis Air Force Bases. In addition, “Pneulog™” will be used at the McClellan AFB project with a focus on optimization and will be coordinated with additional work at California BRAC installations. Cummings indicated that he hopes to secure funding within the next few years. He also solicited expressions of interest in the tool, which could be communicated to the vendors of SVE technologies.

System performance baselining will require a survey of a subset of SVE systems to determine how much information is at each site. Preliminary data elements will consist of cleanup objectives, extent of site characterization, system performance over time, how performance is measured (often based upon soil gas measurements from extraction wells), and optimization efforts (updating the site and how they use the tools) will be needed.

The new tool may provide enough knowledge of the subsurface to optimize SVE installations. Cummings stressed that the profession has learned a lot over the years on SVE, and hopes that tools that enhance consistency may allow quicker closures.

Ground-Water Circulation Wells Technical Review

Robert Hinchee, Parsons Engineering, Denver, Colorado

Ground-water circulation (GWC) wells are an interesting technology, also referred to as UVB (Unterdruck-Verdampfer-Brunnen), NoVOCs, etc. It is a challenge to assess a technology best understood by its vendors. The technology involves extracting ground water from one depth, treating it in the well (usually by aeration), and discharging it at a different depth. The goal is to develop a recirculation cell within the ground water. There is also an application from UVB for treating contaminants in the vadose zone, and a company in New Jersey markets a horizontal well application.

Typically, the GWC well is screened in both the upper and lower parts of the aquifer—usually separated by a seal. The simplest version of the technology is sold by Wasatch Environmental which injects air into the bottom of the well causing water to enter the lower well screen and exit the upper screen—VOCs undergo in-well stripping in the process. The UVB system applies a vacuum to the bottom of the well to pull water into the well. As it rises through the well, it passes through an *in situ* bioreactor before it is discharged back through the upper screen. The NoVOCs system is essentially a hybrid of the Wasatch and UVB systems.

A peer review panel of people who understand GWC has been assembled to evaluate several applications of the technology at Tyndall AFB, Hill AFB, Keesler AFB, Massachusetts Military Reservation, and other sites.

It has been observed that GWC systems are essentially “down-hole pump-and-treat” systems. A close coupled pump-and-treat system can produce the same results in the aquifer. GWC has no apparent treatment advantage in dissolved plumes, but vertical flow has the potential to improve NAPL layer treatment. GWC vendors claim that their technology affords lower costs, fewer wells, lower energy requirements, below ground components, and permitting advantages over pump-and-treat systems. There is currently no available comparative data on the claim that GWC is more efficient than pump-and-treat. It is difficult to assess advantages of GWC, and claims are usually based on modeling or indirect evidence.

There is also little direct evidence that GWC is less expensive than pump-and-treat. The costs of monitoring, engineering, and the O&M of GWC systems are actually greater than pump-and-treat. The relative costs of permitting, energy, and the number of needed wells has not been determined. In GWC systems, only one well is needed for extraction and injection, but the well is more expensive and complex to construct. Pump-and-treat extraction wells have smaller diameters, and the injection wells are shallower. Because the radius of influence of GWC wells is lower than pump and treat wells, fewer wells may not be required.

The claim lower energy requirement is also questionable. Water does not have to be lifted as high in GWC wells, but more air must be injected for the concurrent air stripping action. The evaluation of the 100-ft GWC well Hill AFB revealed that it required more energy than a pump-and-treat system. However, it is likely that energy savings are recognized at some treatment depth.

All components of the GWC, for instance blowers, are not necessarily installed underground, and pump-and-treat systems can be completely underground. However, the advantage of GWC clearly stands out in terms of permitting requirements because water is not brought above ground before it is discharged back into the aquifer. Some sites have not been able to obtain permits for GWC though.

Other considerations in the design of a treatment system is that GWC is complex and not well understood. It is much more sensitive to geologic heterogeneity than pump-and-treat. It is important to install 3-dimensional monitoring networks with GWC because the vertical flow component can only be seen with discrete monitoring points. In regards to O&M, it is more difficult to maintain systems installed below ground. Plugging of GWC injection wells is more problematic, and the effects of multiple GWC wells are little understood.

GWC has undergone testing for over 10 years in over 100 applications. It is still not a well-understood or well-documented technology although it has potential value for NAPL treatment. There is no widespread commercial acceptance of GWC due to the high risk of failure. GWC should be considered for the potential of improved NAPL treatment, or in places with severe permitting problems. A GWC system will be installed at the Massachusetts Military Reservation, because the community is more comfortable with the option.

Questions and Answers

Q: Is biofouling a serious problem with GWC wells?
A: Yes, but iron is the most common fouling problem.

Q: What about the dilution effect of circulating the ground water?
A: This is a good point. Monitoring points deeper in the aquifer may become cleaner as cleaner water flows into the well.

Two comments were also received from the audience: (1) The Technology Innovation Office will soon be releasing a status report on GWC as part of a series of reports on *in situ* treatment technologies. It will be available at http://www.clu-in.org; and (2) GWC failed to treat NAPLs at Keesler AFB in Mississippi.

Remedial Process/Systems Quality Assurance Optimization

Daniel Welch, AFCEE, Brooks AFB, Texas

This optimization process was developed to satisfy AFI 32-7020. The Base Realignment and Closure Agency requested that AFCEE conduct peer reviews, technical assistance visits, and remedial process/systems optimization. As part of the process, AFCEE is working with a number of agencies including the U.S. Army Corps of Engineers, Naval Facilities Engineering Command, and EPA's Federal Facilities Restoration and Reuse Office, Quality Assurance Division, Office of Solid Waste, and Technology Innovation Office.

The Remedial Process/Systems Quality Assurance Optimization (RPO/RSO) is a systematic iterative process designed to maximize remediation effectiveness and assure site closure. It is a program management tool to ensure that remedial action meets established goals in the most cost-effective manner. The process is based on sound engineering and scientific principles, logic, and sound risk management while maintaining or increasing project quality. RPO differs from RSO in that RPO is the optimization of all steps that lead to site closeout; RSO refers to optimizing the operation of remedial equipment and hardware.

The RPO/RSO process can prevent or eliminate common quality assurance deficiencies. Deficiencies arise because data quality objectives (DQOs) are not always defined, and monitoring parameters are established by characterization analytical procedures rather than DQOs. Also, ARARs rather than risk or the attainability of ARARs, tend to drive clean-up goals. The RPO/RSO process can help project managers in decision making by assuring that continuing technology selection decision rules are identified and established and by establishing RAO/LTM decision rules to define how to determine optimum sampling locations and frequency.

The goal of RPO/RSO is to verify that processes and rules for continuous optimization are established to manage and operate the remedial action process through closure. To do this, there are RPO key elements: DQOs and clean-up goals, remedial design, remedial operation, remedial action operation monitoring, long-term monitoring (of the media and the efficiency of the treatment system), field and analytical procedures, and data storage and management. RPO is best done during the feasibility study.

AFCEE will conduct a minimum of four RSO pilot studies at two BRAC sites and two active installations. RSO pilot studies are ongoing at George AFB, McClellan AFB, Massachusetts Military Reservation, and Edwards AFB. The selected sites have active pump-and-treat, SVE, and/or a long-term monitoring program. The RPO study at George AFB is evaluating the Operable Unit 1 pump-and-treat system in terms of its goals and objectives, DQOs, data gaps, and ROD issues.

Steam Injection for Soil and Aquifer Remediation

Eva Davis, U.S. EPA, National Risk Management Research Laboratory, Ada, Oklahoma

Davis provided an overview of research and demonstration activities conducted at Ada on the application of steam injection for remediation purposes. ORD has prepared a research paper on this subject, which is available on the Web, in an effort to dispel misconceptions about the technology and compile information into an understandable form for users.

Originally developed by the oil industry for enhanced oil recovery, steam injection has been used and studied since the 1930s. Although designed for application on viscous crude oils to reduce viscosity, the technology offers a distillation mechanism that also makes it applicable to more volatile oils. Kent Udell (University of California-Berkeley) is credited with the first application of steam injection for remediation purposes. Researchers demonstrated in laboratory environments that volatile contaminants can be recovered from sandpacks, and subsequently implemented a pilot-scale demonstration of the enhancement of soil vapor extraction through steam injection.

The first full-scale field application of steam injection occurred at Lawrence Livermore National Laboratory (LLNL), where it was used in 1993-1994 at a gasoline pad site to recover a 100- to 120-ft deep area of DNAPL. Currently, steam injection is used to recover creosote from Southern California Edison’s Visalia Pole Yard where a total of 865,000 pounds of the plume have been recovered or destroyed since 1997 using 300 million pounds of steam. Approximately one third of the creosote is recovered in the vapor phase, one third in the aqueous phase, and one third is oxidized in place, with carbon dioxide being generated in the subsurface. Mechanisms that enhance contaminant recovery include physical displacement, increased vaporization/distillation, decreased viscosity, increased solubility, decreased adsorption, decreased capillary forces, and increased *in situ* oxidation.

Basic design principles of the system are that the free-phase contaminant (NAPL) should be surrounded by steam injection wells, and the contaminants should be recovered from the center of the contaminant plume in both the liquid and vapor phases. Cyclic injections with continuous vapor extraction have shown to be very effective in increasing vapor-phase recovery.

Davis discussed several misconceptions concerning the use of steam injection:

Misconception 1: *Steam injection is applicable only at shallow depths and in the unsaturated zone.*
Reality: Injection deep into the saturated zone is technically feasible and effective for remediation. Greater depth allows greater steam injection pressures, and thus more efficient remediation. Having been originally developed by the oil industry, the technology was designed for application in deep areas. In fact, recovery of contaminants at deeper levels has been found to be easier than at shallow depths using steam injection.

Misconception 2: *Steam injection will drive contaminants into uncontaminated areas.*
Reality: NAPL is surrounded by injection wells that "herd" it to extraction wells placed in the center of the treatment area. Dissolved-phase liquids initially will be pushed away from the recovery wells. When steam is turned off and the steam zone collapses, dissolved phase liquids are pulled back into the treatment zone. The technology is effective both above and below the water table.

Misconception 3: *Steam channeling in heterogenous soils makes steam injection ineffective for contaminant recovery*.
Reality: Steam will follow the path of least resistance. Heat conduction into lower permeability zones will occur, and low permeability zones contain sand lenses that will carry steam. An entire target zone, therefore, can be heated.

Misconception 4: *Steam injection will allow DNAPLs to move downward.*
Reality: A bank of mobile DNAPL ahead of the steam front may be formed, but steam injection below the DNAPL can vaporize it, halting downward movement. Studies have shown that steam injection is capable of volatilizing DNAPL. Recovery rates of DNAPL in steam zones typically are greater than 90%.

Misconception 5: *Steam injection will sterilize the subsurface*.
Reality: Naturally occurring thermophilic bacteria that can degrade contaminants have been found to exist and survive steam injection. Continued research on these microorganisms is underway.

Misconception 6: *Raising the temperature of the subsurface by small amounts will enhance contaminant recovery.*
Reality: Heating of the area around the injection well, only, will allow condensation of contaminants before they are extracted. The entire area between injection and extraction requires heating.

Misconception 7: *Thermal remediation, including steam injection, is expensive compared to other remediation techniques.*

Reality: Capital costs for steam injection are, indeed, higher than those required for other techniques. Remediation times are greatly reduced, however, which results in reduced operating costs. Analysis has shown that overall costs for steam injection can be lower than costs for other remediation techniques. At the Visalia Pole Yard, for example, estimated costs for enhanced bioremediation were $45 million, while estimated costs for steam injection are $20 million. Unit costs at Visalia are estimated at $65 per cubic yard, including research and profit costs, for the 2-acre treatment area. Termination of the steam injections is anticipated to occur within the next few months.

At the LLNL gas pad site, over 7,600 gallons of fuel were recovered in 60 days, and 30 million pounds of steam were injected to clean approximately 100,000 cubic yards. Operational costs of the steam generator were $158,000, and unit costs were $45 per cubic yard.

A participant inquired if steam injection is applicable only to open areas, and Davis pointed out that it can be used in closed areas, noting that the steam injected for remediation purposes at Visalia also is heating buildings adjacent to the treatment area. Jim Cummings (TIO) noted that a joint EPA/DOE effort is planned for application of steam injection in fractured bedrock.

Davis summarized major conclusions generated from steam injection studies and applications: (1) steam injection is applicable to volatile and semivolatile contaminants; (2) steam injection is applicable to LNAPLs and DNAPLs; (3) proper design and operation of the system is important; and (4) steam injection can be cost-effective compared to other remediation techniques.

Bergstrom Air Force Base Success Stories

Holland Young, City of Austin (TX) New Airport Project Team

Bergstrom AFB was purchased in the 1940s by the War Department and paid for by the City of Austin. Consequently, when Bergstrom was deactivated, it was presented to Austin at no cost, and will be the site of Austin's new international airport. The new facility will cost about $585 million, and the airport is scheduled to open in the spring of 1999. Austin-Bergstrom International Airport (ABIA) was presented as a model for sustainable development and a team approach to resolve significant environmental cleanup delays and reduce costs. ABIA will be the first new airport in Texas since 1975.

ABIA's initiative included: (1) sustainable development through energy efficiency and peak demand reduction, efficient and environmentally sensitive use of raw materials and building materials, environmentally sensitive site construction practices, air quality improvements and water conservation; (2) nearly 2 million square feet of water quality improvements including sedimentation/filtration basins and other runoff controls and sophisticated fuel- and chemical-recovery devices; (3) reuse and recycling of existing building components, concrete, scrap, base housing (which did not meet current code) moved off-site for low-income housing, fuel tanks, trees, and topsoil; (4) reduced noise impacts—the number of residents living in the airport noise area will be reduced from over 30,000 to approximately 1,500; (5) community involvement and outreach to schools and citizens; (6) archaeological and historic preservation; and (7) environmental remediation.

Bergstrom contains 481 hazardous waste sites (mainly petroleum and fuel products), and the Air Force has spent about $45 million to clean up these sites. In response to a question, Young said that Bergstrom was not a Superfund site, and was "pristine" compared to other military bases. He said that there was only one small TCE plume on the property, with concentrations slightly above regulatory levels for drinking water. Young complimented the Air Force for their cooperation and enthusiasm, noting that the present smooth working relationship followed a predictably rocky beginning, in 1992. Austin required an additional 900 acres and needed to reconfigure the base; their problem was that they could not gain access to areas not cleaned up and closed out by the Air Force. Also, Bergstrom was still an active base, with an ongoing mission. ABIA plans called for reusing the existing major runway and constructing an additional runway.

In early 1994, it became clear that cleanup was not progressing according to published schedules. Administrative logjams threatened construction delays and the opening of the new airport. The Air Force was responsible for cleanup, the federal and state regulators provided oversight, and the City was caught in the middle. Young acknowledged that Austin's plans, designs, and schedules were changed frequently, and the City needed the Air Force to be flexible. The City assembled a comprehensive graphics and text database of all known environmental sites on Bergstrom. The database was so vast that the Air Force turned to Austin for information. The Air Force wanted to close sites under the Petroleum Storage Tank (PST) rules rather than under hazardous waste rules. However, the Texas Natural Resources Conservation Commission (TNRCC) did not agree, and the issue was elevated to the Secretary of the Air Force. Austin and the Air Force instituted weekly staff-level meetings to coordinate progress and resolve problems, and executive-level meetings as needed when the problems could not be resolved at a lower level. This "team approach" has been so successful that over 400 sites have been closed out to-date. Austin is adding enhanced cleanup of low-level residuals that the Air Force is not obligated to address in order to provide for any potential future use of the land.

The Air Force has saved about $1.5 million due to a strategic plan for testing and approving the base sanitary sewer system, while the City saved about $500 thousand and the Air Force an additional $1 million by moving a small hill from the proposed new runway area for the Air Force to use on landfills. In recognition of its partnership and cleanup efforts, the Public Employees Roundtable awarded them a Certificate of Excellence in 1996, and the Federal Aviation Administration awarded Austin an Environmental Achievement Award.

Bioventing Design Tool™

Catherine Vogel, Department of Defense, Strategic Environmental Research & Development Program

Vogel introduced the Strategic Environmental Research and Development Program (SERDRP) as a tri-service (Army, Navy, Air Force) cooperative operating out of the office of the Secretary of Defense that funds research and development on bench-scale to early pilot-scale, pollution prevention compliance, site characterization, and environmental remediation technologies and process applications.

The Bioventing Design Tool (BVDT) is a computer model based on the Microsoft Excel spreadsheet, which incorporates customized Visual Basic macros that support computation, drawing, and other analytical functions encountered in the bioventing remediation process. It has a user-friendly interface and extensive online help, datasets, and user guides. BVDT was based primarily on bioventing treatability studies conducted at 135 Air Force sites. BVDT's potential users include both experienced practitioners who can use the tool for data analyses, project notes, and design calculations, and beginners who can use it for its extensive introductory materials on theory and online help. While it was intended for Air Force environmental managers and Air Force contractors, it is available from AFCEE's web site (http://www.afcee.brooks.af.mil/er/toolbox.htm).

BVDT consists of five components:

- Site information, which includes basic site information, room for 15 pages of project notes, and a data summary compatible with the bioventing case study database). The case study database may be useful particularly to beginners who may see how comparable sites have worked. There is a very useful feature that automatically converts units among several dimensions.

- Site characterization, which includes initial depths to ground water and free product, *in situ* respiration test analyses (initial soil gas readings, biodegradation rates, data analyses), soil gas survey, and soil gas permeability test and radius of influence. Respiration test results and radius of influence results are given graphically as well as in tables, and the results can be exported into a field-generated report.

- Full-scale system design, which includes flow-rate calculations necessary to maintain biological oxygen demand, blower selection assistance (based upon vendor data and Air Force treatability studies), vent-well spacing calculations that permit several trial runs and that gives distance between vent wells, and suggested soil gas monitoring point spacing based upon soil types and depth to the top of the vent well screen. This module also contains unit conversions and can generate specific diagrams that can be imported into the site report.

- Process monitoring, once the system is constructed, that includes soil gas monitoring and periodic *in situ* respiration tests (recommended twice annually). A significant drop in soil microbial activity may indicate process completion.

- Three important databases—the bioventing case study, bioventing equipment information, and bioventing cost estimator. The databases can be searched, modified, or supplemented. The cost estimator includes a list of basic parameters developed from AFCEE cost/performance literature as well as a detailed cost estimator that was modified from a similar program developed by the Naval Facilities Engineering Service Center, Port Hueneme.

<u>Questions and Answers</u>

Q: Is there a maintenance program to keep the vendor data current?
A: No. The database was generated by the Air Force Bioventing Initiative, and there are no plans to update it. While BVDT was developed by Tyndall AFB, they are a research organization. AFCEE has assumed responsibility for its distribution and updating.

Q: Does the case study contain any Navy sites?
A: It may have some Navy sites, but the majority are Air Force.

Remediation of Chemical-Warfare-Agent-Contaminated Soils at Dugway Proving Grounds, Utah

Doug Larsen, Utah Department of Environmental Quality, Salt Lake City, Utah

Utah listed chemical agents and chemical agent residues as hazardous wastes in 1988. “P999” standards apply to contaminated soil and debris, and “F999” standards apply to all types of decontaminated chemical agent residues. Dugway was granted interim status in 1991 and is undergoing closure. It is important to note that chemical-agent-related hazardous waste in Utah is not always considered hazardous waste in other states, and it could be managed as a solid waste or otherwise if the Army chose to do so outside of Utah.

The Dugway site has been used as a 3X holding area for decades. Contaminated soil was removed from three locations and taken to the site. All samples seemed to be biased towards red-stained soils (red dyes were used by the Army in testing the agents). Several tons of F999 solids were removed since 1991, and the site has been a RCRA storage area since 1992. The site was also used to store decontaminated chemical agent wastes and unexploded ordnance (UXO).

Utah's goals for waste characterization were to determine the presence of and type of agent in the soil, estimate the concentration, and use the waste characterization and existing air quality data to plan safety, monitoring, and waste management practices. The Army claimed initially that there were no chemical agents or residues in the soil. Soils were tested for agents GB, HD, and VX, (mustard gas and nerve agents) and samples were taken with H at 5 mg/kg and VX at 1 mg/kg. Soils were sampled using a hand auger to 3-ft depths, and homogenized with intentional bias towards the red-dyed soil. The soil was classified as a P999 waste by Utah. Utah wanted to containerize the soil onsite and decontaminate it; the Army wanted to remove the soil offsite. Based on soil and air samples taken, a process approach was taken to containerize 1,800 yd^3 of soil and move it to a TSDF for decontamination. Army research shows that the agent hydrolyzes rapidly in water. Persistence of H and VX agents in soil depend on soil type, amount of mustard, burial depth, and local climate. The agent can persist anywhere from weeks to years. The Dugway normally receives only about 7 inches of rainfall annually. At the disposal site, H appears to form clumps in the soil and resist environmental degradation. Mustard and nerve agents are both persistent in the environment and present in the soil at Dugway. The agent contamination is only found in the red-biased samples, but soils could not be sampled sufficiently to show that the agent was not present in certain soil piles.

Soils were sampled with air bubblers when first excavated. No agent was detected, but the records are not available. Soils sampled again in 1994 using Minicams. Positive results for the agent were not confirmed, but again the records are no longer available. As a result of the lack of information, additional air sampling was required.

Waste was managed using a process approach. The silty clay was size-reduced to identify soil clumps, stained soil, glass, metal, plastic, and wood. Dust was controlled using a spray of bleach (decontamination solution). All coarse soil clumps, stained soil, and debris were containerized in 55-gal drums of bleach. Processed soil was sprayed with bleach daily. Soils were sealed in barrels and moved to a hazardous waste incinerator for eventual land disposal. The Army agreed that the "P999" designation would be associated with the waste even if moved out of state. The transport to the TSDF was coordinated by Utah and the Army, and the Centers for Disease Control and Prevention provided advice.

Because the TSDF workers were not familiar with Army safety monitoring protocols or equipment, and because TSDF workers are inexperienced with managing chemical agents, Utah was concerned for their safety. The processed soil was sampled at the Dugway site prior to moving to the TSDF to meet RCRA requirements for the disposal facilities permit. Samples sent to the TSDF did not contain chemical agents (using Minicams for screening). The Army was very cooperative with the TSDF workers to ensure that the TSDF personnel protection equipment was adequate. At the landfill, the processed soil was spread out and covered with cement kiln dust, which provides extra protection and allows for further decontamination.

The Dugway site will be sampled for agent and agent-breakdown products. If presence is detected, excavation will be required. If breakdown products are found, a risk assessment will be done. If no contamination is found, the site will be deemed clean and closed under RCRA.

<u>Questions and Answers</u>

Q: Does the state-defined hazardous waste have any DOT or EPA controls on shipping manifests?
A: No federal controls. Utah got the Army to agree to abide by state permits and manifests, but it is not enforceable.

Q: Did you look for chemical-agent breakdown products in the soil?
A: Yes.

Q: Did you conduct any investigations inside buildings?
A: They looked only at the excavated soil, not at any facilities.

Q: Does the Army have to meet 5X decontamination requirements?
A: 5X means that the waste is heated to 1,000°C for 20 minutes; 3X is a lower standard, and means that the materials can be moved off site to a TSDF. In Utah, it is a F999 regulated waste.

Q: Who owned the Minicams?
A: The Minicams are small, portable gas chromatographs, and are Army-owned and operated. The equipment was calibrated for agents every day onsite.

Ordnance Risk Assessment Procedures

Arkie Fanning, U.S. Army Corps of Engineers, Huntsville, Alabama

Fanning presented an overview of ordnance risk assessment procedures developed by the U.S. Army Corps of Engineers (USACE) to be used at FUDS and BRAC sites. The Risk Assessment Code (RAC) is a qualitative model used by the Corps to define areas of most likely risk. Thresholds are established within RAC for codes 1-5 ranging from most risk to little or no risk. The Ordnance and Explosives Cost Effectiveness Risk Tool (OECERT) is a dispersal model used to develop a risk estimate that mathematically expresses the risk of exposure to UXO. It is intended bo be used at a point source such as burial pits. Risk drivers considered in OECERT include UXO density, current and future land use, and populations exposed. Neither RAC nor OECERT account for human behavior. Comparative risk, which is based on experienced accidents at 18 ordnance and explosives (OE) sites, is a regression model that takes the results of the OECERT (exposures) and determines the probability of an accident or death. The USACE also employs Sitestats/Gridstats and UXO Calculator as statistical models to determine the amount of UXO in a sector.

The USACE has established specific steps to be followed in ordnance risk assessment at FUDS: (1) An inventory progress report (INPR) is prepared using RAC to determine if a site has potential OE exposure; (2) An archive search report (ASR) involving more detailed use of RAC, a review of historical information, and interviews with neighboring property owners is developed; (3) An engineering evaluation/cost analysis (EE/CA) is prepared using Sitestats/Gridstats and UXO Calculator to determine UXO density per sector and OECERT to determine public risk. (Certain criteria and terminology used by the USACE for determining response actions are unlike those used by EPA under the Superfund Program. For example, the USACE's EE/CA may be compared to a Superfund remedial investigation, while a Superfund removal is considered be a remedial action by the Corps.); (4) Based on results of the EE/CA, a recommendation for an appropriate response action is issued; and (5) The response action is approved through a record of memorandum.

UXO risk determination is conducted to determine UXO density. Generally, a UXO risk determination begins by breaking the subject site into sectors (using randomly placed grids), each of which have sufficient data collected to prove statistical testing using binomial or Chi-Squared distributions. Although the sectors vary in the amount of UXO that may be present, a sector is considered homogenous if it is entirely associated with a variable. A statistical confidence limit is developed from the sector data, using a 90% confidence level for estimated UXO density. A map is developed and updated as more information becomes available, and sectors are further subdivided, if necessary. Finally, a detailed risk report is developed to accompany the EE/CA.

Fanning concluded the presentation by providing detailed information on risk calculations, UXO statistics, statistical requirements, risk management, and technical aspects of each of the models.

Questions and Discussion

Craig pointed out that while the "lifetime exposure" to UXO may be low (Fanning estimated below 0.5 over 20 years), the consequences were significant. They cautioned Fanning that EPA does not equate "exposure" with "risk." Fanning pointed out that at Fort Ord, after the model calculated that the site was clear, public pressure forced two more sweeps, which found nothing. Fanning acknowledged that it is not possible to achieve zero risk or exposure, but felt that the relative risk of public exposure to UXO was insignificant compared to other risks such as smoking. Many EPA participants expressed alarm with Fanning's cumulative and comparative risk estimates, and cautioned that it would be counter-productive for DoD to assert that exposure to UXO by the public at a "cleared" site was insignificant, when such "clearance" is based solely upon a gridded statistical probability founded upon a 3-5% sampling strategy.

EPA participants also took issue with USACE's definitions of UXO (excluding ball ammunition) and "surface" (visible only—burial an inch or a foot deep does not count). EPA participants questioned USACE's reliance upon current intentions for land use, without considering possible eventual or future land use, which could include residential. Bell also expressed concern that the OECERT and other sampling models did not account for overlapping range fans.

Craig and other EPA participants pointed out that if a site is not cleared to below frost depths, frost heave will result in renewed exposures to once-buried UXO. The Defense Department Safety Board (DDSB) requires that the site be re-surveyed if not originally cleared to below frost levels. Fanning said that USACE does not return to a cleared site unless someone actually locates surface UXO, but the DDSB requirement should be addressed in the original Engineering Evaluation/Cost Analysis (EE/CA). He acknowledged that the screening models do not consider frost heave (they do not know how).

Permeable Reactive Barriers Training Update

Richard Steimle, U.S. EPA, Technology Innovation Office

The main push to deploy permeable reactive barriers (PRBs) began in 1994, and since then, 10 to 15 full-scale PRBs using zero-valent iron have been deployed. Several other types of PRBs (such as granulated carbon) have also been installed. Published accounts suggest that more than 500 sites may be appropriate for PRB deployment over the next decade. Compared to conventional remedies for contaminated ground water (such as pump-and-treat), PRBs could save more than $1 million per site over long-term operation if designed, constructed, and monitored appropriately.

The PRB training course was developed jointly by EPA, the Remediation Technologies Development Forum(RTDF), and the Interstate Technology and Regulatory Cooperation (ITRC) to assist regulators in overseeing the design, implementation, and monitoring of PRBs, to consolidate efforts providing design and regulatory guidance on PRB deployment, and to provide a single, highly effective program that has the backing of federal and state groups responsible for the ultimate application of PRBs.

The training course is targeting federal and state regulators preferentially, but will accept industry representatives, consultants, and academics on a space-available basis and perhaps charge them a fee. The 1½-day sessions will be held in each of the 10 Regional Office locations around the country, one in each EPA Region, and will be taught by 3 to 5 federal, state, and private experts. The course covers:

A. Introduction to PRBs for Remediating and Managing Contaminated Ground Water
B. Reactive Materials I (metals)
C. Reactive Materials II (non-metals)
D. Emplacement Techniques
E. Economic Considerations
F. Case Study
G. Collection and Interpretation of Design Data I (Field Characterization)
H. Collection and Interpretation of Design Data I (Laboratory and Pilot-Scale Tests)
I. Compliance and Performance Monitoring/Long-Term Maintenance
J. Permitting and Monitoring Strategies
K. Implementation and Construction
L. Exercise: Design and Implementation (still under development)

Beginning in the spring of 1999, the course will be offered about every two months according to the following tentative schedule:

Region 1 (Boston, MA)	May 20-21, 1999
Region 10 (Seattle, WA)	July 22-23, 1999
Region 3 (Philadelphia, PA)	September 23-24, 1999
Region 6 (Dallas, TX)	November 18-19, 1999
Region 4 (Atlanta, GA)	January 2000
Region 8 (Denver, CO)	March 2000
Region 2 (New York, NY)	May 2000
Region 9 (San Francisco, CA)	July 2000
Region 5 (Chicago, IL)	September 2000
Region 7 (Kansas City, KS)	November 2000

There was considerable concern expressed that the course was spread out over two years; not only will the later sessions be different than the early ones (due to evolving technologies), but participants from one region will be two years ahead of their colleagues in another region on common technological information needs. Steimle indicated that the spacing of the courses over 20 months is due to the fact that Dr. Robert Puls, of EPA's laboratory in Ada, Oklahoma, will be the primary instructor at all 10 sessions. Exact dates will be set in cooperation with Regional Offices. Some participants suggested satellite links or computer-based or other distance-learning options rather than the instructor-lead alternative that would stretch the course over such a long time.

Steimle solicited feedback from all EPA Regions, and encouraged them to respond directly to Dawn Carroll at TIO (703-603-1234) or Bob Puls at NRMRL/Ada (580-436-8543). In particular, Steimle solicited liaisons from each Regional Office to coordinate schedules and logistics for the course, coordinate with the instructional team, help identify participants for the course, and actively participate in the course design and implementation. Also, Steimle indicated that he expected each region to pay for the travel costs for Bob Puls to that region; non-EPA instructors would pay their own costs. Steimle said that he would prepare a memorandum from TIO to regional management soliciting their assistance.

Paul Leonard (Region 3) suggested that the Forums become the regional mechanisms for coordination, and Steimle accepted.

Questions and Answers

Q: Will the course cover innovative techniques for wall emplacement, such as those used at the Massachusetts Military Reservation or Savannah River?
A: Call Bob Puls and make your recommendations.

Q: One and one-half days seems too short. Can the course be longer?
A: Probably not, although the length will depend on the instructors. The dry run has not been held yet, and the feedback from that may affect the length.

Q: Will regional offices be responsible for identifying suitable participants within the region?
A: Yes.