FEDERAL REMEDIATION TECHNOLOGIES ROUNDTABLE MEETING
Arlington, Virginia
December 9, 2004

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ACTION ITEM

< FRTR members are to notify John Kingscott (U.S. EPA/OSRTI) of any potential cost and performance case studies.

WELCOME/OPENING REMARKS

Walt Kovalick (U.S. EPA/OSRTI) welcomed the attendees and opened the meeting of the Federal Remediation Technologies Roundtable (FRTR) with self-introductions of the participants and an overview of the agenda.

Kovalick noted that the Third International Phytotechnologies Conference will be held April 20-22, 2005, in Atlanta, Georgia. Sponsored by EPA's Office of Research and Development and Office of Superfund Remediation and Technology Innovation, the event will provide information on recent research and application developments in using plants for environmental cleanup. Conference information is available at www.cluin.org/phytoconf/.

He also mentioned the Long-Term Groundwater Monitoring Optimization (LTMO) Seminar, which is scheduled for March 30-31, 2005, in Sacramento, California. Jointly sponsored by the Navy, Army Corps of Engineers, EPA, and California EPA, the seminar will provide state and federal regulators with information about new quantitative methods of LTMO and will include hands-on training in the use of some of these methods. For more information, contact Ellen Rubin (EPA/OSRTI) via email at Rubin.Ellen@epa.gov.

Kovalick announced the recent release of a new edition of EPA's national remediation market study, *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends, 2004 Edition*. The report covers the seven major U.S. cleanup markets: Superfund, RCRA Corrective Action, DoD, DOE, USTs, civilian federal agencies, and state voluntary cleanup programs, which includes brownfields. The report is available at http://www.clu-in.org/market/.

Kovalick thanked the Army Corps of Engineers for providing new tracking software for the FRTR website. The software will be used to monitor the site's volume of traffic, which will enable the site developers to identify the pages that are visited most frequently and the products and topics of greatest interest. A handout, illustrating traffic statistics from the website for a three-month period, was distributed (see Attachment A). Also distributed was a four-page handout, "Federal Remediation Technologies Roundtable Web Site Operation Plan" (see Attachment B), which contains planning information and points of contact.

PROJECT UPDATES

Status Report: Technology Cost and Performance Activities

John Kingscott (EPA/OSRTI) updated Roundtable members on the status of the FRTR Technology Cost and Performance case study database (www.frtr.gov/costperf.htm). His presentation covered activities since the June 2004 meeting and expectations for the next update (see Attachment C). Over 600 reports have been gathered to support the four cost and performance study areas of remediation, site characterization and monitoring, long-term monitoring and optimization, and performance assessment. New reports are collected, posted to the website, and distributed as hard copy each spring. For inclusion in the Spring 2005 update, final case studies must be submitted by April 1. A handout, "New Cost and Performance Case Studies" (see Attachment E), listing upcoming reports by category and subject, also was distributed.

The database is growing more slowly now because the rate of contribution has decreased. Kingscott looks to the FRTR members to bring forward new case studies. Field data from operating systems, no matter how seemingly insignificant, can have value to people who are considering a similar cleanup approach. Even very small projects—especially those involving emerging contaminants of concern—could generate great interest if made publicly accessible. Sources from which new case study writeups might be mined include closeout reports, internal memos, networking arrangements, and broad reports of cleanup approaches that incorporated multiple technologies.

The capacity of a single CD-ROM to contain the case studies has been reached. Kingscott is considering the relative merits of weeding out some of the older studies so that the updates can be released on one CD versus releasing the intact set on two CDs. He asked for input from FRTR members to help him in the decision-making process.

Revisions to FRTR Screening Matrix & Reference Guide

Layne Young (U.S. Army/AEC) reported on current work to update the Screening Matrix and Reference Guide (see Attachment E) on the FRTR website. The matrix is a user-friendly tool for screening potentially applicable *in situ* and *ex situ* remediation technologies for soil or groundwater. Each of the 59 technologies has been assessed for the class(es) of contaminants it treats, development status, potential for implementation in a treatment train, overall cost and performance, and availability. The Reference Guide provides additional in-depth information on each technology. These resources are living documents containing technical and cost information that must be periodically checked and updated. They also identify other online resources for which the links must be verified and/or repaired or replaced.

Ongoing work addresses the development of a more user-friendly format that will allow comparison and contrast of multiple technologies. This revision of the matrix includes scrutiny of the technology cost data, which is outdated or difficult to reproduce. AEC has begun to standardize the estimates by using RACER, a cost-estimating tool, to provide a systematic, reproducible process for developing a range of estimates. Future efforts will continue the RACER-based cost update approach for applicable technologies to the point where the revised matrix can be posted on the FRTR website. RACER is updated annually to account for inflation and new technologies, which can help to keep the matrix information current.

The Committee involved in continuing development of the matrix includes members from six FRTR member agencies and the Interstate Technology and Regulatory Council (ITRC). Though previous updates have received funding support from several member agencies, the most recent update was funded by AEC. The Army is interested in returning to joint funding in future and will seek support to accomplish successful, timely, and relevant updates.

Triad Project Profiles

Jean Balent (EPA/OSRTI) presented an update of progress made in populating the project profiles within the Triad Resource Center (TRC) website (www.triadcentral.org). The Triad approach to decision-making for hazardous waste sites offers a technically defensible methodology—systematic planning, dynamic work strategies, and real-time measurement systems—for managing decision uncertainty. TRC is a federal/state interagency partnership resource designed for one-stop shopping to provide the information hazardous waste site managers and cleanup practitioners need to implement the Triad approach effectively. Argonne National Lab was the progenitor of the site, and the agency partners have gathered the resources that make up the site today.

Listed under the "User Experiences" tab on the TRC, nine project profiles have been prepared to expand understanding of the Triad approach by showcasing example applications and linking to case studies, diagrams, technology vendor pages, and other information. Each profile is six to nine pages long. Some of the projects illustrate a standard Triad approach overall, while others are Triad-like in a particular aspect, such as systematic planning. Six new Triad profiles are being prepared for posting to the site. TRC actively seeks additional projects, and contractor support is available for writing up a profile from the information provided. FRTR members with an idea for a profile should contact Jean Balent (balent.jean@epa.gov) and complete the Triad Project Profile form. The presentation (see Attachment F) identifies 39 sites with potential for profiling Triad or Triad-like approaches.

Accelerating Site Closeout, Improving Performance, and Reducing Costs Through Optimization

Kathy Yager (EPA/OSRTI) reported on the June 2004 Optimization Conference via speaker-phone (see Attachment G). During the two and a half days of the conference, 409 registered attendees had access to six plenary talks, four evening workshops, and 70 platform and 35 poster presentations. The $120, 000 event was sponsored jointly by the EPA, Navy, Air Force, Army Corps of Engineers, SERDP/ESTCP, and ITRC. The agenda offered three tracks: (A) Remediation Process Optimization; (B) Site Characterization, Long-Term Monitoring, and Data Management Optimization; and (C) Strategic Considerations for Site Closeout. Attendance was very good; even some of the evening workshops drew as many as 40 participants. The conference included an ITRC workshop, Essentials of Remediation Process Optimization, that was based on ITRC's September 2004 report, *Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation* (available at www.itrcweb.org).

The conference participants had many comments and suggestions, of which more than 85 percent were positive. A conference of this size can take a year or more to put together. EPA has led the last two optimization conferences and is looking for volunteers to lead the next one approximately three years in the future. The full agenda, abstracts, and presentation slides are available online at the FRTR site (www.frtr.gov/optimization/meetings.htm).

In other news, Yager and Beth Moore (DOE/EM) have visited Hanford to observe the Hanford optimization efforts. Despite initial DOE inertia to come on board, Beth has found much information of value, particularly the software developed by the Corps of Engineers. Beth is working with others to generate interest in optimization at DOE facilities.

Decision Support Tools Matrix: Status Update

Richard Hammond (EPA Region 4) updated the assembly on the FRTR decision support tools (DST) matrix (see Attachment H) that FRTR agreed to develop late last year. The DST matrix development team decided to review 20 DSTs, given a limit of 12 LOE hours for each evaluation. There were many more than 20 tools available for review, so the following criteria were used to determine the eligibility of a DST for the matrix:

- The product is intended for end use by a technically proficient field person such as an EPA OSC, someone able to use a computer but not a computer modeling expert.
- The tool must support decision-making with a default predictive output from input.
- The tool must be freely available to the public.

The matrix is being constructed in spreadsheet format in an Excel database. The matrix will identify the tool and specify its function, whether user input is via file or interactive, types of data and graphic input/output options, contaminant class, site media, and the types of expertise required to most effectively utilize the DST. As a user scrolls over the different headers in the matrix, relevant parts of the Excel spreadsheet will be displayed. A submenu will show the tools considered most useful or suitable for a particular type of activity.

The matrix developers have found it to be both challenging and fun to figure out how to convey complex information to a diverse audience, and they hope to bring the DST matrix online ASAP. Ideally, this matrix will become a living document, with regular updates and attention to new products.

Beth Moore observed that for softwares like MAROS, some developers lack the funds or consultation support to continue to support the software. These DSTs could be phased out due to lack of code updating and other support. It's important to identify any potential for support to lapse for each of the products in the matrix. Dan Powell (EPA/OSRTI) suggested that this issue might merit its own column in the matrix. Moore seconded the need for the matrix to indicate consultation support or lack thereof. She also sees a need for informing users of projected changes or updates of each tool.

Question: Why are some well-known software products that meet the selection criteria, like RESRAD, missing from the matrix?

Answer: The presentation slides don't show the complete list of products; approximately four 12-hour software reviews have yet to be completed.

Question: Why does the matrix not contain commercially or academically developed software?

Answer: The products reviewed must be freely available to the public.

Question: Is it possible for an academic entity to get a particular software assessed?
Answer: Although the matrix developers look only for freely available products, they can be flexible. Contact Hammond to discuss a particular DST software.

NEXT MEETING TOPICS

Representatives of each FRTR agency were issued ballots containing a list of five possible technical subjects on which to focus future meeting and were asked to rank their top two choices. The topics were::

(1) Performance-based contracting
(2) Emerging contaminants (other than perchlorate)
(3) Sensor technologies (other than nanotechnologies)
(4) Innovative approaches to small site closure
(5) Case studies of DNAPL cleanups

Kovalick indicated that he would report results of the balloting at the end of the meeting.

TECHNICAL TOPIC: NANOTECHNOLOGY SENSORS FOR MONITORING AND MEASUREMENT

Introduction

Marti Otto (EPA/OSRTI) introduced the technical segment of the meeting with a definition of nanotechnology: Research and technology development at the molecular or macromolecular level. At the last meeting of the Roundtable, the presenters discussed nanotechnology applications in cleanup. The segment for this meeting focuses on nanosensors for chemical and biological monitoring and measurement.

Nanosensors & EPA

Nora Savage (EPA/ORD) presented an overview of EPA spending on nanotechnology research and provided examples of nanotechnology monitoring projects being funded under the Science To Achieve Results (STAR) and Small Business Innovation Research (SBIR) grant programs (see Attachment I). The 2004 STAR solicitation for research in nanoscale science, engineering, and technology received 61 proposals, 20 of which were for sensors. These proposals will be subjected to peer review and then relevancy review early in 2005. In response to the 2004 SBIR regular solicitation, 48 nanotechnology proposals were received. Twelve passed peer review, and five will be funded. Two of these grants will fund nanosensor development. The contracts had not yet been awarded, so Savage was unable to disclose the project titles.

The presentation handouts included a list of 106 EPA Phase 2 SBIR grants awarded between 1997 and 2004 and a list of STAR nanotechnology grantees. The National Center for Environmental Research (NCER) web site (www.epa.gov/ncer) contains abstracts and progress/final summaries for all funded projects. NCER does not seek reviews of the science, but is instead concerned with the applicability of nanotechnology to EPA needs. Savage cited the VOC sensor developed by Mike Sailor and William Trogler of the University of California at San Diego as an example of a nanotechnology project that meet EPA's needs.

Savage pointed out that a Nanotechnology Symposium will be part of the American Chemical Society's March 2004 meeting in San Diego. The symposium will include a session on "Nanotech-Enabled Sensors for Substances of Environmental Interest."

Nanotechnology offers many potential environmental benefits, including improved monitoring and detection capabilities and rapid, inexpensive remediation and treatment technologies. Unfortunately, nanotechnology also may pose unexpected hazards, such as the creation of potentially toxic novel materials with bioaccumulation and biotransformation issues. EPA is paying close attention to basic research efforts to determine both the positive and negative possibilities. NCER has incorporated a new nanotechnology web page (www.epa.gov/ncer/nano) into the Agency site. This page highlights EPA's research in nanotechnology and provides information on related research at EPA and in other organizations.

Low-Cost Printed Electronic Nose Gas Sensors for Distributed Environmental Monitoring

Vivek Subramanian (University of California, Berkeley) reported on research at UC Berkeley to develop printed circuits for environmental sensing (see Attachment J). The research pursues the development of sensors capable of predictive capabilities to allow for proactive response. The researchers hope to develop an ultra low-cost (pennies per unit, not dollars) sensor system for distributed environmental monitoring. Subramanian envisions sensors so inexpensive that they can be copiously dispersed at a field site, perhaps even broadcast from aircraft. His team's approach involves the development of arrayed organic field-effect transistors (FETs) that can be easily arrayed at low cost via printing. The devices have the flexibility for easy dispersal and are trainable via electronic nose architecture. Ideally, these sensor arrays will detect multiple analytes.

His work on sensor arrays began about five years ago as an offshoot of the national product packaging initiative that seeks to replace barcodes on bags and cans with a device that can carry more information. Subramanian's group had the idea of replacing the barcode with a circuit printed directly on the package. They discovered that the inkjet printing process worked, but the circuit degraded quickly, which meant it was not very useful for the purpose. But instead of discarding the idea as a misfire, they examined the technology from another angle: if the circuit degraded quickly upon exposure to trace contaminants in the air, could it not be developed as a detection device?

An extremely important aspect of the UC Berkeley nanocircuit printing technology is that the processes are entirely additive. This means that circuit materials are placed only where they are wanted, which differs dramatically from the waste-intensive conventional process of manufacturing semiconductor circuits. Practically the only waste generated during the printing process comes from evaporating solvents. Theoretically, the evaporating solvents can be captured and recycled, but the Berkeley group has not attempted it yet.

Sensors that indicate when food has gone bad is currently one of the group's areas of interest. For instance, a sensor circuit can be printed on a package of meat to signal when the meat has begun to emit certain organic vapors that indicate the meat is going bad. The presence of these vapors would cause the sensor circuit film to swell, which changes its conductivity and transport characteristics. This would be an excellent application for a sensor with a short shelf life. Subramanian noted that electronic nose technology has been under development long enough for commercial noses to have appeared in the marketplace, but these devices generally are much too expensive for large-scale environmental use and are primarily found in security and manufacturing applications.

The Berkeley sensors are printed with inks that contain nanoparticles. Tremendous coverage of surface areas can be accomplished with tiny amounts of the material, which results in great savings when working with nanoparticles of costly metals. There are a number of issues yet to be addressed, however. For example, to be viable in the long term, to bring costs down significantly and produce a truly inexpensive unit, the sensor array must be completely integrated. The entire unit—the power source and sensing, analysis, and communications circuitry—must all be integrated on the same chip. While Subramanian's group is working to achieve this integration, hurdles remain, and printing does limit how small the sensors can be.

Organic thin-film transistor (OTFT) technology may be an option. OTFT uses organic semiconducting compounds in electronic components. The displays are bright, the colors are vivid, they provide relatively rapid response, and they are easy to read in most ambient lighting environments. Organic displays are fairly cheap, but they are slow in terms of carrier mobility, which can translate into sluggish response time. Subramanian warns that at present, his printed circuits respond in terms of seconds instead of milliseconds.

Subramanian asked FRTR participants for advice on how he can field test his sensors to achieve relevant results, because he can design better sensors if he knows what to look for. Several attendees volunteered to provide Subramanian with samples of arsenic-contaminated groundwater for use in testing a sensor for monitoring arsenic (rather than in a spiked laboratory sample). Subramanian also said he would like to expand his library of analytes in contaminated media. He would like to get feedback and advice on the parameters that are representative of reality in the field and the interactions that he should worry about to determine how these potential interactions should drive his research.

Kovalick pointed out that the majority of EPA-interest sites have chlorinated solvent problems (e.g., TCE) for which sensor reliability is the greatest issue. If you drop the sensor down a well, how do you get a signal back? And over what period of time can you expect it to work? Groundwater monitoring needs are likely to span years, even decades, so a predictable lifetime is important in a groundwater monitoring device. EPA looks for monitoring innovations that can reduce or avoid costs for bailing and transporting samples and analyzing them in the laboratory.

Beth Moore recommended the portfolio of projects in the Characterization, Monitoring, and Sensor Technology Crosscutting Program (CMST-CP) under the management of the National Defense Center of Environmental Excellence as a useful source for technology development for solvents problems.

Dan Powell emphasized the need for sensors that can detect multiple analytes, because contaminated media are affected by more than one contaminant more often than not. If a sensor can detect only one analyte, that means the wells must still be bailed and samples taken for co-contaminant testing.

Question: Is the current system an analog circuit? Can it be transformed to digital operation?
Answer: It is currently analog. Changing it to digital will take more transistors. That will make it more compatible with commonly-used software and equipment.

Question: What concentration level have you been able to achieve with your arrays?
Answer: So far, 2 parts per million in a printed architecture. We can go lower by making the channel extremely thin, but we don't have a convenient or cost-effective way to do that by printing.

Question: How would you envision this technology being deployed at a site with a complex topography and multiple sources of contamination—a dump site, a surface water problem, and contaminated groundwater—such as can be found at a DOE facility?
Answer: There are two possible approaches, examining the problem from a radiofrequency (RF) perspective. One way would be to make a sensor with a paper-based battery. With a long thread-like antenna attached, the sensor can be submerged and still transmit a signal. Imagine flying over a region and deploying your sensors by tossing them from the plane. The typical range of capture for transmission via a built-in power supply is 15 to 20 meters. The data can be acquired by an operator driving past the well in a vehicle. The other method, where you don't have a power source in the sensor, involves power harvesting, i.e., to have the power supply in your meter-reading device. RF broadcast capture powered by the meter-reader itself is limited to just a few meters, which means the reader would have to go to the well to acquire the data.

Question: Will it be possible to build this type of sensor within an engineered system, especially for deployment in a harsh environment such as the unsaturated zone?
Answer: The nanosensor tape can be laminated on anything, but sensor lifetime is currently one of the great concerns, and this problem hasn't been solved yet.

Nanotechnology Applications for Environmental Sensors: Integrated Devices for Real-Time Analyses

Erica Forzani (Arizona State University) discussed her research, which focuses on nanosensor arrays, with emphasis on wireless connectivity (see Attachment K). Air monitoring with wireless connectivity is one of her areas of interest.

An integrated sensor must incorporate sample delivery, sensing elements, and signal processing and transmission. Scientists need to be able to work with a range of dimensions in sensor technology—from nanometer to centimeter—to better develop integrated sensors. Forzani discussed how neuronal synapses form a perfect feed-back system, suggesting that very sophisticated sensor systems could be developed by emulating nature. Currently, she is working to detect small changes in concentration in the nanomolar range and studying how to make a new sensor stable.

The presentation described the different methods of signal transduction—optical, electrochemical, mechanical, or electrical—and identified some of the researchers who are using them in nanosensor development. Forzani prefers an electrical signal, which allows for a high degree of integration in a miniaturized device for simultaneous detection of different species. An electrical signal makes it easy to process, display, and transmit the data, which is important in a fully automated device. An electrical signal also is compatible with microelectronics, which means the developer can take advantage of existing microtechnology.

Nanoparticles can be formed in a variety of structures: rod, carbon tube, wire, belt, particle, resonator, peptide tube, and pyramid. Highly sensitive and selective individual nanosensors have been demonstrated, as well as common platforms for simultaneous detection of different species. One sensing innovation involves a molecular junction sensor, or molecular probe—a single molecule that can recognize a target. A sensor of this type has been developed that can detect a single copper ion.

Gap size is extremely important, and a nanosensor has the advantage of a gap size smaller than 60 nm. In a conventional field-effect transistor (FET), conduction through the channel region is two-dimensional (i.e., there are many pathways). Narrowing the channel to one dimension enhances detection sensitivity. Dimensions of the sensing elements as well as distribution and gap size in an FET is important for good analytical performance. Unique features include reduced sample solutions, fast response time, a high degree of integration, and high sensitivity for single molecule/ion analysis.

The following challenges must be met in future research:

- Miniaturization and integration must be met to develop a fully integrated device.
- A way must be found to deliver the sample to the sensing surface reliably.
- The interface and interconnection issues between nano- and microtechnology must be resolved.
- Power sources must be developed for nanoscale devices.

NCER awarded STAR grants to Arizona State University researchers, N. Tao for "A Nanocontact Sensor for Heavy Metal Ion Detection" (grant R829623), and P. Westerhoff for "The Fate, Transport, Transformation and Toxicity of Manufactured Nanomaterials in Drinking Water" (grant R831713).

Question: You say that polyanaline enhances response. Why?
Answer: With polyanaline nanofibers with a micrometer gap, you have a 2-D sensor, so you have many pathways. When you make the gap smaller, only a few chains of polymer can reach the gap, so basically there are two pathways for the same charge to go from the drain to the source.

Question: What do you mean by “integrated analyses for real-time devices”?
Answer: Basically it means that a signal can reach you right away, in actual time. Normally, there's a step for accumulation that takes several minutes, but the nanosensor can acquire concentration information from the analyte in real time, right away, so there is no need to wait for accumulation. As a result, you can translate that signal to a concentration in real time.

Nanomaterials for Enhanced Environmental Measurements

Shane Addleman (DOE/Pacific Northwest National Laboratory) said that the definition of "better measurements" is constantly evolving. It used to refer to parts per billion concentrations, but now we are looking for parts per trillion. Measurement technology progresses via compromises and incremental improvements. But advanced materials offer new methods for selective capture of analytes and not incrementally improvements to measurement systems.

Researchers at Pacific Northwest National Laboratory (PNNL) refer to the different types of nanomaterials as advanced or "smart" materials; they can enable improved sampling and assay of contaminants in complicated environments. (see Attachment L).

Nanoporous ceramic substrates have been developed with innovative properties: five grams of such substrate in powder form have the overall surface area of a football field. This technology is known as Self Assembled Monolayers on Mesoporous Supports, which is usually referred to as SAMMS. A derivative, Thiol SAMMS, integrates a nanoporous substrate with an innovative method for attaching monolayers (single layers of densely packed molecules) to the pore surfaces throughout the substrate. Thiol-SAMMS coupled with inexpensive X-ray fluorescence technology has been developed into a hand-portable device that provides fast, cheap, on-site, trace-level metal characterization in real time. SAMMS also can also be tailored for radionuclide pre-concentration and measurement in an aquatic environment.

Carbon nanotubes are another form of nanomaterial with characteristics of high surface area, electrical conductivity, thermal conductivity, and mechanical strength, with excellent chemical/physical stability. This type of nanomaterial has been used to create very promising sensors. Emerging nanomaterials include mesoporous carbon, metal oxide frameworks, metal nanoparticles, quantum dot emitters, and modified enzymes.

Question: How have you used the sensors for monitoring radionuclides at Hanford?
Answer: They've previously been tested on water from the Columbia River. They are on the verge of being deployed into selected sampling wells at Hanford.

Question: What is the target radionuclide?
Answer: Materials have been developed for both fission products and actinides. The up coming tests will focus on uranium.

Question: What detection limit are you aiming for?
Answer: As low as possible.

Question: An x-ray fluorescence (XRF) unit alone might run $300 to $500. How much do these SAMMS hybrid units currently cost?
Answer: Each hand-built unit costs about $20,000 right now, and costs are falling while performance is increasing. However, if you divide that cost by the number of times you can use it and figure in the money that each use saves in field labor and lab costs, instrument cost becomes negligible.
Question: Given the capacity to accumulate hazardous ions, have you considered using it for water purification?

Answer: Yes, PNNL has demonstrated its capacity to remove arsenic and mercury, and it performs well, but the material is expensive for bulk separations and the economics must be evaluated on a case by case basis.

Bioavailability: What Does It Mean to Be Nanosized?

Anne Anderson (Utah State University) discussed the connections between nanoparticle chemistry, bioavailability, and reactivity in remediation (see Attachment M). Microbes have developed diversity in their abilities to transfer electrons to different acceptors. In these transactions, the bacteria can produce nanoparticles by reduction of the original complex and generation of a less toxic compound, such as elemental gold, silver, selenium or reduced oxides of iron or uranium. This natural phenomenon may provide an approach for deliberately creating for commerce nanoparticles with different physical structures than those produced chemically as well as providing a method for remediation.

Nanoparticles of iron and modified iron, metal oxides, and metal sulphides, are being studied and tested for their potential for as electron donors in the conversion of environmental contaminants from a variety of sources. Work discussed briefly included nanoparticle studies by:

VIII.Wei-xian Zhang at Lehigh University on an iron/palladium nanoparticles that reductively dechlorinate trichloroethane (TCA) and degrade other chlorinated organics, pesticides (DDT and Lindane), metals, explosives, and fertilizers; and

IX.Daniel Strongin at Temple University in demonstrating nanoparticle reduction of chlorinated compounds and hexavalent chromium.

In these chemically-based examples, the nanoparticles are being used as the electron donors to the pollutant compounds and thus the mechanisms resemble the reduction by electron transfer that occurs in certain bacteria as part of their evolved metabolic pathways of detoxification of potential toxic chemicals.

Anderson described studies conducted to determine if root-colonizing pseudomonads can metabolize selenium oxyanions. Selenium in cretaceous shales and in sediments is a significant environmental problem in Utah and several other states (Colorado and California for instance) with these geological deposits. Selenium oxyanions leached from sediments are a particular issue because of the toxic effects on reproduction and development of accumulation of selenium in fish and birds, which has resulted in advisories to humans not to consume game from certain polluted locations. Anderson's group finds that soil pseudomonads reduce selenium oxyanions to elemental selenium nanoparticles. Such conversion of the soluble oxyanions of selenium to insoluble selenium nanoparticles could be used in "on site" remediation and phytoremediation processes.

The fact that bacteria can transform pollutant compounds can be exploited in the development of biosensors for the real time detection of bioavailable pollutants. Anderson's group has developed biosensors in cells of pseudomonads that will rapidly detect the bioavailable selenium oxyanions. These biosensors are generated through the fusion of promoters of genes that increase in expression when the cells are exposed to the pollutant with genes encoding for luciferase that permits the cells to emit light. Thus, these biosensors are capable of a bioluminescent display when contacts with the pollutant. Other such engineered cell lines respond rapidly with altered light output upon exposure to soluble ionic complexes of copper, zinc, lead, or cadmium. Anderson also reported the unexpected result that biosensors were able to detect chemicals such as ferric oxide, cadmium sulfide and cadmium selenide that are being used commercially as nanosized particles. Thus, although these compounds are regarded as being inert because of their tight chemical complexing, they were bioavailable and caused changes in gene expression in the biosensing microbes.

U.S. EPA/NCER awarded Anderson and two other investigators, Miller and McLean at Utah State University a 2002 STAR Grant for the development and environmental testing of biosensors for copper and cadmium ions. (Grant R830907).

Question: Who is involved in work on DDT reduction?
Answer: Lehigh University. Literature references can be provided.

Question: Is it possible to achieve biological remediation of arsenite/arsenate contamination?
Answer: Yes.

Self-Assembly of Nanoparticles in Sensing Platforms

Zafar Iqbal (New Jersey Institute of Technology) described how “nano-sizing” and assembly is achieved in materials like porous silicon, carbon nanotubes, and hybrid composite structures (see Attachment N). Nanotechnology refers to a spatial scale from about a nanometer to a few hundred nanometers. The fabrication and control of nanomaterials, such as nanotubes, involves "bottom up" strategies of self-assembly and organization starting at the molecular level and proceeding to more complex hierarchical structures, much in the same way as in natural biological systems.

A microtrap approach has been developed for air monitoring in which the sample is pre-concentrated. The concentration is done using nanoparticles. Nanotube silica particles can be functionalized for this purpose. Iqbal's presentation illustrated how the nanotubes assemble within the microtrap via a chemical vapor deposition (CVD) process.

Roman Brukh (New Jersey Institute of Technology) continued the presentation with a discussion of the factors affecting the trapping characteristics and subsequent microtrap performance. Trapping characteristics are affected by the compounds used in CVD; conditions such as temperature, pressure, and time; and the preparation of the surface and catalyst. Multi-wall nanotube (MWNT) microtraps prepared using ethylene and carbon monoxide CVD on untreated steel had a breakthrough time of five hours. MWNT microtraps prepared using ethylene and alcohol CVD on silico-steel versus untreated steel also had a breakthrough time of five hours.

Nanoparticles have much higher sorptive capacity than microparticles because of their relatively large surface area. This capacity makes possible the development of "lab-on-a-chip" devices that will contain all the necessary components (pumps, valves, detectors, etc.) to run an entire analysis, from sample preparation through analysis to detection.

NCER awarded Iqbal and his NJIT colleague, Somenath Mitra, a 2002 EPA STAR grant for "m-Integrated Sensing System (m-ISS) by Controlled Assembly of Carbon Nanotubes on MEMS Structures" (grant R830901).

Nanotechnology Approaches to Sensing and Detection

James Murday (Naval Research Laboratory) provided a quick overview of directions in research and work in progress (see Attachment O). Nanotechnology approaches to sensing and detection include electron tunneling transducers, micromechanical detection, nanowires, nanotubes, and nanoparticles. He pointed out that technology developers can take advantage of the nanostructures themselves, or they can start with the analytical tools used in nanoscience and turn them into sensors; devices used to assess biologic and toxicologic processes at the nanoscale can be adapted to other uses.

Environmental sensors must provide three integrated processes: a recognition step, which detects biologic and chemical analytes in solution or in the atmosphere; a transduction step, which produces and amplifies the signal to be detected; and a detection device, which can translate the signal into qualitative or quantitative information. Nanoscience research has shown that a sensor can be as small as a single molecule. Molecular biosensors can utilize enzymes, nucleic acids, receptors, aptamers, or antibodies as recognition elements. Biologic mechanisms all operate at a molecular (nanoscale) level. Our biochemistry is basically nanosized.

One of the current R&D challenges involves pulling the sample into the detection zone. How can you make sure your analyte contacts the right spot? On a decreasing time scale, that becomes increasingly difficult. And the sensor needs to be selective so that the analyte of interest hangs on just long enough for determination to be made.

Micro cantilevers are the simplest microelectromechanical systems (MEMS) that can be micromachined and mass-produced using conventional techniques. The advantages of microcantilever sensors include extreme high sensitivity, selectivity, and wide dynamic range. Demonstrated examples include detection of ricin, nerve gas simulants, alpha particles, and explosive vapors such as TNT, RDX, and PETN. It is possible to arrange arrays of Micro cantilevers on a single chip for multi-target detection.

In chemical sensing with carbon nanotube networks, the sensor usually is based on the capacitance of a single-walled carbon nanotube (SWNT) network of functionalized arrays. This allows fast, low-power, and highly sensitive detection via field-induced polarization of adsorbates on the SWNT surface. The sensor achieves chemical specificity using chemically selective coatings and can respond to both chemical and biological analytes.

Murday said that additional information about all the topics in his presentation could be found at the National Nanotechnology Initiative website (www.nano.gov). The Initiative maintains a sizeable library of reports and conference proceedings on line, and Murday recommends it as an information resource for nanotechnology, especially the Grand Challenge workshop series.

Question: Are environmental applications outweighed by health, military, and security applications? Or are they interchangeable?

Answer: It is important to look for the similarities among these applications and take advantage of them, rather than concentrating on the differences. Solutions to one problem can lead to solutions for another. The real challenge is getting the different players to talk to each other and work cooperatively instead of inventing the wheel independently.

Question: As detection limits continue to drop, how do you tell if it is a field contaminant or a trace contaminant?

Answer: You have to remember that there generally has to be a certain level of contamination before a substance becomes a biological hazard. To determine the proportional amount of contamination, we'll have to use arrays. If you have 100 arrays and only 50 of them detect the contaminant, that would indicate a certain level of contamination.

Question: How do you deal with the tendency of bacteria (in biosensors) to grow and affect your results?

Answer: That problem has yet to be solved, but using materials like polyethylene glycol helps to avoid it as much as possible. The shape of a particle will influence bacteria, and the topography of a surface can affect whether a cell remains or moves on. There are variables here that have not yet been fully explored.

NEXT MEETING AGENDA AND WRAP-UP

Walt Kovalick reported on the balloting results for the selection of the next meeting topic. The votes were split between performance-based contracting and emerging contaminants. It is so far unclear which of the emerging contaminants is of the greatest interest, so Kovalick will give the matter further consideration before making a decision.

One attendee remarked that no one at today's meeting had made any mention of terrorism or the use of nanotechnology in combating it. He asked whether response to terrorist activities is of any interest to the Roundtable as a meeting topic? Kovalick responded that FRTR certainly would be interested if the results of terrorist activity call for cleanup or measurement and monitoring, but otherwise it is not.

The meeting adjourned.

Attachments

A. Participants
B. WebTrends Complete Report, September-November 2004
C. Federal Remediation Technologies Roundtable Web Site Operation Plan
D. Status Report: Technology Cost and Performance Activities
E. New Cost and Performance Case Studies
F. Revisions to FRTR Screening Matrix & Reference Guide
G. Triad Project Profiles
H. Accelerating Site Closeout, Improving Performance, and Reducing Costs Through Optimization
I. Decision Support Tools Matrix: Status Update
J. Nanosensors & EPA
K. Low-Cost Printed Electronic Nose Gas Sensors for Distributed Environmental Monitoring
L. Nanotechnology Applications for Environmental Sensors: Integrated Devices for Real-Time Analyses
M. Nanomaterials for Enhanced Environmental Measurements
N. Bioavailability: What Does It Mean to Be Nanosized?
O. Self-Assembly of Nanoparticles in Sensing Platforms
P. Nanotechnology Approaches to Sensing and Detection