

**FEDERAL REMEDIATION TECHNOLOGIES ROUNDTABLE MEETING  
Arlington, Virginia  
November 15, 2007**

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**ACTION ITEMS**

- **Carol Dona will help establish an agenda on the topic of sediments for the next meeting.**
- **EMS will provide copies of the reports described by Carl Spreng to meeting participants.**

**WELCOME/OPENING REMARKS**

Norm Niedergang, Director of the Technology Innovation and Field Services Division (TIFSD) in the U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI), welcomed the attendees to the 35<sup>th</sup> meeting of the Federal Remediation Technologies Roundtable (FRTR) and provided a brief overview of the agenda. He indicated that all member agencies present would be asked to cast ballots to select topics for the technical session at the Spring 2008 roundtable, with the results to be announced at the end of the meeting.

Attendees introduced themselves (a list of participants is attached to this copy for EPA's files only; it will not appear on the FRTR website).

**FRTR MEMBER ANNOUNCEMENTS**

Norm Niedergang drew attention to the recent release of the 12<sup>th</sup> edition of EPA's Annual Status Report on Treatment Technologies for Site Cleanup ([www.clu-in.org/asr](http://www.clu-in.org/asr)). The report documents and quantifies the use of treatment technologies at National Priorities List sites. Niedergang also noted that the concept of "green remediation" is growing in interest and importance within EPA. Green remediation involves consideration of the environmental effects of a remediation strategy early in the process and incorporating options to maximize the net environmental benefit of the cleanup action. Not only can cleanups promote the reuse of the site, but environmentally preferable options, such as reducing the carbon footprint by using energy-saving strategies, can be considered in the cleanup phase itself. Niedergang urged participants to consider green remediation as the topic for the next FRTR meeting when they cast their ballots.

Carol Dona (U.S. Army Corps of Engineers [USACE]) said that the Corps' information technology group is moving to another location, and this move is likely to impact USACE's future support for the FRTR website.

Kelly Madalinski (EPA/OSRTI) announced the release of a new report by the National Research Council, "Assessment of the Performance of Engineered Waste Containment Barriers." At the request of the Department of Energy, National Science Foundation, Nuclear Regulatory Commission, and EPA, the National Academies Committee to Assess the Performance of Engineered Barriers was established to provide a technical assessment of the available information on engineered barrier performance over time for containment of solid, hazardous,

and low-level radioactive wastes. The report can be purchased or read on line at [www.nap.edu/catalog.php?record\\_id=11930](http://www.nap.edu/catalog.php?record_id=11930).

John Kingscott (EPA/OSRTI) reported that 24 new case studies are being added to the Technology Cost and Performance page on the FRTR website ([www.frtr.gov/costperf.htm](http://www.frtr.gov/costperf.htm)) this year. These new reports are in the areas of remediation, site characterization and monitoring, technology assessment, and long-term monitoring and optimization.

Beth Moore (U.S. Department of Energy [DOE]) said that two different optimization software packages are arousing considerable interest. One software, developed for the Air Force, is for geotemporal spatial analysis and is in the public domain; and the other software, which has been used at Navy sites, is in the private domain. If contacted, she will provide the URLs to sites where additional information on these software products can be obtained.

Dan Powell (EPA/OSRTI) pointed out the availability of four new reports on the FRTR Long-Term Monitoring page ([www.frtr.gov/optimization/monitoring/ltn.htm](http://www.frtr.gov/optimization/monitoring/ltn.htm)). Each report presents the results of an evaluation of a specific site's ground-water monitoring network using a formal qualitative approach and statistical tools found in the MAROS (Monitoring and Remediation Optimization System) software.

#### **DOE/EM ENGINEERING AND TECHNOLOGY: GROUND WATER AND SOIL REMEDIATION MULTI-YEAR PROGRAM PLAN**

Skip Chamberlain (U.S. DOE) outlined a plan for solving the Department of Energy's site cleanup priority needs and objectives (Attachment A). Eighty needs in six categories have been identified for the priority sites. These needs have been incorporated into a science and technology roadmap. A central element of this plan involves establishing a Center for Sustainable Ground water and Soil Solutions at the Savannah River Site. The process of planning and finding seed money for the center is still underway, but the target date for launch of the center is currently March 2008.

#### **MONITORED NATURAL ATTENUATION (MNA) AND *IN SITU* BIOREMEDIATION OF INORGANICS**

Beth Moore introduced the subjects of the meeting's technical sections: MNA and *in situ* bioremediation for inorganics (part 1) and for radionuclides (part 2).

##### ***MNA OF METALS AND IN SITU BIOREMEDIATION***

Rick Wilkin (EPA/Office of Research and Development [ORD]) introduced "Monitored Natural Attenuation of Inorganics in Ground Water," a new technical framework for MNA of inorganic compounds (Attachment B). He also identified and acknowledged members of the team that has spent five years planning and developing the inorganics framework. EPA is preparing a series of documents that addresses the technical basis for selection of MNA as a component of a remedy for cleanup of inorganic contaminants in ground water. These documents provide an overview of the technical basis for natural attenuation of inorganic contaminants as well as site characterization requirements for application to specific radionuclides and non-radionuclides in

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ground water. Emphasis is placed on characterization of immobilization and/or degradation processes that may control contaminant attenuation, in addition to analytical approaches to assess performance characteristics of the MNA remedy. In these documents, adoption of a tiered analysis process provides a means to screen sites for MNA. This approach is anticipated to be the most effective, because it prioritizes and limits the data that are needed for decision making at each screening step.

Wilkin presented an overview of volumes 1 and 2. Volume 1, subtitled "Technical Basis for Assessment," provides the regulatory context, a discussion of the Tiered Analysis Approach and the role of modeling, an explanation of the technical basis of natural attenuation (NA) in ground water, and an extensive section on site characterization to support MNA evaluation. Volume 2, subtitled "Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium," contains a separate chapter on the attenuation potential of each of the listed contaminants.

MNA is frequently applied as a remediation option for organic contaminants in ground water, especially fuel hydrocarbons and chlorinated compounds. Current lines of research examine whether or not MNA is more broadly applicable to inorganic contaminants, including metals, metalloids, and radionuclides. *In situ* bioremediation approaches for treating inorganic contaminants attempt to enhance either the rate or the capacity of naturally occurring processes strategically in order to impact the solubility, reactivity, and toxicity of contaminant species. There are, however, recognized technical distinctions between organic and inorganic contaminants. These distinctions, which relate to attenuation mechanisms and site characterization requirements, need to be considered to select and monitor the performance of MNA or other active ground-water remedies adequately. Technical distinctions between the applications of MNA for cleanup of organic versus inorganic contaminants are discussed in EPA's OSWER Directive 9200.4-17P (1999). The directive emphasizes that attenuation of inorganic contaminants is often due to sorption onto immobile aquifer solids. Furthermore, it is acknowledged that inorganic contaminants that attenuate via sorption will persist in the subsurface. Thus, developing a site-specific technical basis for MNA as a component of the cleanup action will necessitate determination of the mass transfer process(es) leading to immobilization or degradation of the contaminant within the boundaries of the ground-water plume.

### ***Questions/Answers***

- Q: Does monitoring of inorganic attenuation go on forever? How do you know when to stop?
- A: Monitoring would have to continue as long as the contaminant is present.
- Q: Has consideration been given to changing MNA to monitored and *modeled* NA? This approach would consider transients in the system that often are ignored. If modeling is required, what would be the level of modeling?
- A: This question needs further consideration, although modeling in this context is extremely important, and it would likely involve a range of modeling approaches.

Q: Would land use and long-term stability be considered in the modeling approach?

A: Yes.

***FIELD-INTEGRATED STUDIES OF LONG-TERM SUSTAINABILITY OF CHROMIUM BIOREDUCTION AT HANFORD 100H SITE***

Terry Hazen (Lawrence Berkeley National Laboratory) described a project conducted to explore the hypothesis that lactate (Hydrogen Release Compound, or HRC®) injection into chromium-contaminated ground water through an injection well will cause bioreduction of chromate [Cr(VI)] and precipitation of insoluble species of [Cr(III)] on soil particles, probably catalyzed at oxide surfaces at the field scale (Attachment C). In August 2004, HRC was injected in Hanford sediments (through an injection borehole over the depth interval from 44 ft to 50 ft) to stimulate immobilization of Cr(VI). Within the next 2-3 weeks, the HRC injection induced an increase in biomass by two orders of magnitude—up to more than 10<sup>7</sup> cells/mL, which remained high for over three years. The presence of several types of bacteria was detected in sediment samples identified using the 16S rDNA and newer microarrays, including *Bacillus/Arthrobacter* and *Geobacter* species. These bacteria are known to withstand high concentrations of heavy metals, metabolize recalcitrant chlorinated compounds, and reduce or sorb hexavalent chromium.

The HRC injection also induced the onset of reducing biogeochemical conditions—redox potential decreased from +240 to -130 mV, and dissolved oxygen (DO) was completely removed. The HRC breakdown products were found to cause the microbial population to deplete sequentially the oxygen, nitrate, iron(III), sulfate, and carbon dioxide (transiently). Once the nitrate was depleted, the transformation of Cr(VI) species to Cr(III) species that were precipitated on soil particle surfaces was observed. Sulfate and iron microbial reducers have apparently maintained Cr(VI) reduction below the drinking water standards in the injection well for more than three years. Cr(VI) concentration in the monitoring well decreased below drinking water Maximum Contaminant Level (MCL), remained at this level for about two years, and is still below up-gradient (background) concentration. Iron reduction is still active more than three years after the injection, and the presence of Fe(II) suggests active Cr(IV) reducing conditions. Some HRC or its byproducts may still remain in the area surrounding the injection well; however, it may also be possible that the microbial community is dependent on cryptic growth.

Under field conditions at the Hanford 100H site, a single application of HRC enhanced Cr(VI) immobilization via naturally occurring microorganisms. Adding HRC to a contaminated aquifer may offer a low-cost and effective approach to the treatment of Cr(VI)-contaminated aquifers at Hanford and other Cr(VI)-contaminated sites. Research continues on the resiliency of the microbial community, stability of the reduced Cr(III), continuation of field observations in existing and new boreholes, and the development of a 3D reactive transport code, TOUGHREACT-BIO, to simulate coupled biological and geochemical processes.

***Questions/Answers***

Q: Do you map the evolution of the biological communities? Is it applied only to the saturated zone?

A: It could also be applied to the capillary fringe.

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Q: Is the microarray available for other people to use?

A: Yes. Just contact us. The microarrays are not reusable, so they are expensive—about \$90 per chip—but they give an instantaneous response in air, water, or soil.

Q: Did you acquire depth-specific information for the injectant?

A: Initial emplacement occurred at 16 or 17 feet between two wells. The injectant continues to bleed out of the injection well and, though viscous, is still moving in the subsurface.

Q: How high were the chromate concentrations?

A: Concentrations were fairly low at this site, about 100 parts per billion (ppb), and they had been stable for years. HRC injection dropped the concentrations to 5 ppb. The volume treated was very large. This approach should be effective at concentrations of 1,000 ppb or lower.

### ***MICROBIAL TRANSFORMATION OF ARSENIC AND SELENIUM FOR BIOREMEDIATION STRATEGIES***

John Stolz (Duquesne University) discussed his research into how microbial metabolic processes can affect the bioremediation of selenium and arsenic (Attachment D). Selenium contamination has been associated with agricultural runoff and phosphate mining. Selenate (Se[VI]) is associated with oxic conditions, whereas selenite (Se[IV]) and elemental selenium (Se<sup>0</sup>) are more commonly found in anoxic environments. Despite their toxicity at elevated concentrations, both arsenic and selenium are readily metabolized by prokaryotes, which are a group of organisms that lack a cell nucleus or any other membrane-bound organelles. These metabolic processes include assimilation, detoxification, and energy generation, and can involve oxidation/reduction and methylation/demethylation reactions. Both arsenic and selenium are actively cycled in the environment, and microbial activity can have an impact on the chemical species and thus mobility and toxicity. Biological reactors using Se(VI)-respiring bacteria effectively convert Se(VI) and Se(IV) to elemental selenium. The presence of co-contaminant metals and metalloids, however, can impact the efficacy of these treatments. Choosing the appropriate organism can circumvent these problems.

Arsenic is found at 67 percent of Superfund sites and is categorized as a contaminant of concern at 30 percent. Of the two oxidation states of arsenic commonly found, arsenate (HAsO<sub>4</sub><sup>2-</sup> and H<sub>2</sub>AsO<sub>4</sub><sup>1-</sup>) is typically associated with oxic conditions, whereas arsenite (H<sub>3</sub>AsO<sup>0</sup> and H<sub>2</sub>AsO<sub>3</sub><sup>2-</sup>) is associated with anoxic conditions. Depending on the site, the arsenic may be predominantly As(V) or As(III) or a combination of both. Remediation strategies for arsenic have involved primarily the removal of As(V) (arsenate), and a variety of methods for inorganic complexation (e.g., alumina sorption, anion exchange, ferric chloride coagulation) and phytoremediation have been devised. The effectiveness of these applications may be improved through the biological oxidation of As(III) to As(V). In this regard, As(III)-oxidizing bacteria can enhance the rates of uptake of the arsenic hyperaccumulating fern *Pteris cretica*. Conversely, As(V)-respiring bacteria known to mobilize arsenic from solid substrates may be useful where bound arsenic is a problem.

Stolz's research team has also investigated the transformation of organic arsenic to inorganic arsenic (a known carcinogen) in the context of roxarsone, or 3-nitro-4-hydroxybenzene arsonic

acid, which is routinely used by most U.S. broiler-chicken farms as a feed additive to prevent disease and stimulate growth. Chickens primarily excrete roxarsone unchanged into their waste, which typically is applied as a fertilizer on farmlands. Inorganic arsenic is formed from roxarsone after litter composting or field application. Stolz and his colleagues discovered that roxarsone is transformed rapidly to 3-amino-4-hydroxybenzene arsonic acid and inorganic As(V) in chicken-litter enrichments under anaerobic conditions by bacteria of the *Clostridium* species. *Clostridium* species are the dominant bacteria in chicken cecum and litter, from which As(V) can emerge in less than 10 days. The microbes gain energy from the roxarsone transformation and couple it to growth, presumably through an anaerobic respiration mechanism in which roxarsone serves as the terminal electron acceptor. The organic-rich manure and anaerobic conditions typically associated with composting provide the conditions necessary for the native microbial populations to transform the roxarsone in the litter, releasing the more toxic inorganic arsenic. This rapid conversion of roxarsone into inorganic arsenic may present a serious pathway for the introduction of a known carcinogen into garden compost and agricultural soils.

## **MONITORED NATURAL ATTENUATION AND *IN SITU* BIOREMEDIATION OF RADIONUCLIDES**

### ***SITE CHARACTERIZATION FOR MNA OF RADIONUCLIDES IN GROUND WATER***

Robert Ford (EPA/ORD) provided an overview of attenuation concepts, discussed site characterization goals and potential pitfalls, and outlined some of the challenges involved in site characterization for MNA of radionuclides in ground water (Attachment E). MNA is often evaluated as a component of the remedy for ground water contaminated with radionuclides. When properly employed, MNA can provide an effective knowledge-based remedy if a thorough engineering analysis informs the understanding, monitoring, predicting, and documenting of the natural processes.

For many radionuclide contaminants, sorption onto immobile aquifer solids is the primary attenuation process, resulting in the persistence of the contaminant within the aquifer. This characteristic of radionuclide contaminants necessitates a different approach to site characterization, since the technical evaluation must address both identification of the attenuation process(es) and the long-term stability of the immobilized contaminant to resist remobilization due to potential changes in ground-water chemistry. The data collection and analysis process should support development of a detailed knowledge of the system hydrogeology, the mechanisms and rates of contaminant attenuation, the capacity of the aquifer to sustain attenuation of the mass of contaminant within the ground-water plume, and the long-term stability of immobilized contaminants. Determination of attenuation mechanism(s) can be realized through measurement of the ground-water chemical setting (including redox characteristics), the chemical speciation of the contaminant and key reactants in ground water, and the solid components within the aquifer with which the contaminant reacts.

Successful evaluation of MNA as a component of the ground-water remedy will thus depend on the adequacy of the design and installation of the monitoring network; the procedures for sampling, processing, and preserving aqueous and solid phase samples; and the types and accuracy of chemical measurements to characterize the speciation of contaminants and

subsurface reactants in liquid and solid matrices. Several potential pitfalls in the site characterization effort are highlighted. For example, during well installation and construction, drilling fluids introduced into the well screen may alter the hydraulic conductivity and/or reactivity of aquifer sediments along ground-water flow path, and introduction of bentonite and/or alteration of sediment mineralogy (from degradation of organic drilling fluids) may change the sorption properties of the aquifer sediment adjacent to the well screen. Additional pitfalls may be encountered during sample acquisition and characterization.

### ***BIOREMEDIATION OF ATOMIC BOMB WASTES***

Craig Criddle (Stanford University) described a pilot-scale study conducted at Oak Ridge National Laboratory to develop a biological strategy for immobilization of uranium under field conditions (Attachment F). A team evaluated the potential for field-scale *in situ* biological reduction of U(VI) in Area 3 of the DOE Environmental Remediation Science Program (ERSP) Field Research Center in Oak Ridge, Tennessee. High levels of U are present in the ground water (~60 mg/L—well over 1,000 times the drinking water standard!) and soil (as much as 700 to 1,000 mg/kg). Many other contaminants are also present, including chlorinated solvents. Notably, the ground water contains high levels of nitrate (8 to 10 g/L), calcium (0.9 g/L), and aluminum (0.5 g/L) at a pH of 3.4.

An attempt to neutralize the site had been partially achieved by covering it with a parking lot; however, it continued to be an occasionally active source as contaminants leached into water that passed laterally under the cap. The evaluation of potential remediation processes involved a three-step approach: (1) flushing with low-pH water to remove aluminum, calcium, and bulk nitrate; (2) adjustment of pH to near 6, a range favorable for microbial activity; and (3) ethanol addition to stimulate U(VI) reduction. After flushing the subsurface and adjusting the pH to near 6, which was accomplished in 140 days, *in situ* bioremediation was initiated. Bioreduction was achieved by stimulating growth of denitrifying, Fe(III)-reducing, and sulfate-reducing bacteria through weekly additions of ethanol for two-day periods.

Over a two-year period, *in situ* bioreduction of U(VI) decreased the levels of dissolved uranium in ground water to submicromolar levels. Following sulfite additions to remove dissolved oxygen, aqueous U(VI) concentrations at the monitoring wells fell below the EPA maximum contaminant limit (MCL) for drinking water (< 30 µg/L or 0.126 µM). The low concentrations were stable under anaerobic conditions, even in the absence of added ethanol, but when sulfite additions stopped, and 4.0-5.5 mg/L dissolved oxygen (DO) was allowed into the injection well over a 60-day period, spatially variable changes in aqueous U(VI) occurred, with concentrations increasing rapidly from <0.13 to 2.0 µM at a multilevel sampling (MLS) well located close to the injection well, while changing little at a MLS well located further away. Resumption of ethanol addition after DO exposure restored reduction of Fe(III), sulfate, and U(VI) within 36 hours at all MLS wells. After two years of ethanol addition, X-ray absorption near-edge structure spectroscopy analyses indicated that reduced U(IV) made up 60 to 80 % of the total uranium in sediment samples. MLS well U concentrations were reduced below 0.1 µM at the completion of the project (1,260 days). The microbial community at MLS wells with low U(VI) contained bacteria that are known to reduce uranium, including *Desulfovibrio* spp. and *Geobacter* spp., in both sediment and ground water.

***BIO-IMMOBILIZATION OF RADIONUCLIDES: RESULTS OF FIELD EXPERIMENTS AND BIOGEOCHEMICAL MODELING***

In the first part of his presentation, Jack Istok (Oregon State University) outlined ongoing field manipulation experiments at the Field Research Center (FRC) at Oak Ridge National Laboratory (Attachment G). Field tests were conducted to try to stimulate microbial immobilization of uranium (U) and technetium (Tc) by a series of electron donor (ethanol) additions performed over a series of months in a wide range of initial geochemical conditions. As microbial activity was detected and rates were quantified using single-well push-pull tests, the activity was found to be electron donor limited; tests with no donor showed only dilution losses. The addition of exogenous electron donor stimulated microbial activity in all environments rapidly (within a few weeks). After biostimulation, microbial activity was similar in all environments tested, including those with low initial pH, although *in situ* rates were very different from laboratory rates. Enhanced microbial activity resulted in production of mineral precipitates, biomass, and gas. Addition of nitrate (and other oxidants) to previously reduced sediments reoxidized and remobilized U (but apparently not Tc). Mechanisms of nitrate-dependent microbial U(IV) oxidation were identified using microbial isolates and a range of mineral systems. The results indicated that the form and amount of added substrates can be controlled to favor alternate bioimmobilization strategies. Additionally, the single-well push-pull tests were shown to be a rapid, effective, and inexpensive method for detecting and quantifying effects of chemical amendments on the subsurface.

In part 2 of the presentation, Istok discussed model simulations performed as part of a research project, "Stability of U(VI) and Tc(VII) Reducing Microbial Communities to Environmental Perturbation: Development and Testing of a Thermodynamic Network Model." This project is being conducted by an interdisciplinary team of researchers from Oregon State University, Pacific Northwest National Laboratory, University of Tennessee, and the University of Oklahoma. The overall goal is to predict the effect of various chemical amendments on the subsurface microbial community at the FRC and other DOE sites in order to promote the bioimmobilization of contaminant metals and radionuclides. The model is unique in that it couples the thermodynamics of microbial growth and geochemical reactions, resulting in quantitative and system-specific predictions of microbial community composition and function. Model predictions are being compared with the results of small- to intermediate-scale field experiments conducted at the FRC and other DOE sites.

The overall objective of this project is to improve the ability to use native microbial communities to speed remediation of contaminated ground water and sediments. The broad scientific hypothesis is that a thermodynamic analysis of the energy-yielding reactions performed by broadly defined groups of microorganisms can be used to make quantitative and testable predictions of the change in microbial community composition and system geochemistry (including contaminant chemistry) that occur when a substrate is added to the subsurface and/or when environmental conditions change. The new thermodynamic modeling approach couples microbial growth with geochemical reactions to make useful predictions concerning the effects of chemical additions on complex, highly contaminated environments. This approach builds on well-known geochemical modeling techniques. The only required parameters are the free-energy dissipation for microbial growth on each substrate (e.g., ethanol, lactate, acetate, and hydrogen). Fewer parameters make it possible to model intact microbial communities in highly complex

geochemical environments. Initial porewater and sediment geochemistry data are required inputs. The model predictions are in qualitative agreement with geochemical observations from laboratory batch experiments, field push-pull tests, intermediate-scale column experiments, and field natural gradient tests at three ERSP research sites: FRC, Old Rifle, and the Hanford 100H Area.

***Questions/Answers***

Q: With push-pull tests, is it hard to isolate what you are injecting from the rest of the aquifer? Is there mixing?

A: Mixing doesn't seem to be a problem. Good performance ultimately comes down to having a good tracer.

***EVALUATING THE EFFICACY OF BIOREMEDIATION OF URANIUM IN THE SUBSURFACE***

Phil Long (Pacific Northwest National Laboratory) described the context for field bioremediation research at the Old Rifle Uranium Mill Tailings Site (Attachment H). A goal of the U.S. Department of Energy's ERSP is to infuse coupled physical, chemical, and biological processes into decision-making for environmental remediation and long-term stewardship. Toward that end, ERSP funds research projects that illuminate the underlying mechanisms controlling mobility of selected contaminant metals, including projects that examine those mechanisms at the field scale. At the Integrated Field Challenge Site (IFC) at Rifle, Colorado, an interdisciplinary team of researchers is focusing on the microbial and abiotic processes controlling uranium mobility in the subsurface. This project includes establishing the scientific and technical basis for active *in situ* uranium bioremediation and natural attenuation processes.

Several field-scale biostimulation experiments with acetate amendment conducted under natural gradient conditions have successfully replicated the removal of soluble U(VI) from the ground water via microbially mediated reduction to an insoluble U(IV) mineral. The challenge is to control and monitor long-term uranium bioremediation (or natural attenuation) throughout a contaminated domain. Key issues are the spatial distribution and long-term durability of immobilized uranium resulting from a bioremediation process. These issues are being addressed systematically, including monitoring of microbial metabolic processes via direct measurement of the *in situ* gene and protein expression. Selected genes and proteins will be incorporated into a chip array designed to provide in-field performance monitoring of bioremediation techniques.

The characterization, monitoring, and modeling approaches that have been advanced at DOE IFCs address the broader needs of DOE Environmental Management and DOE Legacy Management, and also can address regulatory needs for evaluating proposed uranium bioremediation sites. The U.S. Nuclear Regulatory Commission is using scientific results from the Rifle IFC and other sites for developing guidance for site-specific characterization, conceptual model development, monitoring, and modeling to assess uranium bioremediation efficacy systematically. The approach encourages sampling consistent with appropriate space and time scales, real-time remote monitoring and event-based sampling, and passive *in situ* geochemical and biological sampling as a means of minimizing long-term monitoring costs while protecting the public health and safety.

***TRANSITIONING FROM ACTIVE TO SUSTAINABLE REMEDIATION FOR METALS AND RADIONUCLIDES***

Miles Denham (Savannah River National Laboratory) explained that *in situ* remediation of metals and radionuclides must demonstrate with high confidence that performance objectives will be met for long periods of time (Attachment I). A remediation that is sustainable meets this requirement while minimizing maintenance, cost, and collateral environmental damage. Evaluating technologies for sustainability or transitioning from active to sustainable remediation requires understanding the factors controlling overall biogeochemical evolution of a waste site following active remediation. For example, acid plume/alkaline treatment involves the injection of alkaline solutions to an acidic plume with the goal of increasing pH and thereby stopping acid-sensitive contaminants. How long is it necessary to continue the injections? The proposed treatment is complicated by the constant fresh inflow of ground water, and the surfaces of the minerals in this area are also acidified. Multiple factors must be considered to arrive at an acceptable pH such that the contaminants remain sequestered. Similar questions must be asked about other metal and radionuclide treatments such as bioreduction or phosphate stabilization. How long can remedial objectives be sustained by these treatments, and what factors control this?

The tendency to rebound toward near natural conditions is controlled by factors similar to those that control contaminant migration. These factors include hydrogeology, aquifer mineralogy, post-treatment mineralogy, aquifer texture, chemical composition of uncontaminated/untreated water entering the system, and status of the source zone. The rate of this rebound determines how long active remediation must proceed to ensure performance objectives are met over the long term and whether additional steps are warranted to enhance contaminant attenuation. Answering these questions will be one focus of a new initiative undertaken by the Savannah River National Laboratory with funding from the DOE Office of Environmental Management.

***Questions/Answers***

Q: Isn't it impossible to characterize every aspect of contaminant migration and risk?

A: Yes. Assessing sustainability may be possible at one site and less so at another.

Q: What is the preferred software for sustainability predictions?

A: Software is still being assessed as this project continues.

Q: Do mixing and dilution cause the results you see when injecting base?

A: Tritium that exists in the ground water at this site makes a wonderful tracer. The contaminant-to-tritium ratio showed that for the main contaminants of concern about 20 percent was mixing, and the rest was actually chemical effects such as enhanced adsorption.

Q: What constitutes an acceptable risk?

A: Regulators, site owners, and stakeholders need to agree on what an acceptable risk is and how long monitoring should be carried out for each specific site.

Q: Is cost built into your definition of sustainability?

A: Costs must be factored in, such as maintenance costs, but our first step is to understand how to evaluate the length of time active treatment is necessary to sustain remedial objectives.

***STATE PERSPECTIVE ON INTEGRATION OF EMERGING TECHNOLOGIES FOR METALS AND RADIONUCLIDE CLEANUP***

Carl Spreng (Colorado Department of Public Health and Environment and the Interstate Technology Regulatory Council [ITRC]) gave examples of how regulators have approached metals and radionuclide cleanups (Attachment J), beginning with work at Rocky Flats. The pathway analysis developed by the Actinide Migration Evaluation (AME) advisory group provided justification for the cleanup concepts for radionuclides established in the Rocky Flats Cleanup Agreement (Attachment K). The study evaluated the potential for contaminant migration in air, surface-water, ground-water, and biological pathways. Based on information from the study, the cleanup agreement required a more extensive cleanup for surface soil but allowed some residual contamination to remain in the subsurface soil. The AME emphasized surface water as a major transport pathway for americium and plutonium, which is supportive of the very conservative cleanup 0.15 pCi/L state surface water standard for those two actinides.

Since the acceptance by regulators of the cleanup goals at Rocky Flats, more progress has been made in introducing the regulatory community to concepts of innovative cleanup at radioactively contaminated sites. Regulators from seven states attended a workshop convened by Oregon State University in 2005, where they were instructed in the basics of radionuclide cleanup by national experts from DOE Labs and academia. The state regulators learned that bioremediation can be a viable option, although there are few completed field studies and even fewer large-scale applications. This meeting resulted in a document, "State Regulators Consensus Workshop: Use of Bioremediation to Treat Radionuclides and Metals: A Report to U.S. DOE" (Attachment L). The report provided a state perspective on what factors should be considered in prioritizing research on the topic. The consensus document also declared that "The US DOE should view state regulators as partners for implementation of bioremediation for radionuclides and metals, not as obstacles" since they have "consistently demonstrated a willingness to consider innovations or alternative technologies that meet cleanup goals." In responding to the lack of a substantive body of field application, the report recommended that research should be focused on real-life problems in situations where no other proven, cost-effective technologies exist and in areas with the most potential for broad application.

EPA has a MNA policy (Directive 9200.4-17P, April 21, 1999) that addresses three general categories of common pollutants susceptible to natural attenuation - petroleum-related products, chlorinated solvents, and inorganics. The policy recognizes that MNA may be an appropriate remediation option that should be evaluated along with other alternatives but indicated that "monitored natural attenuation should not be considered a default or presumptive remedy at any contaminated site." The primary MNA processes for inorganics are likely to be transformation, immobilization, and radioactive decay. This policy conveys the concept that many inorganic contaminants will persist in the subsurface.

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ITRC has approved a new project—Attenuation Processes for Metals and Radionuclides—in cooperation with EPA, DOE, and the Department of Defense. The project is designed to address the lack of regulatory guidance for attenuation-based remedies for radionuclide and metals contamination. This lack contributes to inconsistent approaches and application of those remedies and generally discourages their consideration. The net result is that many sites face intractable closure problems. The preliminary project goals are to develop a Web-based resource guide (2008), convene a case studies forum and prepare a case studies report (2009), and produce technical and regulatory guidance and present a series of Internet-based training seminars (2010).

### ***Questions/Answers***

Q: What process did you go through to determine cleanup levels?

A: It was site specific, involved public involvement and peer review, and generally involved arriving at a middle-of-the-risk-range number that was both defensible and achievable. The process required considerable research to determine appropriate probability distributions for input parameters for both risk and dose assessments.

Q: Did converting data to rad-equivalent units at Rocky Flats require a lot of effort?

A: No. Results were “back-calculated” from dose-based computer codes and risk formulas in units of activity (pC/g) – the units that could be applied in the field. The dose-based and risk-based values were derived directly and not converted from one to the other. Because kidney toxicity rather than cancer is the driver for some uranium species, conversion factors were used to convert total activity of different mixes of uranium isotopes to mass in micrograms. The mass values were then compared to the toxicity based limit (RfD) for total uranium.

### ***INTERAGENCY PANEL: PERSPECTIVES ON RESEARCH AND APPLICATIONS TO FEDERAL AND STATE CLEANUP PROGRAMS***

Tom Nicholson (U.S. Nuclear Regulatory Commission), Carl Spreng, Beth Moore, and Ron Wilhelm (EPA/Office of Radiation and Indoor Air) conducted an informal session that consisted primarily of comments and questions related to the day's presentations.

Wilhelm provided additional information on "Monitored Natural Attenuation of Inorganics in Ground Water," the EPA guidance framework for MNA of inorganic compounds (Attachment M). He explained that Volume 3 contains chapters for americium, cesium, cobalt, iodine, plutonium, radium, strontium, radon, technetium, thorium, tritium, and uranium. Each chapter contains information on element occurrence and distribution, regulatory aspects, geochemistry and attenuation processes, site characterization, long-term stability and capacity, and a tiered analysis. In addition to publication of the framework documents, development of a policy directive is anticipated in 2008.

Q: How does EPA policy relate to the work of the ITRC workgroup?

A: The ITRC provides information and guidance about emerging technologies and regulatory issues. It does not try to recommend or influence policy, but may work with the Agency. The ITRC group may look at enhanced attenuation as well as MNA.

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Q: Has anyone used MNA for inorganics in the field?

A: Yes. The Army Corps of Engineers has used MNA for arsenic at a landfill site.

Nicholson proposed a collaborative effort involving MNA of radionuclides at several well-characterized sites to broaden the base of knowledge and field experience.

Steve Yabusaki (Pacific Northwest National Laboratory) was asked to comment on observations concerning the uranium plume at the Hanford facility. He said that although an exceptionally large characterization effort had attended the response action, remediation of the uranium plume in the 300 Area ground water through MNA has not achieved the remedial action objectives in the 10-year time frame envisioned when the ROD for interim action for ground water was established in 1996. In fact, the plume has not changed substantially over the last 15 years. DOE has initiated additional characterization activities and is evaluating more aggressive treatment alternatives to address the uranium plume.

### **MEETING WRAP-UP**

Norm Niedergang thanked everyone for attending.

Balloting for the next FRTR meeting topic indicated that sediments remediation was of most interest to member agencies. Other topics receiving votes were green remediation and vapor intrusion. Carol Dona volunteered to help establish the sediments agenda for the spring 2008 meeting.

The meeting was adjourned.