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NAB R NEWS

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The Natural and Accelerated Bioremediation Research Program | NABIR

NABIR research grants awarded

In August 1997, the DOE, through its Office of Biological and Environmental Research, awarded $10 million in grants for scientific research in the NABIR program. The scientific awards cover six of NABIR's seven scientific program elements—Acceleration, Assessment, Biogeochemical Dynamics, Biomolecular Science and Engineering, Biotransformation and Biodegradation, and Community Dynamics and Microbial Ecology. Another element, the BASIC (Bioremediation and its Societal Implications and Concerns) program will announce awards shortly. The System Engineering, Integration, Prediction, and Optimization element will be funded at a later date.

The research will be devoted to providing the fundamental scientific understanding needed to make bioremediation a viable option for dealing with DOE's most challenging cleanup problems. The scope of the newly funded research covers experimentation on metal and radionuclide contamination, specifically on such contamination associated with weapons production.

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The grant applicants were peer reviewed by a combination of academic and laboratory researchers, using both individual and committee review processes. A total of 93 reviewers participated. The reviews took place the week of May 12, 1997.

The award recipients are listed below according to the scientific element most closely aligned with their research.

New Projects Funded

Biotransformation and Biodegradation

Harvey Bolton, Pacific Northwest National Laboratory, *Biodegradation of PuEDTA and Impacts on Pu Mobility*

Jim K. Fredrickson, Pacific Northwest National Laboratory, *Microbial Reduction and Immobilization of Uranium in Fe (III)- and Mn (IV)-Containing Sediments*

Kenneth H. Nealson, University of Wisconsin, *Bioremediation of Actinide and Transition Metal Contamination: Mechanistic Studies*

Laura M. Vanderberg-Twary, Los Alamos National Laboratory, *Environmental Actinide Mobility: Plutonium and Uranium Interactions with Exopolysaccharides and Siderophores of Aerobic Soil Microbes*

Murthy A. Vairavamurthy, Brookhaven National Laboratory, *Transformation of Heavy Metal Contaminants in Sulfate-Reducing Subsurface Environments: The Role of Thioloated Compounds and Hydrogen Sulfide*

Community Dynamics and Microbial Ecology

Fred J. Brockman, Pacific Northwest National Laboratory, *Vadose Zone Microbial Community Structure and Activity in Metal/Radionuclide-Contaminated Sediments*

Derek Lovley, University of Massachusetts, *Determination of the Structure of Metal- and Humics-Reducing Microbial Communities in Subsurface Environments Contaminated with Uranium and Other Metals*

Terence L. Marsh, Michigan State University, *Systematic Analysis of Microbial Communities in a Chromium Contaminated Super Fund Site*

Barth F. Smets, University of Connecticut, *Horizontal Gene Transfer as Adaptive Response to Heavy Metal Stress in Subsurface Microbial Communities*

James M. Tiedje, Michigan State University, *Noncompetitive Microbial Diversity Patterns in Soils: Th... es and Implications for Biore...*

Biomolecular Science a... Engineering

Douglas S. Clark, University... nia at Berkeley, *Metabolic E... of Marine Microorganisms f... Metal Removal*

Michael J. Daly, Uniformed... University of Health Scienc... *and Construction of Deinoc... radiodurans for Bioremedia...*

See NEW PROJ...

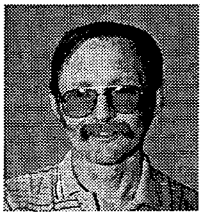
In This Issue

2 Meet NABIR's Scientific Team Leaders

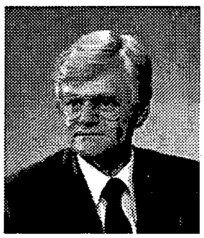
3 Under the Microscope with a rad microbe

6 The BASIC Corner with Dan Drell

MEET THE STLs: NABIR's SCIENTIFIC TEAM LEADERS



Ronald L. Crawford's areas of scientific team leadership are the biotransformation and biodegradation, acceleration, and biomolecular science and engineering program elements. He is professor of microbiology at the University of Idaho, where he directs an internationally recognized research team in environmental biotechnology. He has broad expertise in the biodegradation of hazardous chemicals, bioreactor design and use, development of microbial encapsulation technologies, and subsurface microbiology.



Raymond E. Wildung's areas are the biogeochemical dynamics and acceleration program elements. He is the Program Director responsible for the Environmental Science Research Center at Pacific Northwest National Laboratory. He is also an affiliate professor and a member of the Board of Visitors at Washington State University. Dr. Wildung's research focuses on the soil and subsurface biogeochemical processes controlling metal and radionuclide behavior, and the results of his research have been used worldwide to evaluate and quantify the risk of atmospheric fallout, the nuclear fuel cycle, synfuel development, and defense nuclear production.

David C. White is particularly interested in the community dynamics and microbial ecology, biomolecular science and engineering, and assessment program elements. He is a professor of microbiology/ecology and Executive Director of the Center for Environmental Biotechnology at the University of Tennessee. He also is a scientist in the Environmental Science Division of Oak Ridge National Laboratory. His research focuses on defining interactions between microbes. Under his leadership, the Laboratory developed quantitative measures of microbial viable biomass, community composition, and nutritional/physiological status based on signature lipid biomarker analysis.

NABIR News interviewed the three Science Team Leaders (STLs), asking them about the importance of the program to DOE, their own research, their role in the NABIR program, the future of bioremediation, and how they see NABIR's role vis-a-vis the public.

Why is the NABIR program important to DOE?

Crawford: This program was designed specifically to tackle some of DOE's most difficult problems. For example, the present focus of the program is on metals and radionuclides in the subsurface (below the plant root zone). So far, there are no reliably effective technologies to remedy these particular types of pollution. By focusing NABIR resources specifically on vadose zone and aquifer contamination by metals and radionuclides, we increase the chances for development of technologies genuinely valuable to DOE.

White: Unlike organic contaminants such as petroleum hydrocarbons, halogenated hydrocarbons, or explosives, which are most often considered for bioremediation, heavy metal and radioactive toxicants are not degradable and retain their toxicity. This toxicity is both cumulative and magnified at higher trophic levels in the food chain and is actively accumulated by humans and other animals. Also, toxicity can occur at very low concentrations. Unfortunately, because much of the contamination of DOE sites by these heavy metals and radionuclides is found in the deep subsurface at very low levels, other forms of remediation such as removing the soil are simply not feasible or even close to being cost-effective. Bioremediation is the only currently available technology for effective risk reduction in these cases.

The processes by which the risks from these subsurface contaminants can be decreased are relatively difficult to understand. Rendering the toxicants insoluble and therefore immobile and neutralized, or in a state to be mobilized and collected, requires extraordinary collaboration among diverse scientific disciplines—including geochemistry, hydrology, geophysics, geology, microbiology, toxicology, risk assessment, modeling, and analytical chemistry. NABIR brings together these disciplines to focus on some of the most refractory contaminant remediation problems in the DOE system.

Wildung: Restoration of dispersed, inaccessible subsurface environments contaminated with radionuclides and metals represents a particularly difficult problem for DOE because the current state-of-the-art in "treatment" is largely limited to natural processes of radioactive decay and/or attenuation. Subsurface microbial processes offer a real alternative for *in situ* treatment of radionuclides and metals. The processes can be manipulated, and they offer a broad spectrum of treatment possibilities, including direct alteration of contaminant oxidation state, alteration of the geochemistry of groundwater and subsurface minerals, and degradation of organic compounds that facilitate metal and radionuclide mobility. These processes can be put to use in forming permeable groundwater barriers or in mobilizing radionuclides and metals for treatment on the surface, depending upon site needs.

The challenge for DOE and NABIR will be in developing an understanding of how these processes can function naturally to reduce the need for treatment; and in situations where actual treatment is needed, to harness microbial capabilities with minimal long-term impact on the environment. A critical part of this effort will be to transfer this knowledge to stakeholders who are involved in implementation and acceptance of biologically based approaches.

How can we persuade organizations to look at bioremediation as a more viable and cost-effective way to remediate a site instead of the more traditional methods?

Wildung: Acceptance of bioremediation is going to have to occur at the grassroots level, where the operators at the DOE sites can see its advantages. NABIR will have to offer meaningful alternatives to off-the-shelf technology, such as the pump-and-treat methods in current use. A good model for how to do this was the Environmental Science Research Center, which was operated at Pacific Northwest National Laboratory, for DOE's Subsurface Science Program. In that program, teams of investigators visited the sites, met with site personnel, and talked about the problems they were facing, identifying potential solutions available from the scientific community. This process proved very successful in demonstrating and applying the result of basic research.

Crawford: Within the next five years we need some successful field demonstrations of the bioremediation of metals and radionuclides. Also, by characterizing the microbial community in the subsurface, we'll be able to better manipulate them *in situ* and work directly in the groundwater. [This characterization consists of understanding the complex interactions of the microbes in a particular environment as well as how they relate to that environment.] We won't need to excavate soil as much for treatment, which is quite expensive.

What about your own present research activities? Can you talk a bit about what you are doing now?

White: I've spent 20 years developing a mechanism to examine microbial communities as they really are in the environment. Primarily, this has involved looking at their lipids, which are components of the membrane that form on the outside of the microbe's cell. We can determine about three major features of the community. The first is the viable biomass [the weight of living microorganisms in a particular environment]. Second, we can also measure the community composition. Different

See STLs, page 4

Under the Microscope

This regular feature will showcase interesting microbes that have bioremediation potential. In this issue, we focus our lens on *Deinococcus radiodurans.*

Name: *Deinococcus radiodurans,* or "strange berry that withstands radiation."

Age and Origin: It isn't exactly clear how old *Deinococcus* is. The microbe was first observed in the 1950s in cans of meat that had been exposed to supposedly sterilizing doses of radiation. It is theorized that the organism could be a mutation of a *Streptococcus* strain caused by the sterilization process itself. However, some scientists also believe that *Deinococcus* could be as old as two billion years, perhaps one of the earliest life forms on the planet. Both theories offer intriguing possibilities for bioremediation.

Appearance: Pink microbes with a fragrance reminiscent of rotten cabbage.

Metabolism: Aerobic.

Personal habits: Nonmotile, non-spore-forming.

Outstanding ability: *D. radiodurans* has an extremely powerful gene repair system. It has from four to ten DNA molecules; most other bacteria have only one. The microbe withstands radiation up to 1.5 million rads (500 rads is lethal to humans) when its chromosomes finally shatter into hundreds of fragments. A protein called RecA matches the shattered pieces of DNA and splices them back together. During these repairs, cell-building activities are shut off, preventing the expression of mutations. The talented bacterium gets its DNA back together in perfect order within 12 to 24 hours after exposure.

Other talents: *D. radiodurans* has extreme resistance to genotoxic chemicals, oxidative damage, and dehydration. Its unique DNA repair system is at least partially responsible for its ability to survive extreme environmental insults.

Suitability for bioremediation: *D. radiodurans* is not pathogenic to plants or animals and thus does not require high levels of containment or protection. It readily submits to genetic engineering techniques. These traits might make it adaptable to *in situ* bioremediation.

Compared with other bacteria, *D. radiodurans* has high resistance to hydrogen peroxide. Conceivably, the bacteria could be pumped into the ground together with hydrogen peroxide, which would support growth by providing oxygen as it decomposes to water and oxygen.

The genome of *D. radiodurans* is currently being sequenced under DOE/OBER sponsorship, with the hope of understanding and ultimately taking practical advantage of the bacterium's unusual capabilities.

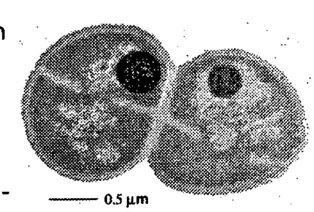


Photo of D. radiodurans taken by John Battista and Peggy O'Cain of Louisiana State University. (Magnification 60,000)

STLs, cont.

groups of organisms have different proportions and patterns of different lipids. This tells us a lot about the community. Third, and possibly most interesting, lipids reflect the physiological nutritional status of the organisms. That tells us a lot about how organisms respond to their environment. From that we can infer metabolic activity, which is what we really want to know. This signature biomarker analysis program will be provided to NABIR so that we can integrate our research and have a baseline study of the relevant microbes.

Wildung: Our research has concentrated on the interactions between microbial and geochemical processes and how these interactions influence contaminant behavior. Our focus has been in two areas. First, we're looking at the complexation of metals and radionuclides with natural and synthetic organic ligands and the potential use of this phenomena in altering contaminant mobility. [Complexation is the chemical association of an inorganic moiety such as a metal or radionuclide with an organic compound such as a ligand.] The second area of research addresses the processes that control a contaminant's oxidation state. The oxidation state, in turn, often markedly influences the mobility, and in many cases, the toxicity of a number of contaminants in groundwater. We have focused on the element technetium, which may exhibit at least four oxidation states in natural systems. We hope to unravel the interrelated microbial and geochemical processes that control the oxidation state and mobility of technetium under different conditions, providing a sound basis for development of *in situ* bioremediation technology.

Crawford: Right now, we're examining the biodegradation of carbon tetrachloride (CT) by a bacterium known as *Pseudomonas stutzeri* strain KC. We're interested in this organism because it converts CT directly to carbon dioxide, a very safe, desirable end product. We're also looking at how the presence of metals in even small amounts acts as a regulator, turning off the CT degradation system of this *Pseudomonas* organism. Since iron and several other metals are present at sites where CT is a problem, such as Hanford, we need to be able to deactivate this regulatory system so that *Ps. stutzeri* can degrade CT all the time. We believe we can do this by disrupting a couple of specific genes in this *Pseudomonas* strain. This will turn off the regulation and create a constitutive strain, one that degrades even when metals are present. The gene we're interested in is called "fur," which stands for ferric uptake regulator. We've cloned the gene, and it's being sequenced. We plan to disrupt it by inserting another small piece of DNA into the gene's middle. This piece will cut the gene in half so that it no longer works. Then we will reinsert the gene into the *Ps. stutzeri* strain. The basic idea is very simple.

What are some of the other exciting activities happening now in the field of bioremediation?

Wildung: In biogeochemistry, the most exciting activities are occurring in two areas. First, we are beginning to understand the mechanisms and dynamics of iron, manganese, and sulfur oxidation/reduction, and how these processes can influence contaminant behavior in groundwaters. This understanding will be the basis of the methods we will use to immobilize or treat radionuclides and metals. Second, new research is being pursued to understand how these processes, which often occur at the angstrom level, can be extrapolated or scaled to heterogeneous subsurface environments. The approach being used in NABIR is to try to understand the master variables that exert control on microbial distribution and function, such as heterogeneous transport processes that control the availability of electron donors and acceptors.

White: Really sophisticated analytical chemistry is getting very good, and has important environmental applications. This can be automated and is very sensitive, down to a few microbes. What will be incredible is the coupling of that science with what is going on in the genome project [the DOE Microbial Genome Program, which is sequencing the DNA of key microorganisms], and being able to understand an organism's genetic potential. We'll be able to know a great deal more about microbial communities, such as the coupling of various kinds of biomarkers. A biomarker is a part of the community that acts differently, so it functions as a signal, telling us about various aspects of microbial community behavior. It could be a sequence of DNA or RNA or it could be a specific lipid or change in the structure of a lipid or protein. No one set of biomarkers will tell you everything about a microbial community. Combinations are extraordinarily powerful.

Crawford: By techniques such as rRNA gene fingerprinting, we can determine what the organisms are in a community even if we can't grow them. Some of the other interesting and relevant bioremediation research going on now includes the discoveries of new microbial processes—such as the degradation of organic pollutants coupled to the reduction of iron and the use by bacteria of chlorinated organic compounds as electron acceptors. [Electron acceptors are atoms, ions, or molecules that gain electrons during an oxidation-reduction reaction. The electron donors give up electrons in such a reaction. A contaminant can act as an electron acceptor or donor, and thereby be changed to a different, less-harmful, compound.] We may be able to manipulate these processes *in situ* at DOE sites to accomplish some cleanups we didn't think feasible a few years ago.

Where is bioremediation technology going over the next 5 to 10 years? Where would you like to see it go?

Wildung: Over the next five years, I hope we can help build an appreciation of the role and value of intrinsic, or naturally occurring, remediation. The DOE has begun to recognize that you can use a basic understanding of these natural processes to reduce the size of plumes requiring treatment and therefore the cost of full treatment with pump-and-treat technologies. Knowledge of intrinsic processes is the basis for accelerated bioremediation. And, intrinsic processes really define the natural endpoint after accelerated remediation has been implemented.

Five years from now I expect we are going to have an improved working knowledge of iron reduction, sulfide immobilization, and complexation processes. Then we'll be at a point where we can conduct limited, controlled field evaluations of these fundamental processes for some specific applications. And ten years from now, I think we'll have the methods in place for scaling our understanding of these processes to different field situations. I also believe there will be an increased acceptance of not just biological processes, but probably an acceptance of the selected use of genetically engineered microorganisms [GEMs]. We're seeing this occurring now in other arenas—food technology, agriculture—and sooner or later it will be more accepted in bioremediation.

Crawford: I think we'll see the testing of GEMs on a small scale at DOE sites within the next five years. Large-scale release probably won't happen, however, for ten years. Presently, there aren't a great number of GEMs out there to test because not very many have been produced that are useful for bioremediation. Groups at Oak Ridge National Laboratory and the University of Tennessee have done the first contained release in a lysimeter of a genetically engineered organism for use in bioremediation. They released a GEM that degrades naphthalene. This organism was genetically engineered to make it easy to track during the bioremediation process.

However, before GEMs are accepted by the stakeholders, there will have to be a lot of public discussion, particularly with stakeholders near any DOE site where the testing might be done. This is why we have the Bioremediation and Its Societal Implications and Concerns

See STLs, page 6

NEW PROJECTS, cont.

Radionuclides and Metals at DOE Waste Sites

John J. Dunn, Brookhaven National Laboratory, *Stabilization of Radionuclides by Anaerobic Bacteria*

Stuart B. Levy, Tufts University, *Genes and Functions Regulated by adnA in Pseudomonas fluorescens*

Abdul Matin, Stanford University, *Metal and Radionuclide Bioremediation by Starvation Promotor-Driven Combinatorial Bacteria*

J. Craig Venter, The Institute for Genomic Research, *Complete Genome Sequencing of Shewanella putrefaciens*

Judy D. Wall, University of Missouri, *Genes for Uranium Bioremediation in the Anaerobic Sulfate-Reducing Bacteria*

X. Sunney Xie, Pacific Northwest National Laboratory, *Single Molecule Studies of Biodegradation of Radionuclide-Organic Complexes*

Biogeochemical Dynamics

Scott C. Brooks, Oak Ridge National Laboratory, *Microbiological Controls of Chelated Radionuclides in Multiscale Structured Media*

Scott E. Fendorf, University of Idaho, *Microbially Induced Reduction of Toxic Metals and Radionuclides: Competing Geochemical and Enzymatic Processes*

Flynn W. Picardal, Indiana University, *Influence of Microbial Nitrate Reduction on Subsurface Iron Biogeochemistry, Microbial Chromium Reduction and Chromium Redox Chemistry*

Joseph M. Suflita, University of Oklahoma, *The Immobilization of Radionuclides and Metals in the Subsurface by Sulfate-Reducing Bacteria*

John M. Zachara, Pacific Northwest National Laboratory, *Solubilization of Radionuclides and Metals by Iron-Reducing Bacteria*

Assessment

Craig C. Brandt, Oak Ridge National Laboratory, *Artificial Neural Networks: An Innovative Tool for the Assessment of Microbial Communities*

Chung-Hsuan Chen, Oak Ridge National Laboratory, *Rapid Gene Probe for Microorganisms Monitoring by Novel MS Approaches*

Kirk Hatfield, University of Florida, *An In Situ Tracer Method for Establishing the Presence and Predicting the Activity of Heavy Metal-Reducing Microbes in the Subsurface*

Acceleration

Ellyn M. Murphy, Pacific Northwest National Laboratory, *The Influence of Heterogeneity and Growth on Microbial Transport in Saturated Porous Media*

Tullis C. Onstott, Princeton University, *Enhancement of Bacterial Transport in Aerobic and Anaerobic Environments: Assessing the Effects of Metal-Oxide Chemical Heterogenity*

Tom J. Phelps, Oak Ridge National Laboratory, *Vibration-accelerated Transport of Microbes in Subsurface Media*

Donald J. P. Swift, Old Dominion University, *Heterogeneity of Sedimentary Aquifers: Expansion of 'System' Stratigraphic Concepts, Calibrated Against 'Geophysical Imaging' by Ground Penetrating Radar*

NABIR on the Web

Did you know you could

- Search the **NABIR Bibliography** on the interaction of microorganisms with radionuclides
- Look up a word in the **Bioremediation Glossary**

`http://www.lbl.gov/NABIR/`

STLs, cont.

(BASIC) component of NABIR and why BASIC is progressing simultaneously with the science elements. I think if we have lots of these public discussions and people are convinced there are no serious safety issues, the acceptance process can go fairly smoothly. However, this is going to require time. If we have one or two demonstrations in the next five years, we will accomplish a lot, and then maybe a few dozen over the next ten years.

White: I would like to see much more focus on the microbial community and less on measuring the product and amounts of material. More than any other branch of ecology, microbial ecology is forced to look at community because you can only grow, at most, 1% of the organisms you see, so you don't know what the other 99% are. You can control the environment, but you can't culture the organisms. Besides, who says when you culture them that they do what they do in the community? There's pretty clear evidence that many times they don't. It's not all competition; sometimes there's collaboration. We know that they signal each other, and we know what some of the signals are. They're communities that act together.

What do you hope to accomplish as a science team leader for NABIR? And how will you achieve this?

Wildung: I see the DOE, the STLs, and the NABIR investigators working as a team to implement the NABIR program. The program recognized early on that it was important to encourage the involvement of a broad range of scientific disciplines. This is necessary to address the key processes and their interactions, which occur simultaneously in the subsurface and control mixed contaminant behavior. The investigators will bring their unique perspective, knowledge, and skills to the program. And I believe the STLs can play an important role in coordination and communication—helping establish cohesive, interactive program elements and transferring the results of their research to the user community.

The planned NABIR field research offers the opportunity to build cohesive interdisciplinary teams and focus efforts on real problems facing DOE. I would particularly like to help in forming these teams and defining fundamental approaches necessary to test bioremediation concepts in the field.

White: The STLs have wide experience in the research communities and know which laboratories and personnel have the special talents needed. We can bring together the best research capabilities without regard to department, geographic location, or type of organization. As an example, the microbiologists who manipulate the bacteria that could immobilize plutonium need to collaborate with radiation experts so that the microbes can be manipulated and the samples containing the plutonium handled safely and without risk. Few microbiologists have the nuclear chemical skills to accurately determine the radioactivity of plutonium in complex samples.

And as the research becomes more comprehensive, more problems will appear, such as those related to microheterogeneity, which is intrinsic to the deep subsurface environment. The changes in this small-scale distribution of microbes and contaminants is difficult to monitor and manipulate. In such an instance, an STL can arrange collab-

The BASIC Corner

This new feature will address current societal issues relevant to NABIR's stakeholders. In this issue Dan Drell, the manager of the BASIC program, discusses his vision for the program.

The mission of the BASIC program (Bioremediation and its Societal Implications and Concerns) is to study the societal issues that are associated with a bioremediation research program. We don't pretend to know what all those issues are. We need to build a program that is open ended, can honestly study new issues as they're defined, and is very firmly rooted in science.

Community issues are going to be important when a site is selected for *in situ* testing. We want to offer information and education to communities so that they have an honest appreciation of the facts. You can't make good policy without the appropriate facts. We must give everyone a better sense of how widely we already use microbiology. The glass of beer or wine, the cup of yogurt, the loaf of bread—that's microbiology in action. All of the current estimates suggest that 99.99% of the biomass on this planet is microbial. We are surrounded by microbes. They're inside of us, on us, all around us. Bacteria are already helping us clean up waste. They break down waste in your local waste dump. The local water treatment plant has made use of microbes for decades. With bioremediation, we're just working to help them do it a little better.

NABIR's job is to provide the research and development to help clean up some of the pollutants at DOE's contaminated sites. When that R&D is ready, we will hand off the knowledge and any technology we've developed to those who will carry out the remediation. But throughout this process, we need to make sure we don't harm the environment more than we help it. One critical question will be the criteria we will need to meet before we propose that it is safe to introduce organisms, native or from elsewhere, selected or engineered with special properties. Then it will be up to those potentially orations with unique DOE facilities, such as the synchrotron light sources, that can map localizations and valences of metals. Experts in confocal microscopy can be brought in to stain specific microbes based on their nucleic acids, and physiologists can be found to localize specific microbial phenotypic activity distributions and ultimately define what limitations are imposed by microheterogeneity. Discerning each *in situ* situation will be the rational avenue to effective solutions.

Crawford: I see the STLs working with the NABIR BASIC investigators—the people trying to better promote interactions among the scientists, the NABIR management, and the stakeholders. We will also be holding a lot of workshops and seminars over the next five years. One of the early ones is likely to be with our first group of NABIR PIs in the area of data management so that the investigators can share the data they generate with one another.

Is there anything you would like to add about where you see bioremediation is heading?

White: We are slowly beginning to understand and utilize microbial communities. They have a much more stable, robust, resilient system for doing bioremediation than a monoculture does. This is the exciting new area in microbial technology. An example is the breakdown of PCBs. No one has found an organism that can do it alone, but the community can.

Wildung: Although bioremediation isn't going to be the complete answer to cleaning up contaminated environments, it is going to serve as one very important tool, with applications to a number of situations. And there will be specific cases where bioremediation is the only answer. I think it will be of particular value in mobilizing or immobilizing contaminants *in situ.* It may apply best in situations where you want to degrade organic contaminants or to immobilize metals/radionuclides for a time in the subsurface and then remobilize them later for treatment. Bioremediation's most important contribution will be in offering less rigorous, natural alternatives to brute force methods, such as hydrofracturing, to address *in situ* contamination problems.

Crawford: I would like to see bioremediation as the first choice for site cleanup, with other processes being tried only when it is not appropriate. I would also like to see bioremediation occurring to some degree at most or all of the DOE sites. My prognosis is that we will get there. Once it becomes clear to DOE site managers and stakeholders how effective bioremediation technology is and how many resources it will save, we will have a very convincing argument to always look for "bioremediation" as one of the first options for cleanup.

NABIR on the Web

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`http://www.lbl.gov/NABIR/news_1.html`

affected to determine if it is time to use bioremediation.

The phrase "genetic engineering" is new, but the concepts behind it are very old. Humans have been doing selective breeding for thousands of years with both plants and animals. The family dog, for example, is a result of this slow and hard-to-control form of genetic engineering. The new technologies of biology and genetics are far more precise and controlled ways of modifying living things so that they will acquire the characteristics and abilities that make them useful. Anyone with diabetes who requires insulin is thankful for "genetically engineered" bacteria that produce absolutely pure human insulin. This new type of insulin is actually safer than the nonengineered cow and pork insulin that used to be the only option. The key question to answer before the introduction of any organism is, How safe is it to use? And this is a function of the organism's stability. The greatest public fear is that something is going to escape, and escape can mean two things—either an engineered bug leaves the confines of the site where it's injected, or some genetic material escapes from the nucleus of an engineered microorganism and gets into a different one. That last point is very important, because bacteria have been swapping plasmids [extrachromosomal rings of DNA that replicate autonomously] and other forms of genetic information for millions of years. If we can find out to what extent these transfers happen, that would directly address one of the principal public concerns.

My personal view is that these things aren't quite as dire as we sometimes fear. We have all sorts of bacteria in our stomachs that potentially are pathogenic but do us no harm. This is because our immune systems keep them under control and they live as part of large communities where they have to struggle for limited resources. Ordinarily, no particular species becomes dominant. And the same thing is true in the environment. The science is fascinating and the challenges are too great to sit and do nothing.

The worst criticism I can think of getting is, "There were some interesting opportunities here and you did nothing." I don't want us to be in that position. Also, it is important to say that BASIC is not a shield for researchers to hide behind. If it looks to us like the cost-benefit analysis is more heavily weighted towards cost, then BASIC is not going to defend bioremediation. Microbiology offers enormous potential. The trick is to make sure we use our knowledge of nature to make a cleaner, safer world.

Calendar

1997

December 2-4 HazWaste World/Superfund XVIII, Washington, D.C., Cosponsored by E.J. Krause & Assoc. and the Environmental Industry Associations. Focusing on hazardous waste remediation and contaminated site cleanup. For more information, go to http://www.ejkrause.com/enviroshows/superfund.

December 8-10 Natural Attenuation '97, Scottsdale, AZ. Sponsored by the International Business Communications group, this program will present the latest research in: soils, sediments, groundwater, pesticides, chlorinated compounds, metals, monitoring, and modeling. For more information, go to http://www.ibcusa.com/conf/attenuation.

1998

January 12-14 NABIR PI workshop. Washington, D.C., location.

May 18-21 The First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA. Sponsored by Batelle. Contact: The Conference Group, 198 West Fifth Ave., Ste. 5, Columbus, OH 43212-1912; 800-783-6338; or 102632.3100@compuserve.com.

June 15-17 Environmental Biotech '98, New York, NY. Focusing on technical, governmental, and societal issues faced by industry as they pertain to waste generation and contamination. For more information, go to http://www.bio.org/meetings.

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