



CONFERENCE ON THE REMEDIATION OF SEDIMENTS

**MAY 4-6, 1992
EAST BRUNSWICK, NEW JERSEY**

GUIDANCE DOCUMENT

SPONSORED BY THE

**INSTITUTE OF MARINE AND COASTAL SCIENCES
AT RUTGERS - THE STATE UNIVERSITY OF NEW JERSEY**

AND

THE PORT AUTHORITY OF NEW YORK/NEW JERSEY

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Conference on the Remediation of Sediments

**May 4-6, 1992
East Brunswick, New Jersey**

Guidance Document

On May 4-6, 1992, a conference was held at the Ramada Inn Renaissance Hotel in East Brunswick, New Jersey to assess the current state of the science associated with the remediation of sediments, especially biological approaches to remediation.

The conference was organized by the Institute of Marine and Coastal Sciences at the request of The Port Authority of New York and New Jersey which is interested in a federal pilot project to demonstrate the feasibility of making contaminated dredged material cleaner and safer through remediation. Co-sponsors for the conference were the Center for Agricultural Molecular Biology, Environmental and Occupational Health Science Institute, and the Department of Chemical and Biochemical Engineering--each an element of Rutgers University.

More than 70 scientists, managers and environmentalists attended the conference (list of attendees and conference agenda enclosed). Formal presentations from recognized experts in the field of bioremediation highlighted current research and demonstration programs close to or already underway. The conference emphasized bioremediation approaches to the treatment of contaminated sediments and did not consider the full range of remediation approaches; other approaches need to be evaluated.

From the conference, it is quite clear that the vast bulk of dredged material which is considered Class 1 material, will be disposed of in some manner that does not require remediation. However, it remains unclear which sediments or what quantity of dredged material requires remediation. These questions cannot be addressed until a fine-scale characterization of sediment content and distribution is conducted for the New York Harbor region. Bioremediation was viewed by the participants as a viable strategy for some sediments where they are contained, where there is a restricted range of contaminants and the remediation processes have a long time to work; it is not a panacea for the management of dredged material.

Following a series of formal presentations, the participants divided into two groups to develop recommendations on future research requirements and the most promising pilot scale approaches to bioremediation. A summary of these discussions and list of recommendations is provided below.

Research Discussion

The research panel discussion was chaired by Ken Nealson of the Center for Great Lakes Studies.

The panel recognized that current research programs target individual contaminants for bioremediation. However, in many cases, pollutants in sediments around New York Harbor are present as a complex mixture of contaminants. It is unlikely that bioremediation can provide a cost-effective means to mitigate sediments containing mixed contaminants, especially when metals are present. This led the panel to conclude that one of the central research questions is how to handle biotransformation of mixed contaminants.

Where particular contaminants are of concern, then bioremediation becomes a more appropriate method. Even so, cost-effectiveness must be considered along with the environmental benefits prior to any decision to bioremediate sediments. For some compounds, natural processes can be just as effective as remediation. To address this point, the panel suggested more information is needed to understand how natural processes can remediate contaminated sediments, especially information on bioavailability and biodegradation. In some cases, manipulation of kinetics may provide a relatively straightforward means to improve the natural rates of biodegradation or immobilization.

The panel stated that PAHs and PCBs are amenable to biodegradation. However, at present pesticides and dioxins are not and much more research is needed. Metals are problematic and are not good prospects for bioremediation. However, they may be managed in other ways such as chelation or desorption.

Some discussion focused on the research requirements for remediation of oil spills, which have occurred frequently in the Arthur Kill over the past few years. Recent research efforts on petroleum bioremediation are encouraging.

Although the panel was charged with developing recommendations for future bioremedial demonstrations, considerable discussion focused on the use of deep underwater pits with caps as an effective and likely alternative to manage dredged material. Control of material dispersion in the water column during transport from the surface to the pit may be required. Once sequestered, this method may have some biological advantages in that metal constituents of the sediments may be immobilized in an anaerobic environment. Thus, some of the advantages of biological processing may be realized from placement of sediments in pits. Since bioremediation might be occurring within pits, conceivably some research could be conducted to accelerate or facilitate remediation. Obviously, the occurrence of any bioremedial processes in pits must be documented. Further,

the location of these pits is a contentious issue that has to be addressed with this alternative. The design and engineering of offshore pits will be one of the primary topics for discussion at a follow-on conference scheduled for Fall 1992.

A prerequisite to any research program is a fine-scale characterization of the sediment distribution, contaminant concentration and bioavailability for the entire New York Harbor area. In this manner, alternate disposal methods could be used for different sediments. Relatively clean sediments could be handled differently than highly contaminated sediments.

Another area that has to be addressed prior to any pilot scale treatment operation is public education. The public must understand what remediation can and cannot do. Some panelists also believed that the public should be involved in the decision-making process.

One final point which received attention by the panel was that remediation will not be effective if the sources are not controlled. Precise determination of the distribution of contaminants in sediments should be part of a long-term strategy to reduce the amount of sediments which have to be treated prior to future disposal. By going closer to the sources, areas that have primarily one or two contaminants could be the site of a demonstration project. Bioremediation becomes most feasible at sites close to the historic source where concentrations of particular sediment contaminants is highest.

Research Recommendations

- 1A. In most cases, pollutants in the New York Harbor area are present in complex mixtures. Where metals are among the contaminants of concern, bioremediation may not be a cost-effective solution. A spatially intensive characterization of contaminants in areas to be dredged and potential source areas is required.
- 1B. Bioremediation may be appropriate where contaminants are found individually.
- 1C. Research requirements are:
 - o Biotransformation of mixed wastes,
 - o Bioavailability,
 - o Natural rates of biodegradation,
 - o Manipulation of kinetics to improve natural rates of biodegradation or immobilization, and
 - o Bioremediation as part of a spill response.

2. The most effective, likely disposal method for Class 1 dredged material is the use of deep, underwater pits with caps. Should dilution calculations warrant, a placement mechanism that does not disperse pollutants may be required.
3. Public education on what bioremediation can and cannot do is strongly recommended. This information must be considered during the decisionmaking process.
4. Controlling sources of pollution is critical to the long-term management of dredged material.

Demonstration Project Discussion

This discussion panel was chaired by Fred Grassle of the Institute of Marine and Coastal Sciences.

It was quite evident from this panel discussion and the plenary sessions held at the end of the conference that bioremediation is but one approach to treatment of contaminated sediments. There are other alternatives which must be considered as treatment or disposal options.

The panel discussed the feasibility and cost of a pilot scale operation to remediate sediments. Although one panelist believed more information was necessary to determine at what scale a full remediation program needed to be developed for the harbor, generally, the panel concluded that new technology needs to be developed for a large scale remediation system to be practical and cost-effective. To achieve a significant reduction in sediment contamination with present technology may cost between \$50 and \$100 per cubic yard, not including the cost of a treatment facility. Some panel members thought the discussion of cost was premature because the alternatives were not clearly defined and that cost had to be considered against alternatives in the context of the whole problem. However, they thought this situation should not preclude a demonstration project to investigate remediation methods relevant to New York Harbor sediments. One of the models discussed was the Sheboygan project now being conducted in the Great Lakes by the Environmental Protection Agency. The research activities of the TNO Institute of Environmental and Energy Technology in the Netherlands are also of interest.

As with the research panel, the demonstration panel had a considerable discussion on characterization of the sediments and use of a fine scale assessment to direct treatment and disposal options. It was stated that a grid scale on the order of one hundred meters or less should be conducted for sediments and some suite of contaminants. Tiedo Vellinga, a representative from the Port of Rotterdam pointed out that they test for contaminants most amenable to analysis over a two-year period on a fine grid scale.

A fine-scale characterization could be used to focus treatment alternatives at sediment sources and depositional areas in the estuary.

The panel discussed whether the characterization should be based on toxicological or chemical approaches. The Rotterdam approach is to define the average sediment quality in different areas. For the relatively clean areas, the bulk of the dredged material is disposed in the ocean or specially engineered pits. For those areas with highest concentrations of potentially toxic compounds, additional studies are used to identify how the chemicals are bound, what would the environmental effects be if this material were disposed in the ocean or a pit and, where this type of disposal is not feasible, separation and remediation then become alternatives. This is a chemical classification where there is a correction for grain size. (Data that exists for New York harbor material is not corrected for grain size or organic matter content.)

For bioremediation approaches to be cost-effective however, they need to be highly focused. This presupposes that the sediment characterization goes beyond an assessment of the sediments and contaminants, and considers fractions, bioavailability, biodegradation and the feasibility of separating contaminants in the demonstration project.

In addition, the panel discussed the possibility of using a source or depositional area for the location of the demonstration plant. There is an advantage in going to these types of areas (such as the Passaic River where dioxin concentrations are high or the depositional environment of Newark Bay) where the potential for improvement is greater. In this context, the panel discussed techniques to separate out sediment fractions where higher concentrations of contaminants are bound. For example, the hydrocyclone and flotation techniques could be used for separation.

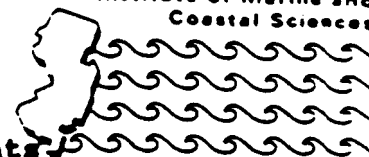
Another point discussed by the panel was the approach used in Glasgow where dredged material is applied to beneficial uses on land. The areas where this might be applied are those places where a heavy contaminant loading already exists in the soil. Several sites exist in New Jersey where even a fairly significant contaminant loading would be an improvement in the soils. It is quite clear from the beneficial use in Glasgow that attractive gardens can be developed on dredged material despite contaminant loadings. Potential affects on ground water need to be considered. This land application and soil development process needs to be considered in the context of other approaches to bioremediation. It has the advantage that port lands might be used and the goals of the project could be very well defined.

The panel considered the fact that present management of point source discharges in the New York Harbor area has been based on

water quality criteria. Leachability and bioavailability of material now sequestered in sediments is not considered by this approach. Most pollutants adsorb onto particles that may be redistributed after initial deposition. For disposal of dredged material, leachability and bioavailability are considered. Some discussion supported replacement of this approach with sediment-based management schemes. Using the sediment-based approach, potential sites for bioremediation could be selected and management of the entire system could be directed to pollutant sources.

Demonstration Project Recommendations

1. Bioremediation approaches need to be discussed with the public so that everyone has the same understanding on the time, effort and sediment product resulting from this technique. This demands that a public dialogue be maintained throughout the decision-making process.
2. A fine-scale characterization of sediments is a prerequisite for managing dredged material in the New York Harbor area. For bioremediation, this characterization should provide information on bioavailability and biodegradation in addition to sediment distribution and contaminant concentration.
3. Contaminant source or depositional areas should receive priority as sites for future demonstration projects.
4. Land application, where appropriate, should be considered as an alternative for disposal of some dredged material.
5. When treatment is necessary, bioremediation is one of a wide range of techniques for the management of dredged material. It is suitable for specific contaminants found in small quantities. Other alternatives must be considered when treatment is required for a vast quantity of dredged material and for problematic metals in sediments.
6. A large scale bioremediation system is neither practical nor cost-effective at the moment. However, this situation should not preclude a demonstration project to investigate remediation methods relevant to New York Harbor sediments.



Agenda

Conference on the Remediation of Sediments

May 4-5, 1992

Ramada Renaissance Hotel
East Brunswick, New Jersey

Monday, May 4, 1992

- | | | |
|-----------|--|--------------|
| 1:00 p.m. | Welcome and Conference Overview | F. Grassle |
| 1:15 | Formal presentations | |
| | Environmental Chemistry of Metals in
Sediments and Dredged Materials | B. Gambrell |
| 1:45 | The Coupling of Anaerobic Organic Carbon
Oxidation to the Reduction of Iron,
Manganese or Sulfur by <i>Shewanella</i>
<i>putrefaciens</i> | K. Nealson |
| 2:15 | Bioremediation of Hexavalent Chromium
Using Sulfate Reducing Bacteria | L. DeFilippi |
| 2:45 | Overview of Bacterial Heavy Metal
Resistances | P. Corbisier |
| 3:15 | COFFEE BREAK | |
| 3:30 | Slurry-Phase Bioremediation of Contaminated
Sediments | H. Stroo |
| 4:00 | A View Toward Bioremediation Based on
Micro-biological Studies of a Contaminated
Aquifer | G. Madsen |
| 4:30 | Biological Treatment of Chlorinated Organics | R. Unterman |
| 5:00 | Biodegradation of Polycyclic Aromatic
Hydrocarbons by a <i>Mycobacterium</i> sp. | C. Cerniglia |
| 5:30 | Assessing Bioremediation in Prince William
Sound | R. Prince |
| 6:00 | RECESS | |

Tuesday, May 5, 1992

8:00 a.m. Formal Presentations Resume

	PCB Biodegradation in the Laboratory and the Environment	D.Abramowicz
8:30	Decontamination of PCB-Contaminated Sediments Through Use of Bioremediation Technologies	J. Jones
9:00	Sheboygan River Sediment Bioremediation Project - Development of the Confined Treatment Facility	M. Brown
9:30	COFFEE BREAK	
9:45	Reductive Dechlorination of Polychlorinated Biphenyls (PCBs) in Sediments	L. Nies
10:15	Dredged Material to Soil - UK Examples of a Beneficial Use	J. Riddell
10:45	Remediation of Contaminated Sediments in the Netherlands	H.J.van Veen
11:15	Management of Dredged Material in the Port of Rotterdam	T. Vellinga
12:00	BUFFET LUNCH	
1:15	Panel Discussions	F. Grassle M. De Luca
4:00	Adjourn	

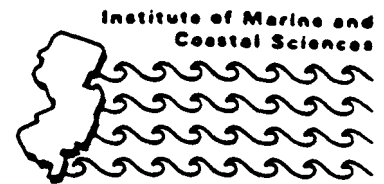
Wednesday, May 6, 1992

9:00	Steering Committee Meeting	F. Grassle
11:00	Adjourn	

CONFERENCE ON
THE REMEDIATION OF SEDIMENTS
MAY 4-5, 1992
Attendees

FRED GRASSLE - IMCS, Rutgers Univ.
MIKE DE LUCA - IMCS, Rutgers Univ.
ROSE PETRECCA - IMCS, Rutgers Univ.
DAVID BERKOVITS - Port Authority of NY/NJ
COLEEN CAMP - Port Authority of NY/NJ
JOE BIRGELES - Port Authority of NY/NJ
JOE MONACO - Port Authority of NY/NJ
CHRIS ZEPPIE - Port Authority of NY/NJ
THERESA BOYLE - Port Authority of NY/NJ
DANIEL ABRAMOWICZ - General Electric Res. & Development Ctr.
BOB GAMBRELL - LSU-Wetland Biogeochemistry Inst.
PHILIPPE CORBISIER - Univ. of Illinois at Chicago-Dept. of
Microbiology
JOHN RIDDELL - Univ. of Strathclyde, Glasgow, UK
HANS STROO - Remediation Technologies
RONALD UNTERMAN - Envirogen, Inc.
CARL CERNIGLIA - National Ctr. for Toxicological Research
LOUIS DE FILIPPI - Allied-Signal
LORING NIES - Univ. of Michigan-Environmental & Water Resources
Engineering
JACK JONES - EPA-Environmental Research Lab
GENE MADSEN - Cornell Univ.-Dept. of Microbiology
ROGER PRINCE - Exxon Research and Engineering
H.J. VAN VEEN - T.N.O.-Dept. of Environ. Technology, The
Netherlands
MARK BROWN - Blasland, Bouck & Lee
KEN NEALSON - Ctr. for Great Lakes Studies
TIEDO VELLINGA - Dept. of Public Works, The Netherlands
DAVID KOSSON - Dept. of Chemical & Biochemical Engineering-Rutgers
Univ.
ANDREW MARINUCCI - DEPE-NJ
MARY DOWNES-GASTRICH - DEPE-NJ
ROBERT TUCKER - DEPE-NJ
ROGER SMITH - DEPE-NJ
BETSY ADAMSON - DEP-NYC
KAREN SCHAFFER - DEPE
BRUCE RUPPEL - DEPE-Div. of Science and Research

AUDREY MASSA - US/EPA
DARVENE ADAMS - US/EPA
DOUG TOMCHUK - US/EPA
SARA CLARK - Environmental Defense Fund
RICK FOX - EPA-Great Lakes National Program
MARK BURLAS - Army Corp of Engineers
SIMIAN HOOK - Army Corp of Engineers
LEONARD HOUSTON - Army Corp of Engineers
BRYCE WEISSMILLER - Army Corp of Engineers
JOE OLHA - Army Corps of Engineers
JOHN TAVOLARO - Army Corps of Engineers
PETER SMOUSE - Genetics Ctr.-Rutgers Univ.
MARK ROBSON - EOHSI-Rutgers Univ.
PETER DAY - AgBioTech Ctr.-Rutgers Univ.
GERBEN J. ZYLSTRA - AgBioTech Ctr.-Rutgers Univ.
LAURA MEAGHER - Ctr. for Advanced Food Technology-Rutgers Univ.
SPIRO AGATHOS - Chem. & Biochem. Engineering-Rutgers Univ.
RICHARD BARTHA - Biochemistry & Microbiology Dept.-Rutgers Univ.
PETER STROM - Environmental Sciences-Rutgers Univ.
BURT ENSLEY - Envirogen, Inc.
TOM BOTT - Stroud Water Research Ctr.
CARA LEE - Scenic Hudson
MICHAEL SHIARIS - Univ. of Massachusetts at Boston
ALLEN LASKIN - Laskin/Lawrence Associates
DR. STAINKENS - Malcolm Porne, Inc.
DENNIS SUSZKOWSKI - Hudson River Foundation
ANN SECORD - US Fish & Wildlife Service
BRIDGET BARCLAY - Hudson River Sloop Clearwater
G. YULL RHEE - NY Department of Health-Wadsworth Lab
ROGER SOKOL - NY Dept. of Health-Wadsworth Lab
LILY YOUNG - NY Univ.-Dept. of Microbiology
ARTHUR KAMIN - Board of Dir.-Monmouth Ocean Development Council
ANN & LEO KRUGER - Passaic River Coalition
ALLEN BEAVEN



**Conference
on the
Remediation
of Sediments
ABSTRACTS**

May 4-5, 1992

**Ramada
Renaissance**

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RUTGERS

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**Environmental Chemistry of Metals in
Sediments and Dredged Materials**

The physical and chemical properties of sediments have an important influence on how strongly trace and toxic metals are immobilized. Depending on disposal methods selected for contaminated dredged sediments, metals may be effectively immobilized at a disposal site, or, changes in sediment chemistry may occur that will result in some release to more mobile and biologically available forms.

The chemistry of metals in sediments and dredged material will be discussed in terms of sediment properties, and examples given from various research projects demonstrating how selection of disposal methods and management of dredged sediments may be used to minimize contaminant release.

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**The coupling of anaerobic organic carbon oxidation
to the reduction of iron, manganese, or sulfur
by *Shewanella putrefaciens***

During our studies of the geochemistry of metals in freshwater and marine ecosystems during the past few years, we have isolated microbes in the group *Shewanella putrefaciens*, which have the ability to grow anaerobically using manganese or iron oxides as oxygen substitutes for respiration. These bacteria can utilize a wide variety of different electron acceptors in addition to Mn or Fe, including oxygen, sulfite, thiosulfate, elemental sulfur, nitrate, nitrite, trimethylamine-N-oxide, dimethyl sulfoxide, fumarate and glycine. Strains of *S. putrefaciens* have been isolated from a wide variety of marine and freshwater environments, suggesting that this group is ubiquitously distributed in environments containing oxic/anoxic interfaces. The reduction of iron, manganese or elemental sulfur, all of which are solid substrates, requires cell contact with the substrates, and during the reduction. This raises the possibility that such organisms can be isolated, or genetically engineered, which can be used to oxidize specific contaminating substrates, such as phenolics, naphthalenes, etc., using metal oxides or sulfur as electron acceptors. With regard to the latter possibility, we have now isolated key mutants with impaired abilities to anaerobically reduce iron, manganese and sulfur compounds, as well as regulatory mutants which are incapable of anaerobic respiration. These mutants have been complemented using a library prepared from wild type *S. putrefaciens*. Methods for introducing attached organisms to polluted environments are now under development in our laboratory and will be presented.

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Bioremediation of Hexavalent Chromium Using Sulfate Reducing Bacteria

Chromates [hexavalent chromium, Cr(VI)] have found their way into the marine environment. This is of potential concern since Cr(VI) is a strong oxidant, is toxic, has a propensity to pass through mammalian cell membranes and, due to its high water solubility, has the potential for groundwater migration. Furthermore, Cr(VI)-contaminated groundwater or industrial effluent is often at an extreme pH, necessitating pH adjustment prior to treatment. In comparison to Cr(VI), the reduced form, Cr(III), possesses the properties of low toxicity, resistance to passage through membranes, low aqueous solubility (K_{sp} for $\text{Cr(OH)}_3 = 6.7 \times 10^{-31}$) and, consequently, low potential for groundwater migration. Therefore, reduction of Cr(VI) to Cr(III) is desirable from multiple standpoints. In a marine environment reduction of Cr(VI) by bacterially produced H_2S occurs naturally (1) as long as the appropriate nutrients are present. We have developed a bioremediation process for rendering Cr(VI) present in aqueous and solid wastes (especially those containing a high concentration of ionic species) insoluble by reductive precipitation as Cr(III). The method first involves adaptation of a marine-derived, anaerobic, sulfate reducing consortia for growth on an inexpensive carbon source, such as molasses or acetate, in a high ionic strength, sulfate-containing mineral salts medium. Bacterially produced H_2S yields Cr(VI) reduction to Cr(III) which precipitates as an extremely insoluble species within the pH range at which the fermentation is conducted. For Cr(VI)-containing waste of an alkaline nature we have adapted the consortia for growth at a high pH as follows. Mineral media supplemented with various nutrients and sodium thioglycollate was adjusted to pHs ranging from 6.75 to 9.52 placed under a nitrogen blanket in a sealed vessel and inoculated with a mixed sulfate reducing culture. At pHs up to about 9 sulfate reducing microorganisms grew readily. H_2S and black metal sulfides were produced. For a continuous process, standing water in contact with chromium ore tailings at a NJ site, possessing a Ph of 12 and containing 11 ppm Cr(VI), and supplemented with 38mM SO_4^{2-} , was passed into a mixing tank where the pH was adjusted to between 7 and 8 with 25% v/v acetic acid and then into a gravel and sulfate reducing sludge blanket-containing, 6 x 36 cm (ID x h) anaerobic column reactor in a upflow fashion. At dilution rates up to 0.05 h^{-1} the effluent contained $<0.21 \text{ ppm}$ Cr(VI). Inclusion of micronutrients allowed an increase to 0.1 h^{-1} with no detectable effluent Cr(VI).

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**A View Toward Bioremediation Based on Micro-biological Studies
of a Contaminated Aquifer**

Decades of research using laboratory flask assays have proven that microorganisms are capable of detoxifying and/or completely mineralizing many environmental pollutants. Bioremediation is a promising technology that would manage microbial processes in order to destroy contaminant compounds in field sites. Although microorganisms have successfully and spontaneously maintained the biosphere since its inception, industrialized societies now produce undesirable chemical compounds at rates that outpace naturally occurring microbial detoxification processes. An essential step toward attaining reliable bioremediation technologies is the development of criteria which prove that microorganisms in contaminated field sites are truly active in metabolizing contaminants of interest. These criteria rely upon genetic, biochemical, physiological, and ecological principles and apply to both *in situ* and *ex situ* bioremediation strategies. My research group has studied a field site whose ground water is contaminated with polycyclic aromatic hydrocarbons (PAHs) derived from coal-tar waste. We discovered that the naturally occurring ground-water microbial community was metabolically adapted to PAHs and contained enhanced numbers of protozoan predators inside but not outside the plume of contamination. *In situ* biodegradation was inferred because predators can only be supported by *in situ* growth of prey, which was linked to the contaminant PAHs (Sciences. 1991. 252:870). These results are an example of how the science of biodegradation can begin to deliver the technology of bioremediation.

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Biological Treatment of Chlorinated Organics

Over the past 20 years there has been extensive research into the microbiology, biochemistry, and most recently, process development for the biological destruction of chlorinated organics. This paper describes some of the alternative systems that are currently under development for bioremediation systems. These include the contrasting, yet complementary approaches of: 1) aerobic vs. anaerobic microbes, 2) indigenous vs. exogenous microbes, and 3) *in situ* vs. *ex situ* (reactor-based) treatment cells.

Naturally occurring bacteria are capable of degrading nearly all natural organic compounds. However, bacteria capable of degrading many synthetic chemical substances (such as PCBs and TCE) are much rarer. In addition, these synthetic chemical compounds tend to be more stable, which means that it may take years before such compounds are naturally degraded.

Bioremediation companies are now using isolated superior natural strains of bacteria that partially or completely degrade or accelerate the degradation of a number of complex hazardous wastes, including PCBs, TCE and other chlorinated solvents and PAH. These improved bacteria are generally isolated from contaminated sites using sophisticated enrichment techniques which allow scientists to select and isolate superior strains from the general population found at these sites. There is also activity in the design and testing of genetically modified bacteria for commercial use. These strains have many advantages over naturally occurring bacteria, including the ability to degrade wastes faster and to lower levels and at a lower overall cost. Also under development are pretreatment techniques for separating contaminants from the media in which they are found (such as soil or water) in order to enhance the effectiveness of the bacteria in degrading the hazardous waste.

Engineered systems using bioreactors or contained environments in which biodegradative microorganisms make contact with the contaminated air, water, sediment, or sludge are also under development. By use of a bioreactor, variables such as temperature and pH can be controlled and measured amounts of oxygen and nutrients can be added to the mixture of microorganisms and contaminated materials, thereby optimizing the degradation environment. *In situ* approaches are also under development for soil, sediment, and groundwater and ultimately these should be the most cost effective clean up technologies.

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Slurry-Phase Bioremediation of Contaminated Sediments

Slurry-phase bioremediation is one option for biologically treating contaminated sediments. The paper will present the basic concepts of the technology, and experiences with slurry-phase treatment. The advantages of this system for contaminated sediments will be discussed, and laboratory-scale results will be presented for three sediments. The results will be compared to conventional bioremediation (land treatment), and thermal desorption treatment. The design and operation of a currently operating mobile pilot-scale slurry-phase bioreactor will be presented. Finally, a conceptual approach to full-scale treatment will be development, to allow an initial assessment of the feasibility of the approach from an engineering and economic perspective.

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Overview of Bacterial Heavy Metal Resistances

Bacterial plasmids determine resistance to a wide range of toxic metals including Hg^{2+} , Cd^{2+} , Zn^{2+} , AsO_2^- , AsO_4^{3-} , CrO_4^{2-} , Cu^{2+} , Pb^{2+} , SbO_2^- and Tl^+ . Our laboratories in Mol and Chicago are involved in studies of the basic mechanisms of bacteria resistance to heavy metals with the hope that someday the bacterial resistance systems may provide a basis for bioremediation of toxic waste or biosensing of environmental contamination. Different possible resistance mechanisms for mercury, cadmium, arsenic and copper will be presented. It will be shown how a reporter gene such as lux when fused to heavy metal operon can provide a rapid measurement of bioavailable toxic metals in aqueous environments, a mer-lux fusion, ars-lux fusion, cop-lux fusion and th-lux fusion will be presented. An experimental flat sheet reactor used to remove cadmium from polluted waste water using immobilized *Alcaligenes eutrophus* bacteria will be presented as an example of bacterial bioremediation.

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**Biodegradation of polycyclic aromatic hydrocarbons by a
Mycobacterium sp.**

Bacteria capable of polycyclic aromatic hydrocarbon (PAH) degradation in pure culture and under simulated environmental conditions, including some that are able to oxidize or co-oxidize higher molecular weight PAHs, have been isolated in several laboratories. Research in my laboratory has documented the extensive mineralization of pyrene and fluoranthene by a *Mycobacterium* sp. originating from a chronically polluted location. Additionally, this *Mycobacterium* sp. has been shown to mineralize naphthalene, phenanthrene, 1-nitropyrene, anthracene, 6-nitrochrysene and 3-methylcholanthrene. Addition of the *Mycobacterium* sp. to non-sterile microcosms containing soil with no additional organic carbon source significantly enhanced pyrene and fluoranthene mineralization over that performed by the indigenous biota alone. The effect of one PAH on the mineralization rate of another PAH in multicomponent mixtures and the potential usefulness of the *Mycobacterium* sp. for the bioremediation of higher molecular weight PAHs in mixtures will be discussed.

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Assessing Bioremediation in Prince William Sound

Bioremediation played an important role in the clean-up of the oil spill in Prince William Sound, Alaska. Widespread application of fertilizers to oiled beaches was accompanied by a substantial monitoring program that focussed on assessing the safety and efficacy of the process. A variety of samples were collected and analyzed; interstitial water from within the oiled sediment was analyzed for nitrogenous nutrients (NH_4^+ , NO_3^- , soluble organic N), phosphate, dissolved oxygen, salinity, temperature and pH, sediment samples were analyzed for microbial populations and activities, and oil content and chemistry, and nearshore water was analyzed for acute toxicity, increased algal productivity, and hydrocarbons. Taken together, the data clearly indicated that bioremediation was both safe and effective in stimulating the natural process of biodegradation of the spilled oil.

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PCB Biodegradation in the Laboratory and the Environment

Aerobic PCB biodegradation and anaerobic PCB dechlorination have been demonstrated in the laboratory with contaminated soils and sediments. In the summer of 1991, GE performed a large scale test of aerobic PCB biodegradation in the Upper Hudson River. The experiments involved six sealed caissons (six feet in diameter) lowered into the contaminated sediments. Results demonstrated good correlation between laboratory derived expectations and actual field performance. A large scale test of anaerobic PCB dechlorination in Housatonic River sediments is planned for the summer of 1992.

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Decontamination of PCB-Contaminated Sediments Through the Use of Bioremediation Technologies

Pollution control agencies have launched a concerted effort to reduce the environmental levels of accumulated polychlorinated biphenyls (PCBs) because of their persistence, toxicity and tendency to bioconcentrate (1-3). PCBs can be transformed into less harmful compounds by chemical, physical and biological methods; e.g., ultraviolet radiation, microwave treatment, and incineration (4). For contaminated sediments, microbial degradation offers a cost-efficient method of reducing PCB levels. Consequently, the coupling of anaerobic dechlorination to aerobic metabolism has been suggested as a possible cleanup method.

Results from bench scale studies suggest that PCBs can be biodegraded by both aerobic and anaerobic microbial processes (5,6). Aerobic bacteria usually degrade PCB congeners having one to five chlorine atoms, but not the higher-chlorine substituted congeners. The rate and extent of degradation, however, is influenced by the position of the chlorine atoms on the biphenyl ring (7, 8). For example, congeners with open 2, 3- or 3, 4-positions are degraded faster than congeners with chlorine atoms at these positions. These sites are necessary for the action of dioxygenase enzymes to effect the fission of the biphenyl ring. Several bacterial strains have been isolated from enrichments of contaminated soils and sediments that can biodegrade PCBs aerobically. These strains vary in their abilities to degrade PCBs; some degrade only mono-, di and trichlorobiphenyls, and others degrade tetra- and pentachlorobiphenyls (7). Anaerobic reductive dechlorination of PCBs was first proposed by Brown and coworkers (9). Later reports from laboratory studies provided unequivocal evidence that reductive dechlorination could occur in anaerobic sediments (10). Under anoxic conditions, the highly chlorinated PCB congeners are degraded readily, whereas the less chlorinated congeners and the biphenyl nucleus are more persistent (5). There is a preferential removal of chlorines from the para and meta positions. The products of anaerobic dechlorination, therefore, are mainly ortho-substituted congeners, which have fewer chlorine atoms on the biphenyl ring. Such congeners are less toxic and may serve as substrates for aerobic dechlorinating bacteria (10).

The objective of the current study is to determine the dechlorinating capacity of naturally occurring microbes in PCB-contaminated sediments from selected Great lakes sites. The dechlorination of indigenous PCB congeners in contaminated sediment

from the Saginaw River was determined under aerobic conditions. The initial chromatographic profile of Saginaw sediment indicated a preponderance of PCB congeners with one to four chlorine atoms, which suggested that the original Aroclor contaminant had been transformed from a mix of congeners of low and high chlorine content to primarily low-chlorine congeners. Aerobic incubation for 6 months resulted in a net loss of total congeners reported to be amenable to aerobic degradation. These congeners included 4-chlorobiphenyl, 2, 2'-trichlorobiphenyl (tri-CB), 2, 4', 5-tri-CB, 2, 4, 4'-tri-CB, 3, 4, 4'-tri-CB, 2, 3', 5', 6-tetrachlorobiphenyl (tet-CB) and 2, 2', 3, 4'-tet-CB.

Contaminated sediments collected from the Ashtabula River and Sheboygan Harbor were incubated under anaerobic conditions. These sediments also were depleted of highly chlorinated congeners. The Ashtabula sediment was amended with 2, 3, 4, 4'-pentachlorobiphenyl (penta-CB), 2, 3, 3', 4, 4', 5-hexachlorobiphenyl (hexa-CB), and 2, 2', 3, 4, 5, 6, 6'-heptachlorobiphenyl (hepta-CB) to determine the potential for dechlorination of highly chlorinated congeners. Each congener was added individually and in combination with the other two congeners. Reductive dechlorination was observed after lag periods of 5, 3, and 4 months for the penta-CB, hexa-CB and hepta-CB, respectively. The Sheboygan sediment was amended with three concentrations of 2, 2', 3, 3', 4, 5, 6, 6'-octachlorobiphenyl (octa-CB). After a lag phase of 5 months, a decrease in many of the higher chlorinated congeners was observed in all the samples amended with the octa-CB, but not in the unspiked and autoclaved sterile controls. These preliminary data suggest the presence of actively dechlorinating microorganisms in the sediments from these Great Lakes sites. Further research will include studies to determine the factors that will enhance the dechlorinating activity of these microorganisms.

A field demonstration is proposed for the Sheboygan River area using dredged sediment that has been placed in a Confined Treatment Facility. This study will examine the effects of alternating aerobic and anaerobic conditions, with and without the addition of inorganic nutrients, on the rate of extent of PCB biotransformation under simulated field conditions. Collecting biotransformation data under conditions that closely resemble a large scale treatment of PCBs will provide valuable information regarding the correlation of laboratory and field data and the development of scenarios for enhanced bioremediation.

Addition of inorganic nutrients and anaerobic-aerobic cycling are currently the most promising treatment options; both will be examined in the field scale study. During the aerobic phase, the bioavailabilities of PCBs may be enhanced through the degradation of naturally occurring organic compounds as well as contaminants such as oil and grease, all of which are known to bind PCBs. Further, biphenyl and lower chlorinated PCB congeners, primarily mono- and dichlorinated PCBs, are degraded preferentially under aerobic conditions (7, 8). Anaerobic conditions favor the biotransformation of the more highly chlorinated PCB congeners (6,

7, and 8 chlorines) through reductive dechlorination reactions (9, 10), producing lower chlorinated products amenable to aerobic attack. Taken together, the alternating aerobic/anaerobic scheme seems promising for more extensive bioremediation of PCBs (6). Concurrent lab experiments will verify and expand the field study.

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**Sheboygan River Sediment Bioremediation Project -
Development of the Confined Treatment Facility**

A Confined Treatment Facility (CTF) was designed to demonstrate the bioremediation of PCBs in sediments removed from the Sheboygan River, Wisconsin. The pilot-scale project is being conducted by Blasland & Bouck on behalf of the Tecumseh Products Company and in cooperation with the USEPA. The CTF was designed and constructed to receive 2,500 cubic yards of sediment. The purpose of the CTF was to maintain an "aquatic" environment and enhance anaerobic dechlorination or aerobic biodegradation of PCBs. The design requirements included environmental controls such as water treatment and multiple barriers to chemical migration; ability to manage solutes within the interstitial water; and, the need to simultaneously evaluate different experimental treatments with appropriate controls.

The resulting CTF structure is an open vessel occupying 14,000 square feet of floodplain adjacent to the Sheboygan River. The CRF is constructed with interlocking sheetpiling walls and double high-density polyethylene (HDPE) liners along the walls and bottom. Other features include independent leachate collection and detection systems and a "passive" water-treatment system. The CTF was divided into four separate cells: two large cells for experimental treatments and two small cells to serve as corresponding controls. At the bottom of each cell is a separate amendment-delivery system consisting of perforated HDPE pipe. The cells were filled during 1989 and 1990 with sediment removed from selected deposits which contained the highest PCB concentrations in the Sheboygan River. The extent of PCB dechlorination evident in the baseline samples from the CTF is significant. The course of future work in the CTF, which is being undertaken in cooperation with the EPA's Assessment and Remediation of Contaminated Sediments program, and the parallel bench-scale treatability studies are described in following presentations.

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**Reductive Dechlorination of Polychlorinated
Biphenyls (PCBs) in Sediments**

Polychlorinated biphenyls (PCBs) have on occasion partitioned into sediments at concentrations sometimes greater than 50 ppm near sites of previous industrial discharges. Some locations with elevated PCB sediment concentrations are being considered for remediation. These PCBs are potentially available for microbially-mediated transformations, such as reductive dechlorination. Anaerobic reductive dechlorination of PCBs has been observed both in the environment and in laboratory studies. Dechlorination may reduce toxicity and increase the fraction of PCB congeners that are more readily biodegraded by aerobic microorganisms. Hence, the ability to enhance reductive dechlorination in natural sediments would be beneficial. Anaerobic batch incubations, using naturally occurring microorganisms from sediment-substrate enrichments, were tested to assess the potential for bioremediation of PCB dechlorination, or if dechlorination rates were limited by lack of microorganisms, or the bioavailability of the PCBs. The experiments show that in some cases the substrate (electron donor) can affect the dechlorination rate. The rate of reductive dechlorination of PCBs was proportional to the amount of organic substrate available in some sediments. However, the relative rates of reductive dechlorination of PCBs added to sediments in the laboratory were faster than the dechlorination rates of "weathered" PCBs that may have resided in sediments for years.

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Dredged Material to Soil - UK Examples of a Beneficial Use

Changing patterns of shipping and trade have resulted in many traditional dock facilities in cities worldwide becoming redundant. As the facilities are closed, redevelopment of the sites takes place, work which frequently involves the creation of large areas of amenity landscaping and environmental improvement. This creates a demand for soil able to support trees, shrubs, grass and flowers.

The closure of the shipping facilities may also mean a reduction in the need to undertake maintenance dredging of the docks and channels. Silt, much of which is derived from land erosion, starts to accumulate and may build-up to create environmentally unattractive mudbanks.

The recycling of the mud deposits to create a low cost source of amenity landscaping soil is a beneficial use of dredged material which has now been undertaken in a number of UK cities. The paper describes some of the difficulties and solutions appropriate to reuse, including contamination, drying, desalination and amelioration. Two case studies are examined in detail. In one the recovery and reuse is now undertaken on a fully commercial basis by a private contractor.

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Remediation of Contaminated Sediments in the Netherlands

Contaminated sediment is a high-priority environmental problem in the Netherlands. It is mainly a dredged-material problem: many Dutch watercourses must be dredged for nautical reasons and for water management. Consequently, remediation of contaminated sediments in the Netherlands refers specifically to dredging and dredged-material treatment. Until a few years ago, all dredged material was removed to confined disposal facilities. Recently, treatment technology has been applied in sediment remediation actions. Jointly with these full-scale operations, a research programme has been executed: the first phase of this Development Programme Treatment Processes Programme was executed in 1989 through 1991, which the second phase is to start in 1992.

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Management of Dredged Material in the Port of Rotterdam

About 23 million m³ of dredged material must be removed from the port of Rotterdam yearly. Thirteen million m³ of this, mainly of marine origine, is relocated in the sea. The remaining 10 million m³, is contaminated to such a degree, that disposal into the sea or relocation on land sites is not permitted, unless special measures are taken.

The long term strategy of the port is that the dredged material should be clean. This will entail an improvement in quality of between 70% and 90%. In the meantime (until 2002 A.D.) the contaminated dredged material will be disposed into 2 specially constructed disposal sites. Strategy for these disposal sites is an efficient and sound use of the precious disposal capacity. Therefore research and experiments have been carried out to examine the possibilities for separation of fractions (contaminated versus non-contaminated) dewatering and re-use. Next to that the port of Rotterdam participates in the national "Development Program Treatment Processes". In this program all kinds of treatment and cleaning techniques are examined on different scales.

To implement the long term strategy, the Rhine Research Project (RRP) was initiated. This project aims to contribute to the ultimate goal through technical and legal investigation, public relations activities and a dialogue with the discharges of effluent. To date these efforts have resulted in agreements between the city of Rotterdam and effluent discharges in Switzerland, France and Germany.

The framework for all these activities is the management program for dredged material.

During the presentation the features and results of this management program will be highlighted.

