Bioremediation: Expanding the Toolbox

2019 SRP Risk e-Learning Fall Series

William A. Suk, Ph.D., M.P.H.

Director, Superfund Research Program

Chief, Hazardous Substances Research Branch

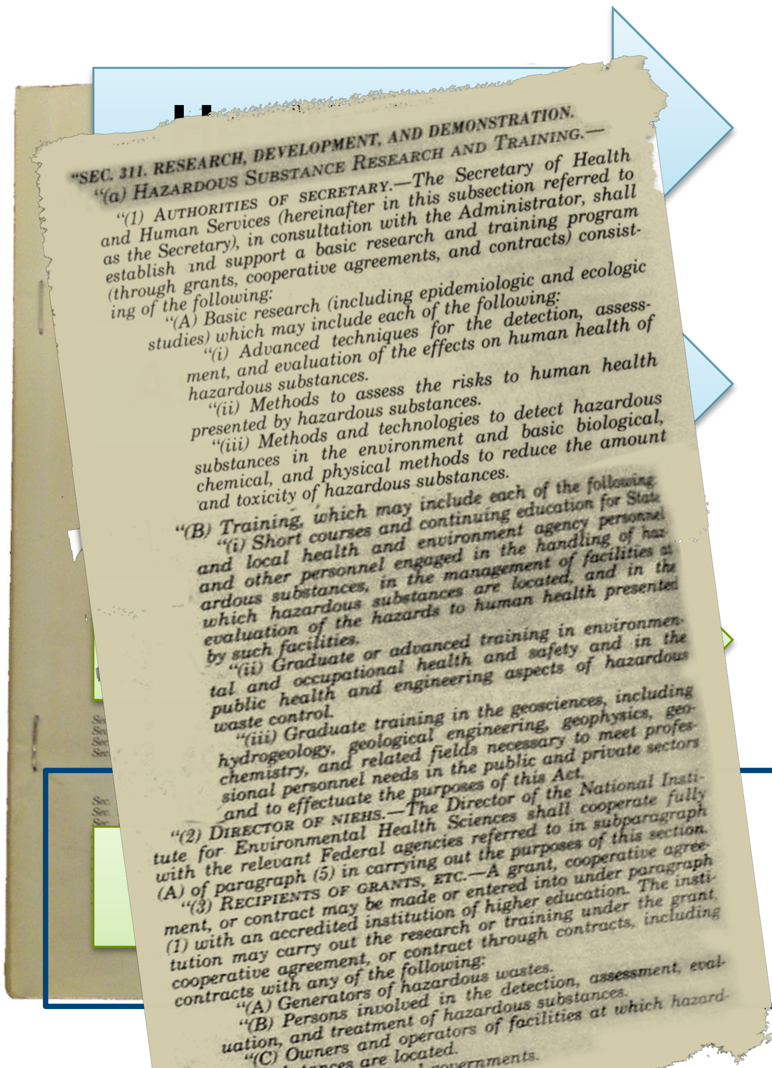
Division of Extramural Research and Training
National Institute of Environmental Health Sciences

NIEHS Superfund Research Program (SRP)

- Formed in 1986 under the Superfund Amendment Reauthorization Act.
- Assigned to NIEHS, part of the National Institutes of Health
- **Unique team-science approach**
  - Brings together diverse disciplines: health researchers, engineers, biologists, ecologists, earth scientists, and social scientists
  - Aims to understand & reduce exposure to potentially harmful contaminants and improve health
- Works closely with industry, government, tribal, and business partners to deliver practical solutions

SRP Mandates

University-based basic research program for development of:



"SEC. 311. RESEARCH, DEVELOPMENT, AND DEMONSTRATION.

"(a) HAZARDOUS SUBSTANCE RESEARCH AND TRAINING.—

"(1) AUTHORITIES OF SECRETARY.—The Secretary of Health and Human Services (hereinafter in this subsection referred to as the Secretary), in consultation with the Administrator, shall establish and support a basic research and training program (through grants, cooperative agreements, and contracts) consisting of the following:

"(A) Basic research (including epidemiologic and ecologic studies) which may include each of the following:

"(i) Advanced techniques for the detection, assessment, and evaluation of the effects on human health of hazardous substances.

"(ii) Methods to assess the risks to human health presented by hazardous substances.

"(iii) Methods and technologies to detect hazardous substances in the environment and basic biological, chemical, and physical methods to reduce the amount and toxicity of hazardous substances.

"(B) Training, which may include each of the following:

"(i) Short courses and continuing education for State and local health and environment agency personnel and other personnel engaged in the handling of hazardous substances, in the management of facilities at which hazardous substances are located, and in the evaluation of the hazards to human health presented by such facilities.

"(ii) Graduate or advanced training in environmental and occupational health and safety and in the public health and engineering aspects of hazardous waste control.

"(iii) Graduate training in the geosciences, including hydrogeology, geological engineering, geophysics, geochemistry, and related fields necessary to meet professional personnel needs in the public and private sectors and to effectuate the purposes of this Act.

"(2) DIRECTOR OF NIEHS.—The Director of the National Institute for Environmental Health Sciences shall cooperate fully with the relevant Federal agencies referred to in subparagraph (A) of paragraph (5) in carrying out the purposes of this section.

"(3) RECIPIENTS OF GRANTS, ETC.—A grant, cooperative agreement, or contract may be made or entered into under paragraph (1) with an accredited institution of higher education. The institution may carry out the research or training under the grant, cooperative agreement, or contract through contracts, including contracts with any of the following:

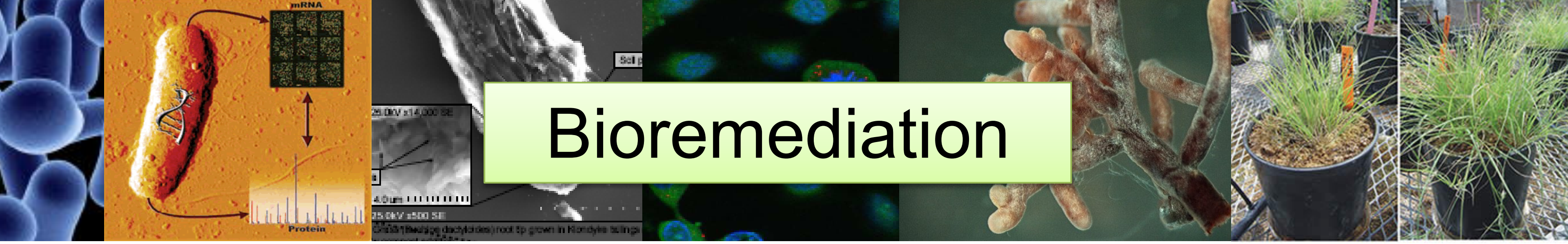
"(A) Generators of hazardous wastes.

"(B) Persons involved in the detection, assessment, evaluation, and treatment of hazardous substances.

"(C) Owners and operators of facilities at which hazardous substances are located.

... and local governments.

- Advanced techniques for the detection, assessment, and evaluation of the human health effects of hazardous substances
- Methods to assess the risks to human health presented by hazardous substances
- Methods and technologies to detect hazardous substances in the environment
- Basic biological, chemical, and physical methods to reduce the amount and toxicity of hazardous substances



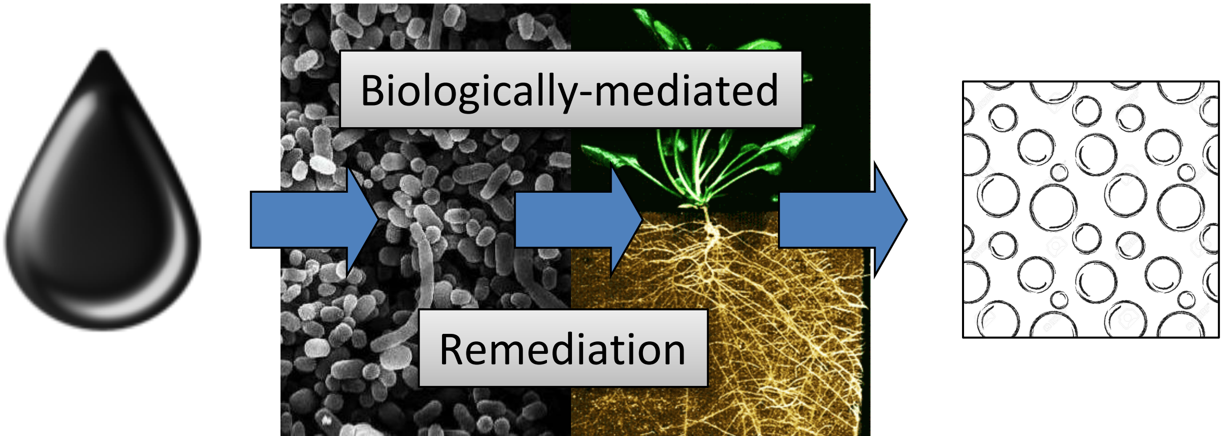
Bioremediation

Bioremediation refers to the use of biota to reduce or detoxify hazardous substances in the environment.

- Bacteria, algae, fungi, plants, etc.
- Soil, sediments, groundwater/hydraulics, air
- Cost-effective, low-energy-intensive remedy
- Closure / de-listing of Superfund, RCRA, and other sites

Pros/Cons to Bioremediaton:

- Effective, but not a “rapid cleanup” process
- Natural system = many unknowns
  - Unintended byproduct formation
  - Uptake into food chain must be controlled
- Requires careful site analysis, optimization, nurturing



Looking Back: SRP Bioremediation Research

1987 — **First SRP grants awarded**

1988 — The University of Washington's first Center included **research focused on phytoremediation** led by Milt Gordon

1990 — SRP sponsored a **"Biodegradation of Hazardous Wastes"** conference in Utah

2002 — SRP awarded their **first small business grants**, including funding for bio- and phtyo-remediation tools

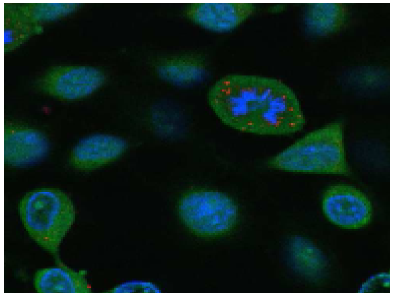
2009 — **SRP began funding "phytoscholars,"** providing funding for trainees to attend the annual International Phytotechnologies Conference

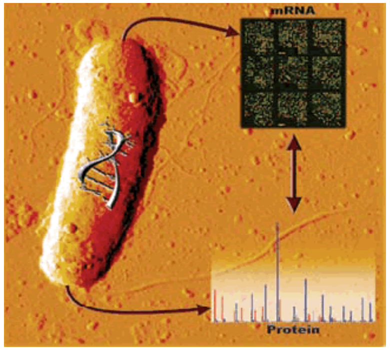
2010 — SRP hosted a **state-of-the-science workshop on the role of the microbiome**

2019 — **SRP currently funds 22 projects with a bioremediation component**

SRP Snapshot: Bioremediation Research

- SRP grantees develops technology-driven bioremediation solutions based on solid, basic science
- These bioremediation technologies include:
  - Extracting / degrading chlorinated compounds
  - Stabilizing metals in soils in challenging conditions
  - Amendments to enhance bioremediation
  - Utilizing isotopes and ‘omics to monitor the progress
- Innovative research approaches advance the practice
  - Influenced remedy selection at sites
  - Led to small business spin-offs





Phytoremediation with Hybrid Trees

Milt Gordon, Ph.D. & Lee Newman, Ph.D., University of Washington (P42ES004696)

Pioneering use of genetically modified poplar and cypress trees to remediate contaminated groundwater (Newman et al. 1999)

- Cost-effective method saves money and attractive natural approach gains community acceptance
- **$8.5–$10.5 million in savings** at the Undersea Naval Warfare Center at Keyport, WA
- **$2.4 million in savings** at Argonne National Laboratory at Batavia, IL
- According to the ESTCP estimates, as many as 1,000 DOD cleanup sites worldwide could utilize this technology, **saving hundreds of millions of dollars**

Groundwater Bioremediation Approach

Kate Scow, Ph.D., UC Davis (P42ES004699)

Enhancing PM1-mediated bioremediation of MTBE in groundwater (Hristova et al. 2001; Hristova et al. 2003)

- Bioremediation brought groundwater from >100,000 ppb of MTBE to <1 ppb in North Hollywood, CA
- Sustainable technology relied on naturally occurring bacteria and use of oxygen and simple nutrient supplementation
- Method allowed re-injection of groundwater into the aquifer, which was extremely valuable in the drought-stricken region
- **$14–$21 million in savings** by eliminating the need to drill 2–3 replacement wells at the site

Phytoremediation to Remove PCBs

Jerald Schnoor, University of Iowa (P42ES013661)

- **Mechanisms involved in how plants degrade PCBs**, including identifying PCB-degrading microbes and the functional genes and enzymes involved.
- Characterized removal of PCBs in soil by plants and their associated microbes in the root zone.
- **Field-scale use of poplar trees in a PCB-contaminated lagoon** in Altavista, Virginia.
  - Interaction has helped the town and its community find solutions for the PCB contamination of the lagoon.
- In a recent study, found that pumpkin seedlings can break down TBBPA, the most widely used brominated flame retardant

Characterizing Microbial Communities

Gerben J. Zylstra, Rutgers University, MSU SRP (P42ES004911)

- Characterizing the microbial response to understand the limitations on environmental detoxification
- To explore and recover nature's catalytic diversity with the goal of developing a comprehensive profile of microbial community metabolic capabilities for degradation

Brenda Casper, University of Pennsylvania (P42ES023720)

- Examining whether chemical alteration of asbestos particles by plants and/or fungi, either directly or indirectly via plant exudates or fungal metabolites, may be useful for bioremediation of asbestos-contaminated sites.

Jon Chorover, University of Arizona (P42ES004940)

- Identifying how arsenic can be sequestered in both the root exterior and interior vacuoles in the root zone of Prosopis juliflora (mesquite) to prevent the spread of arsenic

Understanding Mechanisms of Sorption and Bioavailability

Stephen A. Boyd, Michigan State University (P42ES004911)

- Understanding the mechanisms of polychlorinated dibenzo-p-dioxins (PCDD) sorption to soil particles and the effects of sorption on bioavailability

Mark Brusseau, University of Arizona (P42ES004940)

- Investigating key physical and biogeochemical processes that control migration and attenuation of mine-drainage contaminants in groundwater
- Incorporating innovative methods to examine the biogeochemical processes that control contaminant behavior

Jose Manuel Cerrato, University of New Mexico (P42ES025589)

- Developing cost-effective remediation strategies that immobilize arsenic, uranium, and metal mixtures
- Investigating reactions and mechanisms at the molecular level to understand macro-scale processes influencing water quality

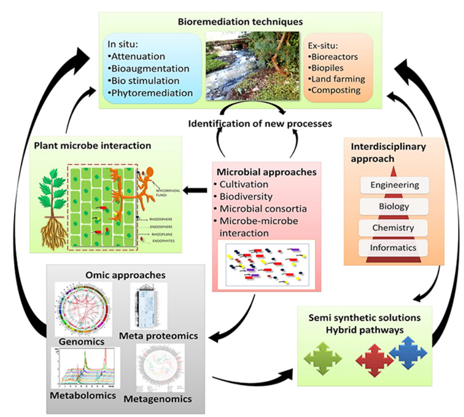
Measuring Success of Bioremediation

Mike Aitken, UNC Chapel Hill (P42ES005948)

- Understanding the relationship between incomplete PAH metabolism by bacteria based on genetic determinants and observed effects of bioremediation on the toxicity of the soil.

Staci Simonich, Oregon State (P42ES016465)

- Measuring toxicity of PAH breakdown products in complex environmental mixtures at Superfund sites
- Found that some breakdown products may be more toxic than original compounds



Tom Young, UC Davis (P42ES004699)

- Developing and evaluating analytical, computational, and bioassay based approaches to assess toxicity reductions from bioremediation of Superfund sites.

In situ: Biogeochemical Factors Impacting Remediation

Frank Loeffler, University of Tennessee (R01ES024294)

- Found how chemical modifications to corrinoid co-factors, including vitamin B12, can affect how well bacteria degrade chlorinated pollutants, such as TCE and PCE.

Lisa Alvarez Cohen, UC Berkeley (R01ES024255, P42ES004705)

- Evaluating how microbes used for TCE bioremediation interact with co-existing organisms in various conditions.
- Applying systems biology approaches to study interactions within microbial communities involved in the bioremediation of groundwater mixtures containing arsenic in combination with TCE and BTEX.

Edward Bouwer, Johns Hopkins University (R01ES024279)

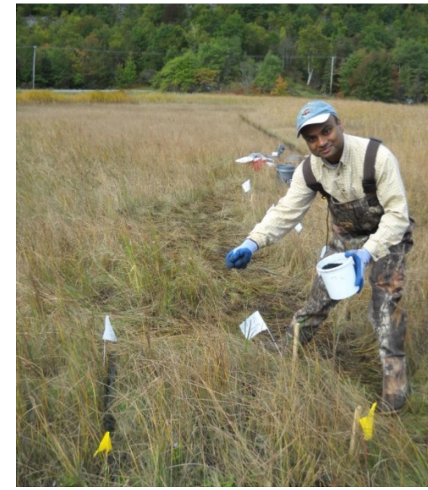
- Evaluating a flow-through barrier containing granular activated carbon coated with anaerobic and aerobic microorganisms to see if it can completely break down chlorobenzenes and benzene contaminants.

See recent Clu-in webinars:
Biogeochemical Interactions Affecting Bioavailability for in situ Remediation
April 22, 2019 and May 20, 2019

In situ: Biogeochemical Factors Impacting Remediation

Upal Ghosh, UM Baltimore County (R01ES024284)

- Identifying biogeochemical characteristics that make sites suitable for remediation with sorbent remediation approaches, such as activated carbon amendments.
- Designing sorbent amendment/capping strategies that reduce methylmercury bioavailability.



Heileen Hsu-Kim, Duke University (R01ES024344)

- Studying sediment dwelling microorganisms that methylate mercury and identifying factors that may be used to control and reduce toxic methylmercury production.
- Focused on strategies to measure mercury bioavailability and biomethylation

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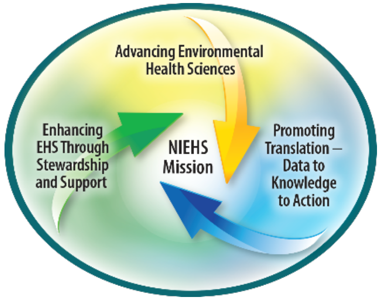
Bioremediation – Looking Forward

Microbiome

- What synergies exist between approaches in bioremediation and the growing field of the human microbiome?
  - Opportunities to test feasibility of building linkages with other microbiome fields of study
  - Presenters in this session will touch on opportunities to build linkages with other microbiome fields of study, such as the human microbiome.



NIEHS Strategic Plan Goal: Expand focus on the role of the microbiome as both a target and a mediator of exposures.

Expanding future directions of bioremediation

- New, promising bioremediation ideas, and optimize for field application
- We have asked each presenter to discuss their thoughts on opportunities and challenges ahead

Join us for Sessions II and III

- Session II - Novel Omics Approaches
- **October 3, 2019 • 1:00 – 3:00 p.m. EDT**
  - **Claudia Gunsch, Ph.D.**, Duke University
  - **Julian Schroeder, Ph.D.**, UC San Diego

- Session III - Emerging Opportunities
  October 11, 2019 • 1:00 – 3:00 p.m. EDT
  - **Pedro Alvarez, Ph.D.**, Rice University
  - **Dora Taggart**, Microbial Insights
  - **Ameen Razavi**, Microvi Biotechnologies

Today we will hear from:

- **James Tiedje, Ph.D.**, Michigan State University
  - For the MSU SRP Center, Tiedje provides methodology development and microbial informatics services.
  - Will discuss the past and future of microbiome science
- **Raina Maier, Ph.D.**, and **Paul Carini, Ph.D.**, University of Arizona
  - SRP research focuses on revegetation of mining wastes in arid and semiarid environments
  - Will discuss new integrative tools important to both phytoremediation processes and human health