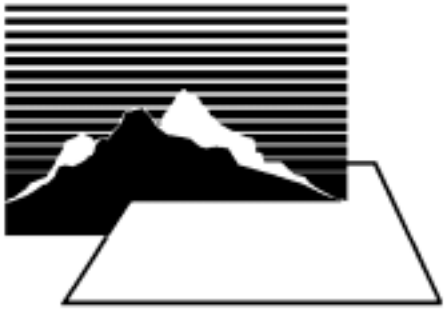
ANNUAL REPORT

of the

Great Plains/Rocky Mountain Hazardous Substance Research Center



December 2000

CONSORTIUM MEMBERS

Colorado State University
Haskell Indian Nations University
Kansas State University
Lincoln University
Montana State University
Montana Tech of the University of Montana
South Dakota State University
University of Iowa
University of Missouri
University of Montana
University of Nebraska
University of Northern Iowa
University of Utah
University of Wyoming
Utah State University

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GREAT PLAINS/ROCKY MOUNTAIN

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Montana Tech of the University of Montana
South Dakota State University
University of Iowa
University of Missouri–
Columbia, Kansas City, and Rolla
University of Montana
University of Nebraska
University of Northern Iowa
University of Utah
University of Wyoming
Utah State University

Other Participants

Colorado School of Mines
University of Colorado
Iowa State University

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THE CENTER AT A GLANCE

Kansas State University (KSU) leads the consortium comprising the Great Plains/Rocky Mountain Hazardous Substance Research Center, which serves Environmental Protection Agency (EPA) Regions VII and VIII. Other member universities are Colorado State University, Haskell Indian Nations University, Lincoln University, Montana State University, South Dakota State University, Utah State University, and the Universities of Iowa, Missouri, Montana, Nebraska, Northern Iowa, Utah, and Wyoming. All are located in EPA Regions VII and VIII. The center was established in February 1989 to conduct research pertaining to the identification, treatment, and reduction of hazardous substances resulting from agriculture, forestry, mining, mineral processing, and other activities of local interest. In 1994, efforts of center principal investigators were broadened to include programs for minority academic institutions, technical outreach services for communities, and research and re-education for displaced military and Department of Defense personnel.

The center is headed by Dr. Larry E. Erickson, professor of chemical engineering at Kansas State University (KSU). Dr. Erickson is responsible for coordinating all of the center's activities. He is assisted by Dr. Lakshmi N. Reddi, who is the associate director, and by Dr. Richard B. Hayter, associate dean for extension and outreach and director of engineering extension programs, who oversees the conduct of the center's training and technology transfer program. The center benefits from guidance supplied by a 16-person Science Advisory Committee and a 14-person Training and Technology Transfer Advisory Committee. Members of these committees are listed in Tables 1(A) and 1(B).

Table 1(A): Science Advisory Committee

Member	Affiliation	Expertise
Robert Ahlert, Ph.D.	RAMS Env. Consultants	chemical engineering
Terry Baxter***, Ph.D.	Northern Arizona Univ.	environmental engineering
Tim Canfield	U.S. EPA	biology
Ramesh Chawla, Ph.D.	Howard University	chemical engineering
David Constant, Ph.D.	Louisiana State University	hazardous waste engineering, chemical engineering
Carol L. Dona, Ph.D.	U.S. Army Corps of Engineers	environmental engineering
Mitchell Erickson**, Ph.D.	U.S. Department of Energy	chemistry
Felix Flechas	U.S. EPA, Region VIII	environmental engineering
Randy Freeman*, Ph.D.	ABS Group, Inc.	chemical engineering
Craig McFarlane, Ph.D.	U.S. EPA	plant physiology
Michael Norland	South Florida Natural Resource Center	plant science
Catherine A. Peters	Princeton University	environmental engineering
Robert Peters, Ph.D.	TechSavants, Inc.	chemical/environmental engineering
Steven Rock	U.S. EPA	phytoremediation
Thomas B. Stauffer	U.S. Air Force	chemistry
Michael Tucker	U.S. EPA, Region VII	biology

*Chair, 1992-1994
**Chair, 1995-1998
***Chair, 1998-Present

Table 1(B): Training and Technology Transfer Advisory Committee

Member	Affiliation	Expertise
Martha Boss	industry	certified industrial hygienist
Ronald Hammerschmidt	govt/state	environmental chemistry
Edward Heyse	govt/USAF	environmental science and engineering
Stephen Hoffman	govt/EPA	environmental management
Caren Johannes	govt/state	hazardous waste corrective action
Michael Kukuk	industry	environmental engineering
Jim Lehr	govt/EPA	environmental management
Jack Lonsinger*	industry	industrial processes
Dale Manty (ex officio)	govt/EPA	federal program management
Edward Mead	govt/Corps of Engineers	industrial processes
Robert Mournighan	govt/EPA	environmental engineering
Ella Mulford	industry	industrial processes
Dennis Murphey	govt/city	professional training
Tim Ward	University of New Mexico	environmental engineering

*Chair

Researchers and extension faculty from various academic programs interact through the center, bringing a diversity of perspectives to address complex problems associated with hazardous substances. Table 2 lists key personnel from each participating consortium institution and related non-consortium universities.

Key investigators at non-consortium institutions include Tissa H. Illangasekare, Colorado School of Mines; Joseph B. Hughes, Rice University; Carl G. Johnston, Mycotech Corporation; and Joel R. Coats, Iowa State University.

Table 2: Key Personnel in the Center

Haskell Indian Nations University
Jamison O. Bear
Brenda Brandon
George L. Godfrey
Daniel R. Wildcat

Lincoln University
Frieda Eivazi
Mary Wyatt

University of Northern Iowa
Barbara A. Hetrick
Catherine Zeman

Kansas State University
Philip L. Barnes
Bertram R. Biles
Terrie K. Boguski
Lawrence C. Davis
Vernon Deines
Larry E. Erickson
L.T. Fan
William G. Fateley
Richard E. Faw
Steven J. Galitzer
Larry A. Glasgow
Wendy M. Griswold
William J. Hankley
Richard B. Hayter
Prasanta K. Kalita
Kenneth J. Klabunde
Peter Kulakow
Michael W. Lambert
Blase A. Leven
Alexander P. Matthews
Gene M. Meyer
Frederick W. Oehme
Gary M. Pierzynski
Lakshmi N. Reddi
Charles W. Rice
John R. Schlup
James C. Shanteau
J. Kenneth Shultis
James M. Steichen
Daniel W. Sweeney
Walter P. Walawender
LaBarbara Wigfall

University of Missouri
John Atkinson
Stephen H. Anderson
Daniel W. Armstrong
Rakesh K. Bajpai
Shankha K. Banerji
V.M. Boddu
Joel G. Burken
P.C.-H. Chan
Thomas E. Clevenger
T.L. Feldbush
Daniel Forciniti
Syed E. Hasan
Shubhender Kapila
S.K. Loyalka
Stanley E. Manahan
Deborah J. Mossman
Thomas J. O'Keefe
R. Lee Peyton
Richard Potter
George Preckshot
Ravi K. Puri
Robert L. Segar
Dabir S. Viswanath
John L. Watson

Montana State University
Anne Camper
J. William Costerton
Al B. Cunningham
Douglas J. Dollhopf
John Goering
William P. Inskeep
Stuart R. Jennings
Warren L. Jones
Zbigniew Lewandowski
Frank F. Munshower
Dennis R. Neuman
Paul J. Sturman
Robert V. Thurston
Bryan K. Warwood
Jon M. Wraith
Nick Zelver

University of Nebraska
Istvan Bogardi
Stephen D. Comfort
Mohamed F. Dahab
Bruce Dvorak
Robert D. Grisso
Larry Hammer
Herb Hoover
D. Lewis
Dennis L. McCallister
Shirley M. Niemeyer
William L. Powers
Patrick J. Shea
David P. Shelton
Wayne E. Woldt
Tian C. Zhang

University of Utah
Sam Ghosh
Andrew P. Hong
Jan D. Miller
Robert W. Okey
Russ Price
H.Y. Sohn

Colorado State University
Harry W. Edwards
Elizabeth Pilon-Smits
Kenneth F. Reardon

Utah State University
Carolyn Abbot
Bruce Bugbee
William J. Doucette
R. Ryan Dupont
Conly L. Hansen
Joan E. McLean
Russ Price
Judith L. Sims
Ronald C. Sims
Darwin L. Sorenson
Daniel Smith
David K. Stevens
Stephen B. Turcotte

South Dakota State University
Suzette Burckhard
Susan A. Gibson
James A. Rice
Vernon P. Schaefer
John C. Tracy

University of Iowa
Pedro J.J. Alvarez
David T. Gibson
Craig Just
Burt C. Kross
Gene F. Parkin
Barbara Pies
Michele Scherer
Jerry L. Schnoor
M.I. Selim
Josef Simeonsson
Richard L. Valentine

University of Montana
Jerry J. Bromenshenk
Chris Heyer
D.G. Klarup

Montana Tech
Karl Burgher
Kevin Mellott

University of Wyoming
Lee A. Bulla
Benito M. Chen
P.S. Colberg
Jerry J. Cupal
William P. Iverson
Robert F. Kubichek
K.J. Reddy
Quentin D. Skinner
John P. Turner
George F. Vance
Roger Wilmot

EPA Regions VII and VIII have a curious diversity of interests resulting from the grouping of mineral-rich states such as Colorado, Montana, and Utah, with the states of the Great Plains whose economic foundations rest on agriculture and animal husbandry. The center defined its original mission in terms of these wide-ranging activities and has undertaken research in the following areas:

- Studies of soil and water contamination by heavy metals and mining wastes.
- Research on soil and groundwater contamination from a variety of sources.
- Development of incineration, biodegradation, and immobilization technology.
- Development of simplified and inexpensive methods for analyzing contaminated soil.
- Hazardous waste minimization.
- Determination of safe concentration levels of hazardous substances in soils and in water.

A decision was made in May 1990 to assign the highest priority to risk-reduction research on soil and processes to clean up contaminated soil. Research proposals were requested based on the following needs and problems, listed here in order of their priority based on the center's current mission:

- Soil and water contamination by heavy metals such as cadmium, chromium, copper, lead, and zinc associated with mining wastes and other industrial activities. Mine tailings from past mining operations have resulted in contaminated surface and groundwater. The heavy metals listed are very similar to the heavy metals that contaminate DOE sites, except that DOE must also deal with some heavier metals.
- Soil and groundwater contamination by organic chemicals from a variety of sources. Wood preservatives, including pentachlorophenol and creosote, polynuclear aromatic hydrocarbons, carbon tetrachloride, trichloroethylene, vinyl chloride, and other chlorinated aliphatic hydrocarbons, polychlorinated biphenyls (PCBs), and dioxin have been identified as priority substances contaminating groundwater. Numerous pesticides have been identified to be hazardous substances; the fate and transport of pesticides are of particular interest because of the agricultural orientation of Regions VII and VIII. A general need exists for research to develop treatment technologies to clean up contaminated soil.
- Development of improved technologies and methods for characterization and analysis of contaminated soil. Simple inexpensive methods are desired. DOE is interested in developing improved and innovative technologies, including real-time and non-intrusive evaluation and characterization of sites.
- Development of innovative treatment technologies for remediation of contaminated soil and groundwater and for rendering wastes nonhazardous. Technologies that will lead to an *in situ* resolution of the problem are emphasized.
- Development of waste minimization and pollution prevention methods and technologies. The highest priority in this category is assigned to application of these methods to site characterization and remediation processes.

The center has supported research projects at non-consortium institutions through contracts. Less than 10% of the center's funds are allocated for projects at non-consortium institutions.

Diversity of interests in Regions VII and VIII and the large geographic area represented are further reflected in the training and technology transfer program the center currently supports. Much of the center's efforts are dedicated to support of activities that can reach large audiences with a minimum of resources. For example, issues of the center newsletter, *HazTech Transfer,* have been widely disseminated across the nation; an information clearinghouse at the Kansas State University Hale Library has been established and contains over 1,000 publications, including center-funded theses, dissertations, reports, and videos; the center has held annual conferences on hazardous waste research since 1986 with more than 70 papers presented at each conference; and general public environmental information activities are ongoing. Proceedings of the 1995, 1996, 1997, 1998, and 1999 conferences have been published on the Internet and in print form. Many center publications are now available on the World Wide Web at http://www.engg.ksu.edu/HSRC/. These activities, augmented by some carefully selected special audience functions, appear to provide the most effective means of disseminating necessary technical information across this large and varied area.

The center's base support comes from EPA. Participating schools have all made substantial contributions as well. The U.S. Departments of Defense and Energy have partially supported several research projects. Contributions in support of the center have been received from individuals. Additional funding is also being sought through private industry and other public sector organizations; Boeing Commercial Airplane Group, Chevron Inc., Conoco Inc., Dupont, and Phytotech have contributed to the center through the Kansas State University Center for Hazardous Substance Research Industrial Partnership Program. Montana State University also has an industrial partnership program. The center's funding is summarized in Table 3.

Table 3: Great Plains/Rocky Mountain Hazardous Substance Research Center Funding

FUNDING SOURCES	CURRENT FUNDING PERIOD (May 18, 1997-Sept. 30, 2000)	SECOND AWARD PERIOD (May 17, 1992-Sept. 30, 1997)	FUNDS TO DATE (Since Feb. 22, 1989)
EPA: Five Centers Progs.	$3,754,189	$5,353,515	$13,592,194
EPA: Other	2,247,633	1,974,470	4,693,848
Other Govt.: Federal			
U.S. Dept. of Defense	397,091	3,423,358	3,820,449
U.S. Dept. of Energy	0	365,000	915,000
Other Govt.: State			
Consortium Universities	1,680,026	4,618,552	10,510,240
Nonconsort. Universities	55,947	279,013	533,403
Private Sector	30,000	42,000	104,000
TOTAL	$8,164,886	$16,055,908	$34,169,134

STUDENT SUPPORT	NUMBER	FUNDING*
Undergraduate	10	$59,900
Graduate	24	547,152
Post Doctoral	5	182,695
TOTAL	39	$789,747

*Includes tuition and travel (rounded annual values)

CENTER DIRECTOR'S REPORT

The center provides a focal point for hazardous substance research and training and technology transfer in the Great Plains and Rocky Mountain areas comprising EPA Regions VII and VIII. A long-term goal is to serve the needs of the 10-state area using as many available resources within Regions VII and VIII as possible. For instance, training and technology transfer events offered by consortium universities and other institutions are listed in the quarterly newsletter, *HazTech Transfer*. Information about the center, the annual report, and proceedings of the annual conference are available on the Internet at http://www.engg.ksu.edu/HSRC. Through personal visits, the newsletter, telephone calls, the Internet, and direct mailings, center staff have emphasized inclusiveness and the idea of "working together for a better environment." Center personnel have made visits to all of the consortium universities, several other universities, EPA regional offices, and other state and federal offices. A variety of professional gatherings and conferences have been sponsored and attended. More than 25,000 individuals have benefited directly through center activities.

A large number of the projects funded by the center include a cooperative element. Many of them involve more than one principal investigator; there is cooperation across academic department boundaries as well as institutional cooperation. In some cases, investigators are cooperating with support through two separate projects. Often publications are co-authored by two or more faculty members. Faculty from several universities have participated in workshops offered by the center. These cooperative activities have helped to strengthen environmental research and technology transfer programs at participating universities. Participating students have benefited from working with a team of investigators.

The advisory committees have been most valuable in guiding the center in selecting research and technology transfer areas to pursue and projects to support. On the advice of the Science Advisory Committee in May 1990, the director assigned the highest priority to research involving soil and processes to clean up contaminated soil, thus pursuing a focal area. Many of the new projects reflect the priority on soil-related research. Members of the committee have encouraged research on innovative applications of vegetation in bioremediation and stabilization of soil. Cooperation with other institutions and organizations has been enhanced because of leadership of committee members.

The center's administrative office is in Ward Hall at Kansas State University. Blase Leven, program manager, manages the office and provides a variety of public services, including responding to many requests for information on the activities of the center and other environmental issues. Wendy Griswold, project manager, provides administrative management for the Native American and Other Minority Academic Institutions (NAOMI) Program at Haskell Indian Nations University. Terrie Boguski, project manager, provides outreach services. Brenda Schaffer is the project accountant for the center.

HIGHLIGHTS

February 2000 marked the completion of 11 years of federally funded center activities. During this time, over 100 projects have been funded, with over 250 principal investigators and students working on these projects.

In March 1997 a peer-review panel of environmental professionals reviewed the center's renewal proposal, reports, publications, and other documents. At the conclusion of their site visit, they prepared a report which included the following summary conclusions and recommendations:

> "The Peer Review Panel's opinion of the technical quality and management capabilities of the Great Plains/Rocky Mountain Hazardous Substance Research Center's activities over the past eight years was very favorable. The Center's research is considered to have made important contributions to the areas delineated in its proposals; productivity of most of its funded investigators is of high quality; the training and technical transfer program is effective; and the management of the Center is in the hands of a capable and dedicated Director and staff.
>
> "The Panel considers the Center to have been an effective expenditure of EPA funds and the Panel strongly recommends EPA continued funding of the Center. In addition, the timing of such funding should be sensitive to the uninterrupted support of students on the various Center projects."

As a result of this favorable review, the center received a three-year renewal award in 1997. In September 2000, the center received a two-year extension of the project and budget periods to September 30, 2002.

While it is very difficult to follow all of the positive impacts of the research, training, and technology transfer activities of the center, estimates show that cost savings due to technology innovation are more than 10 dollars for each dollar expended through the center. After 11 years of research through the center, utilization of vegetation in the remediation and/or stabilization of contaminated soil is becoming a widely used technology. The number of contractors actively incorporating vegetation into remediation processes is growing rapidly and the number of field sites where vegetation is part of the solution is increasing exponentially. Field studies often show cost savings of more than 60% compared to conventional pump-and-treat technology. This savings has caught the attention of those who are responsible for remediation within federal agencies and the private sector.

Research on the beneficial effects of vegetation in metals-contaminated soils and mine tailings has been applied at several field sites. The influence of mycorrhizal symbiosis on plant growth and heavy metal tolerance in mine tailings has been demonstrated and communicated. Laboratory and field research has demonstrated which soil amendments are essential to revegetate mine tailings because of the need to improve nutrient availability and water-holding capacity. Results have shown that concentrations of arsenic and cadmium in poplar tree leaves are below the level where they would be a health concern for deer and other animals. Vegetation reduces soil erosion and sediment transport to streams and rivers. Center investigators are providing information and advice to those who are revegetating heavy metal-contaminated sites. Vegetative stabilization is often the only cost-effective solution for large acreages of soils and mine tailings containing heavy metals.

Reactive barriers using zero-valent iron and microbial populations to transform contaminants such as chlorinated solvents and nitrate have been investigated and found to provide faster and more complete dechlorination and nitrate removal.

Center investigators have developed new approaches to identify and select chelators for separating heavy metals from soil. Quantitative structure-activity relationships and molecular descriptors can be incorporated into models that allow computers to be used to help identify chelators. These concepts were presented at two workshops.

The comprehensive approach to process synthesis and design developed through the center has been incorporated into spreadsheet software by a commercial firm and is now available for

implementation by those who do process synthesis for chemical process industries. This will lead to significant advances in pollution prevention, save design costs, and increase profitability.

Center investigators have demonstrated that Fenton reagent is effective for oxidation of a variety of contaminants, including munitions compounds such as TNT. The work provides new information on the mechanisms of the oxidation process.

Several field projects conducted through the center have demonstrated that bioremediation occurs in the field as predicted by laboratory studies. Availability of oxygen has been shown to be an important consideration for contaminants that must be degraded aerobically. Further research is being conducted to develop cost-effective oxygen-transfer technologies. Several companies have provided partial support for these field studies.

With greater emphasis being placed on risk-based hazardous substance management, the center has supported projects designed to understand the fate of environmental contaminants that are bound strongly to soil organic matter. Analytical methods have been developed and applied to investigate contaminant fate. The new knowledge and methods are important to risk-based decision making.

The Research and Re-education for Displaced Defense Personnel (R2D2) program was in place from 1995 to 1998. The R2D2 program was national in scope, with all five centers receiving funding to involve former defense personnel in research programs working on center-funded research projects at center consortium universities. This program enrolled more than 70 displaced Department of Defense employees at HSRC consortium universities. These students worked on center projects to improve remediation technologies at defense sites. New technologies are now available for field application and graduates of the program have advanced to professional positions. One result of the R2D2 program has been better communication with professionals at defense locations. This has resulted in additional projects to address their research needs.

The Technical Outreach Services for Communities (TOSC) program continues to provide assistance to communities impacted by hazardous waste in EPA Regions VII and VIII. Blase Leven and Terrie Boguski provide leadership for this program and the Technical Assistance to Brownfields (TAB) program. Recent projects include presentations and workshops for citizens in affected communities, and assistance to community groups in South Dakota, Montana, Iowa, Wyoming, Kansas, Colorado, and Missouri. This program matches expertise of center professionals with needs of communities to provide customized education and assistance to community groups dealing with hazardous waste cleanups, permitting, and risk-assessment issues.

The Native American and Other Minority Institutions (NAOMI) program has benefited over 60 minority academic institutions (MAIs). Faculty members and students from several MAIs—historically black universities, Native American universities, and predominantly Hispanic universities—have participated in the annual conference and/or the NAOMI Summer Cooperation Program. The NAOMI program has also produced or co-produced several video seminars and satellite-uplinked seminars.

The Technical Outreach Services for Native American Communities (TOSNAC) program has a full-time professional, Brenda Brandon, to provide services to tribal communities. The Oglala Lakota Nation in South Dakota, which has concerns because of the Badlands Bombing Range, is one of many tribal groups being helped through this nationwide program.

A very important event this year was the 2000 Conference on Hazardous Waste Research, held in Denver, Colorado, May 23-25, 2000. The conference, workshops, and tours attracted approximately 200

participants. Conference topics included phytoremediation, metals-contaminated soil, remediation processes, biofilms, and barriers. The proceedings are being made available in print form and on the Internet at http://www.engg.ksu.edu/HSRC.

Amy Ryser, a high school student from Wamego, Kansas, was honored for her poster "Phytoremediation of Crude Oil-Contaminated Soil" at the 12th Annual Conference. Peter Kulakow, one of the center's investigators, advised Amy in her research.

Louis Licht, University of Iowa bioremediation researcher and CEO of Ecolotree, Inc., was honored in 1996 for utilizing a poplar tree technology developed by Licht and Jerald Schnoor. The American Council of Engineering Consultants selected Ecolotree, Inc., for an Honor Award in the 1996 Engineering Excellence Awards competition for its role in the design, installation, and management of an innovative, engineered plant system project for the Woodburn, Oregon, wastewater treatment plant. Poplar trees have been installed at over 50 sites in 11 states and Europe.

Kenneth Klabunde, distinguished professor of chemistry at Kansas State University and a center researcher since 1990, is behind a Manhattan, Kansas, business, Nantek, Inc., which will commercialize the destructive adsorbent technology that has been developed at the laboratory scale. Nantek, which received one of the six 1997 Silicon Prairie Technology of the Year Awards, now has a valuation of about $65 million.

A team of chemical engineering seniors under the direction of HSRC faculty designed a plant-based landfill leachate treatment process for Riley County, Kansas. Alfalfa and cottonwood trees have been planted at the site. Use of this innovative technology is expected to save Riley County several million dollars.

Joel Burken and Jerry Schnoor won the 1998 Rudolph Hering Medal from the American Society of Civil Engineers for their paper "Phytoremediation: Plant Uptake of Atrazine and the Role of Exudates" in the *Journal of Environmental Engineering* (ASCE).

Since 1997, the center has become more involved in assisting with brownfield projects and remediation activities at contaminated field sites. Center investigators have responded to requests for assistance from consultants, responsible parties, EPA professionals, state regulators, and community leaders. Funding in support of brownfield activities has enabled the center to provide considerable assistance to community leaders. Educational workshops have been offered in several locations.

HazTech Transfer, the center's quarterly newsletter, has been published since 1989. *Centerpoint* and *Newspoint*, joint publications of the five centers, have continued to be published with responsibility for managing and editing of each issue revolving among the HSRCs. *Earth Medicine*, the newsletter of the NAOMI program, is published and distributed to minority academic institutions, center consortium universities, tribal offices, government agencies, and other interested individuals.

This year the center has added many pages on the World Wide Web. Center pages include a wealth of information about the center and its programs. Individuals all over the world can access the center's Web pages and find copies of center publications, conference proceedings, journal papers, funded project descriptions, information about center personnel, and general information about the center. The center's home page can be accessed at http://www.engg.ksu.edu/HSRC. There is also a home page for the national HSRC program and information on the four other centers at http://www.hsrc.org. The Magellan Internet Guide recently gave the HSRC Web site a rating of three out of a possible four

stars. The center's Internet site has approximately 10,000 hits per month; about 15% of these are from outside the United States.

The popular workshop on "Beneficial Effects of Vegetation in Contaminated Soil" was presented in January 1998 for the sixth time. In May 2000, a new phytoremediation workshop with emphasis on the state of the science and practice was presented in Denver at EPA Region VIII. The center, in cooperation with Kansas Department of Health and Environment, Interstate Technology and Regulatory Cooperation Working Group, and the Remediation Technologies Development Forum, conducted a workshop on "Natural Attenuation of Chlorinated Solvents in Groundwater," in Kansas City. A workshop on environmental analysis of surface and groundwater contaminants was conducted for members of several Native American tribes by faculty from Sinte Gleska University and the University of Nebraska.

Professionals at Montana State University provided leadership for the 8th Billings Symposium on Disturbed Land Rehabilitation, which was held March 20-24, 2000. This symposium focused on land reclamation and rehabilitation issues relevant to the Great Plains and Intermountain West.

As shown by the listing of theses and dissertations in the bibliography, many students have helped with center projects while conducting research required for their advanced degrees. Many of these graduates now have important positions with contractors, industry, government, and universities. Their movement from the university to their places of employment has resulted in technology transfer that has enhanced innovation.

The center repository continues to be a resource for researchers nationwide. Publications that result from funded center projects are placed in the repository at Kansas State University's Hale Library and are available through interlibrary loan.

The Great Plains/Rocky Mountain Hazardous Substance Research Center, the National Mine Land Reclamation Center, and the Waste-management Education and Research Consortium have initiated a cooperative effort to address the following environmental research and technology transfer needs associated with mining and mine lands: 1) national environmental leadership in research and technology transfer, 2) research to develop innovative technologies to reclaim and restore mine lands and recover minerals from mine spoil, 3) professional support on scientific issues to bring good science into decision making, 4) advanced degree graduates with environmental expertise in mine land reclamation and resource recovery, and 5) environmental expertise to support mining and mineral processing industries with special consideration for small-scale operators.

REVIEW OF RESEARCH AND TECHNOLOGY TRANSFER ACTIVITIES

Progress in Remediation of Contaminated Soil and Groundwater

Since February 1989, when the Hazardous Substance Research Centers were created, innovative technologies have been developed for remediation of contaminated soil and groundwater.

Alternatives to conventional pump-and-treat technologies have been developed. The center has supported biobarrier technologies that can be used for plume management and containment. This technology has shown promise in the laboratory, and field testing is now in progress. Plant systems are being used for plume control, either alone or in combination with conventional pump-and-treat technologies. Vegetation brings contaminated water to the root zone of the plants. Biodegradation occurs when the contaminants can be biodegraded aerobically. Root-zone biodegradation has been observed for compounds such as toluene, phenol, and polynuclear aromatic hydrocarbons. Some volatile compounds,

such as chlorinated aliphatic hydrocarbons, diffuse into the atmosphere. These compounds move through the soil and the vegetation. The plants enhance the transport to the atmosphere by removing water from the soil, by transporting contaminated water upward through the roots and stem, and by lowering the water table to expose volatile compounds to an unsaturated environment where gas-phase transport occurs. In the atmosphere, these compounds are degraded by sunlight and chemical processes.

Another technology that has been developed for plumes is to allow the contaminated water to flow through a treatment zone where degradation occurs. Zero-valent metal processes and biodegradation processes have been investigated for use in this and other applications. Microbial degradation processes, when combined with zero-valent metal abiotic processes, have been demonstrated to be more effective than either process alone.

Management of groundwater flow in the subsurface is complex. Center faculty have contributed to a better understanding of contaminant transport at sites where nonaqueous-phase contaminants are present. This includes progress in understanding groundwater flow, dissolution of contaminants which are present in a nonaqueous phase, and entrapment of nonaqueous-phase liquids.

Research has advanced our knowledge of the fate of organic compounds when bioremediation and phytoremediation are applied. Some organic contaminants bind to organic matter associated with the soil. By using radio labeling and fractionating, center investigators have shown that most bound organic contaminants are associated with humic acid and the lipid components of humin in soil. In both bioremediation and phytoremediation, some compounds are transformed to other chemical forms. Some contaminants react to form dimers and other higher molecular weight compounds. Others are incorporated into microbial and/or plant biomass. Toxicity tests provide one method of evaluating the reduction of risk associated with a remediation process.

Results of center research have been applied by consultants, regulators, and many others. New companies such as Ecolotree, Phytokinetics, and Phytotech have been established to provide professional remediation services. Established companies such as CH2MHill have hired center graduates and employed them in positions where the innovative technologies are applied. Other companies such as Nantek have been formed to commercialize products that can be used in a variety of environmental applications.

From the Flask to the Field: Vegetative Remediation of Mine Tailings

Since the mid-1980s, the Reclamation Research Unit (RRU) at Montana State University-Bozeman has performed treatability studies and designed land reclamation/restoration techniques for a complex of Superfund sites in the Butte and Anaconda, Montana, areas. Beginning in 1993, the GP/RM HSRC and the state of Montana funded benchtop, greenhouse, and field-scale development of a mine tailings re-processing and vegetation method. This technique was successfully demonstrated in bench and greenhouse work and is now being field tested at an operating mine. Work to stabilize and prevent the spread of contamination using vegetation has also been funded by the HSRC in other mining areas.

The method involves use of conventional ore-processing techniques (gravimetric or flotation separation) to remove sulfide minerals from mine tailings. This is an alternative or supplementary method to the use of chemical amendments to reduce acids and metals resulting from weathering of sulfide minerals in tailings over time. The goal is to produce soil-like material that can support vegetation for caps placed over large areas of tailings. Suitable topsoil for vegetated caps is usually not available close to tailings.

Reprocessing of sulfide tailings to decrease plant-inhibitory metal and arsenic levels was successfully completed at the bench scale (~200 kg, three different samples) and at the field pilot scale (~200 tons, one site). Analytical results indicate metal levels were typically decreased in cleaned tailings and were concentrated into approximately 10% of the pretreatment mass. Revegetation of the cleaned tailings (approximately 90% of the pretreatment mass) is analogous to revegetation of silicate-dominated sand. Requirements for addition of lime to prevent future acidity in reprocessed tailings are typically reduced by approximately 95%. None of the high-grade concentrates resulting from treatment failed TCLP analysis, and therefore they can be either disposed as non-hazardous waste or further processed to recover metals (when feasible).

Vegetation establishment was successfully demonstrated during greenhouse evaluation of bench-cleaned tailing material. Basin wild rye (*Leymus cinereus*) and Kentucky bluegrass (*Poa pratensis*) grew adequately in reprocessed tailings and in tailings amended with lime and compost, compared to plants grown in greenhouse potting soil. However, when the common sunflower (*Helianthus annus*) was planted in both reprocessed and amended tailings from one site, only the reprocessed tailing supported plant growth.

Treatment effectiveness and cost appear to vary from site to site, but the prevalence and technological maturity of mineral separation equipment in use in the mining industry suggest a strong potential for low-cost adaptation of mining technology to remedial treatment. At the Anaconda, Montana, Superfund site, use of chemical amendments to create vegetated caps alone will save more than $150 million over the use of topsoil. Stabilization of contaminated materials with vegetated caps, instead of removal and disposal of all tailings, will save over $1.0 billion.

Work has also been underway at Superfund sites along Whitewood Creek in South Dakota and in southeast Kansas to stabilize and prevent the spread of contamination from streamside tailings and smelter wastes, respectively, using poplar trees, grasses, and other forms of vegetation. In the Galena, Kansas, area, researchers are evaluating effectiveness of vegetation treatments on chat tailings to prevent erosion and ground / surface water quality impacts. Much work remains to understand how to establish self-sustaining vegetative ecosystems and their effects on preventing the spread or transport of contaminants, and to evaluate the permanence of this approach.

Technology Transfer in Indian Country

To improve the ability of tribal nations to address their environmental issues, the Great Plains/Rocky Mountain Hazardous Substance Research Center (GP/RM HSRC) provides environmental training, technology transfer services, and public education to tribal communities. The main thrust of the HSRC's Native American programs has been provided by Haskell Indian Nations University through the Haskell Environmental Research Studies Center (HERS). Haskell, a GP/RM HSRC consortium member, is a keystone institution for education, research, and extension in environmental science for American Indian tribal nations and Alaska Native communities.

Currently, there are over 771 federally recognized American Indian tribes and Alaska Native villages. This number represents a broad range of diversity with respect to cultural, economic, and environmental issues. Examples of these issues include several related to hazardous wastes. Wastes from gold mining (Fort Belknap Reservation, Montana; Cheyenne River, South Dakota) and coal mining (Northern Cheyenne Tribes, Montana) have possibly led to contamination of drinking water supplies. Closure of uranium mines and stored tailings are only some of the environmental challenges facing the Navajo Nation in Arizona and New Mexico. Unexploded ordnance and unknown contaminants on gunnery ranges in the Oglala Lakota Nation (Pine Ridge, South Dakota) and Cheyenne River Reservation

(South Dakota) threaten soil and water contamination. In addition to hazardous waste issues, many tribes have brownfield properties within their borders. Issues of concern for these tribes are varied, ranging from remediation of abandoned rail yards to contamination from coal-burning residue and asbestos releases.

While many tribes in the U.S. are faced with serious environmental challenges, their ability to address them is hindered by several issues. Many tribal governments lack the funds and, consequently, the infrastructure to adequately protect their natural resources. HERS assessments of several tribes revealed that some of the reservations had environmental professionals who could quickly pinpoint the environmental degradation on their lands and its causes, while in other cases, responsibility for environmental activities fell to those with little training in this area–the tribal real estate agent or the tribal treasurer. Staff in tribal environmental programs play many roles. Environmental issues can lose focus due to political and financial situations. There is also a high turnover rate for environmental professionals in many tribal programs due to tribal political structure. In addition, there are a limited number of Native American environmental professionals from which tribes can draw qualified environmental staff.

With funding provided from the Native American and Other Minority Institutions (NAOMI) program, the HSRC was able to support a collaborative training effort between Sinte Gleska University (a tribally controlled college) and the University of Nebraska-Lincoln (a GP/RM HSRC consortium member) in 1996. A workshop was developed that focused on water quality parameters, basic environmental analysis techniques, data, and use of field sampling and environmental analysis equipment. This type of training benefits tribes in many ways. With proper training in water quality monitoring, tribal water resources offices can become more self-sufficient. Although the GP/RM HSRC provided funding for SGU and UNL to offer one workshop, Ben Whiting (SGU) and Bruce Dvorak (UNL) were able to obtain subsequent funding from EPA to offer the workshop for additional tribes. A modified version of the workshop was also presented at the Kickapoo Nation of Kansas in summer 1997 with support from Haskell's natural resources program. Throughout successive years, HERS has coordinated the delivery of other technical training to tribal environmental professionals. Topics include air quality management, environmental cleanup and compliance issues, and field-based site characterization and analytical and sampling technologies.

In addition to providing training opportunities for tribal environmental professionals, the GP/RM HSRC has established programs to provide personalized, on-site assistance to tribal environmental programs and communities dealing with hazardous waste and brownfield issues. The Technical Outreach Services for Native American Communities (TOSNAC) program was officially established in March 1998. The goal of this program is to provide educational resources concerning hazardous substance contamination to individuals, community groups, and environmental programs in affected tribal communities. TOSNAC draws upon the expertise of several HSRC consortium members to provide assistance to tribal communities throughout the U.S.

The TOSNAC program has provided assistance to more than 45 tribal nations and pueblos. One of the tribal nations assisted is the Passamoquody Nation in Maine. The tribe is dealing with PCB contamination of rivers and lakes on tribal land from a nearby Army surplus salvage yard. TOSNAC has provided education to the tribe on the impacts of PCB contamination, conducted ecological and cultural risk assessments, and helped the tribe to compile its comments to the Environmental Protection Agency on this issue. At this particular site, TOSNAC worked with the Technical Outreach Services for Communities (TOSC) staff from the Northeast HSRC to provide the Passamoquody with technical assistance.

In order to provide resources for future and current tribal environmental professionals, the GP/RM HSRC funds the Haskell Environmental Seminar Series (HESS). The purpose of HESS is to provide resources on environmental issues relevant to Indian Country, tribal colleges, environmental offices, and community programs. Of the 129 participants in the seminar program approximately 50 members are based at a tribal college or environmental program. Throughout its history, HERS has produced more than 20 video and satellite uplink programs in support of the seminar series. The seminar programs are used in classrooms at tribal colleges as teaching aids and are also used by tribal environmental offices as continuing educational materials. Only limited resources are available that feature Native American environmental professionals presenting information relevant to tribal environmental issues.

While tribal nations have great needs with respect to environmental challenges, the GP/RM HSRC framework has provided a mechanism for beginning to address them. Combining the cultural knowledge of a Native American educational institution with the technical knowledge of HSRC consortium institutions has opened a door to providing technical assistance to Indian Country.

FUTURE DIRECTIONS

The 2001 Annual Conference on Environmental Research has been set for May 22-24 at Kansas State University. This year's conference theme is "Environmental Challenges and Solutions to Resource Development, Production, and Use." Conference co-sponsors are U.S. Environmental Protection Agency, National Institute for Environmental Health Sciences, Mine Waste Technology Program, WERC, and several other organizations.

With the ever-increasing number of users of the Internet and, more specifically, the World Wide Web, center personnel plan to increase availability of center resources through this medium. Many center publications have already been put on the Web, including electronic publishing of the center's conference proceedings. Peer-reviewed papers are published in the electronic *Journal of Hazardous Substance Research*. Hypertext Markup Language (HTML) and Adobe Acrobat are utilized to publish the journal. Through use of electronic media, this document can be published quickly and inexpensively and has the capability to provide hyperlinks to references as well as graphics, video, and sound. These features can be used to allow users to run simulation models.

During the past 10 years, significant progress has been made in developing the capability of the consortium faculty to conduct research in support of Superfund and problems associated with contaminated soil. As a result, many more consortium faculty are actively conducting hazardous substance research now than before the center was established. These faculty are supported with center funds and/or funds from other sources. Because of technological developments associated with the research and growth in faculty expertise, there are more opportunities for site-specific projects. Some of these are funded through the center while others are funded directly.

The research activities conducted by center investigators are expected to have a positive impact on the environmental/geoenvironmental curricula at the consortium universities. Center investigators are planning to integrate findings from the past 10-year research activities into graduate and undergraduate curricula. Efforts to secure extramural funding to aid integration of research and education are underway.

PROGRAM SUMMARY

February 22, 1989 - September 30, 2000

HEAVY METAL CONTAMINATION OF SOIL/WATER

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Keefer	$54k/$0k	3 1990	Metal Recovery and Reuse Using an Integrated Vermiculite Ion Exchange-Acid Recovery System
Hansen, Stevens	$167k/$0k	89-09 1991	Optimal Bioreactor Design for Biological Removal of Mercury
O'Keefe, Watson	$129k/$0k	17 1991	Characterization and Treatment of Hazardous Materials from Metal Mineral Processing Wastes
Walton	$150k/$0k	89-19 1992	An Electrochemical Method for Acid Mine Drainage Remediation and Metals Recovery
Lewandowski	$96k/$0k	89-22 1992	Heavy Metals Removal from Dilute Aqueous Solutions Using Biopolymers
Faw	$78k/$0k	89-29 1992	Neutron Activation Analysis for Heavy Metal Contaminants in the Environment
Clevenger, Hinderberger	$224k/$0k	2 1992	Reclamation of Metal- and Mining-Contaminated Superfund Sites Using Sewage Sludge/Fly Ash Amendments
Pierzynski, Schwab	$94k/$0k	89-30 1992	Reducing Heavy Metal Availability to Perennial Grasses and Row Crops Grown on Contaminated Soils and Mine Spoils
Ghosh	$140k/$0k	4 1992	Removal of Heavy Metals from Hazardous Wastes by Protein Complexation for Their Ultimate Recovery and Reuse
Dollhopf	$132k/$0k	89-21 1992	Sulfide Size and Morphology Identification for Remediation of Acid-Producing Mine Wastes
O'Keefe, Cole, Watson	$206k/$0k	90-16 1994	Development of Electrochemical Processes for Improved Treatment of Lead Wastes
Banks, Hetrick, Schwab	$306k/$0k	90-11 1994	Impact of Soil Microflora on Revegetation Efforts in Southeast Kansas
Schnoor, Licht	$213k/$0k	90-05 1994	Innovative Treatment and Bank Stabilization of Metals-Contaminated Soils and Tailings Along Whitewood Creek, South Dakota
Pierzynski, Davis, Reddi, Erickson, Schnoor	$247k/$0k	92-05 1997	Use of Poplar Trees in Remediating Heavy Metal-Contaminated Sites
Lewandowski, Geesey, Roe	$283k/$0k	92-08 1997	Heavy Metals Removal from Contaminated Water Solutions
Schnoor, Licht, St. Clair, Just, Erickson	$214k/$0k	92-11 1996	Metals Soil Pollution and Vegetative Remediation

HEAVY METAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Munshower, Jennings	$270k/$0k	93-12 1999	Acid-Producing Metalliferous Waste Reclamation by Material Reprocessing and Vegetative Stabilization
Hong, Okey, Banerji	$239k/$0k	93-22 1997	Chelating Extraction of Heavy Metals from Contaminated Soils
Schwab, Banks, Erickson, Tracy	$401k/$0k	93-06 1998	Fate and Transport of Heavy Metals and Radionuclides in Soil: The Impacts of Vegetation
Hetrick, Pierzynski, Erickson, Govindaraju, Sweeney	$419k/$21k	93-07 2000	Vegetative Interceptor Zones for Containment of Heavy Metal Pollutants
O'Keefe	$336k/$23k	94-05 2000	Design and Development of an Innovative Industrial-Scale Process to Economically Treat Waste Zinc Residues

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Hunter, Culver	$28k/$0k	15 1990	Computer Method to Estimate Safe-Level Water Quality Concentrations for Organic Chemicals
Schlup	$60k/$0k	18 1991	Adsorption of Hazardous Substances onto Soil Constituents
Kross	$160k/$0k	16 1991	Removal of Nitrogenous Pesticides from Rural Well Water Supplies by Enzymatic Ozonation Process
Dickey, Shelton, Steichen, Barnes	$338k/$0k	89-31 1993	Alachlor and Atrazine Losses from Runoff and Erosion in the Blue River Basin
Ghosh	$218k/$0k	89-06 1992	Biodetoxification of Hazardous Solid Wastes by Staged Anaerobic Fermentation Conducted at Separate Redox and pH Environments
Parkin	$84k/$0k	90-04 1992	Biotransformation of Alachlor and Atrazine Under Denitrifying Conditions in Soil-Water Systems
Erickson, Fan	$224k/$0k	6 1992	Development of *In Situ* Biodegradation Technology
Illangasekare	$196k/$0k	89-01 1992	Distribution and Recovery of Refinery Waste Products in Groundwater Aquifers: Experimental Study and Model Evaluation

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Parkin, Gibson	$259k/$0k	5 1992	Feasibility of *In Situ* Anaerobic Bioreclamation of Mixtures of Toxic Chemicals: Feasibility of Using Genetically Engineered Bacteria to Degrade Trichloroethylene in Activated-Sludge Systems
Characklis, Jones, Cunningham, Lewandowski	$394k/$0k	89-23 1992	*In Situ* Bioremediation of Organic Groundwater Contaminants
Banerji, Bajpai	$323k/$0k	7 1992	Migration and Biodegradation of Pentachlorophenol in Soil Environment
Schnoor, Parkin	$349k/$0k	10 1992	Modeling Dissolved Oxygen, Nitrate, and Pesticide Contamination in the Subsurface Environment
Yanders, Kapila	$327k/$0k	9 1992	Time-Dependent Movement of Dioxin and Related Compounds in Soil
Glasgow	$141k/$0k	11 1992	Vadose Zone Decontamination by Air Injection
Schnoor, Licht	$246k/$0k	89-10 1994	Deep-Rooted Poplar Trees as an Innovative Treatment Technology for Pesticide and Toxic Organics Removal from Groundwater
Schnoor, Licht	$39k/$0k	R-1 1993	The Role of Deep-Rooted Poplar Trees in Adding Organic Carbon to the Soil for Pesticides and Toxic Organics Removal
Parkin	$135k/$0k	91-08 1994	The Effect of Redox Conditions on Transformations of Carbon Tetrachloride
Kapila, Armstrong, Puri	$282k/$0k	91-04 1994	Laboratory and Field Evaluation of Upward Mobilization and Photodegradation of Polychlorinated Dibenzo-P-Dioxins
Cunningham, Costerton	$306k/$0k	91-25 1994	Microbial Transport in Porous Media
Tracy, Davis, Erickson, Schnoor	$367k/$0k	90-13 1995	Modeling the Use of Plants in the Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances
Licht, Schnoor	$349k/$0k	91-03 1995	Riparian Poplar Tree Buffer Impact on Non-Point Source Surface Water Contamination
Parkin	$214k/$0k	91-07 1995	Formation and Transformation of Pesticide Degradation Products Under Various Electron Acceptor Conditions
Illangasekare	$477k/$0k	91-10 1997	Modeling for Design and Testing of Treatment and Remediation Technologies for Aquifer Soils Contaminated with Organic Waste Chemicals
Erickson, Fan	$269k/$0k	91-29 1996	Remediation of Soil Contaminated with an Organic Phase

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Coats, Anderson	$152k/$0k	93-05 1997	Use of Vegetation to Enhance Bioremediation of Surface Soils Contaminated with Pesticide Wastes
Kapila, Forciniti, Armstrong	$142k/$0k	93-16 1996	Laboratory and Field Evaluation of Upward Mobilization and Photodegradation of Polychlorinated Aromatics in Soil
Bajpai, Banerji, Puri, Zappi	$281k/$0k	94-08 1998	Remediation of Soils Contaminated with Wood-Treatment Chemicals (PCP and Creosote)
Gibson, Tracy, Kennedy	*	NCIBRD 1 1997	Use of C_2 to C_{18} Organic Acids and Selected Surfactants to Enhance Bioremediation of DNAPL-Contaminated Aquifers
Parkin,Schnoor, Alvarez	$416k/$21k	93-02 2000	The Role of Metallic Iron in the Biotransformation of Chlorinated Xenobiotics
Parkin	$198k/$13k	93-24 2000	Application of Anaerobic and Multiple-Electron-Acceptor Bioremediation to Chlorinated Aliphatic Subsurface Contamination
Segar	$204k/$11k	94-07 2000	Trichloroethene (TCE) Cometabolism in Fluidized-Bed Bioreactors
Schnoor, Burken	$475k/$21k	94-25 2000	Uptake of BETX Compounds and Metabolites by Hybrid Poplar Trees in Hazardous Waste Remediation
Davis, Erickson	$345k/$16k	94-27 2000	Plant-Assisted Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances: Experimental and Modeling Studies
Illangasekare	$521k/$26k	94-29 2000	Extension of Laboratory-Validated Treatment and Remediation Technologies to Field Problems in Aquifer Soil and Water Contamination by Organic Waste Chemicals
Miller	$158k/$0k	94-15 1998	Removal of Chlorinated Hydrocarbons from Contaminated Water Using Air-Sparged Hydrocyclone Technology
Doucette, Bugbee, Stevens	$504k/$124k	95-10 2000	Fate of Trichloroethylene (TCE) in Plant/Soil Systems: Evaluating Phytoremediation
Zhang, Comfort, Shea	$394k/$33k	95-32 2002	Simultaneous Transformation of Atrazine and Nitrate in Contaminated Water, Sediment, and Soil by Zero-Valent Iron-Promoted Processes
Schnoor	$323k/$24k	95-29 2000	Plant Enzyme Systems for the Phytoremediation of Chlorinated Aliphatics in Contaminated Soils
O'Connor, Brazos	$61k/$0k	89-17 1991	The Response of Natural Groundwater Bacteria to Groundwater Contamination by Gasoline in a Karst Region

*Funded through the Great Lakes/Mid-Atlantic Hazardous Substance Research Center

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Alvarez, Parkin, Schnoor	$150k/$150k	98-01 2001	Iron-Enhanced Bioremediation of Aquifers Contaminated with Chlorinated Solvents, Hexavalent Chromium, and Nitrate
Erickson, Davis	$180k/$180k	98-03 2002	Plant-Assisted Remediation of Soil and Groundwater Contamination by Hazardous Organic Substances: Experimental and Modeling Studies
Illangasekare	$114k/$114K	98-05 2001	Non-Aqueous Phase Waste Chemicals in the Subsurface: Site Characterization and Remediation
Simeonsson	$77k/$77k	98-08 2001	Changes in the Speciation and Biological Volatization of Environmental Arsenic as a Result of Phytoremediation of Hazardous Waste Sites
Reardon	$200k/$200k	SP99-1 2002	Transformation Mechanisms of High Molecular-Weight Polycyclic Aromatic Hydrocarbons in the Rhizosphere
Schwab, Banks, Leven	$84k/$84	SP96-Riley 2000	Field Validation of an Optimal Design Methodology for Vegetative Remediation of Sediments from the Central Vehicle Wash Facility, Custer Hill, Fort Riley, Kansas
Erickson	$150K/$50K	RTDF 2002	Data Management and Horticultural Evaluation of Field Sites for the RTDF Phytoremediation Field Test of Petroleum Hydrocarbon-Contaminated Soils

ANALYSIS/TREATMENT OF CONTAMINATED SOIL

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Walawender, Fan	$149k/$0k	12 1991	Thermochemical Treatment of Hazardous Wastes
Viswanath, Kapila, Clevenger	$462k/$0k	13 1992	Development, Characterization, and Evaluation of Adsorbent Materials for Waste Streams
Fan	$153k/$0k	1 1992	Experimental Study of Stabilization/Solidification of Hazardous Substances
Peyton, Anderson	$154k/$0k	89-14 1992	Simulation of Three-Dimensional Transport of Hazardous Chemicals in Heterogeneous Porous Media Using X-Ray Computer Tomography
Valentine	$172k/$0k	89-11 1994	*In Situ* Soil and Aquifer Decontamination Using Hydrogen Peroxide and Fenton's Reagent
Klabunde	$394k/$0k	92-03 89-26 1996	Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances

ANALYSIS/TREATMENT OF CONTAMINATED SOIL (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Comfort, Shea, McCallister, Powers	$294k/$0k	92-24 1997	Fate and Transport of Munitions Residues in Contaminated Soils
Dupont, Sorensen, Doucette	$439k/$0k	93-20 1998	Evaluation of Biosparging Performance and Process Fundamentals for Site Remediation
Faw, Shultis	$134k/$0k	94-02 1997	Application of PGNAA Remote-Sensing Methods to Real-Time, Non-Intrusive Determination of Contaminant Profiles in Soil
Dupont, Sorensen, Kemblowski, Smith	$62k/$0k	SP95-TCE 1996	TCE Attenuation in Groundwater in Severe Northern Climates
R.C. Sims	$430k/$13k	93-21 2000	Field-Scale Bioremediation: Relationship of Parent Compound Disappearance to Humification, Mineralization, Leaching, and Volatilization of Transformation Intermediates
Inskeep, Johnston, Wraith	$264k/$0k	94-09 1999	Effects of Surfactants on the Bioavailability and Biodegradation of Contaminants in Soils
Rice	$242k/$0k	94-11 1999	Contaminant Binding to the Humin Fraction of Soil Organic Matter
Tracy, Van Lent, Schaefer	$196k/$18k	94-12 2000	Development of a Systematic Methodology for Optimally Designing Vegetative Systems for Remediating Contaminated Soil and Groundwater
Kubichek, Iverson, Cupal	$329k/$0k	94-24 1999	Identifying Groundwater Threats from Improperly Abandoned Boreholes
Turner, Bulla, Skinner	$229k/$0k	94-26 1998	Biofilm Barriers for Waste Containment
Cunningham, Chen	$399k/$20k	93-11 94-28 2000	Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence
Klabunde	$354k/$117k	95-04a 2002	Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances in Air, Water, and/or as an Alternative to Incineration

WASTE MINIMIZATION

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Fan	$194k/$0k	14 1992	Computer-Aided Design and Control of Systems for Treatment of Hazardous Waste and Minimization of Waste Production
Fan	$179k/$0k	91-36 1996	Intelligent Process Design and Control for the Minimization of Waste Production and Treatment of Hazardous Waste

TRAINING AND TECHNOLOGY TRANSFER

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Gilliland, Kelly	$128k/$0k	1991	Hazardous Waste Management in Rural Communities in EPA Regions VII and VIII
Harbourt	$265k/$0k	1992	Introduction to Hazardous Waste Management
Hiskey	$68k/$0k	1992	Introduction to Waste Minimization Technology and Applications
Kross	$31k/$0k	1992	Remediation of Pesticide Spills: Technology Transfer to Volunteer Firefighters
Biles	$45k/$0k	1992	Technology Database
Edwards	$20k/$0k	1992	Transfer of Manufacturing Pollution Prevention Technology
Hayter	$52k/$0k	1992	Video Conference
Hayter	$35k/$0k	1993	Five-Center HSRC Training and Technology Transfer Conference
Grant	$65k/$0k	PRP	Superfund PRP Conference
Kelly, Keefer, Rohde, Woldt	$77k/$0k	TR92-03a 1995	A Short Course on Remediation of Contaminated Soils and Sediments
Dahab, Woldt	$78k/$0k	TR92-03b 1995	Development of Pollution Prevention Programs for Small Quantity Generators in EPA Regions VII and VIII
Niemeyer, Woldt, Dahab, Grisso	$38k/$0k	TR92-04 1995	Waste Management: Development of Pollution Prevention Educational Materials for Farms and Small Acreages
Grant	$141k/$0k	TR92-PI 1995	HSRC Technology Transfer Public Information Services
R.C. Sims	$212k/$0k	TR-LIBBY 1997	Libby, Montana, Superfund Site: Prepared-Bed Bioremediation in Buried Lifts as Affected by Oxygen Concentration in Soil Gas
Thurston	$54k/$0k	TR94-02 1995	Training to Advance Environmental Research in Lithuania
Cunningham, Warwood, Zelver	$53k/$0k	TR93-02 1996	Engineering Scaleup of *In Situ* Bioremediation Processes: A Workshop on Biotreatability

TRAINING AND TECHNOLOGY TRANSFER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Grant, Griswold	$804k/$0k	NAOMI 1998	Native American and Other Minority Institutions Program
Erickson, Leven	$402k/$6k	TR-01 2002	Conferences and Workshops
Hayter, Leven	$134k/$3k	TR-01 2002	HSRC Contribution Repository and Information Clearinghouse
Reddi, Leven	$360k/$14k	TR-01 2002	HSRC Newsletter, *HazTech Transfer*
J.L. Sims, R.C. Sims	$182k/$0k	TR93-07 1997	Guidance for the Use of Prepared-Bed Land Treatment as a Bioremedial Technology
Banks, Schwab, Govindaraju	$301k/$0k	D93-01 1997	Bioremediation of Petroleum-Contaminated Soil Using Vegetation
McDonald, Leven, Deines, Wigfall	$402k/$150k	SP93-01 2002	Technical Outreach Services to Communities Program, Technical Support to Brownfields
Leven, Grant	$638k/$0k	R2D2 1998	Research and Re-Education for Displaced Defense Personnel Program
Erickson	$37k/$0k	TR95-10 1998	Virtual Library
Reddi	$18k/$0k	TR95-11 1997	Environmental Data Technology Transfer Project
Leven, Godfrey Griswold	$142k/$10k	TR96-05 2000	Collaborative Environmental Seminar Series
Griswold, Brandon	$662k/$403k	TOSNAC 2002	Technical Outreach Services to Native American Communities
J.L. Sims	$81k/35k	TR97-07 2000	Development of a “State-of-the-Science and Technology” Report on Site-Characterization Technologies

RESEARCH PROJECT DESCRIPTIONS
May 18, 1995 - September 30, 2000

Vegetative Interceptor Zones for Containment of Heavy Metal Pollutants

B.A.D. Hetrick, University of Northern Iowa; and G.M. Pierzynski, L.E. Erickson, R.S. Govindaraju, P. Kalita, and D. Sweeney, Kansas State University

Project no.: 93-07

Goals: The following were objectives of this project:

- to assess optimum plant species for survival, growth, and containment of heavy metals
- to quantify the ability of mycorrhizal fungi to facilitate revegetation and plant tolerance to heavy metals
- to evaluate vegetative zones for dissipation and containment of heavy metal runoff and erosion
- to evaluate chemical changes in mine spoil material induced by the vegetation and soil amendments
- to develop a physically based model for the movement of heavy metals in the presence of vegetation

Rationale: In southeastern Kansas, heavy metals were mined until the middle of this century. The result of this mining activity is the presence of large piles of gravel tailings with extremely high levels of cadmium, lead, and zinc. The presence of these metals poses a serious environmental and health risk which led the U.S. Environmental Protection Agency to designate this area as a Region VII Superfund Site in 1985. In areas not designated as Superfund sites, a need also exists for development of economic strategies for containment of heavy metal contamination. Vegetation interceptor strips have been used extensively in agricultural settings to reduce surface water contamination by agricultural herbicides and pesticides. However, the ability of vegetation buffer strips to limit spread of heavy metal contamination in surface water has not been studied. The use of vegetation interceptor strips could represent an economical alternative with broad application to mine spoils and areas of acid mine drainage as well.

Approach: Revegetation of Superfund and non-Superfund areas will be undertaken to stabilize the sites and reduce wind and water erosion from the tailings. Previous research by these investigators and that of the Bureau of Mines has suggested that certain soil microorganisms, the mycorrhizal fungi, contribute significantly to and may be mandatory for survival and establishment of vegetation on mine spoils. Both the ability of various vegetation regimes to limit surface water erosion and spread of heavy metal contamination, and the ability of these vegetation regimes to act as interceptor strips for contamination uphill from the vegetation strips will be studied in this project.

Status: This project was completed in June 2000. Six treatments with four replications were installed in a field test in Galena, Kan. The treatments involved revegetation of chat, a lead/zinc mine waste material, with tall fescue grass. The chat was amended with cattle manure to provide plant nutrients. The treatments consisted of adding mycorrhiza fungi, periodic treatment with Benomyl fungicide to prevent mycorrhiza fungi, and neither adding nor preventing mycorrhiza fungi. Soil and plant samples were collected annually. Mycorrhiza fungi added to the soil did not thrive and there were no measurable effects on biomass production, ground cover, or tissue composition. Efforts to collect runoff from the plots were generally unsuccessful because rainfall rapidly infiltrated the chat. Ground cover measurements were the primary indicator of revegetation success. Ground cover peaked at 75% after one year for all treatments. Ground cover steadily declined to about 30 % in subsequent years. Major conclusions from this work are the promising results from mycorrhiza fungi treatment found in the

greenhouse did not transfer well to the field; long-term viability of vegetation is a concern. Uptake of cadmium and lead by fescue did not appear to present any significant threat of food-chain transfer.

Technology Transfer and Outreach: Results of this research have been presented at numerous professional meetings and articles have been published. The investigators have communicated with members of affected communities and remedial project managers who have expressed interest in understanding the beneficial effects of vegetation in metals-contaminated soil.

Keywords: heavy metals, interceptor zones, mycorrhizal fungi, Superfund, vegetation.

Design and Development of an Innovative Industrial-Scale Process to Economically Treat Waste Zinc Residues

T.J. O'Keefe, University of Missouri - Rolla

Project no.: 94-05

Goal: The primary goal of this project was to design and develop a hydrometallurgical flow sheet to treat waste zinc residues containing iron and other heavy metal impurities such as lead and cadmium. The resulting flow sheet is to be used at Big River Zinc Co., or any other industry desiring to treat similar wastes.

Rationale: A major problem faces the minerals industry in the form of huge tonnages of environmentally unacceptable zinc residues. Previously these oxidized dusts, which contain high iron and zinc contents with lead, cadmium, and other heavy metals, were precipitated in chemical forms acceptable for standard landfills. Under current laws, this practice will not be allowed and costs of compliance are expected to increase dramatically. In fact, it may even be necessary to reprocess all the wastes that have been stored and accumulated over the years. The technical challenge is to develop metallurgical and chemical processes to treat these hazardous wastes in an economically viable manner. The most serious technical impediment preventing treatment of these wastes is the inability to separate the iron from the zinc. The investigator on this project has developed a process, galvanic stripping, to separate the iron from the zinc. As the next step, it is important to develop unique in-line processes specifically for handling diversity in feedstock, particularly when certain categories of impurities are present in low concentrations. Many existing processes are basically sound, but supplementary unit processes must be developed to make them more amenable to treat impure metal wastes and residues in an economic fashion.

Approach: This project is being conducted in conjunction with Big River Zinc Co., where the commercial plant to treat 50 tons per day of residue will be located. Ultimately, this technology will be transferred to others in the industrial sector for use in treating a variety of similar wastes generated in the mining and mineral community. Research is being conducted in three areas. Process parameters needed to optimize the reduction of Fe^{+3} to Fe^{+2} are being evaluated. The type of aqueous stripping solution and design procedure alternative to be used to separate and recover the Fe^{+2} and produce the best, salable iron product are being determined. The influence of the various heavy metal impurities in the solutions are being identified and their distribution (aqueous vs. organic) and effect on subsequent iron and zinc recovery are being evaluated.

Status: This project was completed in June 2000. The two principal objectives of the project, to develop a specific flow sheet design for the treatment of oxidized residues and to obtain a better understanding of the mechanisms of the galvanic stripping process, have been realized. The preliminary economic analyses

are favorable and the work is projected to continue under the direction and with the support of Big River Zinc.

Technology Transfer and Outreach: Results from this research have been published in various technical publications. This project involves industrial participants from three different companies.

Keywords: heavy metals, extraction, flow sheet, galvanic stripping, zinc.

The Role of Metallic Iron in the Biotransformation of Chlorinated Xenobiotics

G.F. Parkin, J.L. Schnoor, and P.J.J. Alvarez, University of Iowa

Project no.: 93-02

Goal: This research investigates the hypothesis that both microbial and abiotic processes contribute to reductive dechlorination of xenobiotics in methanogenic incubations with elemental metals, such as iron, serving as an ultimate electron donor.

Rationale: Polychlorinated compounds such as carbon tetrachloride (CT) are known to be transformed via sequential reductive dechlorination by both abiotic and microbial mechanisms under anaerobic conditions. However, existing treatment processes that utilize reductive dechlorination suffer from several drawbacks including inefficient transfer of electrons from the ultimate electron donor to the chlorinated compound and slow rates of reaction, thereby resulting in possible accumulation of transformation products of equal or even greater toxicity. Elemental metals in aqueous solution can act as an energy source for methanogens via production of hydrogen. Using elemental metals as an energy source, reductive dechlorination of chlorinated compounds may proceed by three mechanisms:

(1) abiotic processes whereby electrons are transferred directly from the elemental metal to the chlorinated compound,
(2) microbial processes whereby electrons from H_2 that are involved in biosynthetic processes are diverted to the chlorinated compound, and
(3) microbial-catalyzed abiotic processes whereby electrons from the elemental metal are transferred to the chlorinated compound via biological electron carriers.

Approach: Experiments were conducted in batch and column-reactor systems. Initial studies investigated iron and carbon tetrachloride (CT). Various chlorinated organics are also being assayed. A hydrogen-utilizing, mixed, methanogenic culture was developed as an inoculum source for all experiments. Initial batch studies were performed to determine the general time-course that the reactions would follow. Inhibition studies using 2-bromoethanesulfonate (BES), a specific methanogenic inhibitor, addressed the role of methanogens. Analytes measured in headspace gas samples include CT, chloroform (CF), dichloromethane (DCM), chloromethane (CM), hydrogen, and methane. Subsequent, detailed, batch kinetic studies were performed and, where appropriate, analytes included ferrous iron, total soluble iron, CT, CF, DCM, CM, hydrogen, methane, and oxidation-reduction potential. The stoichiometry and kinetics of all pertinent reactions were determined. Electron balances were conducted to provide insight into important abiotic and biotic processes. Flow-through column experiments using adjustable-bed-length, glass chromatographic columns packed with steel wool were conducted to simulate long-term *in situ* treatment and to validate the kinetics determined in batch studies. A one-dimensional, finite-difference, numerical model is being developed to simulate the performance of the column reactors. The

model includes advection, dispersion and sorption, and the appropriate degradation kinetics as determined from batch experiments.

Status: This project was completed in June 2000. Investigators have established stock-mixed-culture reactors and two pure cultures of methanogens, and conducted a variety of batch, serum-bottle experiments with iron alone, and with iron in combination with pure and mixed cultures. Experiments suggest it is possible to control the rate and direct the products of contaminant degradation. Four column reactors were constructed and have been operating for more than two years. Two pilot-scale steel wool columns were installed at Dover Air Force Base in Delaware to field test the technology. Studies with PCE and 1,1,1 TCE have been conducted to assess the usefulness of methanogen-iron systems. A bacteria-free steel wool column fed a mixture of CT, perchloroethylene (PCE), 1,1,1 trichloroethane, and a biocide has been operated to study the abiotic removal of a mixture of these compounds. Steel wool column studies involving the abiotic conversion of PCE to ethene and studies with nitrates have been completed. Various aspects of this work will be continued with funding from the GP/HSRC (Project 98-1), DOE and the Iowa Biotechnology Byproducts Consortium (funded by a grant from USDA).

Technology Transfer and Outreach: A patent application has been filed for Fe(0)-based remediation. Investigators have made numerous presentations of this research at technical conferences. Results have been published in peer-reviewed journals.

Keywords: dechlorination, xenobiotics, heavy metals, iron.

Iron-Enhanced Bioremediation of Aquifers Contaminated with Chlorinated Solvents, Hexavalent Chromium, and Nitrate

G.F. Parkin, M.M. Scherer, and P.J.J. Alvarez, University of Iowa

Project no.: 98-01

Goal: This project continues the work completed in project 93-02. Research objectives are as follows:

1. To explore the applicability and limitations of zero-valent iron barriers to manage groundwater plumes containing mixtures of common pollutants.
2. To evaluate combined zero-valent iron and microbial treatment systems.
3. To determine how environmental factors, system upsets, and substrate interactions affect treatment efficiency and to evaluate the effect of microbial growth on the performance of zero-valent iron (Fe(0)) barriers.

Rationale: Experiments performed to date suggest that an integrated microbial-Fe(0) system holds great promise for treating a variety of redox-sensitive contaminants, including mixtures; that indigenous microorganisms can colonize Fe(0) surface, presumably to exploit cathodic depolarization, Fe(III) respiration, and bioremediation as metabolic niches; and that the Fe(0) surface area concentration is an important design variable to optimize microbial activity and prevent inhibitory effects when multiple contaminants compete for sites on the Fe(0) surface.

Approach: Column experiments were started in December 1999. Bromide tracer studies were done to establish a baseline for future determination of changes in porosity and permeability as a result of different treatments, bioaugmentation, or colonization by indigenous microbes. The columns have been continuously fed by a mixture of TCE, sulfate, hexavalent chromium, and nitrate since March 4, 2000. The contaminants are dissolved in synthetic groundwater. These columns are being used to investigate

how adding iron reducers or sulfate reducers to Fe(0) affects treatment efficiency. This effect will also be compared to the effect of microbial colonization by indigenous micobes that may colonize Fe(0). Six columns packed with different layers of porous media are being used.

Status: This project is in its first year. Contaminant concentration profiles have been determined along the lengths of all columns at different times. The profiles show extensive degradation of some pollutants, primarily in the Fe(0) layer.

Technology Transfer and Outreach: Investigators have made numerous presentations of this research at technical conferences. Results have been published in peer-reviewed journals.

Keywords: dechlorination, xenobiotics, heavy metals, iron.

Application of Anaerobic and Multiple-Electron-Acceptor Bioremediation to Chlorinated Aliphatic Subsurface Contamination

G.F. Parkin, University of Iowa

Project no.: 93-24

Goal: The goal of this project was to advance understanding of anaerobic and mixed-electron-acceptor bioremediation of chlorinated aliphatics to a level that full-scale evaluation of these processes is possible.

Rationale: The U.S. EPA Hazardous Substance Research Centers and national agencies such as the Department of Defense and Department of Energy have identified research on remediation processes for chlorinated aliphatic-contaminated subsurfaces as a high priority. A promising technique is use of *in situ* bioremediation, and full-scale evaluations of this process are ongoing at trichloroethene-contaminated sites. All of these efforts have focused on use of aerobic bacteria, particularly methanotrophs. However, aerobic bacteria do not degrade several of the chlorinated aliphatics of greatest concern. Unlike aerobic biological processes, anaerobic biotransformations of all chlorinated aliphatics occur. This lack of specificity, coupled with the fact that most contaminated aquifers are anaerobic, may make anaerobic bioremediation an alternative or supplement to aerobic processes.

Approach: This research focuses on three chlorinated aliphatics that are not degraded by aerobic bacteria: perchloroethene (PCE), 1,1,1-trichloroethane (1,1,1 TCA), and carbon tetrachloride (CT). If successful, field-scale evaluation of technologies developed in this research will be pursued. In order to accurately assess potential for anaerobic or combined electron-acceptor bioremediation technology, all experimental systems are operated under conditions similar to those observed in contaminated aquifers. Additionally, soil cores are obtained from contaminated sites as a source of organisms that are indigenous to contaminated areas. These cultures may be considerably different than those obtained from anaerobic digesters and may contain organisms particularly suited for chlorinated aliphatic degradation.

Status: This project was completed in June 2000. The research showed that chlorinated aliphatics are difficult to completely mineralize using a single anaerobic process. Sequential anaerobic-aerobic treatment demonstrated the ability to reduce chlorinated aliphatics to concentrations below the MCLs. Several anaerobic bacteria cultures were developed as part of the project. One showed the ability to transform higher concentrations of PCE at higher rates than the other two. Specific dechlorinating organisms were capable of transforming mixtures of chlorinated aliphatics.

Technology Transfer and Outreach: This project has been the subject of a poster presented at a technical conference, and two articles have been submitted for publication in a peer-reviewed scientific journal.

Keywords: anaerobic, bioremediation, chlorinated aliphatics, mixed-electron acceptor.

Trichloroethene (TCE) Cometabolism in Fluidized-Bed Bioreactors

R.L. Segar Jr., University of Missouri

Project no.: 94-07

Goal: The goal of this project is to develop a bench-scale, fluidized-bed bioreactor (FBBR) to degrade TCE in extracted groundwater. This study of FBBRs is expected to yield the high performance necessary for pilot or field testing.

Rationale: Our knowledge of organic-contaminant biodegradation has advanced from fundamental biochemical/microbiological studies to a stage of active treatment process development. Trichloroethene (TCE), once considered to be nonbiodegradable, can be cometabolized by microorganisms with oxygenase enzymes. The phenol-degrading organisms selected for this work readily form cohesive biofilms, which is a prerequisite for their use in biofilm reactors such as the fluidized-bed bioreactor (FBBR). Development of FBBRs for cometabolizing trace contaminants in extracted groundwater is attractive because they are compact, relatively simple to operate, and their use is widespread in several industries. Biological oxidation of TCE should be less costly than advanced chemical oxidation techniques that use combinations of ultraviolet light, ozone, and hydrogen peroxide. Ongoing research with bioreactors continues to yield improvements in performance as better operating strategies and configurations are tested. Studies with FBBRs, which will be conducted under this project, are expected to yield the high performance necessary for pilot or field testing.

Approach: A mixed culture of phenol-utilizing microorganisms enriched from domestic wastewater will be grown on sand to form bioparticles in a bench-scale FBBR. Reactor inlet conditions will be varied and TCE removal will be measured. Concentrations of phenol, oxygen, and trichloroethylene (TCE) will be determined at various points in the reactor to select inlet conditions or design variations that improve TCE removal. Several sizes and types of sand will be evaluated to increase biomass holdup and control biomass thickness. Facilitating spatial sequencing of bioparticles between growth and degradation zones will be an important factor in designing high performance FBBRs. High- and low-dispersion conditions in the reactor will be obtained by modifying the reactor inlet distributor. Periodic pulsing of phenol will be used in some experiments to increase TCE removal by temporal sequencing of substrates. A draft tube reactor will allow greater control over internal sequencing (via circulation) of bioparticles between phenol and TCE degradation. Performance of this innovative reactor type will be characterized in the same manner as the conventional type of FBBR.

Status: All controllable operational problems related to the bioreactor have been solved. Investigators have completed and evaluated abiotic TCE loss rates, oxygen delivery, and dechlorination effectiveness of the new reactor configuration and feed system. Work has also included characterization of the phenol growth period for fresh and reused 30/35 garnet sand to determine the duration of the start-up and regrowth period, start-up procedures and substrate requirements, and the resulting biomass. Conductivity tracer test data has also been obtained, completed, and evaluated for the 1995 FBBR experiments, including the effect of effluent recirculation on TCE removal and quantification of detention times and

dispersion numbers for representative experiments. Investigators have completed and tested a numerical biofilm reactor simulation model for cometabolism. Time-course TCE feeding experiments have been completed for evaluating TCE removal with 30/35 garnet and for verification of variable phenol loading effects observed in prior experiments. Work has also included development of a technique for in-bed sampling of bioparticles and water, which resulted in obtaining phenol and biomass profiles within the bed. Dominant microorganisms in the reactor effluent have been identified. In batch studies, the abiotic reaction rate of various reactor sands with TCE and PCE under oxic and anoxic conditions was assessed. Future plans include design, fabrication, and troubleshooting of a dual-chamber reactor, as well as reactor operation and measurement removal. The overall objective of additional research is to determine operating conditions that will sustain a high removal rate for TCE for a prolonged period of time. This project is in its fifth year.

Technology Transfer and Outreach: This research has been the subject of a master's thesis at the University of Missouri-Columbia. Results of this research were presented at the May 1999 HSRC conference. Other technology transfer efforts will be made as research progresses.

Keywords: trichloroethene, cometabolism, fluidized-bed bioreactors, chlorinated solvents, water.

Uptake of BTEX Compounds and Metabolites by Hybrid Poplar Trees in Hazardous Waste Remediation

J.L. Schnoor and S.C. Lang, University of Iowa

Project no.: 94-25

Goal: The goal of this research was to determine feasibility and efficacy of vegetative bioremediation, specifically poplar trees, at sites contaminated with benzene, toluene, ethylbenzene, and xylene (BTEX) compounds.

Rationale: Vegetative remediation has become a promising, inexpensive, publicly accepted, and innovative technique for cleaning contaminated hazardous waste sites. This technique is best suited for sites of shallow contamination that are in the zone of impact for deep-rooted poplar trees. BTEX contamination is ideally suited for vegetative remediation. Being light, nonaqueous-phase liquid (LNAPL) contaminants, BTEX compounds are often located near the surface at hazardous waste sites. BTEX contamination is also ubiquitous in today's environment, and many of these sites are located in rural and abandoned areas where little money is available for more expensive traditional remediation.

Approach: This research explores whether vegetative remediation with poplar trees is a fundamental approach for remediation of BTEX-contaminated sites. Poplar uptake of BTEX compounds is being monitored and translocation within plant tissues is studied. Plant tissues and aerial compartments are examined to measure accumulation in plant tissues and volatilization from leaf surfaces, respectively. Poplars are widely adapted to a wide variety of temperate and boreal environments; they are fast growing, hardy, and easily reproduced from parental cuttings; they are easily rooted at variable and great depths; and they have been successfully grown from tissue cultures.

Status: This project was completed in May 2000. The study yielded results on four objectives. The capacity for uptake and translocation of BTEX compounds and other volatile organic compounds (VOC) by poplar trees was evaluated. It was demonstrated that a wide variety of organic chemicals are taken up and translocated in hybrid poplars using a series of radio-labeled chemicals in the laboratory. Structure

activity relationships (SAR) were formulated to determine which chemicals are best treated with vegatative remediation. Octanol-water partition coefficients were the best predictor of plant uptake found. The effects of root sorption and transpiration of VOC chemicals in a vegetative remediation treatment site were quantified. Sorption of substituted benzenes and other compounds was determined using root concentration factors (RCF). It was concluded that the Briggs root concentration factor (RCF) is somewhat misleading because some classes of compounds (nitroaromatics, phenols, and aromatic amines) are tightly bound to roots and not translocated. The impact of root exudates and oxygen transfer on microbial degradation/mineralization was evaluated. Several chemical and physical methods for passively supplying oxygen to the root in contaminated soils were examined in the greenhouse using site soils. Studying the root densities suggests that a supply of oxygen in the smear zone-soils is the most effective way to increase the amount of roots produced by a hybrid poplar. The technology was transferred to a two-acre site. This site was used for a demonstration and greenhouse study for Unocal and Ashland Chemical Corporation.

Technology Transfer and Outreach: This research has been the subject of several published articles. There have also been several presentations of this research at technical conferences. Technology transfer to two field sites is in progress.

Keywords: vegetative remediation, poplar trees, BTEX, soil, plants.

Plant-Assisted Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances: Experimental and Modeling Studies

L.C. Davis and L.E. Erickson, Kansas State University

Project no.: 94-27 , 98-03

Goals: There are four main objectives for this project. Experimental systems to improve oxygen availability for enhanced aerobic biodegradation will be developed. Transfer of contaminants through plants will be monitored. A mathematical model to describe fate of water, contaminant, root exudes, plants, microbes, and oxygen in laboratory and field systems will be applied. This technology will be applied to one or more field sites by working with professionals elsewhere. New funding since May 1998 emphasizes issues of concern during aircraft operations and de-icing.

Rationale: Much of the population in U.S. EPA Regions VII and VIII relies on groundwater for its potable water, but many groundwater aquifers within this region have been contaminated with hazardous organic chemicals. Such chemicals may be by-products of agricultural and industrial production, or may have leaked from fuel storage tanks or ruptured soil liners at disposal sites. Soil contamination involved in these types of problems is often very dispersed so that conventional soil and groundwater remediation techniques would be very expensive or, in some cases, impractical. Plants can play an important role in remediating soil and groundwater contaminated with organic substances. To put this new technology to effective use, we need to better understand and predict effects that plants have on soil and groundwater remediation, so that effective planting and management plans can be developed.

Approach: Previously a prototype system has been built by these researchers and used for study of bioremediation of groundwater assisted by plants. Based on experience with the prototype system, a new system has been constructed with more but shorter path-length channels and a depth of 60 cm. It permits introduction of controlled amounts of air into the soil, either above or below the water table, in two of the channels. By use of evolutionary operation design, performance of the system will be optimized to

minimize air input and maximize degradation of target substances. Material balance measures are used to determine the fate of target substances. Potential intermedia transfer is monitored by FTIR measurements on the gas phase above the growing plants. Changes in contaminant concentration in the groundwater are monitored by headspace gas chromatography or FT-IR of aqueous samples. The groundwater flow and transport model is used to model behavior of contaminants in the new system under several experimental conditions. The model will be further refined to improve the fit of predicted and observed behavior. It will then be applied to field situations where monitoring wells are in place, such as near landfills.

Status: Three years of experiments on treating TCE-contaminated water with alfalfa showed decreasing levels of TCE escaping to the atmosphere through the soil. Similar results were achieved with sunflowers and a simple model was presented at the 1999 annual conference explaining these results, which were consistent with other studies treating TCE with poplar cuttings. Three cycles of experiments with MTBE have been completed. Research has shown that adsorption of contaminants within the plant must be considered to accurately describe transient contaminant fluxes through plants. Studies on the jet fuel JP-8 and on de-icers have been done. Jet fuel experiments were done with alfalfa and horseradish plants. De-icer experiments were done with hydroponically grown sunflowers. Corrosion inhibitors in de-icing fluids appear to inhibit root growth of plants. Improving analytical detection of the corrosion-inhibitor methylbenzotriazole took considerable effort because it is reactive with metals, including the HPLC system used for analysis. Studies have continued using sunflowers and fescue grass. Two papers by Muralidharan were publised in the *Journal of Hazardous Substance Research*, fully documenting the modeling efforts for this research. The researchers have worked with the Riley County engineering staff to develop plans for control of leaching through the use of plants and trees. The researchers have also worked with two private corporations to design plant-based remediation for sites in the Kansas City area. The fate of the corrosion-inhibitor benzotriazole in soil in the vicinity of plants is a high priority and is being pursued. Future work will focus on developing the soil model for a reacting system to predict the development of anaerobic conditions and to assemble a package of modeling programs that follows the contaminant from groundwater through the plant and into the atmosphere. This project is in its seventh year.

Technology Transfer and Outreach: Results have been presented to consultants, regulators, and other researchers at workshops and conferences. The investigators have visited field sites and provided recommendations to responsible parties and regulators regarding applications of vegetation for specific problems. Publications have been prepared for peer-reviewed scientific journals and for regulators and consultants.

Keywords: plants, soil, groundwater, alfalfa, poplar trees.

Extension of Laboratory-Validated Treatment and Remediation Technologies to Field Problems in Aquifer Soil and Water Contamination by Organic Waste Chemicals

T.H. Illangasekare, University of Colorado

Project no.: 94-29

Goal: The primary goal of this research was to develop and implement systematic procedures for applying, in the field, treatment and remediation technologies for jet fuel and de-icing compounds that have been developed in the laboratories, taking into consideration the complexities which are encountered in the field.

Rationale: The primary hypothesis is that natural variability of soil characteristics and variability due to nonaqueous-phase liquid (NAPL) entrapment result in preferential flow of water and treating agents. These constraints to flow and delivery of treating agents alter effectiveness of treatment schemes in the field. This research will attempt to identify the basic processes affected by these complexities and determine the parameters that control the behavior at the field scale.

Approach: A systematic procedure to extend to the field the knowledge gained through experimentation at the laboratory scales of pore, cell, column, and soil flumes will be developed. Laboratory research, modeling, and field investigations will focus on issues related to transport; entrapment; recovery; dissolution; fingering; physical, chemical, and thermal mobilization; blob dispersion to increase dissolution, etc., which are of fundamental importance in developing remediation technologies. Laboratory experiments in cells, columns, and large tanks will be continued to identify basic parameters which need to be upscaled to field problems. Some of the parameters that have been identified for study include hydraulic conductivity, capillary pressure versus saturation, relative permeability, entry pressure, pore-size distribution, dispersivity, sorption coefficient, mass transfer coefficients, and dissolution parameters. Investigators will use chemical mixtures to look at multicomponent mass transfer and realistic field soils. Sites in Kansas, Colorado, Wyoming, and Louisiana will be selected for field studies. Once effective parameters are identified, techniques will be developed to obtain these in the field.

Status: This project was completed in October 2000. Behavior of nonaqueous-phase liquids (NAPLs) found at manufacturing and industrial sites, especially the dissolution of entrapped NAPLs into groundwater, was studied. The use of conservative tracers to estimate the effective flow and transport parameters of NAPLs was demonstrated. A fundamental understanding of the efficacy of partitioning in the subsurface was gained by this research. New prediction models that take into account the flow dimensionality and up-scalable dissolution lengths were developed to simulate natural and surfactant-enhanced dissolution. An *in situ* treatment process using surfactants and heat to enhance solubilization and mobilization of entrapped chemical wastes in the subsurface was investigated. Preliminary findings allowed the researchers to develop a proposal to the Department of Defense to test this remediation technique at a field site. Two field investigations relating to this work have been funded by other sources, Union Pacific Railroad and Chevron.

Technology Transfer and Outreach: Numerous lectures and workshops have been conducted to share the results of this research with consultants, regulators, and other researchers. The principal investigator has conducted EPA-sponsored workshops, prepared chapters for two different books, and given several lectures about this research project. The principal investigator has also engaged in collaborative research with other universities in the U.S. and Europe. Several articles have been published in refereed journals.

Keywords: aquifers, organic chemicals, nonaqueous-phase liquids, remediation.

Field-Scale Bioremediation: Relationship of Parent Compound Disappearance to Humification, Mineralization, Leaching, and Volatilization of Transformation Intermediates

R.C. Sims, Utah State University

Project no.: 93-21

Goal: The overall goal of this research effort is to provide new information about the distribution of polycyclic aromatic hydrocarbon (PAH) biotransformation products in the solid and liquid fractions of soil. Another goal is to determine the effect of environmental variables and amendments on biodegradation of PAH and chemical association with solid and liquid phases.

Rationale: There is a lack of information concerning transformation intermediates regarding their reactions, measurement, and management in soil bioremediation systems. Specifically, the role of the humification process is currently unknown in prepared-bed systems. Disappearance of compounds within soil treatment systems does not necessarily indicate mineralization or detoxification of toxic and hazardous compounds. The formation of intermediates and the fate of those intermediates with regard to association with the soil solid phase in the process of humification is an area where information is needed in order to fully assess the treatment effectiveness of soil bioremediation systems. Development of information addressing behavior of transformation intermediates with an emphasis on characterizing humification of target organic chemicals would increase our understanding of soil bioremediation processes with regard to protection of public health and the environment. Based on information developed in this project, techniques for management of the humification process may be identified and applied to soil bioremediation systems.

Approach: The approach in this project is to use samples of soil taken from field-scale bioremediation systems treating creosote- and creosote/PCP-contaminated soil. Soil samples have been taken from the Champion International Superfund site in Libby, Montana, and the McCormick/Baxter site in Stockton, California. The first activity involves identification of PAH and PCP transformation products that occur in soil systems and that can be extracted. The second activity involves chemical mass balance and toxicity determinations during treatment and development of instrumental approaches for evaluating humification. The approach is used to generate information concerning (1) chemical bonding of PAHs and PCP/intermediates with the soil solid phase, humic and fulvic acid fractions, and leachate; (2) effects of environmental variables (light, temperature, soil moisture) on the humification process; and (3) effects of amending soil with electron acceptors on humification, mineralization, and volatilization.

Status: Researchers have isolated and characterized four bacterial strains responsible for mineralization in soil from the Libby site. Sequestration/humification studies using the MIBK fraction procedure are complete. A journal article describing these experiments and results has been published. Studies on the effects of alternate electron-acceptor additions on mineralization of pyrene are complete and a manuscript has been prepared for publication. Experiments to evaluate the effects of moisture, temperature, and addition of electron acceptors on the fate of target compounds are complete and a manuscript has been prepared for publication. Toxicity assay results for aqueous-phase samples have been performed and indicate that toxicity decreases with time during biological treatment. PAH and PCP intermediates have been characterized. Chemical mass balance experiments have been performed for PCP. The effect of oxygen concentration on pyrene and PCP transformation and biodegradation, and on abiotic transformation, has been studied. Results of these studies have been published in refereed journals. Experiments with electron-acceptor additions to McCormick/Baxter site soil were completed. Experiments of PCP reactions with manganese oxides as a function of pH and redox potential have been completed. Fugacity modeling proved to be useful and was used to guide analytical determinations of PAH intermediates. A new test to evaluate the effectiveness of mixing treated soil with untreated soil has been initiated. The project has been expanded to include cooperation with the U.S. EPA Cincinnati NRMRL concerning treatability and technology transfer of “presumptive remedies” for soil contaminated with wood preservative. Plans for future work include studying the application of adapted/acclimated soil to unacclimated soil to evaluate the management option of incorporating untreated soil into treated soil to increase the rate of bioremediation. Field-scale studies on toxicity reduction rates are planned, as well as

continued analytical work regarding intermediate characterization. This project has been completed; however, researchers recently received access to the DOE-funded advanced light source synchroton, which will allow them to further explore the process of microbial PAH degradation and bound-residue formation.

Technology Transfer and Outreach: Results from this project are being used at a site in Libby, Montana. Findings from this site are being applied to the Montana Pole Superfund Site. Techniques developed through this project will be applied to other sites as well. Presentations of this work have been incorporated into the U.S. EPA technology transfer course on natural attenuation. This course has been conducted 10 times throughout the United States.

Keywords: bioremediation, humification, mineralization, leaching, volatilization, intermediates.

Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence

A.B. Cunningham, Montana State University, and B.M. Chen, University of Wyoming

Project no.: 94-28, 93-11

Goal: The overall goal of this project was to understand factors which promote or retard biomass accumulation in porous media with an intent to apply such understanding toward prediction and beneficial manipulation of permeability and mass transport properties.

Rationale: A concept which appears promising in the manipulation of biological and chemical processes for remediation of subsurface hazardous waste sites is the creation of biobarriers for containment and remediation of soil and groundwater contaminated with organics and heavy metals. Biobarriers are formed by stimulating the growth of microbial biomass. The free-pore space-flow paths through porous media are plugged by the microbial biomass, thereby reducing permeability and mass transport. Selective plugging of permeable strata is currently being explored as a means of preventing contaminant migration of groundwater contaminants from hazardous waste sites. Penetration of bacteria through porous media varies between extensive penetration of ultramicrobacteria and formation of plugging biofilms on the proximal formations by well-fed cells of the same organisms. Investigators will attempt to use simple nutritional differences to deliver bacteria to any location in the subsurface environment to resuscitate and either plug the formation or carry out specific biodegradation.

Approach: Test organisms will include a *Klebsiella pneumoniae,* as well as these same bacteria starved for ultramicrobacteria size. Experimental objectives will be carried out using a series of flowing packed-bed reactors, including flat-plate flow cells and packed columns. Procedures will be developed for applying bacterial inoculum, along with subsequent resuscitation with nutrients, so as to produce controlled reduction of porous media permeability and dissolved oxygen transport. Researchers will quantify and model temporal and spatial variability in the biofilm accumulation (and mass transport) using bioluminescence. Finally, a mathematical model for biofilm accumulation and corresponding permeability and dissolved oxygen gradients in porous media will be developed and evaluated.

Status: This project was completed in May 2000. Investigators have determined quantitative relationships that describe biomass accumulation and corresponding mass transport properties in saturated porous media. Methods for controlling biobarrier thickness, longevity, and degree of permeability reduction have been established. The efficacy of using biobarriers to create and maintain

anaerobic conditions has been assessed. Funding from a major oil company funded a pilot project that tested the feasibility of installing a biobarrier at a field site to control hydrocarbons leaching from the groundwater system into a nearby river. This project revealed the presence of at least three strains of bacteria capable of producing large amounts of extra-cellular polymer to support biobarrier formation. Methods for injecting starved bacteria into the subsurface and recovering them *in situ* have been developed. Up to 80 percent recovery has been realized. These methods will substantially reduce the cost of inoculum preparation in the field. Experiments with the lysimeters constructed for this project indicate that barriers built under normal field hydraulic-gradient conditions can be maintained indefinitely without incurring significant costs for injecting additional nutrients. Experiments simulating radial-flow conditions in the field have been completed and indicate that biobarrier formation methods are effective under radial-flow conditions. A second set of radial-flow reactor experiments has been run to develop protocol for extending and maintaining the biobarrier above the ambient water table. A mathematical model has been developed and improved so that the effects of thick biofilms on the plugging of the pores can be simulated. Multispecies biofilm experiments have been completed. The project team worked with MSE Technologies to construct a field demonstration lysimeter facility in Butte, Montana. A flow field was established over a 180-foot dimension. As the 180-foot biobarrier formed, hydraulic conductivity reductions of over 99% were measured across the barrier. This work will continue with industry funding.

Technology Transfer and Outreach: This research has been published in the chapters of two different books and in various conference proceedings and journals. A patent disclosure was filed in 1996.

Keywords: biofilms, hydraulic conductivity, ultramicrobacteria, waste containment, barriers.

Plant Enzyme Systems for the Phytoremediation of Chlorinated Aliphatics in Contaminated Soils

J.L. Schnoor and C. Just, University of Iowa

Project no.: 95-29

Goal: The goal of this project was to determine the feasibility of using plants to remediate soils contaminated with chlorinated aliphatic compounds by studying their uptake, translocation, and resulting metabolites, and by investigating plant enzyme capabilities to degrade these compounds.

Rationale: Based on previous research, there are several potential mechanisms for the uptake and transformation of TCE in a plant-soil system. Understanding these mechanisms will lead to improved remediation techniques.

Approach: Investigators will research potential mechanisms and the feasibility of phytoremediation to enhance the cleanup of TCE-contaminated sites. Studies will examine the uptake of TCE or its metabolites into the roots, xylem transfer of the compounds to the leaves, volatilization from the leaves, foliar uptake of TCE from air, phloem transfer, and bound-residue formation throughout the plant.

Status: This project was completed in September 2000. Progress was made in achieving the three objectives. The uptake, translocation, and accumulation of TCE and related chlorinated aliphatics in various plants were evaluated. The relative phytotoxicity of various chlorinated aliphatic compounds to hybrid poplar trees and tissues was determined. Progress was made in studying plant enzyme activity and a screening methodology to enhance phytoremediation of TCE-contaminated soils.

Technology Transfer and Outreach: The investigators have transferred the technology to a field site at the AVX Corporation in Myrtle Beach, South Carolina. The effort is being used as a demonstration for EPA and South Carolina regulators on the effectiveness of phytoremediation in such applications. A U.S. patent application has been made. Presentations of the results of this research have been made to consultants, government staff, and other researchers at several different technical conferences. Research results have been published in two peer-reviewed journals.

Keywords: plant enzyme systems, chlorinated aliphatic compounds, TCE, phytoremediation.

Simultaneous Transformation of Atrazine and Nitrate in Contaminated Water, Sediment, and Soil by Zero-Valent Iron-Promoted Processes

T.C. Zhang, P.J. Shea, and S.D. Comfort, University of Nebraska

Project no.: 95-32

Goal: The objectives of this project are to 1) develop and test zero-valent iron-promoted processes for simultaneous remediation of atrazine and nitrate in contaminated ground and surface water, sediment, and soil; 2) investigate the technical and economic feasibility of the iron-promoted systems for above-ground and *in situ* remediation of ground and surface water, sediment, and soil contaminated with atrazine and nitrate; and 3) elucidate mechanisms of transformation and determine kinetics associated with the proposed processes.

Rationale: Preliminary studies demonstrate the potential use of iron-promoted processes to remediate ground and surface waters contaminated with atrazine and nitrate.

Approach: Investigators are using zero-valent iron-promoted processes, employing fine-grained iron metal as a reducing agent, to simultaneously transform atrazine and nitrate found in contaminated water, sediment, and soil.

Status: This project was closed in September 2000. Initial batch tests are complete and the column reactors have been fabricated. Experiments were conducted to determine the feasibility of using the iron-promoted process to remediate waters containing 20 μg atrazine L^{-1} and 20 mg atrazine L^{-1}. The distribution of atrazine and its transformation products has been determined using ^{14}C-ring-labeled atrazine. The mechanisms of nitrate removal in the iron-water system were investigated and results were verified. The abiotic transformation of nitrate using iron and electrokinetics was explored also. Experiments to evaluate the iron process coupled with biofilms have been completed. Results indicate that the iron-promoted treatment wall coupled with biofilm processes is efficient for *in situ* remediation of nitrate- and atrazine-contaminated groundwater for quite a long period of time. Experiments investigating nitrate and atrazine removal under different pH/redox conditions have been performed. The results indicate that the formation of magnetite may be a critical step in the nitrate reduction process. A series of adsorption/desorption studies with atrazine and iron has been conducted. Experiments to determine atrazine removal from solution and transformation after prolonged exposure to zero-valent iron are continuing. The researchers have collaborated with two environmental consulting companies at a demonstration site. The results indicate the effectiveness of zero-valent iron in combination with acetic acid and/or aluminum sulfate in reducing concentrations of atrazine and five other pesticides in the soil.

Technology Transfer and Outreach: Investigators have published articles in peer-reviewed scientific journals, presented results at numerous technical conferences, and incorporated the technology into

university classroom instruction. In addition, the investigators are disseminating the project findings within EPA Regions VII and VIII.

Keywords: atrazine, nitrate, groundwater, surface water, contamination, zero-valent iron-promoted processes.

Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances in Air, Water, and/or as an Alternative to Incineration

K.J. Klabunde, Kansas State University

Project no.: 95-04a

Goal: The goal of this project is to develop a one-step process that uses ultra-high-surface-area metal and metal oxide particles for destroying hazardous substances, including chlorocarbons, chlorofluorocarbons, organophosphorus, nitrogen, and sulfur compounds.

Rationale: Zinc is an effective metal in the dehalogenation of chlorocarbons that contaminate groundwater. This reagent can help efficiently remove chlorinated hydrocarbons with high capacity. Trichloroethylene (TCE), one of the most common pollutants, was found to be degraded by zero-valent zinc in aqueous solutions under neutral pH conditions.

Approach: To gain more insight into the dominant pathway and general mechanism involved, important intermediates of different systems were investigated. A variety of techniques were used to analyze the gaseous, aqueous, and solid phases. Ethylene, ethane, and monochlorinated hydrocarbons were identified as the hydrogenation or elimination products. Dehydrochlorination or beta-elimination was also evident by acetylene appearance. Other related C_1 or C_2 compounds were produced in much smaller yields. Under similar conditions, experiments were also performed to assess the mass balance and carbon distribution. Both kinetic and mechanistic aspects were explored. In anaerobic environments, zinc generally provides electrons to organic molecules and further promotes hydrocarbon formation. In a separate study, pH changes in Zn and Sn reductive systems were measured and compared. The catalytic effects of Ag^0 and Pd^0 promoters were also studied.

Status: At the beginning of this project, high-surface-area zinc metal particles were used to destroy chlorocarbon contaminants in water. The understanding about the reactions of aluminum (Al), zinc (Zn), and tin (Sn) zero-valent particles with chlorocarbons in water improved a great deal, but these reactions must be cataloged for all reactive metals in order to extend the technology to field applications. Tests on a variety of core/shell nanoparticles with shells of transition metal oxides and cores of magnesium oxide (MgO) and calcium oxide (CaO) have been performed. The purpose of these tests is to help determine which combinations of metal oxides are most effective overall for treating contaminated water, and whether larger and less expensive microparticles can substitute for nanoparticles. Studies of doping zinc with silver, palladium, and gold indicate that reactivity towards carbon tetrachloride in water is increased significantly. New metal oxide nanoparticle formulations have been prepared and characterized this year, including MnO, CuO, NiO, and ZnO. Several of these formulations have proven very effective in adsorption of toxins, and they bring a photochemical degradation possibility as well. Three patents have been obtained and work continues to transfer this technology to the private sector via a partnership with a small business. This project is in its fifth year.

Technology Transfer and Outreach: The investigators are working in partnership with a small start-up company to transfer the technology to the private sector. Investigators continue to present papers at meetings and technical conferences, publish papers, and answer many inquiries regarding this technology.

Keywords: nanoscale, nanoparticle, DAT, destructive adsorption technology, metal oxide.

Nonaqueous-Phase Liquid Waste Products in the Subsurface: Tools for Remediation Design, Regulation, and Site Characterization

T.H. Illangasekare, Colorado School of Mines

Project no.: 98-05

Goal: The goal of this project is to compile and evaluate existing information on the behavior of nonaqueous-phase liquid (NAPL) chemical wastes in the subsurface. The objectives are to develop methods for characterization of sites for the purpose of obtaining the necessary data for accurate simulation of contaminant fate and transport, and to validate multiphase models that can be used in EPA's regulatory programs for remediation design and site characterization.

Rationale: Compiling and evaluating existing information will improve the effectiveness and efficiency of future research efforts.

Approach: The project is organized with eight tasks: compilation of existing knowledge, assembly of a set of multimedia test codes, surveying and compiling laboratory data sets, generating a laboratory data set for code validation, compiling field data for demonstration case studies, developing standard procedure for validation/verification, development of characterization methods, and development of a state-of-the-science report on validation/verification.

Status: This project is a continuation of a previous project. A review of existing information and data suggests that accurate prediction of NAPL flow in the subsurface is not possible using numerical models. A set of multimedia models to assess NAPL behavior in the subsurface was assembled and reviewed. A literature review showed that it would be difficult to obtain laboratory data that met the selection criteria. Efforts on compiling laboratory data focused on the past research of the investigators. Laboratory data sets are currently being used to validate the models that have been assembled. Work continues on developing standard procedures for validation/verification of characterization methods.

Technology Transfer and Outreach: Investigators have published several articles in peer-reviewed journals. They have written articles for the proceedings of many conferences and made presentations about this work.

Keywords: NAPL, remediation, site characterization, regulation.

Changes in the Speciation and Biological Volatilization of Environmental Arsenic as a Result of Phytoremediation of Hazardous Waste Sites

J.B. Simeonsson, University of Iowa

Project no.: 98-08

Goal: The main objectives of this project are to determine whether phytoremediation of arsenic-contaminated soils results in a significant change in arsenic speciation and, specifically, whether volatilization of arsenic species is a significant outcome. Hybrid poplars are the plants under investigation in this study. If arsenic volatilization is determined to be significant, the secondary objectives of the study are to determine the chemical and physical conditions that either enhance or inhibit volatilization processes.

Rationale: Soil contamination by metals is a common problem at hazardous waste sites that can lead to contamination of groundwater supplies. Phytoremediation is a promising remediation process that can be used to treat contaminated soils. However, there is relatively little that is known about the environmental outcomes of the phytoremediation process, particularly with respect to metals and metalloids that may be volatilized by biological processes. There is laboratory evidence demonstrating that hazardous elements such as selenium (Se), arsenic (As), and antimony (Sb) can be volatilized at potentially significant rates by biological reactions mediated by microorganisms. The importance of these processes in contaminated environments and subsequent mobilization of these elements by volatilization has not been evaluated and needs to be addressed in order to understand the overall impact of phytoremediation activities. It is also important to evaluate volatilization because of the potentiality that it could pose an additional environmental complication in the form of airborne exposures to As and other elements.

Approach: Studies of As volatilization will be conducted in controlled environments at the University of Iowa. Poplar saplings contained in isolated enclosures will be exposed to varying amounts of soil-based arsenic. Volatilization of As will be monitored in collected air samples taken from the test chambers and tested for vapor-phase and particle-phase As species. Segregation of air in the chambers will be maintained in order to determine whether the volatilized As emanates primarily from the roots/soil and lower parts of the plants or from the foliar region of the plants. A major goal that will be achieved in these studies is the determination of the chemical composition of the As species that are volatilized and their relationship to the As content and As speciation in the soil environment. Arsenic volatilization will be investigated directly at a hazardous waste site known to be contaminated by As. Volatile and particulate As species will be collected in the field. Soil and plant samples will also be collected to study associations of levels and speciation of soil- and plant-based As and volatilized As at the site.

Status: This project is in its first year. Major accomplishments have been the development of an air-sampling and collection system, development of analytical measurement procedures suitable for detection and speciation of ultratrace levels of arsenic in air (particulate and vapor phase), soil and water samples and the initiation of plant growth experiments, and analysis of samples collected from the plant chambers. Future efforts will focus on performing laboratory-scale plant growth experiments with the next step being a transition from hydroponic to soil-based systems.

Technology Transfer and Outreach: Investigators have prepared an article for publication. They have made presentations about this work at three conferences. A patent disclosure on the measurement apparatus and method is being prepared.

Keywords: arsenic, phytoremediation

Transformation Mechanisms of High-Molecular-Weight Polycyclic Aromatic Hydrocarbons in the Rhizosphere

K.F. Reardon, E. Pilon-Smits, Colorado State University

Project no.: SP99-01

Goal: The main objectives of this project are to elucidate the mechanisms for enhanced removal of PAHs in the rhizosphere of certain plants, to understand the roles of plants and microorganisms, and ultimately to devise remediation strategies based on these findings.

Rationale: Attention needs to be focused on chemicals released by plant roots. Root exudate and root lysate are both considered a potentially important source of chemicals for rhizosphere microorganisms. The term "root-released chemicals" is used to include both mechanisms.

Approach: The specific tasks for this project include identifying plants with higher rates of PAH degradation; assessment of the relative importance of plants, microorganisms, and plant-microbe interactions; and assessment of root exudate effects on microbial PAH degradation and identification of highly active exudates for further testing. Research activities have been organized into the following three tasks: screen rhizospheres of 12 plants for enhanced PAH removal, assess contributions of potential PAH removal mechanisms (microbial growth, stimulation, gene induction, and enhanced PAH bioavailability), and develop a molecular biological method to test gene induction by exudate compounds.

Status: This project is in its first year. Screening for enhanced PAH removal in rhizosphere soil has begun. Texas City soil has been obtained to start screening experiments. A mini-microenfractionator was used to homogenize the soil to reduce pot-to-pot variabilities. Thirty-two plants of seven different species were placed in one-gallon pots for the screening experiment. The Texas City soil contains PAHs and metals at toxic concentrations. Experiments to assess the contributions of potential PAH removal mechanisms are planned and experiments of Type I (agar plates) and Type 2 (bioluminescence) have been conducted. Preliminary results indicate that root-released chemicals support the growth of PAH-degrading microbes. There is also preliminary evidence of induction of genes for PAH-degrading enzymes. Work on developing a molecular biological method to test gene induction by root-released chemicals is beginning.

Technology Transfer and Outreach: A paper was presented at the HSRC 2000 conference in Denver. Investigators plan to contact operators of PAH-contaminated sites to investigate the possibility of conducting field projects.

Keywords: PAH , rhizosphere.

Data Management and Horticultural Evaluation of Field Sites for the RTDF Phytoremediation Field Test of Petroleum Hydrocarbon-Contaminated Soils (RTDF)

L.E. Erickson and P. Kulakow, Kansas State University

Project no.: Research Technology Development Forum (RTDF)

Goals: The goal of this project is to test phytoremediation of contaminated soils at six to twelve locations to gather data in support of the use of phytoremediation and its acceptance by the regulatory community. The trials will compare petroleum hydrocarbon dissipation in vegetated soils and unvegetated soils for a three-year period.

Rationale: The EPA-sponsored Research Technology Development Forum (RTDF) for Phytoremediation, Total Petroleum Hydrocarbon (TPH) Subgroup has developed a protocol for a nationwide field test of phytoremediation of petroleum hydrocarbon-contaminated soils. This project will enter appropriate field sites into a testing program and develop a database of the field test results. Results of this project will provide valuable scientific information about the use of phytoremediation to clean up soils contaminated with petroleum hydrocarbons.

Approach: Data will be collected from the field sites and laboratories and sent to Kansas State University (KSU). The data will be cataloged, stored, and distributed in accordance with the data sharing and site confidentiality agreements arranged for this program. KSU will format all of the data into a common format to support data summary, statistical analysis, and reporting. Annual visits by KSU researchers will be made to several locations for the purpose of evaluating plant growth and development. Plant growth parameters will include vegetation coverage, species composition, aboveground biomass production, and plant-rooting characteristics such as root length and diameter. Soil analyses will be performed at each field site as needed. Analyses will include pH, nitrogen, potassium, and phosphorus. Initial sampling will also include soil texture, organic matter, available zinc, available iron, cation exchange capacity, and salt alkali. An annual report of research progress will be prepared for internal use by the RTDF. A separate public report will be prepared following recommendations from the RTDF.

Status: As of May 2000, 11 sites are entered into the RTDF trial. Ten of the sites have received regulatory approval to proceed with the trial. Nine sites have been planted. The RTDF committee has been meeting by conference call on a monthly basis. One of the field trials is at Fort Riley, Kansas. This site was planted on September 15, 1999. Site visits have been made to three other locations and root samples have been collected at two sites to document plant growth after one growing season. Future work on this project will include site visits and analysis of root growth at sites completing the first growing season, continued development of the database, participation in the RTDF conference calls, and assistance to RTDF participants, depending on need.

Technology Transfer and Outreach: Technology transfer for this project has included regular interaction with all project participants including representatives from EPA, DOD, industry, and universities. A poster abstract has been submitted for the Partners in Environmental Technology Technical Symposium and Workshop sponsored by SERDP and ESTCP. An annual report for use by RTDF participants was completed in March 2000. The annual report was presented at the Phytoremediation: State of the Science conference in Boston, Mass., in May 2000. A summary of this report will be prepared for public release.

Keywords: phytoremediation, vegetation, soil, fate and transport.

TRAINING AND TECHNOLOGY TRANSFER PROJECT DESCRIPTIONS

May 18, 1994 - September 30, 2000

HSRC Technology Transfer Program

L.N. Reddi, R.B. Hayter, and B.A. Leven, Kansas State University

Project no.: TR-01

Goal: Core training and technology transfer activities integrate new information and technology, primarily from HSRC research activities, into use by public and private organizations. The center accomplishes this by hosting annual conferences and workshops; publishing newsletters, proceedings, and other documents; developing and maintaining an HSRC information repository; responding to requests for information and educational services; and administering competitively selected training and technology transfer projects. Center staff provide support to several special HSRC programs with important technology transfer components to ensure integration of results from concurrent HSRC activities and to learn of technology needs for future HSRC research efforts.

Rationale: Many barriers to rapid, cost-effective implementation of environmental research results and new technologies exist due to unique regulations, liabilities, and specific issues associated with environmental cleanup sites. A variety of technology transfer and training activities are necessary to adequately address the full spectrum of issues and audiences involved in cleanup situations.

Approach: The center maintains communication with its consortium members, more than 90 principal investigators, non-consortium institutions, government offices, and interested businesses and individuals through newsletters, press releases, the Internet, workshops, and conferences. To keep pace with changing issues, resources, and needs for technology transfer, greater emphasis is being placed on information exchange systems that will allow centers to address specific on-the-ground needs for this broad audience.

Status: Principal investigators on essentially all HSRC research and technology transfer projects continue to publish papers in technical journals, books, and conference proceedings. The center publishes this information in a less technical format for quick review by consultants, industry, and regulators in newsletters such as *HazTech Transfer* and *Centerpoint*, as well as in periodic e-mail bulletins (*E-Briefs*), guidebooks, and video productions. *HazTech Transfer* was published quarterly for eleven years and distributed in hard copy to more than 5,000 addressees, with readership estimated at 20,000 per issue. The last issue of *HazTech Transfer* was published in October 2000. Many of these center and other non-center publications are maintained in the HSRC Information Repository at KSU, and can be accessed through the GP/RM HSRC World Wide Web site (http://www.engg.ksu.edu/HSRC). Every week the center receives many requests for information from individuals and groups of stakeholders. Responses to these requests range from simple verbal and e-mail messages to oral presentations on the collective thoughts of several HSRC researchers on specific technical issues. Center staff frequently make informational presentations to program managers in state and EPA regional offices.

Recent and future technology transfer activities include the following:

- Cooperating with the Interstate Technology Regulatory Cooperation (ITRC) Workgroup to develop and deliver a series of workshops — Phytoremediation: The State of the Science and Practice. The first of these workshops was offered in May 2000.
- A workshop on the use of phytoremediation at brownfield sites was presented at the EPA Brownfields 2000 Conference in October 2000.
- A workshop for oil and gas producers was delivered in November 2000. This workshop is being developed in partnership with the Petroleum Technology Transfer Council.

Technology Transfer and Outreach: The entire purpose of this program is to transfer technology developed by the HSRC to practicing environmental professionals in government agencies, businesses, interested individuals, and other researchers. This is accomplished through the various communication methods discussed above.

Keywords: collaborative problem solving, partnerships, technology transfer, newsletter, repository, communication, training, World Wide Web.

Conference on Hazardous Waste Research

L.N. Reddi, L.E. Erickson, and B.A. Leven, Kansas State University

Goal: The goal of this project is to hold an annual research conference on hazardous substance research and to provide opportunities for individuals from public and private sectors to share technical information regarding the management of hazardous substances.

Rationale: Conferences provide good opportunities for the exchange of information. The conference serves as a mechanism of technology transfer by bringing together researchers, regulators, and industry to discuss relevant and timely research impacting everyday government and business decisions.

Approach: Kansas State University's approach has been to expand the Conference on Hazardous Waste Research to include issues of technology transfer and training. Other universities host the conference in alternate years.

Status: The 15th Annual Conference on Hazardous Waste Research was held in Denver, Colorado, May 23-25, 2000, with more than 200 people participating. Researchers from around the country and abroad attended the conference to present and hear papers, participate in panel discussions, and view posters and exhibits. The 2000 conference involved several co-sponsors and cooperating supporters, including the American Society of Civil Engineers Geo-Institute, Colorado School of Mines, Integrated Petroleum Environmental Consortium, U.S. EPA Mine Waste Technology Program, National Institute of Environmental Health Sciences, National Mine Land Reclamation Center, Petroleum Technology Transfer Council, WERC, and U.S. EPA. The 2001 Conference on Environmental Research will be held in Manhattan, Kansas, May 22-24, 2001. It will be co-sponsored by other co-funding organizations. The 2000 conference proceedings are being prepared for publication on the Internet and in print form.

Technology Transfer and Outreach: This annual conference brings together researchers, regulators, and industry for the express purpose of exchanging information and transferring technology.

Keywords: conference, information exchange, research.

Virtual Library: Transferring HSRC Research Results Through the Internet

L. E. Erickson, Kansas State University

Goal: The goal of this project is to publish the *Journal of Hazardous Substance Research*, an electronic, peer-reviewed journal distributed via the Internet.

Rationale: Investigators believe distributing this journal via the Internet will improve the delivery time of HSRC findings and information about related research. It should also provide an inexpensive alternative to library subscriptions and offer a means for evaluating the Internet as a vehicle for the delivery of refereed research results.

Approach: The journal publishes selected papers on hazardous substance research. Manuscripts are selected for publication by a team of editors following peer review by members of the editorial board, HSRC advisory committees, and other qualified individuals. The journal is freely accessible via the Internet to industry as well as the public at large. Interested parties are able to easily follow up with researchers by electronic mail or other means of communication.

Status: An editorial team and advisory board have been established and a Web site is in place at http://www.engg.ksu.edu/HSRC/JHSR. Information concerning manuscript submission is on-line, and a call for papers has been created and distributed. A number of manuscripts have been submitted and peer reviewed, and 14 articles are posted on the Web site. The articles are posted in portable document format (pdf) with searchable abstracts also available in HTML. A print copy of Volume I of the journal has been published. Future plans include marketing research and studies to identify reliable methods for indexing, cataloging, and archiving the journal. Efforts to identify funding sources continue. This project is in its fourth year.

Technology Transfer and Outreach: This form of virtual publishing offers tremendous cost/benefit potential to industry, academia, and the general public by providing more fluid access and distribution of scientific and technological information.

Keywords: *Journal of Hazardous Substance Research*, publishing, Internet, World Wide Web, Web site, manuscripts, editorial.

Technical Outreach Services to Communities (TOSC) Program

B.A. Leven, T. Boguski, V. Deines, and L. Wigfall, Kansas State University

Goals: Technical Outreach Services for Communities (TOSC) provides technical assistance to communities, groups, and individuals affected by hazardous substances at EPA Superfund/RCRA, brownfield, former defense, and tribal sites. This includes providing information on the underlying issues related to the cleanup and reuse of sites with real or perceived environmental impacts.

Rationale: EPA and Congress have shown increasing interest in the level of community involvement in the decision-making process at hazardous waste sites in general, and specifically under the Superfund process. In 1986, Congress strengthened requirements for community participation in Superfund when it passed the Superfund Amendments and Re-authorization Act. These requirements were further strengthened when the revised National Oil and Hazardous Substances Contingency Plan (NCP) was released in 1990. One effort in support of furthering community involvement is EPA's Technical

Assistance Grants program, where EPA provides community groups up to $50,000 per site for the purpose of obtaining outside technical assistance. This program has had success, but has been hampered by administrative burdens placed on community groups to obtain the grants and is limited to sites designated on the NPL.

Approach: The program provides a variety of services to interested citizens in the 10-state region:

- Toll-free telephone access to the TOSC program office.
- In-community presentations, workshops, and handouts on health risk and remediation issues. A listing of workshops appears in the final section of this report.
- In-community technical assistance to small groups by university staff and researchers with expertise in a variety of technical areas ranging from toxicology to engineering.
- Assistance with review of technical documents including site characterization reports, risk assessments, feasibility studies, and remedial designs.
- Attendance at public hearings and assistance in preparing written comments.
- Public education on hazardous substance issues.

Status: The TOSC program continues to provide education and outreach services to communities impacted by hazardous waste cleanup projects. Last year the TOSC program supported 26 communities. This support has grown to include 33 communities. The TOSC base program is currently supporting communities at 11 sites, as well as providing most of the technical and administrative resources for all technical outreach programs including Technical Assistance to Brownfields (TAB) and the national Technology Outreach Services to Native American Communities (TOSNAC) program. In addition to base TOSC funding, the TOSNAC program at Haskell Indian Nations University is providing support to 15 communities. TOSNAC also works to coordinate support to develop the capacity of tribal governments to address environmental concerns. These activities will help tribal communities affected by hazardous substance contamination issues overcome significant cultural and legal barriers in dealing with these issues. In addition to providing tribal communities with workshops, hands-on assistance, and personal expert assistance, TOSNAC activities will include needs assessment and communications techniques targeted specifically for Native Americans. TOSC is also receiving funds to support redevelopment of abandoned or underutilized sites through the EPA Brownfields program. Support is currently being provided to seven pilot projects in EPA Regions VII and VIII and may be provided to additional sites in the future. This project is in its seventh year.

Technology Transfer and Outreach: This program assists in technology transfer from university research projects by providing information and technical assistance to communities in a format that is more easily understood. A greater level of understanding sometimes increases the chances of considering new cleanup options.

Keywords: communities, outreach services, Technical Assistance Grants, National Priority List.

Collaborative Environmental Seminar Series

G.L. Godfrey, Haskell Indian Nations University; and W.M. Griswold and B.A. Leven,
Kansas State University

Project no.: TR96-05

Goals: The goal of this project is to produce a series of seminars primarily for audiences at tribal environmental offices, Haskell Indian Nations University (HINU), and other American Indian Higher

Education Consortium (AIHEC) colleges and universities. The seminars provide technical information to students, faculty, and tribal environmental professionals throughout the U.S. through quality videotaped seminars, and to students and faculty at HINU through traditional seminars on campus.

Rationale: Although NAOMI program funds expired in December 1997, the most successful elements of this program receive continued support through center funds awarded in open competition. Seminars produced under the NAOMI program are distributed to approximately 130 participants at AIHEC colleges and universities, tribal environmental offices, other minority academic institutions, Kansas colleges, and HSRC consortium institutions. In a survey, these participants indicated that the videos are the most effective delivery method and that they are used primarily as classroom tools and staff development tools.

Approach: The HINU Environmental Seminar Series has produced four high-quality video programs, companion on-campus seminar presentations at HINU, and semi-annual production of *Earth Medicine* newsletter. Video topics include a panel discussion of tribal environmental planning and management and pollution prevention opportunity assessments. A peer review of the program scripts has been recently implemented.

Status: This project will be completed by May 2001.

Technology Transfer and Outreach: This program is similar to the TOSC program in that it assists in technology transfer by providing information and technical assistance to Native American communities in an easily understood format.

Keywords: Native American, minority colleges, seminar, training.

Development of a "State-of-the-Science and Technology" Report on Site Characterization Technologies

J.L. Sims and R.C. Sims, Utah State University

Project no.: TR 97-07

Goals: The goal of this project is to prepare a "State-of-the-Science and Technology" report for site characterization technologies.

Rationale: Effective site characterization technologies are essential to the effective implementation of remedial action programs. The Office of Research and Development (ORD) of the U.S. Environmental Protection Agency (U.S. EPA) identified a need to have a "State-of-the-Science and Technology" report developed for site characterization technologies, with an emphasis on defining required improvements that will enhance understanding of subsurface conditions in soils, groundwater, and bedrock that affect the fate and transport of contaminants. The Utah Water Research Laboratory is preparing this report.

Approach: The report will be based on recently published research, research presently being conducted, and innovative activities being implemented and tested in field applications. Gaps in knowledge and technology and future areas of research will also be identified. The report will be prepared in hard copy and in interactive CD-ROM form, with Internet delivery capability.

Status: Library and Internet database searches have been conducted and major sources of published information on site characterization technologies have been identified. Site characterization technologies and technology categories have been identified and reviewed. The current development and application of identified technologies have been reviewed and evaluated. Information has been collected from published resources and from known researchers in the given fields. An open request for information was sent to e-mail news groups dealing with environmental characterization in an effort to collect current information on the selected technologies. The draft final report will be completed in spring of 2001.

Technology Transfer and Outreach: This "State-of-the-Science and Technology" report will be a valuable resource for other technology transfer activities.

Keywords: technology, site characterization, remediation.

Field Validation of an Optimal Design Methodology for Vegetative Remediation of Sediments from the Central Vehicle Wash Facility, Custer Hill, Fort Riley, Kansas—A Technology Transfer Project

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Project no.: SP96-Riley

Goals: The goals of this project are to develop an optimal remediation design using vegetative systems; to obtain regulatory approval for use of this technique to treat sediments on an ongoing basis; and to transfer this technology through computer software, demonstrations, and involvement of environmental professionals.

Rationale: The Central Vehicle Wash Facility concrete sedimentation basin and other surface water impoundments at Fort Riley produce petroleum hydrocarbon-contaminated sediments on an ongoing basis. Vegetative remediation is potentially an inexpensive and acceptable innovative technique for treating these contaminated sediments. Results from this study could allow vegetative treatment of contaminated materials from other locations such as wastewater lagoons and UST sites, or for on-site treatment of miscellaneous petroleum spills.

Approach: This project primarily involves two phytoremediation field trials to evaluate vegetative treatments for petroleum hydrocarbon contaminated sediments. The first field trial began in the fall of 1997, using sediments collected from the Central Vehicle Wash Facility with an average Total Petroleum Hydrocarbon (TPH) concentration of 821 mg/kg. The second trial began in the fall of 1999, using sediments from a motor pool waste lagoon with average TPH concentration measurements of 13,750 mg/kg. The second trial is part of the Remediation Technologies Development Forum (RTDF) nationwide phytoremediation field trial at 11 sites. Sediments in the Fort Riley studies were spread to depths of 30 cm in Trial 1 and 45 cm in Trial 2. In each trial, four treatment plots of native grass or switchgrass, a grass/legume mixture, and an unvegetated control were established in a randomized block design (12 plots in each trial). Petroleum hydrocarbon concentrations, soil physical/chemical parameters, soil microbial activity, and above and below ground biomass data are being collected from each trial. Results from these and other field trials are being used in development of a multimedia decision support system to guide evaluation and implementation of phytotreatment of washrack sediments.

Status: TPH concentrations in Trial 1 declined 75% during the first year of the study and stabilized near 200 mg/kg through the second year. No significant differences were observed between the vegetated and unvegetated treatments. It is important to note that both the unvegetated and vegetated treatments were fertilized. The background concentration of TPH in the native soil, as determined from samples collected below treatment plots and upslope from treatment plots, is near 100 mg/kg. No increase in TPH concentration was detected in native soils below sediments. Hydrocarbon degrading microbes were more numerous in vegetated plots compared to unvegetated plots, particularly in the upper 15 cm of the sediment profile. End-of-growing-season sampling events took place in October of 2000 for Trial 1 (36-month event) and for Trial 2 (12-month event). Analytical results will be available in early 2001. Information on other initial sampling results for Trial 2 and other RTDF field trials is in an annual report on the world wide web at http://www.rtdf.org/public/phyto/phytodoc.htm and http://www.engg.ksu.edu/HSRC/RTDFtphrp1.html. A multimedia decision support system consisting of a: 1) phytoremediation wizard; 2) graphical user interface and simulation model; 3) phytoremediation manual; and 4) phytotechnologies brochure is being completed and linked electronically with a tutorial for operations in an MSWindows PC environment. The wizard uses a series of ten questions and databases on climate, soil, and other factors to assess feasibility of phytotreatment and to recommend candidate plant species. The GUI and simulation model predicts the number of growing seasons necessary to reach desired treatment levels, and leaching potential to groundwater. All components should be complete and posted to the internet in the spring of 2001.

Technology Transfer and Outreach: Technology transfer activities include simultaneous involvement of environmental professionals at Fort Riley, the Army Environmental Center, and state regulatory and private contractors throughout this project. A written guide and Internet-based software product are being developed. Broad dissemination of project protocols and results is planned through workshops and platform presentations at various conferences. Participation in the RTDF nationwide phytoremediation field trial involving EPA, DOD, industry, and university collaborators will validate and promote regulatory acceptance of phytoremediation of TPH-contaminated soils.

Keywords: vegetation, phytoremediation, petroleum hydrocarbons.

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G. BULLETINS AND SPECIAL PUBLICATIONS

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H. CONFERENCES AND WORKSHOPS

Three-day workshop — Introduction to Hazardous Waste Management, Sioux Falls, South Dakota, November 9-11, 1989 — University of Missouri, Columbia, Missouri.

Three-day workshop — Introduction to Hazardous Waste Management, Denver, Colorado, January 18-20, 1990 — University of Missouri, Columbia, Missouri.

One-day conference — Hazardous Waste Minimization, Omaha, Nebraska, January 23, 1990 — Iowa Department of Natural Resources, Des Moines, Iowa; and Nebraska Department of Environmental Control, Lincoln, Nebraska.

Three-day workshop — Introduction to Hazardous Waste Management, Overland Park, Kansas, February 15-17, 1990 — University of Missouri, Columbia, Missouri.

Two-day cluster of conferences — Agricultural Impacts on Groundwater Quality; Groundwater Geochemistry; Groundwater Management and Wellhead Protection; Environmental Site Assessments: Case Studies and Strategies, Kansas City, Missouri, February 20-21, 1990 — National Water Well Association and Association of Groundwater Scientists and Engineers, Columbus, Ohio.

Two-day conference — Controlling Water Contamination, Manhattan, Kansas, March 7-8, 1990 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Helena, Montana, March 15-17, 1990 — University of Missouri, Columbia, Missouri.

Five-day conference — 1990 Billings Reclamation Symposium, Billings, Montana, March 25-30, 1990 — Montana State University, Bozeman, Montana.

Three-day workshop — Introduction to Hazardous Waste Management, Kansas City, Missouri, April 18-20, 1990 — University of Missouri, Columbia, Missouri.

One-day teleconference — Ask the Experts: Third Annual Hazardous Materials and Waste Management Update, Manhattan, Kansas, May 11, 1990 — Oklahoma State University, Stillwater, Oklahoma.

Two-day conference — Conference on Hazardous Waste Research, Manhattan, Kansas, May 21-22, 1990 — Kansas State University, Manhattan, Kansas.

One-day workshop — Minimizing Hazardous Waste: A Workshop for Metal Finishers, Manhattan, Kansas, May 23, 1990 — Kansas State University, Manhattan, Kansas.

Three-day conference — Interfacial Microbial Process Engineering, Bozeman, Montana, July 18-20, 1990 — Montana State University, Bozeman, Montana.

Five-day workshop — Summer Institute on Hazardous Waste Management, Columbia, Missouri, August 6-10, 1990 — University of Missouri, Columbia, Missouri.

Five-day symposium — Mineral and Hazardous Waste Processing Symposium, Butte, Montana, September 30-October 5, 1990 — Montana College of Mineral Science and Technology, Butte, Montana; and the Northern Rocky Mountain Water Congress.

Three-day workshop — Introduction to Hazardous Waste Management, Des Moines, Iowa, October 18-20, 1990 — University of Missouri, Columbia, Missouri.

Three-day conference — 25th Midwest Regional Meeting of the American Chemical Society, Manhattan, Kansas, November 7-9, 1990 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Salt Lake City, Utah, November 29-December 1, 1990 — University of Missouri, Columbia, Missouri.

Two-day video conference — The Environment: Corporate Stewardship and Business Opportunity in the Decade of Global Awakening, Manhattan, Kansas, December 5-6, 1990 — Business Week and World Resources Institute.

Three-day workshop — Introduction to Hazardous Waste Management, Lincoln, Nebraska, December 14-16, 1990 — University of Missouri, Columbia, Missouri.

Three-day workshop — Introduction to Hazardous Waste Management, St. Louis, Missouri, February 6-8, 1991 — University of Missouri, Columbia, Missouri.

Two-hour video conference — Pollution Prevention in Business: How Small Rural Businesses Can Minimize Their Pollution, Manhattan, Kansas, February 21, 1991 — Kansas State University, Manhattan, Kansas.

Two-day conference — Water and the Future of Kansas, Manhattan, Kansas, March 4-5, 1991 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Kansas City, Missouri, March 6-8, 1991 — University of Missouri, Columbia, Missouri.

Four-day conference — Hydrology Days, Fort Collins, Colorado, April 2-5, 1991 — Colorado State University, Fort Collins, Colorado.

One-day workshop — Underground Storage Tanks, St. Louis, Missouri, April 11, 1991 — University of Missouri, Columbia, Missouri.

One-day workshop — Sampling and Identification of Hazardous Waste, St. Louis, Missouri, April 12, 1991 — University of Missouri, Columbia, Missouri.

One-day conference — Hazardous Waste Management Conference: Remediation Alternatives and Case Studies, Kansas City, Missouri, April 23, 1991 — University of Missouri, Columbia, Missouri.

One-day workshop — Underground Storage Tanks, Kansas City, Missouri, April 25, 1991 — University of Missouri, Columbia, Missouri.

One-day workshop — Sampling and Identification of Hazardous Waste, Kansas City, Missouri, April 26, 1991 — University of Missouri, Columbia, Missouri.

Four-day conference — On-Site Bioremediation Conference, Hickory Corners, Michigan, May 19-22, 1991 — University of Michigan, Ann Arbor, Michigan.

Two-day conference — Conference on Hazardous Waste Research, Manhattan, Kansas, May 29-30, 1991 — Kansas State University, Manhattan, Kansas.

Two-day workshop — Primer in Environmental Initiatives, St. Louis, Missouri, May 30-31, 1991 — University of Missouri, Columbia, Missouri.

Two-day workshop — Primer in Environmental Initiatives, Kansas City, Missouri, June 13-14, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Cape Girardeau, Missouri, July 9, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Sikestone, Missouri, July 10, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Kirksville, Missouri, July 30, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Hannibal, Missouri, July 31, 1991 — University of Missouri, Columbia, Missouri.

Five-day workshop — Hazardous Waste Management Summer Institute, Columbia, Missouri, August 5-9, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Kansas City, Missouri, August 20, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, St. Joseph, Missouri, August 21, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, St. Louis, Missouri, September 10, 1991 — University of Missouri, Columbia, Missouri.

Three-day workshop — Beneficial Effects of Vegetation in Contaminated Soils, Manhattan, Kansas, January 7-9, 1992 — Kansas State University, Manhattan, Kansas.

One-day workshop — Bioremediation: The State of Practice in Hazardous Waste Remediation Operations, A Satellite Seminar, held at eight sites in EPA Regions VII and VIII, January 9, 1992 — Air and Waste Management Association, Pittsburgh, Pennsylvania.

Three-day workshop — Hazardous Waste Management, Casper, Wyoming, January 16-18, 1992 — University of Missouri, Columbia, Missouri.

Two-day workshop — Primer in Environmental Initiatives, Columbia, Missouri, January 23-24, 1992 — University of Missouri, Columbia, Missouri.

One-day conference — 42nd Environmental Engineering Conference, Lawrence, Kansas, February 5, 1992 — University of Kansas, Lawrence, Kansas.

Two-day workshop — Our Changing Environment, AGU 1992 Front Range Meeting, Boulder, Colorado, February 10-11, 1992 — Rush Services Technical Communications.

Three-day workshop — Hazardous Waste Management, Columbia, Missouri, February 13-15, 1992 — University of Missouri, Columbia, Missouri.

Four-day workshop — Project Management for the Hazardous Waste Professional, Columbia, Missouri, February 19-22, 1992 — University of Missouri, Columbia, Missouri.

Two-day conference — Waste Management Conference, Logan, Utah, March 4-5, 1992 — Utah State University, Logan, Utah.

Three-day workshop — Hazardous Waste Management, Wichita, Kansas, March 26-28, 1992 — University of Missouri, Columbia, Missouri.

Two-day workshop — Waste Minimization Technology and Applications, Salt Lake City, Utah, April 29-30, 1992 — University of Missouri, Columbia, Missouri.

Two-day seminar — Technical Seminar on Groundwater, Topeka, Kansas, May 12-13, 1992 — Kansas Water Well Association.

Two-day workshop — Waste Minimization Technology and Applications, Wichita, Kansas, May 13-14, 1992 — University of Missouri, Columbia, Missouri.

Two-day conference — Alternate Fuels Conference, Manhattan, Kansas, May 14-15, 1992 — Kansas State University, Manhattan, Kansas.

Two-day conference — 7th Annual Conference on Hazardous Waste Research, Boulder, Colorado, June 1-2, 1992 — Kansas State University, Manhattan, Kansas.

One-day workshop — Impact of Heavy Metals on Mine Land Restoration Workshop, Boulder, Colorado, June 3, 1992 — Kansas State University, Manhattan, Kansas.

Five-day workshop — Hazardous Waste Site Operations Training, Kansas City, Kansas, June 15-19, 1992 — University of Kansas, Lawrence, Kansas.

Four-day conference — Subsurface Restoration Conference, Dallas, Texas, June 21-24, 1992 — Rice University, Houston, Texas.

Six-day workshop — Shaping Our Environmental Heritage, Kansas City, Missouri, June 21-26, 1992 — Air & Waste Management Association, Pittsburgh, Pennsylvania.

Two-day conference — Annual Conference and Exhibition Application of Geostatistics and Kriging to Spatial Estimation Problems in Groundwater, Golden, Colorado, July 16-17, 1992 — Colorado School of Mines, Golden, Colorado.

Five-day workshop — 11th Annual Hazardous Waste Management Summer Institute, Columbia, Missouri, August 10-14, 1992 — University of Missouri, Columbia, Missouri.

Five-day workshop — Principles and Applications of Modeling Chemical Reactions in Groundwater, Golden, Colorado, August 10-14, 1992 — Colorado School of Mines, Golden, Colorado.

Four-day workshop — Transport and Fate of Organic Chemicals in Multimedia Environmental Systems, Golden, Colorado, August 17-20, 1992 — Colorado School of Mines, Golden, Colorado.

Five-day workshop — Fundamentals of Bioremediation of Hazardous Waste-Contaminated Soils, Logan, Utah, August 24-28, 1992 — Utah State University, Logan, Utah.

Five-day workshop — Introduction in Groundwater Modeling, Golden, Colorado, September 14-18, 1992 — Colorado School of Mines, Golden, Colorado.

Four-day workshop — Primer in Environmental Initiatives, Columbia, Missouri, September 20-23, 1992 — University of Missouri, Columbia, Missouri.

One-day workshop — Sampling and Laboratory Analysis of Hazardous Substances, Columbia, Missouri, September 25, 1992 — University of Missouri, Columbia, Missouri.

Two-day workshop — Pollution Prevention Technology and Applications, Columbia, Missouri, October 14-15, 1992 — University of Missouri, Columbia, Missouri.

Three-day workshop — Five-Center Technology Transfer and Training Meeting and Workshop, Excelsior Springs, Missouri, October 14-16, 1992 — Kansas State University, Manhattan, Kansas.

Two-day conference — Total Quality Environmental Management, 6th Annual Colorado Hazardous Waste Management Society Conference and Exhibit, Denver, Colorado, October 22-23, 1992 — Hazardous Waste Management Society, Denver, Colorado.

Two-day workshop — Pollution Prevention Technology and Applications, St. Louis, Missouri, February 17-18, 1993 — University of Missouri, Columbia, Missouri.

Four-day workshop — Project Management for the Hazardous Waste Professional, Kansas City, Missouri, February 23-26, 1993 — University of Missouri, Columbia, Missouri.

Three-day workshop — Introduction to Hazardous Waste Management, Helena, Montana, March 17-19, 1993 — University of Missouri, Columbia, Missouri.

One-day workshop — Remedial Design Issues...Keeping Your Projects on Schedule and Within Budget, Kansas City, Missouri, March 25, 1993 — University of Missouri, Columbia, Missouri.

Two-day conference — Potentially Responsible Parties Superfund Settlement Incentives, Denver, Colorado, April 15-16, 1993 — Kansas State University, Manhattan, Kansas.

One-day workshop — Pollution Prevention Workshop for the Electroplating Industry, Manhattan, Kansas, May 24, 1993 — Kansas State University, Manhattan, Kansas.

Two-day conference — 8th Annual Conference on Hazardous Waste Research, Manhattan, Kansas, May 25-26, 1993 — Kansas State University, Manhattan, Kansas.

One-day workshop — Underground Storage Tank Site Characterization and Remediation Technologies, Manhattan, Kansas, May 27, 1993 — Kansas State University, Manhattan, Kansas.

Two-month workshop — Environmental Biotechnology Workshop for Thai Professors, Manhattan, Kansas, June 7-July 30, 1993 — Kansas State University, Manhattan, Kansas.

Four-day convention — National Groundwater Association's 45th Annual Convention and Exposition, Kansas City, Missouri, October 17-20, 1993 — National Groundwater Association, Dublin, Ohio.

One-day course — The Annual HAZMAT Update, St. Louis, Missouri, November 3, 1993 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT Employee Training, Testing and Certification, St. Louis, Missouri, November 4, 1993 — University of Missouri, Columbia, Missouri.

One-day course — Hazardous Waste Sampling, St. Louis, Missouri, November 5, 1993 — University of Missouri, Columbia, Missouri.

Four-day course — CHMM Review Course and Exam, St. Louis, Missouri, November 17-20, 1993 — University of Missouri, Columbia, Missouri.

One-day course — Hazardous Waste Sampling, Kansas City, Missouri, November 18, 1993 — University of Missouri, Columbia, Missouri.

One-day course — Advanced Hazardous Waste Management, Columbia, Missouri, November 30, 1993 — University of Missouri, Columbia, Missouri.

Three-day course — Introduction to Hazardous Waste Management, Kansas City, Missouri, December 1-3, 1993 — University of Missouri, Columbia, Missouri.

Three-day course — Three-Day Short Course on Soil Contamination, Kansas City, Missouri, December 2-3, 1993 — University of Nebraska, Lincoln, Nebraska.

Three-day workshop — Beneficial Effects of Vegetation in Contaminated Soils, Manhattan, Kansas, January 5-7, 1994 — Kansas State University, Manhattan, Kansas.

Three-day course — Introduction to Hazardous Waste Management, St. Louis, Missouri, January 5-7, 1994 — University of Missouri, Columbia, Missouri.

One-day course — CHMM Examination, St. Louis, Missouri, January 8, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Air Quality Management Update, Kansas City, Missouri, January 25, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT 8-Hour Refresher Course, Kansas City, Missouri, February 3, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, Springfield, Missouri, February 3-4, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT Transportation Safety, Kansas City, Missouri, February 4, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Project Management for the Hazardous Waste Professional: Phase I, St. Louis, Missouri, February 8-19, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Air Quality Management Update, St. Louis, Missouri, February 23, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, St. Louis, Missouri, February 24-25, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Working Trees—Farming in the 1990s: Ecolotree™ Buffers for Riparian Edge Management, Owatonna, Minnesota, March 3, 1994 — Minnesota Soil & Water Conservation Association, Owatonna, Minnesota.

Two-day course — Project Management for the Hazardous Waste Professional: Phase II, Kansas City, Missouri, March 10-11, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, Kansas City, Missouri, March 18-19, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Advanced Water Treatment, Columbia, Missouri, March 24-25, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, Springfield, Missouri, April 7-8, 1994 — University of Missouri, Columbia, Missouri.

Four-day course — CHMM Review and Examination, St. Louis, Missouri, April 20-23, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT 8-Hour Refresher Course, Cape Girardeau, Missouri, May 5, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT Transportation Safety, Cape Girardeau, Missouri, May 6, 1994 — University of Missouri, Columbia, Missouri.

Five-day course — 40-Hour HAZWOPER, Columbia, Missouri, May 16-20, 1994 — University of Missouri, Columbia, Missouri.

Two-day workshop — Beneficial Effects of Vegetation in Soils Contaminated with Heavy Metals, Denver, Colorado, May 23-24, 1994 — EPA Region VIII, Denver, Colorado; and Kansas State University, Manhattan, Kansas.

Two-day course — Primer in Environmental Initiatives, Columbia, Missouri, May 24-25, 1994 — University of Missouri, Columbia, Missouri.

One-day field trip — Mine Lands Revegetation Field Trip, Butte, Montana, June 7, 1994 — Montana State University, Bozeman, Montana.

One-day workshop — Synergistic Solutions: A Conversation Among Industry, Government, and Academia, Bozeman, Montana, June 7, 1994 — Montana State University, Bozeman, Montana.

Three-day conference — 9th Annual Conference on Hazardous Waste Remediation, Bozeman, Montana, June 8-10, 1994 — Kansas State University, Manhattan, Kansas; and Montana State University, Bozeman, Montana.

One-day field trip — Mine Waste Field Trip, Butte, Montana, June 11, 1994 — Montana State University, Bozeman, Montana.

Five-day course — Hazardous Waste Management Summer Institute, Columbia, Missouri, August 8-12, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Primer in Environmental Laws and Multimedia Auditing, Columbia, Missouri, September 22-23, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Introduction to Sampling, Columbia, Missouri, September 28, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HazMat Refresher, Springfield, Missouri, October 6, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Introduction to Sampling, Columbia, Missouri, October 12, 1994 — University of Missouri, Columbia, Missouri.

One-day course — ASTM—Risk-Based Corrective Action for Petroleum Sites, Columbia, Missouri, October 19, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Hazardous Waste Sampling, Columbia, Missouri, November 3, 1994 — University of Missouri, Columbia, Missouri.

Seminar — The NAOMI Program and HERS: New Opportunities in Environmental Research, Lawrence, Kansas, November 2, 1994 — Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Comparison of Native American and European Worldviews: A Native American Viewpoint, Lawrence, Kansas, November 4, 1994 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — Advanced Hazardous Waste Management, St. Louis, Missouri, November 16, 1994 — University of Missouri, Columbia, Missouri.

Three-day course — Introduction to Hazardous Waste Management, Denver, Colorado, December 1-3, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Advanced Hazardous Waste Management, Kansas City, Missouri, January 25, 1995 — University of Missouri, Columbia, Missouri.

Seminar — Environmental Impacts of Gold Mining Operations Near the Fort Belknap Reservation, Lawrence, Kansas, January 26, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — Environmental Risk Management, Kansas City, Missouri, January 26, 1995 — University of Missouri, Columbia, Missouri.

One-day course — 8-Hour HazMat Refresher, St. Louis, Missouri, February 9, 1995 — University of Missouri, Columbia, Missouri.

One-day course — HazMat HM-126/181, St. Louis, Missouri, February 10, 1995 — University of Missouri, Columbia, Missouri.

One-day course — Air Quality Management Update, St. Louis, Missouri, February 22, 1995 — University of Missouri, Columbia, Missouri.

Seminar — Comparison of Native American and European Worldviews: A European Viewpoint, Lawrence, Kansas, March 3, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — Air Quality Management Update, Kansas City, Missouri, March 8, 1995 — University of Missouri, Columbia, Missouri.

Three-day course — Introduction to Hazardous Waste Management, St. Louis, Missouri, March 16-18, 1995 — University of Missouri, Columbia, Missouri.

Two-day course — Advanced Water Treatment, Columbia, Missouri, March 23-24, 1995 — University of Missouri, Columbia, Missouri.

Seminar — Basin Creek Mine Closure Reclamation Techniques, Butte, Montana, April 13, 1995 — Mine Waste Technology Program, Butte, Montana; and Haskell Indian Nations University, Lawrence, Kansas.

Seminar — PCBs in Our Environment—The Legacy Continues, Flagstaff, Arizona, April 21, 1995 — Northern Arizona University, Flagstaff, Arizona; and Haskell Indian Nations University, Lawrence, Kansas.

Four-day seminar — A Gathering for the Earth, Washington, DC, April 21-23, 1995 — U.S. Department of Agriculture, Washington, DC; and Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Topics in Pollution Prevention, Lawrence, Kansas, May 2, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — 8-Hour HAZWOPER Refresher Course, Manhattan, Kansas, May 22, 1995 — Kansas State University, Manhattan, Kansas.

One-day workshop — Bioremediation of Munitions-Contaminated Soil, Manhattan, Kansas, May 22, 1995 — Kansas State University, Manhattan, Kansas; and Western Governors' Association Military Munitions Waste Working Group.

Two-day conference — 10th Annual Conference on Hazardous Waste Research, Manhattan, Kansas, May 23-24, 1995 — Kansas State University, Manhattan, Kansas.

Two-day workshop — Chelating Agents Design and Application in Heavy Metals Extraction from Contaminated Soils, Manhattan, Kansas, May 23-24, 1995 — University of Utah, Logan. Project no. 93-22.

One-day workshop — Beneficial Effects of Vegetation in Contaminated Soils, Manhattan, Kansas, May 25, 1995 — Kansas State University, Manhattan, Kansas.

One-day workshop — Designer Chelators: Study of Structure-Activity Relationships to Obtain the Ideal Chelator, Manhattan, Kansas, May 25, 1995 — University of Utah, Salt Lake City, Utah; and Kansas State University, Manhattan, Kansas.

One-day workshop — Environmentally Conscious Printing, Manhattan, Kansas, May 25, 1995 — Kansas State University, Manhattan, Kansas.

Five-day seminar — Freight Pipeline Seminar, Columbia, Missouri, July 10-14, 1995 — University of Missouri, Columbia, Missouri.

Two-week workshop — Technologies in Cleanup and Compliance, Lawrence, Kansas, July 16-29, 1995 — Haskell Indian Nations University, Lawrence, Kansas; Kansas State University, Manhattan, Kansas; and Kansas State University, Salina, Kansas.

Five-day course — Hazardous Waste Summer Institute, Columbia, Missouri, August 7-11, 1995 — University of Missouri, Columbia, Missouri.

Two-day seminar — Phytoremediation of Soil and Water Contaminants, Orlando, Florida, August 25-30, 1996 — 212th National Meeting of the American Chemical Society.

Seminar — Comparison of Native American and European Worldviews: A Roundtable Discussion, Lawrence, Kansas, September 20, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

Five-day workshop — 40-Hour HAZWOPER Training, Missoula, Montana, October 9-13, 1995 —University of Montana, Missoula, Montana.

Seminar — The Badlands Bombing Range Project, Lawrence, Kansas, October 11, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

Five-day workshop — 40-Hour HAZWOPER Training, Missoula, Montana, November 13-17, 1995 — University of Montana, Missoula, Montana.

One-day workshop — Advanced Hazardous Waste Management, St. Louis, Missouri, Nov 29, 1995 — University of Missouri, Columbia, Missouri.

One-day workshop — Annual Hazardous Materials Update (8-Hour Refresher), television simulcast from Kansas City, St. Louis, and Columbia, Missouri, Oct 25, 1995 — University of Missouri, Columbia, Missouri.

One-day workshop — Bioremediation Alternatives, Helena, Montana, December 7, 1995 — Montana State University, Bozeman, Montana.

Five-day workshop — 40-Hour HAZWOPER Training, Missoula, Montana, December 11-15, 1995 — University of Montana, Missoula, Montana.

Five-day workshop — 40-Hour HAZWOPER Training, Manhattan, Kansas, January 15-19, 1996 — Kansas State University, Manhattan, Kansas.

Seminar — Comparison of Native American and European Worldviews: A Roundtable Discussion, Part II, Lawrence, Kansas, January 23, 1996 — Haskell Indian Nations University, Lawrence, Kansas.

One-day workshop — Advanced Hazardous Waste Management Course, Kansas City, Missouri, February 8, 1996 — University of Missouri, Columbia, Missouri.

Two-day workshop — Real Estate Site Assessment, Phase I, Kansas City, Missouri, March 5-6, 1996 — University of Missouri, Columbia, Missouri.

Three-day workshop — Bioremediation Alternatives, Annual UST/LUST National Conference, Chicago, Illinois, March 11-13, 1996 — Montana State University, Bozeman, Montana.

One-week symposium — Billings Reclamation Symposium, Billings, Montana, March 17-23, 1996 — Montana State University, Billings, Montana.

Two-day workshop — Real Estate Site Assessment, Phase I, Omaha, Nebraska, March 19-20, 1996 — University of Missouri, Columbia, Missouri.

Two-hour video conference — An Environmental Legacy for Our Grandchildren, Lawrence, Kansas, April 11, 1996 — Haskell Indian Nations University.

Seminar — Geoscience Education in Native American Communities, Rapid City, South Dakota, April 19, 1996 — South Dakota School of Mining and Technology, Rapid City, South Dakota and Haskell Indian Nations University, Lawrence, Kansas.

One-day exposition — Solvent Alternative Expo, Salina, Kansas, April 25, 1996 — Kansas State University, Manhattan, Kansas.

One-day workshop — Beneficial Effects of Vegetation in Metals-Contaminated Soils, Albuquerque, New Mexico, May 20, 1996.

One-day workshop — HAZWOPER Refresher, Columbia, Missouri, May 21, 1996 — University of Missouri, Columbia, Missouri.

Two-day workshop — Real Estate Site Assessment, Phase I, Salt Lake City, Utah, May 21-22, 1996 — University of Missouri, Columbia, Missouri/ASTM.

One-day workshop — Bioremediation Alternatives, HSRC/WERC Joint Conference on the Environment, Albuquerque, New Mexico, May 21-23, 1996 — Montana State University, Bozeman, Montana.

Three-day conference — HSRC/WERC Joint Conference on the Environment, Albuquerque, New Mexico, May 21-23, 1996 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Five-day workshop — HAZWOPER 40-Hour Course, Columbia, Missouri, May 20-24, 1996 — University of Missouri, Columbia, Missouri.

One-day workshop — Remediation of Munitions-Contaminated Soil and Water, Albuquerque, New Mexico, May 23, 1996.

Two-day workshop — HAZWOPER 8-Hour Refresher Short Course, Albuquerque, New Mexico, May 23-24, 1996.

Two-day workshop — Selection of Remediation Technologies Short Course, Albuquerque, New Mexico, May 23-24, 1996.

Two-day workshop — Risk-Based Corrective Action, Wichita, Kansas, June 25-26, 1996 — University of Missouri, Columbia, Missouri/ASTM.

Five-day workshop — Hazardous Waste Summer Institute, Columbia, Missouri, July 29-August 2, 1996 — University of Missouri, Columbia, Missouri.

Two-day training — Environmental Analysis Training, Rosebud, South Dakota, November 20-22, 1996 — Sinte Gleska University and University of Nebraska-Lincoln.

Seminar — Biology of the Earth: All Things Are Connected, Lawrence, Kansas, January 28, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Two-day workshop — Risk-Based Corrective Action (ASTM Standards), Kansas City, Missouri, January 28-29, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Air Quality Management Update, St. Louis, Missouri, February 13, 1997 — University of Missouri-Columbia, Missouri.

Two-day workshop — Real Estate Phase I Assessment (ASTM Standards), Memphis, Tennessee, February 25-26, 1997 — University of Missouri-Columbia, Missouri.

Seminar — Biology of the Earth: Our Connection to the Land, Lawrence, Kansas, February 28, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

One-day training — 8-Hour HAZWOPER Refresher, Columbia, Missouri, March 4, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Advanced Hazardous Waste Management, Columbia, Missouri, March 5, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Air Quality Management Update, Kansas City, Missouri, March 6, 1997 — University of Missouri-Columbia, Missouri.

Two-day workshop — Department of Transportation Requirements for Hazardous Materials Handling, Columbia, Missouri, March 6-7, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Advanced Water Treatment, Columbia, Missouri, March 20, 1997 — University of Missouri-Columbia, Missouri.

Seminar — Biology of the Earth: Water – Going Beneath the Surface of the Issue, Lawrence, Kansas, March 20, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Two-day workshop — ISO 14000 Auditing for Managers, Kansas City, Missouri, April 8-9, 1997 — University of Missouri-Columbia, Missouri.

Two-day conference— WERC/HSRC Joint Conference on the Environment, Albuquerque, New Mexico, April 22-24, 1997 — Waste-management Education and Research Consortium and the South/Southwest Hazardous Substance Research Center.

Seminar — Biology of the Earth: Air-Ensuring Quality for the Future, Lawrence, Kansas, April 22, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Six-week video course — Certified Hazardous Materials Manager Review, various locations throughout Missouri, April 24-May 29, 1997 — University of Missouri-Columbia, Missouri.

Test — Certified Hazardous Materials Manager Examination, Columbia, Missouri, April 26, 1997 — University of Missouri-Columbia, Missouri.

Two-day course — Risk-Based Corrective Action: The Standard for Petroleum Release Sites ASTM Standard E 1739, St. Louis, Missouri, April 29-30, 1997 — University of Missouri-Columbia, Missouri.

Two-day course — ISO 14000 for Auditors, Kansas City, Missouri, May 13-14, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — 8-Hour HAZWOPER Refresher, Kansas City, Missouri, May 19, 1997 — Kansas State University, Manhattan, Kansas.

One-day workshop — Acid Mine Drainage Short Course, Kansas City, Missouri, May 19, 1997 — West Virginia University.

One-day course — 8-Hour HAZWOPER Refresher, Columbia, Missouri, May 20, 1997 — University of Missouri-Columbia, Missouri.

Three-day conference — 12th Annual Conference on Hazardous Waste Research, Kansas City, Missouri, May 20-22, 1997 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop — Application of Chelating Agents for Removal of Heavy Metals from Soils, Kansas City, Missouri, May 22, 1997 — Utah State University, Logan, Utah. Project no. 93-22.

One-day workshop — Prepared-Bed Bioremediation of Contaminated Soils, Kansas City, Missouri, May 22, 1997 — Utah State University, Logan, Utah.

One-day workshop — Water Quality Workshop, June 3, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Three-day conference — EPA Region 7 Pollution Prevention Conference, Kansas City, Missouri, June 3-5, 1997 — Kansas State University, Manhattan, Kansas.

Five-day seminar — 16th Annual Hazardous Waste Summer Institute, Columbia, Missouri, August 4-8, 1997 — University of Missouri-Columbia, Missouri.

Two-day workshop — Environmental Site Assessment Practices for Commercial Real Estate ASTM Standard E 1527 and 1528, St. Louis, Missouri, August 12-13, 1997 — University of Missouri-Columbia, Missouri.

Three-day workshop — Symposium on Science in the Tallgrass, 53rd Southwest Regional Meeting, Tulsa, Oklahoma, October 1-3, 1997 — American Chemical Society, Washington, DC.

Three-day workshop — Certified Hazardous Materials Manager Review, St. Louis, Missouri, October 15-17, 1997 — University of Missouri-Columbia, Missouri.

Seminar — Native American Environmentalism at the Cusp of the Millennium, Lawrence, Kansas, November 5, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Effects of the 1997 Nuclear Waste Policy Act, Lawrence, Kansas, November 10, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Three-day workshop — Compacted Clay Liners, Columbia, Missouri, November 11-13, 1997 — University of Missouri-Columbia, Missouri.

Five-day workshop — HAZWOPER 40-hour Course, Manhattan, Kansas, January 5-9, 1998 — Kansas State University, Manhattan, Kansas.

One-day workshop — HAZWOPER Refresher, Manhattan, Kansas, January 7, 1998 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Workshop on Beneficial Effects of Vegetation in Contaminated Soil, Manhattan, Kansas, January 7-9, 1998 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Columbia, Missouri, January 12-14, 1998 — University of Missouri-Columbia, Missouri.

Two-day workshop — Compliance with DOT Regulations Training, Testing, and Certification, Columbia, Missouri, January 15-16 — University of Missouri-Columbia, Missouri.

Seminar — Environmental Justice in Indian Country, Lawrence, Kansas, March 20, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Nine-day conference — Wetlands Engineering and River Restoration Conference, Denver, Colorado, March 20-29, 1998 — American Society of Civil Engineers, Reston, Virginia; and Society of Wetland Scientists, Lawrence, Kansas.

Three-day conference — Joint Conference on the Environment, Albuquerque, New Mexico, March 31-April 2, 1998 — Waste-management Education and Research Consortium, Las Cruces, New Mexico; Western Region HSRC, Stanford, California; and New Mexico Hazardous Waste Management Society.

Seminar — Microscale Chemistry in the Classroom, Lawrence, Kansas, April 11, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Three-day workshop — Certified Hazardous Materials Manager Review Course, Columbia, Missouri, April 15-17, 1998 — University of Missouri-Columbia, Missouri.

One-day workshop — On-Site Insights: Innovative Technologies for Site Assessment and Monitoring, Snowbird, Utah, May 18, 1998 — Northeast HSRC, Newark, New Jersey.

One-day workshop — Predictive Modeling of Pitlake Chemistry: Theory, Methods, Application, and Regulatory Issues, Snowbird, Utah, May 18, 1998 — Montana Tech of the University of Montana, Butte, Montana.

One-day workshop — Quantitative Assessment of Natural Attenuation Processes for Site Remediation, Snowbird, Utah, May 18, 1998 — Utah State University, Logan, Utah; and Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day conference — 13th Annual Conference on Hazardous Waste Research, Snowbird, Utah, May 19-21, 1998 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Two-day workshop — Natural Attenuation of Chlorinated Solvents in Groundwater, Salt Lake City, Utah, July 15-16, 1998 — Utah Department of Environmental Quality, Salt Lake City, Utah; Hill Air Force Base, Utah; Utah State University, Logan, Utah.

Four-day conference — Animal Production Systems and the Environment: An International Conference on Odor, Water Quality, Nutrient Management, and Socioeconomic Issues, Des Moines, Iowa, July 19-22, 1998 — Iowa State University, Ames, Iowa.

Seminar — Wetland Ecology and Indian Culture, Lawrence, Kansas, September 10, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Water Resource Protection Programs — A Tribal Perspective, Lawrence, Kansas, September 11, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Two-day workshop — Natural Attenuation of Chlorinated Solvents in Groundwater, Kansas City, Kansas, September 16-17, 1998 — Kansas Department of Health and Environment, Topeka, Kansas and Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day workshop — Fate, Transport, and Remediation of Nonaqueous-Phase Liquids (NAPLs), Helena, Montana, September 22-24, 1998 — Colorado School of Mines, Golden, Colorado; Colorado State University, Fort Collins, Colorado; and University of Nevada, Las Vegas, Nevada.

Five-day workshop — HAZWOPER 40-hour Course, Manhattan, Kansas, January 4-8, 1999 — Kansas State University, Manhattan, Kansas.

One-day workshop — HAZWOPER Refresher, Manhattan, Kansas, January 6, 1999 — Kansas State University, Manhattan, Kansas.

Three-day conference – Tailings and Mine Waste '99 Conference, Ft. Collins, Colorado, January 24-27, 1999 – Colorado State University.

Two-day course – Introduction to Hazardous Waste Management, Columbia, Missouri, January 25-27, 1999 – University of Missouri-Columbia.

Two-day course – Compliance with DOT Regulations: Training, Testing, and Certification, Columbia, Missouri, January 27-29, 1999 – University of Missouri-Columbia.

Four-day conference – Ninth Annual Waste-management Education and Research Consortium Conference on the Environment, Las Cruces, New Mexico, April 26-29, 1999 – WERC.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, Sioux Falls, South Dakota, May 4, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, Des Moines, Iowa May 6, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, St. Louis, Missouri, May 24,1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day conference — 14th Annual Conference on Hazardous Waste Research, St. Louis, Missouri, May 25-27, 1999 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Community Involvement Strategies, Wellston, Missouri, May 27, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Permeable Reactive Barriers, St. Louis, Missouri, May 27, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, Salt Lake City, Utah, June 3, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Five-day workshop — HAZWOPER 40-hour Course, Manhattan, Kansas, June 14-18, 1999 — Kansas State University, Manhattan, Kansas.

Five-day workshop – Field-Based Site Characterization Technologies Course, Haskell National Training Center, Lawrence, Kansas, June 21-25, 1999, Haskell Environmental Resources Study Center, Lawrence, Kansas.

One-day workshop — HAZWOPER Refresher, Manhattan, Kansas, June 21, 1999 — Kansas State University, Manhattan, Kansas.

One-day workshop – Assessment and Cleanup Strategies Workshop, Denver, Colorado, July 8, 1999 – GP/RM HSRC and EPA Brownfields and Community Involvement Offices.

Three-day tour – Nebraska Summer Water Tour "Opportunities and Alternatives in Water and Agriculture," July 19-21, 1999 – University of Nebraska-Lincoln and other sponsors; Kearney Area Chamber of Commerce.

Three-day course – Introduction to Hazardous Waste Management (Course 2), August 2-4, 1999, Columbia, Missouri – University of Missouri-Columbia.

One-day course – Advanced Hazardous Waste Management, August 5, 1999, Columbia, Missouri – University of Missouri-Columbia.

One-day course – Hazardous Waste Management Update, August 6, 1999, Columbia, Missouri – University of Missouri.

Four-day conference – 5th International Petroleum Environmental Conference, Albuquerque, New Mexico, October 20-23, 1999 – Integrated Petroleum Environmental Consortium and Waste-management Education and Research Consortium.

Five-day symposium — 2000 Billings Land Reclamation Symposium, March 20-24, 2000, Billings, Montana — Montana State University.

One-day workshop — Phytoremediation Workshop: The State of the Science and Practice, May 22, 2000, Denver, Colorado — Great Plains/Rocky Mountain Hazardous Substance Research Center, Manhattan, Kansas.

One-day workshop — Technology Transfer for the Domestic Petroleum Industry: A State Regulator Workshop, May 22, 2000, Denver, Colorado — Great Plains/Rocky Mountain Hazardous Substance Research Center, Manhattan, Kansas.

Three-day conference — 15th Annual Conference on Hazardous Waste Research, May 23-25, 2000, Denver, Colordao — Great Plains/Rocky Mountain Hazardous Substance Research Center, Manhattan, Kansas.

One-day workshop — Workshop on Environmental Disclosure in Real Estate Transactions, May 25, 2000, Denver, Colorado — Great Plains/Rocky Mountain Hazardous Substance Research Center, Manhattan, Kansas.

Three-day course — Introduction to Hazardous Waste Management, August 7-9, 2000, Columbia, Missouri — University of Missouri-Columbia.

One-day course — Advanced Hazardous Waste Management, August 10, 2000, Columbia, Missouri — University of Missouri-Columbia.

One-day course — Hazardous Waste Management Update, August 11, 2000, Columbia, Missouri — University of Missouri-Columbia.

Three-day conference — Central States Agricultural Health and Safety Conference: A Working Conference to Develop a Plan of Action, September 20-22, 2000, Kansas City, Kansas — University of Iowa.

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