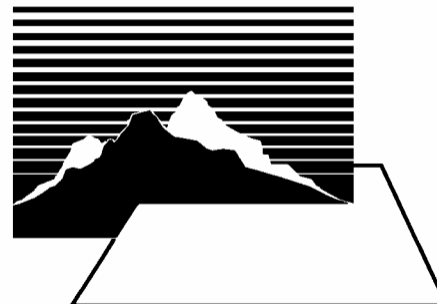


FINAL REPORT

of the

Great Plains/Rocky Mountain Hazardous Substance Research Center



December 2003

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*

Edited by

Wendy M. Griswold, Angie R. Burgoon, Larry E. Erickson, Mary M. Rankin, and Lakshmi N. Reddi
Great Plains/Rocky Mountain Hazardous Substance Research Center
Kansas State University
104 Ward Hall
Manhattan, KS 66506-2502

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Hazardous Substance Research Center
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GREAT PLAINS/ROCKY MOUNTAIN HAZARDOUS SUBSTANCE RESEARCH CENTER

Director Dr. Larry E. Erickson
Great Plains/Rocky Mountain Hazardous Substance Research Center
104 Ward Hall
Kansas State University
Manhattan, KS 66506-2502
Phone: (785) 532-4313/2380
Fax: (785) 532-5985
E-mail: lerick@ksu.edu

***Associate
Director*** Dr. Lakshmi N. Reddi
Great Plains/Rocky Mountain Hazardous Substance Research Center
104 Ward Hall
Kansas State University
Manhattan, KS 66506-2502
Phone: (785) 532-1586
Fax: (785) 532-5985
E-mail: reddi@ksu.edu

***Technology
Transfer Director*** Dr. Richard B. Hayter
College of Engineering
1042 Rathbone Hall
Kansas State University
Manhattan, KS 66506-2508
Phone: (785) 532-5590
Fax: (785) 532-7810
E-mail: rhayter@ksu.edu

Participants

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—
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, Montana Tech, 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. Funding from EPA for the center ended in 2003.

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 external affairs, 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.	University of Alabama at Birmingham	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, 1998-2003

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

Member	Affiliation	Expertise
Martha Boss	industry	certified industrial hygienist
David Carty	industry	remediation and soil chemistry
Ronald Hammerschmidt	govt/state	environmental chemistry
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, 1989-2000

**Chair, 2001-2003

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
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
Brenda Brandon
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 Zelter

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 R. 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 surfacewater and groundwater. The heavy metals listed are very similar to those that contaminate Department of Energy (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, although less than 10% of its funds are allocated for such projects.

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 1995-2001 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. In recent years electronic mail has been used to distribute information as well.

The center's base support comes from EPA. Participating schools have 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 also been received from individuals. Additional funding is from 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. The EPA award ended on September 30, 2003.

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

FUNDING SOURCES	CURRENT FUNDING PERIOD (May 18, 1997- Sept. 30, 2003)	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	2,522,633	1,974,470	4,968,848
Other Govt.: Federal			
U.S. Dept. of Defense	497,171	3,423,358	3,920,529
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	63,947	279,013	541,503
Private Sector	30,000	42,000	104,000
TOTAL	\$8,547,966	\$16,055,908	\$34,552,214

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. The goal is to serve the needs of the 10-state area using available resources within Regions VII and VIII. 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.

In 2001, several new Hazardous Substance Research Centers were established. Technology transfer and outreach activities are now being provided through the new centers. Some of the staff of the Great Plains/Rocky Mountain HSRC are now serving in similar positions in the Midwest HSRC, which can be checked out on the Internet at <http://www.mhsrc.org>.

A large number of the projects funded by the center include a cooperative element. Many involve more than one principal investigator; there is cooperation across academic department boundaries as well as institutional cooperation. In some cases, investigators have cooperated 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 HSRC 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 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, assistant director, 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. Terrie Boguski, assistant technical director, provides outreach services. Wendy Griswold, project manager, provides administrative management for the Native American and Other Minority Academic Institutions (NAOMI) Program at Haskell Indian Nations University. Brenda Brandon provides outreach services to Native American communities. Brenda Schaffer is the project accountant for the center.

HIGHLIGHTS

February 2003 marked the completion of 14 years of federally funded center activities. During this time, more than 100 projects have been funded, with more than 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. In 2002 the project and budget periods were extended to September 30, 2003. This report is the final report.

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 14 years of research through the center, utilization of vegetation in the remediation and/or stabilization of contaminated soil are 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 has increased 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 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.

A very important event was the 2002 Conference on "Application of Waste Remediation Technologies to Agricultural Contamination of Water Resources," which was held in Kansas City, July 30-August 1, 2002. Conference topics included remediation of fumigants, volatile organic compounds, nitrogen compounds, pesticides, and livestock wastes in soil and water. The proceedings are available as a CD and on the Internet at <http://www.engg.ksu.edu/HSRC>.

Tanner Callender, a high school student from Wamego, Kansas, was honored for his poster at the 2002 Conference. Larry Davis, one of the center's investigators, advised Tanner in his 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, Nanoscale Materials, Inc., which has commercialized destructive adsorbent technology that has been developed at the laboratory scale. This company received one of six 1997 Silicon Prairie Technology of the Year Awards.

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). Jerry Schnoor was elected to membership in the National Academy of Engineers. This is a significant honor in recognition of the leadership he has provided for the development of plant-based bioremediation.

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, was published from 1989-2000. *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, was published and distributed from 1995-1999 to minority academic institutions, center consortium universities, tribal offices, government agencies, and other interested individuals. Because of advances in electronic communication, *HazTech Transfer* was discontinued. Information is now being distributed electronically.

The center has added many pages on the World Wide Web, including 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 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, "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. Center staff are working with others at EPA and the Interstate Technology and Regulatory Cooperation Working Group to conduct phytoremediation workshops. 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 have provided leadership for many years for the Billings Symposium on Disturbed Land Rehabilitation. The ninth symposium was held recently. This symposium focuses on land reclamation and rehabilitation issues relevant to the Great Plains and Intermountain West.

Workshops are being conducted to transfer phytoremediation science and technology to regulators, consultants, and site owners through a cooperative effort which includes EPA, the Interstate Technology and Regulatory Cooperation Working Group (ITRC), the Remediation Technologies

Development Forum (RTDF), and center professionals. Faculty associated with the center worked with other professionals on an edited book, *Phytoremediation: Transformation and Control of Contaminants*, edited by Steve McCutcheon and Jerry Schnoor, on plant science and technology applied to phytoremediation. This book is a significant addition to the published literature on phytoremediation.

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 participated in a cooperative effort to address environmental research and technology transfer needs associated with mining and mine lands.

The Technical Outreach Services for Communities (TOSC) program continues to provide assistance to communities impacted by hazardous waste. Blase Leven and Terrie Boguski provide leadership for this program and the Technical Assistance to Brownfields (TAB) program. The TOSC 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. There is funding and cooperation with the new HSRCs in carrying out these activities. An overview of selected communities served by these programs follows. More information on communities served by the TOSC and TAB programs is available at <http://www.engg.ksu.edu/HSRC/Tosc/toschome.html>.

Former Amoco Refinery, Sugar Creek, Missouri

From 1904 to 1982, Amoco Oil Company (now BP) operated a petroleum refinery in Sugar Creek, Missouri, along the southern bank of the Missouri River east of Kansas City. In 1981, refinery officials began groundwater monitoring and found contamination of soil and groundwater. During the past several years, the community has been polarized about the way and speed that concerns about health, property values, and cleanup issues have been addressed. A local environmental activist group comprised of some local residents, CLEANUP, helped organize a law suit, numerous protests, and media attention. City government and other citizens, on the other hand, were generally satisfied with efforts at the former refinery. Initially, TOSC was unable to serve any of these parties as they were caught up with emotional issues and did not trust anyone.

At the request of the EPA, state, and other government agencies, the city began hosting public meetings in which all stakeholder groups could participate, including CLEANUP and BP. TOSC was asked to serve as a technical resource and began writing articles for the group's newsletter about technical topics of interest. However, the city would sometimes not publish the TOSC articles due to behind-the-scenes input from certain stakeholders, and the EPA decided to host an additional series of public meetings to ensure a more neutral setting. TOSC continues to participate and support both series of meetings. Over the years, TOSC slowly established working relationships with all of the stakeholders, and now meets and assists them each individually as well as in a group. Even CLEANUP, which was occasionally verbally abusive to TOSC (and especially the other parties) in the early years, has requested reviews and summaries of site investigation and cleanup documents – something this group has never

requested anyone to do for them in the past. Progress has been slow, but all parties are beginning to more smoothly share information and work together on technical matters, with less emotional hype.

Oak Grove Neighborhood Association—Kansas City, Kansas

In May of 2001, TOSC began working with the Associated Youth Services (AYS) Director in Kansas City, Kansas, to provide information to the Oakgrove Community Group about environmental conditions and redevelopment options at the closed Kansas City, Kansas, Sanitary Landfill at 5th and Cleveland. This activity was initially part of a community outreach plan to discuss the possibility of AYS building a commercial greenhouse on the landfill. The developer for the greenhouse project, Associated Youth Services, subsequently decided not to pursue the project due to the changing economic landscape. Rather than abandon the community, TOSC continued to explore environmental issues and reuse potential for the park. In agreement with the Oakgrove Community Group and with supplemental funding from AYS, TOSC conducted a series of environmental visioning workshops for the community. LaBarbara Wigfall led the visioning sessions. A student, Sylvia Lira-Machaelis, assisted with the workshops and developed a final design option for returning the landfill to a park. As a result of this work, Oak Grove Neighborhood Association president, Clintel Betts, was awarded EPA's Citizen of the Year award in 2003. A poster about the work with this community won awards at the 2002 Brownfields Conference and 2003 Community Involvement Conference. This project was completed; however, TOSC plans to stay in contact with Oak Grove Neighborhood Association to assist and advise them as they seek funding for redevelopment of the landfill site.

Native American Programs

The Native American and Other Minority Institutions (NAOMI) program has benefited more than 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 (<http://www.tosnac.org>) 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. There is funding and cooperation with the new centers in carrying out this program. An overview of a community served by this program follows. More information on communities served by the TOSNAC program is available at <http://www.engg.ksu.edu/HSRC/Tosc/toschome.html>.

Elem Nation, Sulfur Bank Mercury Mine, Clearlake, California

Tribal land and members are located on or around mine tailings associated with the Sulphur Bank Mercury Mine, which is situated on the perimeter of a geothermal lake. Acidic conditions and high mercury levels from mining areas have impacted fishery resources, wetlands, and associated wildlife habitats. The Tribal EPA Environmental Agency (consisting of one person) is working with the federal EPA and others to restore safe living, fishing, and gathering areas for this subsistence-based community, or at least to mitigate some very serious health and safety risks. The Army Corps of Engineers is the federal cleanup agency, and emergency response and reclamation activities have been unsatisfactory to the tribe and neighboring communities, and in some respects have exacerbated conditions.

At the request of the tribal and federal EPA, TOSNAC has coordinated community outreach activities with the Western Region HSRC and EPA Region IX Tribal Coordinator. Other experts on environmental and cultural risk are involved, and TOSNAC is working to help the tribe articulate input that is normally outside of conventional risk assessment and environmental decision making but that is of

critical importance to the tribe. TOSNAC delivered community training with a focus on the Superfund process, environmental justice, and cultural risk assessment, and has reviewed a draft RI/FS, and a geologic material sampling plan to provide input on risk considerations—most revolving around protected wetlands and archeological sites. This type of input takes special expertise and has required a unique trust relationship with the tribe, one that TOSNAC has been able to establish and maintain.

ENVIRONMENTAL CHALLENGES AND SOLUTIONS: A REVIEW OF RESEARCH AND TECHNOLOGY TRANSFER ACTIVITIES

Since the creation of the Great Plains/Rocky Mountain Hazardous Substance Research Center, consortium researchers have been engaged in developing solutions to the most pressing environmental challenges prevalent in EPA regions VII and VIII. Key achievements in developing solutions to challenges presented by contaminated soil and groundwater include developing innovative technologies for managing contaminant plumes and groundwater flow, using phytotechnologies in cleaning up contaminated water and soil, using vegetation to stabilize and restore land covered by mine tailings, and providing environmental training and technical assistance to many communities including tribal communities in Indian country.

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 funding for field testing has been obtained. Biobarrier technology is more flexible and economical than use of slurry walls or grout curtains in controlling contaminant plumes. 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. Methyl tert-butyl ether (MTBE) can be removed from soil and groundwater and degraded in the atmosphere using plants to facilitate transport. Increased knowledge in the use of plant systems to treat contaminated soil and water has led to increased regulatory acceptance of this innovative technology and its widespread use at polluted sites.

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. This technology can potentially enhance the capability of reactive barriers to intercept important exposure pathways, thus reducing public and environmental health risks.

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. Knowledge and insight gained from this research could lead to better design of remediation treatment systems.

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. New knowledge gained from this research may help researchers to eventually control the fate, transport, and bioavailability of contaminants in natural environments.

Results of center research have been applied by consultants, regulators, and many others. New companies such as Ecolotree and Phytokinetics 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 Nanoscale Materials, Inc. 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 reprocessing and vegetation method. This technique was successfully demonstrated in bench and greenhouse work and is 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. One 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 nonhazardous 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 annuus*) was planted

in both reprocessed and amended tailings from one site, only the reprocessed tailing supported plant growth.

Treatment effectiveness and costs 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 have evaluated 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. In 2001, the new HSRCs included the outreach to Native American communities in their programs. Thus, the outreach activities have continued through the Midwest HSRC.

Currently, there are more than 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 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 to individuals, community groups, and environmental programs in affected tribal communities, concerning hazardous substances. 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 funded 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 education materials. These videos supplement the limited resources 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

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 13 years, significant progress has been made in developing the capability of 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. Many of these faculty are supported with 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.

Research activities conducted by center investigators are expected to have a positive impact on environmental/geoenvironmental curricula at the consortium universities. Center investigators are planning to integrate findings from past research activities into graduate and undergraduate curricula. Extramural funding is being provided to aid integration of research and education in the area of geoenvironmental engineering.

Several new hazardous substance research centers were established by EPA in 2001 in order to involve new investigators and universities in the EPA Hazardous Substance Research Centers program. EPA support through the Great Plains/Rocky Mountain Center has ended in order to provide funding through the new centers. Many of the faculty who have participated in the research activities of the center have ongoing research efforts which continue to be supported from multiple sources. Some faculty who have participated in the Great Plains/Rocky Mountain HSRC will be faculty participants in one of the new centers. Professionals associated with the new centers are working cooperatively with center faculty to continue to serve communities with contaminated sites and/or brownfields.

PROGRAM SUMMARY
February 22, 1989 - September 30, 2003

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/\$0k	93-07 2000	Vegetative Interceptor Zones for Containment of Heavy Metal Pollutants
O'Keefe	\$336k/\$0k	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	Biotoxification 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 <i>In Situ</i> 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 <i>In Situ</i> 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	<i>In Situ</i> 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

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Erickson, Fan	\$269k/\$0k	91-29 1996	Remediation of Soil Contaminated with an Organic Phase
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/\$0k	93-02 2001	The Role of Metallic Iron in the Biotransformation of Chlorinated Xenobiotics
Parkin	\$198k/\$0k	93-24 2001	Application of Anaerobic and Multiple-Electron-Acceptor Bioremediation to Chlorinated Aliphatic Subsurface Contamination
Segar	\$204k/\$0k	94-07 2000	Trichloroethene (TCE) Cometabolism in Fluidized-Bed Bioreactors
Schnoor, Burken	\$475k/\$0k	94-25 2000	Uptake of BETX Compounds and Metabolites by Hybrid Poplar Trees in Hazardous Waste Remediation
Davis, Erickson	\$345k/\$0k	94-27 2000	Plant-Assisted Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances: Experimental and Modeling Studies
Illangasekare	\$521k/\$0k	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/\$0k	95-10 2000	Fate of Trichloroethylene (TCE) in Plant/Soil Systems: Evaluating Phytoremediation
Zhang, Comfort, Shea	\$394k/\$0k	95-32 2001	Simultaneous Transformation of Atrazine and Nitrate in Contaminated Water, Sediment, and Soil by Zero-Valent Iron-Promoted Processes

*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
Schnoor	\$323k/\$0k	95-29 2001	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
Alvarez, Parkin, Schnoor	\$150k/\$0k	98-01 2001	Iron-Enhanced Bioremediation of Aquifers Contaminated with Chlorinated Solvents, Hexavalent Chromium, and Nitrate
Erickson, Davis	\$180k/\$0k	98-03 2003	Plant-Assisted Remediation of Soil and Groundwater Contamination by Hazardous Organic Substances: Experimental and Modeling Studies
Illangasekare	\$114k/\$0K	98-05 2001	Non Aqueous-Phase Waste Chemicals in the Subsurface: Site Characterization and Remediation
Simeonsson	\$77k/\$0k	98-08 2001	Changes in the Speciation and Biological Volatization of Environmental Arsenic as a Result of Phytoremediation of Hazardous Waste Sites
Reardon	\$300k/\$0k	SP99-1 2003	Transformation Mechanisms of High Molecular—Weight Polycyclic Aromatic Hydrocarbons in the Rhizosphere
Schwab, Banks, Leven	\$268k/\$0K	SP96-Riley 2003	Field Validation of an Optimal Design Methodology for Vegetative Remediation of Sediments from the Central Vehicle Wash Facility, Custer Hill, Fort Riley, Kansas
Erickson	\$250K/\$0K	RTDF 2003	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

ANALYSIS/TREATMENT OF CONTAMINATED SOIL (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
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	<i>In Situ</i> 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
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 PGNA 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/\$0k	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 Humic Fraction of Soil Organic Matter
Tracy, Van Lent, Schaefer	\$196k/\$0k	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/\$0k	93-11 94-28 2000	Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence

ANALYSIS/TREATMENT OF CONTAMINATED SOIL (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Klabunde	\$354k/\$0k	95-04a 2003	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

TRAINING AND TECHNOLOGY TRANSFER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
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 <i>In Situ</i> Bioremediation Processes: A Workshop on Biotreatability
Grant, Griswold	\$804k/\$0k	NAOMI 1998	Native American and Other Minority Institutions Program
Erickson, Leven	\$404k/\$0k	TR-01 2003	Conferences and Workshops
Hayter, Leven	\$134k/\$0k	TR-01 2003	HSRC Contribution Repository and Information Clearinghouse
Reddi, Leven	\$360k/\$0k	TR-01 2002	HSRC Newsletter, <i>HazTech Transfer</i>
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/\$0k	SP93-01 2003	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/\$0k	TR96-05 2003	Collaborative Environmental Seminar Series
Griswold, Brandon	\$298k/\$0k	TOSNAC 2003	Technical Outreach Services to Native American Communities
J.L. Sims	\$81k/0k	TR97-07 2001	Development of a "State-of-the-Science and Technology" Report on Site-Characterization Technologies
B.A. Leven	\$59k/\$1k	2003	EPA Conference on Application of Waste Remediation Technologies to Agricultural Contamination of Water Resources

RESEARCH PROJECT DESCRIPTIONS

May 18, 1995 – September 30, 2003

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

Investigators: K.J. Klabunde, Kansas State University

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University

Project Number: 95-04a

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$354,000

Research Category: Analysis/Treatment of Contaminated Soil

Goals and Objectives: The goal of this project was 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 C₁ or C₂ 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 the hydrocarbon formation. In a separate study, pH changes in Zn and Sn reductive systems were measured and compared. The catalytic effects of Ag⁰ and Pd⁰ promoters were studied also.

Project Findings: A new technology was devised for the one-step destruction of hazardous substances, including chlorocarbons, chlorofluorocarbons, and organophosphorus, nitrogen, and sulfur compounds. This new technology is based on nanoparticles and porous pellets formed by pressing these powders. Important properties of these nanoparticles are their ability to destructively absorb the toxins in high

capacity. The investigators are also developing semiconductor nanoparticles and investigating their photocatalytic activity for degradation of toxins.

Technology Transfer: The investigators are working in partnership with a small start up company to transfer the technology to the private sector. The company (NanoScale Materials, Inc.) has grown to 30 employees. Investigators continue to present papers at meetings and technical conferences, publish papers, and answer many inquiries regarding this technology.

CURRENT PERIOD PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS

Decker, S.P., J.S. Klabunde, A. Khaleel, and K. Klabunde, "Catalyzed Destructive Adsorption of Environmental Toxins with Nanocrystalline Metal Oxides. Fluoro, Chloro, Bromocarbons, Sulfur, and Organophosphorus Compounds," *Envir. Sci. Technol.*, vol. 36, pages 762-768, 2002.

Diao, Y., W.P. Walawender, C.M. Sorenson, K.J. Klabunde, and T. Ricker, "Hydrolysis of Magnesium Methoxide. Effects of Toluene on Gel Structure and Gel Chemistry," *Chem. Mater.*, vol. 14, pages 362-368, 2002.

PRESENTATIONS

None reported.

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

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC>

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

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

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University

Project Number: 98-03

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$225,000

Research Category: Organic Chemical Contamination of Soil/Water

Goals and Objectives: There were four main objectives for this project. Experimental systems to improve oxygen availability for enhanced aerobic biodegradation were developed. Transfer of contaminants through plants was monitored. A mathematical model to describe fate of water, contaminant, root exudates, plants, microbes, and oxygen in laboratory and field systems was applied. This technology was applied to field sites by working with professionals elsewhere. New funding since May 1998 emphasized issues of concern during aircraft operations and deicing.

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 the 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 was optimized to minimize air input and maximize degradation of target substances. Material balance measures were used to determine the fate of target substances. Potential intermedia transfer was monitored by FTIR measurements on the gas phase above the growing plants. Changes in contaminant concentration in the groundwater were monitored by headspace gas chromatography or FTIR of aqueous samples. The groundwater flow and transport model was used to model behavior of contaminants in the new system under several experimental conditions. The model was further refined to improve the fit of predicted and

observed behavior. It has been applied to field situations where monitoring wells are in place, such as near landfills.

Project Findings: 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 deicers have been done. Jet fuel experiments were done with alfalfa and horseradish plants. Deicer experiments were done with hydroponically grown sunflowers. Corrosion inhibitors in deicing fluids appear to inhibit root growth of plants.

Technology Transfer: 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. The investigators have worked with university and city entities to apply the research to solving local problems. Publications have been prepared for peer-reviewed scientific journals and for regulators and consultants.

CURRENT PERIOD PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS

Castro, S., L.C. Davis, and L.E. Erickson, "Phytotransformation of Benzotriazoles," *International Journal of Phytoremediation*, In Press 2003.

Davis, L.C., and T. Callender, "Nitrification Inhibition using Benzotriazoles," *Proceedings of the Conference on Application of Waste Remediation Technologies to Agricultural Contamination of Water Resources*, Kansas State University, pages 193-204, 2003.

Davis, L.C., and L.E. Erickson, "A Review of the Potential for Phytoremediation of the Volatile Contaminants Ethylene Dibromide, Ethylene Dichloride, and Carbon Tetrachloride," *Proceedings of the Conference on Application of Waste Remediation Technologies to Agricultural Contamination of Water Resources*, Kansas State University, pages 205-220, 2003.

Davis, L.C., and L.E. Erickson, "Prospects for Bioremediation and Natural Attenuation of MTBE," *Environmental Progress*, submitted 2003.

Davis, L.C., L.E. Erickson, M. Narayanan, and Q. Zhang, "Modeling and Design of Phytoremediation," In *Phytoremediation: Transformation and Control of Contaminants*, S.C. McCutcheon and J.L. Schnoor, Editors, Wiley, New York, pages 663-694, 2003.

Dokken, K.M., J.A. Reffener, L.C. Davis, and D.L. Wetzel, "Spectroscopic Examination of Root Cell Walls of Plants Grown under Chemical Stress with Reflection Absorption and Diamond ATR Microspectroscopy," *Proceedings of the 2nd International Conference on Advanced Vibrational Spectroscopy*, University of Nottingham, Nottingham, England, In Press, 2003.

Hart, D.S., L.C. Davis, L.E. Erickson, and T.M. Callender, "Sorption and Partitioning Parameters of Benzotriazole Compounds," *Microchemical Journal*, In press, 2003.

Karthikeyan, R., L.C. Davis, L.E. Erickson, K. Al-Khatib, P.A. Kulakow, P.L. Barnes, S.L. Hutchinson, and A.A. Nurzhanova, "Potential for Plant-Based Remediation of Pesticide-Contaminated Soil and Water Using Non-Target Plants such as Trees, Shrubs, and Grasses," *Critical Reviews in Plant Science*, submitted 2003.

Karthikeyan, R., K.R. Mankin, L.C. Davis, and L.E. Erickson, "Experimental Investigation of Fate and Transport of Jet Fuel (JP-8) in Soils with Plants," *International Journal of Phytoremediation*, Accepted 2003.

Karthikeyan, R., K.R. Mankin, L.C. Davis, and L.E. Erickson, "Modeling Jet Fuel (JP-8) Fate and Transport in Soils and Plants," *International Journal of Phytoremediation*, Accepted 2003.

Winnike-McMillan, S.K., Q. Zhang, L.C. Davis, L.E. Erickson, and J.L. Schnoor, "Phytoremediation of MTBE," In *Phytoremediation: Transformation and Control of Contaminants*, S.C. McCutcheon and J.L. Schnoor, Editors, Wiley, New York, pages 805-828, 2003.

PRESENTATIONS

Dokken, K.M., L.C. Davis, L.E. Erickson, D.L. Wetzel, and N. Marinkovic, "The Use of Infrared Microspectroscopy to Determine the Biotransformation of Benotriazole by Sunflowers (*Helianthus annuus* L.), "38th Midwest Regional Meeting of the American Chemical Society, University of Missouri, Columbia, MO, November 5-7, 2003.

Dokken, K.M., J.A. Reffener, L.C. Davis, and D.L. Wetzel, "Spectroscopic Examination of Root Cell Wall of Plants Grown Under Chemical Stress with Reflection Absorption and Diamond ATR Microspectroscopy," 2nd International Conference on Advanced Vibrational Spectroscopy, University of Nottingham, Nottingham, England, August 24-29, 2003.

Erickson, L.E., "Environmental Stewardship: Working with Nature on Remediation of Contaminated Sites," Kansas State University, Manhattan, KS, September 11, 2003.

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

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC>

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

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

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Colorado State University

Project Number: SP99-01

Project End Date: December 31, 2002

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$300,000

Research Category: Organic Chemical Contamination of Soil/Water

Goals and Objectives: The main objectives of this project were 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: Specific tasks for this project included 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.

Project Findings: Thirty-two plants of each of seven species were planted in 12-inch pots in PAH-contaminated soil from Texas City. After 18 months, PAH removal had occurred, with planted soils generally lower than non-planted controls. However, these results were not significantly different and overall levels of PAH removal were lower than expected. The PAH degraders were significantly higher in most planted treatments, suggesting the role of vegetation in increasing pollutant-degraders in the rhizosphere over time. The conflicting finding of increased PAH-degrader populations in the presence of plants but relatively low extents of PAH removal has two basic causes: the hydrophobic nature of the soil and a high metal content. A separate set of greenhouse experiments were conducted with PAH-contaminated soil from Alameda NAS. In general, PAH concentrations were significantly lower than the starting concentrations. The results demonstrate that a variety of plant species have characteristics leading to increased pollutant-degraders in the rhizosphere and enhanced removal of recalcitrant organic pollutants in aged soils. The soil from Alameda was also used in greenhouse experiments to compare the effects of agronomic practices on PAH removal in nutrient-poor soil. In general, soils with no fertilization

showed the highest PAH removal. Additionally, clipped treatments resulted in the greatest removal of PAH from the soil.

In assessing the contributions of potential PAH removal mechanisms, researchers worked to determine whether plant root exudate/lysate enhances PAH biodegradation by acting as a growth substrate, inducing genes for PAH-degrading enzymes, or stimulating biosurfactant production. Findings indicate that root-released chemicals support growth of bacteria and planted soils contain more biosurfactant.

Researchers used molecular biological tools to evaluate gene induction in mixed-soil microbial populations upon exposure to root-released chemicals (RRC). The focus of the testing was strain HK44 with plant RRCs and pure plant chemicals as potential inducers, along with positive and negative controls. In induction tests, researchers noted widespread ability to induce transcription of mRNA from nahA. This may be the first direct evidence of such induction by plants' root-released chemicals.

Technology Transfer: Papers have been presented at conferences and many publications are in preparation. Personnel at the Naval Facilities Engineering Service Center are being kept informed of the progress of the project. The Navy may be interested in conducting field trials if promising plant species are identified.

CURRENT PERIOD PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS

Olson, P.E., K.F. Reardon, and E. Pilon-Smits, "Ecology of Rhizosphere Bioremediation," *Phytoremediation: Transformation and Control of Contaminants*, S.C. McCutcheon and J.L. Schnoor, eds., Wiley-Interscience, Inc., pages 317-353, 2003.

PRESENTATIONS

Reardon, K.F., and M.B. Joern, "Stimulation of Biosurfactant Production by Plant-Released Compounds in PAH-Contaminated Soils," *Annual Meeting of the American Institute of Chemical Engineers*, Indianapolis, IN, November 3-8, 2002.

Supplemental Keywords: bioremediation, PAH, rhizosphere

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC>

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

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

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University

Project Number: RTDF

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$250,000

Research Category: Organic Chemical Contamination of Soil/Water

Goals and Objectives: The goal of this project was to test phytoremediation of contaminated soils at 13 locations to gather data in support of use of phytoremediation and its acceptance by the regulatory community. The trials have compared petroleum hydrocarbon dissipation in vegetated soils and unvegetated soils for a five-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 has entered appropriate field sites into a testing program and developed a database of field test results. Results of this project have provided valuable scientific information about use of phytoremediation to clean up soils contaminated with petroleum hydrocarbons.

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

Project Findings: The RTDF TPH subgroup phytoremediation trials are nearing their conclusion. There are 13 field sites entered in the program. Eleven of these sites are in the United States. Two of these 11 field sites will have completed their final sampling in fall 2003. The remaining two locations are in Canada. These sites were started later and will finish in fall 2004 and fall 2005. Analytical data is available from 42 data sets. Considered as a group, it appears some field sites show significantly

enhanced hydrocarbon degradation with vegetative treatments while other field sites do not show enhanced treatment during the time of field trials. Differences among field sites may be related to differences in hydrocarbon composition and weathering. Several indicators of hydrocarbon weathering are discussed in the report.

Technology Transfer: Technology transfer for this project has included regular interaction with all project participants, including representatives from EPA, DoD, industry, and universities. The first annual report for use by the RTDF participants was completed in March 2000. A public release version of the annual report is posted on the Internet. This report was cited by a number of technical outreach publications. The second annual report was completed in September 2001. After an EPA review, it was decided to delay posting of the annual report until the next report was completed so additional approaches for data interpretation could be included. A final report is currently in preparation and will be available in 2004.

CURRENT PERIOD PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS

Camp, H., P. Kulakow, D.R. Smart, and K. O'Reilly, "Application of chemical tools to evaluate phytoremediation of weathered hydrocarbons," *Proceedings of the Twenty-Fifth Arctic and Marine Oilspill Program Technical Seminar*, Environment Canada, Calgary, 2003.

PRESENTATIONS

Kulakow, P., "Phytoremediation of petroleum hydrocarbon-contaminated soil: Results from cooperative field tests," International Symposium on Biochemical Interactions of Microorganisms and Plants with Technogenic Environmental Pollutants, Saratov, Russia, July 2003. Abstracts, p. 19.

Kulakow, P. A., "Plant growth and diversity during phytoremediation: Opportunities for restoration," Assembling the Pieces: Restoration, Design, and Landscape Ecology, Fifteenth Annual SER Conference, Austin, TX, November 2003.

Kulakow, P., and X. Feng, "Phytoremediation of petroleum hydrocarbon-contaminated soil: Results from RTDF cooperative field tests," Nineteenth Annual International Conference on Contaminated Soils, Sediments, and Water, Amherst, MA, October 2003.

Kulakow, P., and X. Feng, "The RTDF TPH subgroup phytoremediation trials: Results and preliminary conclusions," U.S. EPA International Applied Phytotechnologies Conference, Chicago, IL, March 2003. <http://www.clu-in.org/studio/2003phyto/prez/46.pdf>

Kulakow, P. A., B. A. Leven, and L. Erickson, "Phytoremediation of petroleum hydrocarbon-contaminated soil: Results from RTDF cooperative field tests," Ninth International Petroleum Environmental Conference, Houston, TX, November 2003.

Kulakow, P. A., B. A. Leven, and J. Landmeyer, "Phytotechnologies: Ready for application at Brownfields," Brownfields 2002: Investing in the Future, Charlotte, NC, November 2002. Proceedings CD.

McMillan, D. E., M. M. Mikha, and P. A. Kulakow, "Vegetation effect on contaminant and soil quality during phytoremediation," Annual Meetings of American Society of Agronomy, Denver, CO, November 2003.

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

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC>
<http://rtdf.org/public/phyto/protocol/protocol99.htm>
<http://rtdf.org/public/phyto/protocol/uptake.pdf>
<http://www.clu-in.org/studio/2003phyto/prez/46.pdf>
<http://www.rtdf.org/public/phyto/minutes/tph.html>

TRAINING AND TECHNOLOGY TRANSFER PROJECT DESCRIPTIONS

May 18, 1994 – September 30, 2003

Title: HSRC Technology Transfer Program

Investigators: L.N. Reddi, and B.A. Leven, Kansas State University

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University

Project Number: TR-01

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$360,000

Category: Training and Technology Transfer

Goals and Objectives: 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 accomplished 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 provided 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 maintained 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 the need 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.

Project 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 has published 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 11

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 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. These workshops were offered several times.
- A workshop on the use of phytoremediation at brownfield sites was presented at the EPA Brownfields 2002 Conference in November 2002.
- Center representation on the Kansas Petroleum Council and the Interstate Oil and Gas Compact Consortium, as well as liaison efforts with other industries, university consortia, and stakeholder groups.

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

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

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC>

Title: Conference on Hazardous Waste Research

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

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University

Project Number: TR-01

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$404,000

Category: Training and Technology Transfer

Goals and Objectives: The goal of this project was 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 management of hazardous substances.

Rationale: Conferences provide good opportunities for 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 hosted the conference in alternate years.

Project Status: The first Application of Waste Remediation Technologies to Agricultural Contamination of Water Resources Conference was held in Kansas City, Missouri, July 30-August 1, 2002, with approximately 130 people participating. Researchers, state regulators, and private consultants from around the country attended the conference to present and hear papers, participate in a forum discussion, and view posters and exhibits. The conference involved several co-sponsors and cooperating supporters, including the U.S. Environmental Protection Agency ORD, Office of Science Policy; U.S. EPA Region 7 Superfund Program and Office of Drinking Water and Groundwater Program; Kansas Department of Health and Environment; Kansas Center for Agricultural Resources and the Environment; and the Nebraska Department of Environmental Quality. The conference proceedings are available in CD-ROM form and on the Internet at <<http://www.engg.ksu.edu/HSRC/Proceedings.html>>.

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

Supplemental Keywords: conference, information exchange, research.

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC/>

Title: Virtual Library: Transferring HSRC Research Results Through the Internet

Investigators: L. E. Erickson, Kansas State University

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, KSU

Project Number: TR 95-10

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$37,000

Category: Training and Technology Transfer

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

Rationale: Investigators believed distributing this journal via the Internet would improve delivery time of HSRC findings and related research information. It also provides an inexpensive alternative to library subscriptions and 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.

Project Status: An editorial team and advisory board have been established and a Web site created at <http://www.engg.ksu.edu/HSRC/JHSR>. Manuscript submission information is on-line, and a call for papers has been distributed. A number of manuscripts have been submitted and peer reviewed, and 27 articles posted on the Web site. The articles are posted in portable document format (pdf) with searchable abstracts also available in HTML. Print copies of Volumes I through III of the journal have been published. This project is in its seventh year.

Technology Transfer: 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.

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

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC/JHSR>

Title: Technical Outreach Services to Communities (TOSC) Programs

Investigators: B.A. Leven, T.K. Boguski, L.J. Wigfall, B. Brandon, P. Kulakow, S. Martin, B.J. Johnson, and W.M. Griswold, Kansas State University

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University

Project Number: SP93-01/TOSNAC

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$402,000/\$298,000

Category: Training and Technology Transfer

Goals and Objectives: Technical Outreach Services for Communities (TOSC) provides free 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 underlying issues related to the cleanup and reuse of sites with real or perceived environmental impacts.

Rationale: The U.S. Congress and various federal, state, and local agencies have shown increasing interest in the level of community involvement in the decision-making process at Superfund, brownfield, former defense, and other types of sites where environmental factors are an issue. 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 National Priority List.

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 at a basic level and from researchers 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.

Project Status: KSU completed a transition from support to communities in EPA Regions 7 and 8, as part of the GP/RM HSRC, and to communities in Regions 5 and 7, as part of the Midwest HSRC headed by Purdue University. KSU's primary responsibility is to serve communities in Region 7 and to help

Haskell Indian Nations University run the national Technical Outreach Services to Native American Communities (TOSNAC) Program. Support has been provided to TOSC communities at up to six sites, including four Superfund and two RCRA sites. In addition, we are currently providing support at up to four Technical Assistance to Brownfields (TAB) communities, and are on call to support others. TOSNAC provides support to up to six communities.

Technology Transfer: This program assists in technology transfer of 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 remediation options that can be considered.

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

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC>
<http://www.engg.ksu.edu/HSRC/Tosc/toschome.html>
<http://www.mhsrc.org>
<http://www.tosnac.org>

Title: Collaborative Environmental Seminar Series

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

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University and Haskell Indian Nations University

Project Number: TR96-05

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$142,000

Category: Training and Technology Transfer

Goals and Objectives: The goal of this project was to produce a series of seminars primarily for audiences at Haskell Indian Nations University (HINU) and other American Indian Higher Education Consortium (AIHEC) colleges and universities. The seminars provided 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 were 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 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 produced four high-quality video programs, companion on-campus seminar presentations at HINU, and semi-annual publications of the *Earth Medicine* newsletter. Video topics included a panel discussion of tribal environmental justice issues, presentations on cultural risk assessment and pollution prevention opportunities, and a demonstration on microscale chemistry for the classroom.

Project Findings: In previous years, the Haskell Environmental Seminar Series (HESS) produced two video seminar programs and filmed four lectures at HINU. In October 2002, "Guarding the Circle: Pollution Prevention in Indian Country" and "Microscale Chemistry in the Classroom" were distributed. The final program in the seminar series, "Native American Perspectives of Risk Management," was filmed and distributed in September 2003. This program featured TOSNAC coordinator, Brenda Brandon, discussing cultural risk assessment.

Technology Transfer: This program resembles 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. Video programs were distributed to 130 participants at tribal colleges and universities,

tribal environmental offices, other minority academic institutions, Kansas colleges, and HSRC consortium institutions.

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

Relevant Web Sites: <http://www.engg.ksu.edu/HSRC>

Title: 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

Investigators: P. Kulakow, and B.A. Leven, Kansas State University; M.K. Banks, and A.P. Schwab, Purdue University; and S.R. Burckhard, South Dakota State University

Institution: Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University, Purdue University, South Dakota State University

Project Number: SP96-Riley

Project End Date: September 30, 2003

Report Period: October 2002-September 2003

EPA Project Officer: Dale Manty

Project Amount: \$137,931

Category: Training and Technology Transfer

Goals and Objectives: The goals of this project were 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 at Fort Riley produces 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 lead to feasibility evaluations and design of vegetative treatment systems for contaminated materials from other locations such as wastewater lagoons and UST sites, or for on-site treatment of miscellaneous petroleum spills.

Approach: This research involved establishing several vegetative treatment plots at the site, monitoring and comparing results, and calibrating evolving computer models and design tools. Additional field tests of this technology were conducted at other unique cleanup sites, or for other waste types as funds became available. Technology transfer was an ongoing part of this project.

Project Findings: The RTDF cooperative trials include both common datasets based on the RTDF protocol and unique research conducted independently at each location. Total amount of information being generated on the mechanisms and response of phytoremediation is extensive and will bolster conclusions from the field trials. Some research areas include characterization of microbial populations, tree growth analysis, plant root exudate studies, phytoremediation modeling, phytoremediation treatment from natural vegetation, and bioavailability assays. Results from the two phytoremediation field trials suggest that while risk-based concentrations of petroleum hydrocarbon-contaminated sediments can be achieved by land spreading without vegetation, the additional benefits of including revegetation in the sediment management plan will achieve additional benefits at reasonable cost. The field experimentation portion of this project has been completed. Final results are in preparation for publication. The larger

RTDF program involving 13 field sites is continuing with the preparation of a final report for all locations that will include the Fort Riley site.

Technology Transfer: Technology transfer activities included 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 products are being developed to assess the feasibility and help implement phytoremediation of washrack sediments. Broad dissemination of project protocols and results is planned through workshops and platform presentations at various conferences. Participants in this study are also participating in the Remediation Technologies Development Forum (RTDF) involving EPA, DoD, industry, and university collaborators to validate and promote regulatory acceptance of phytoremediation of TPH-contaminated soils.

CURRENT PERIOD PUBLICATIONS AND PRESENTATIONS

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Supplemental Keywords: vegetation, phytoremediation, petroleum hydrocarbons.

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H. CONFERENCES AND WORKSHOPS

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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.

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

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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.

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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 — Eight-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 — Eight-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 — Eight-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 — Eight-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 — Eight-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, Colorado — 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.

One-day training — Eight-Hour HAZWOPER Refresher Course, May 21, 2001, Manhattan, Kansas — Great Plains/Rocky Mountain Hazardous Substance Research Center, Manhattan, Kansas.

Half-day course — Engineering and Technology: Pollution Prevention Workshop, May 21, 2001, Manhattan, Kansas — Great Plains/Rocky Mountain Hazardous Substance Research Center, Manhattan, Kansas.

Two-day conference — 2001 Conference on Environmental Research, May 22-23, 2001, Manhattan, Kansas — Great Plains Rocky/Mountain Hazardous Substance Research Center, Manhattan, Kansas.

One-day workshop — Cost-Effective Maintenance and Surface Remediation for Oil and Gas Producers, May 24, 2001, Manhattan, Kansas — Great Plains/Rocky Mountain Hazardous Substance Research Center, Manhattan, Kansas.

Two-day workshop — ITRC Phytotechnologies: Mechanisms and Application, September 12-13, 2001, Austin, Texas — Interstate Technology and Regulatory Cooperation Work Group.

Two-day workshop — ITRC Phytotechnologies Classroom Training, October 24-25, 2001, Amherst, Massachusetts — Interstate Technology and Regulatory Cooperation Work Group.

Seminar — Guarding the Circle: Pollution Prevention in Indian Country, April 12, 2002, Lawrence, Kansas — Haskell Indian Nations University.

Three-day conference — 2002 Conference on Application of Waste Remediation Technologies to Agricultural Contamination of Water Resources, July 30-August 1, 2002, Kansas City, Kansas — Great Plains Rocky/Mountain Hazardous Substance Research Center, Manhattan, Kansas and EPA Region 7, Kansas City, Kansas.

Seminar — Native American Perspectives of Risk Management, September 12, 2003, Lawrence, Kansas — Haskell Indian Nations University.

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